Patent statistics: A good indicator for innovation in China? Patent subsidy program impacts on patent quality

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Abstract

Using a merged dataset of Chinese patent data and industrial survey data, we make a bibliometric analysis of patenting activities of Chinese large and medium-sized enterprises under local patent subsidy programs and test whether patent statistics are a good indicator of innovation in China. Our empirical results show that patent count is correlated with R&D input and financial output, which suggests that patent statistics are meaningful indicators. However, patent subsidy programs increase patent counts more than 20%. We emphasize the necessity of adjustments and provide a novel method of using the number of nouns in claims to quantify the claim scope, thereby overcoming the shortcomings of Chinese patent data that have no citations or lack well-documented patent claim information. We extend prior studies on patent subsidy programs by providing a detailed clarification of policy designs and their impacts and by evaluating policy impacts on both the quantity and quality of patent applications.

Keywords: patent; subsidy; quality; innovation; China

JEL codes: O32 O34 O38

1 Introduction

A recent surge of patent applications in China has aroused significant research interest in investigating whether the surge is an indicator of the growth of innovative capabilities in Chinese industries and a change from "imitation" to "innovation." Although the rapid increase of Chinese patent applications can be explained by the nation's technology catching up with international players in developed economies, patent quality concerns arise as studies have suggested that such applications are largely supported by local government patent subsidy programs (Li, 2012). Thus, can we rely on patent statistics as an indicator of innovation in China? Several studies have analyzed the determinants of patent application growth, but few have provided empirical evidence on the quality of these patents. It particularly remains unclear whether patent subsidy programs have resulted in the deterioration of the quality of Chinese patent applications.

As patents contain rich and timely information on inventive activities, patent statistics are increasingly used to analyze and measure innovations. While R&D expenditures are widely used as a proxy for innovation input, patent statistics can measure the output. This measure is also more easily obtainable than other proxies for outputs, such as total factor productivity (TFP) (Nagaoka, Motohashi, & Goto, 2010). However, patent statistics are not perfect as innovations are not necessarily patentable or patented, and patent quality varies (Griliches, 1998). The former is generally treated by controlling for industry differences, which largely explains variations in patenting propensity. For instance, patents are more effective in protecting pharmaceutical, chemical, and electronics technology. The latter problem is treated by weighting patents by citations, as frequently cited patents have been proven to have higher technological and economic value (Arora, Fosfuri, & Gambardella, 2001; Harhoff, Scherer, & Vopel, 2003; Trajtenberg, 1990). However, special care is needed when using patent statistics in China as institutional factors could have distorted patenting behaviors and ultimately patent statistics. One needs to evaluate to what extent Chinese patent statistics have drifted away from the "real" output, which should be highly correlated with R&D expenditures as has been observed in other countries (B. Hall, Griliches, & Hausman, 1986; Pakes & Griliches, 1984).

Using survey data from the National Bureau of Statistics (NBS) of China, Hu and Jefferson (2009) estimate a patent production function for Chinese enterprises, finding significantly low patent-R&D elasticity and claim that foreign direct investment, institution change, and other factors are behind the patent surge. A recent study shows that patenting propensity has been boosted as much as 160% by patent promotion policies (Li, 2012). These two studies underscore the need to adjust quantitative statistics for patent applications in China. However, it is unclear whether granted patents have also been boosted significantly, which prevents granted patents from being a valid indicator of innovations. Unfortunately, pioneer studies (Hu & Jefferson, 2009; Li, 2012) that use industrial survey data cannot answer this question because firms can only provide the number of their applications in the year a survey is conducted; they cannot provide the number of granted patents as that figure can only be known several years later when examination decisions are issued. A more difficult aspect lies in assessing the different qualities of patents. Patent quality is generally assessed using detailed patent information, including citation, renewal information, and patent claims. Several studies that use renewal information demonstrate that Chinese-granted patents have lower value than patents by foreign players (Thoma, 2013; Zhang & Chen, 2012). However, using renewal information has its disadvantages in terms of timeliness and thus cannot reflect recent changes in patent quality. Moreover, the two lines of research seem to be parallel when dealing with patent quality. Studies based on survey data have illustrated exaggerated growth of patent applications compared to growth of R&D but cannot answer whether the quality of granted patents has been affected. On the contrary, studies using patent information can make horizontal comparisons of patent quality but cannot determine whether this is a new phenomenon that resulted from patent subsidies. The solution should be found in exploiting both data sources. By matching industrial survey data with patent data, a bibliometric analysis of patent statistics can be performed to evaluate the policy impacts on applications, grants, and quality of granted patents. To the best of our knowledge, no such analysis has been performed previously.

Therefore, this study makes the first attempt to match China's patent data with widely used industrial survey data, and then uses this dataset to obtain a clear view on how patent statistics serve as an indicator of output of R&D investment and answers to what extent the statistics are biased by policy incentives. The matched dataset enables us to extend current research in several directions: first, to test whether granted patents, rather than applications, are valid indicators of innovations, second, to analyze patent quality using patent claim information, and third, to investigate whether the policies affect state-owned enterprises (SOEs), privately owned enterprises (POEs), and foreign funded enterprises (FFEs) differently.

We also extend Li's pioneering study of patent subsidy programs by classifying patent subsidies into three categories that reflect their timing and conditions: filing fee subsidies, examination fee subsidies, and rewards contingent on patent grants (hereinafter "grant-contingent rewards"), and empirically investigate their effects in the patenting process. The detailed examination can provide insights on effective policy designs.

Our empirical results show that subsidies increased patent-R&D elasticity. For a "typical" firm, the average number of patent applications may have been increased by 23% and granted patents by 26%. Thus, quantitative statistics of both patent applications and granted patents need downward adjustments. The result is contrary to general intuition as one would expect a large number of low-quality patents were rejected in the examination phase and granted patents would not be boosted as much as applications. Further investigation reveals that grant-contingent rewards encouraged strategies to narrow patent claims to obtain patents more easily.

This study contributes to literature on Chinese innovation. First, we merged industry survey data with Chinese patent data, thus linking finance information with patent information. Though our study is conducted from the patent production perspective and emphasizes the usage of R&D data and patent examination information, future studies can exploit the merged data in various directions, including evaluating the contribution of innovation activities on financial performance and market value. Second, by detailed classification of patent subsidies, we empirically demonstrate the effects of different policy designs--findings that provide useful policy insights.

The study proceeds as follows. Section 2 briefly introduces the background and theory. Section 3 describes the data and variables. Section 4 presents our econometric results. Section 5 discusses implications for policy and academic research. Section 6 concludes.

2 Background and theory

2.1 Discussion of Chinese patent statistics as an innovation indicator

China established its patent law in 1985, and patent applications grew rather modestly until the end of the 1990s. Since 2000, patent applications have surged dramatically. Applications from domestic inventors in particular surged at an annual rate of 30% from 1999 to 2009 (Figure 1).

(Figure 1)

Rapid growth of patent applications in China is not unexpected given the technological production and market perspectives, Technological development and attractive markets enhance patenting benefits for Chinese firms. Successful Chinese companies, such as Huawei and ZTE, have grown rapidly in technological capabilities and market share (Motohashi, 2009) and patent aggressively in both the domestic and global markets.[1] The surge of patents could indicate growth in "real" innovations as firms invest more in R&D, finally create attractive products, and actively seek patent protection. However, Hu and Jefferson (2009) estimate the patent production function at the firm level and conclude that China's recent R&D intensification is unlikely to be the primary force behind the patent explosion because the elasticity of patenting with respect to R&D is small.

Several scholars list foreign direct investment (FDI) as a contributor to patent growth from a market perspective and assert that patenting by foreign firms increases the propensity to patent among domestic innovators, who need larger patent portfolios to create market barriers or achieve better positions in cross-licensing negotiations (Hu, 2010; Thoma, 2013). Studies have examined other hypotheses, including pro-patent legal changes and the exit of low-patenting-propensity SOEs (Hu & Jefferson, 2009).

Li (2012) confirms with empirical data that subsidy programs established by local governments stimulate patent applications. A natural question is whether patent subsidy programs have caused Chinese applicants to file low-quality patents. Li (2012) finds that the grant rate of patent applications did not decrease in recent years and draws a preliminary conclusion that subsidy programs did not generate patent bubbles. However, various controls are needed to reach a solid conclusion. Several studies take another approach by comparing the economic value or quality of Chinese patents with those requested by foreign firms. Using patent renewal information in the Chinese patent office (SIPO), Zhang and Chen (2012) estimate that patents requested by domestic applicants have a lower value than those requested by foreign applicants and argue that Chinese firms may patent under local policy demand rather than market competition (Zhang & Chen, 2012). However, a time trend analysis has not been performed to verify whether the lower value of domestic patents is a new phenomenon accompanied by the recent explosive growth of patenting. Thoma (2013) assesses the quality of Chinese patent applications in the European Patent Office (EPO), concluding that applications have shorter renewal life cycles. However, because of the high cost of patenting abroad, firms may patent only inventions with high economic value in the EPO or U.S. Patent Office. Firms that actively patent abroad are generally larger, younger, and more export-oriented than those that patent solely in the domestic market (Eberhardt, Helmers, & Yu, 2011).

[1] Huawei Technologies Co. Ltd. topped the list of Patent Cooperation Treaty (PCT) applicants in 2008 according to the World Intellectual Property Organization (WIPO, 2009).

One limitation of using patent renewal data is the inadequate timeliness because of the uncertainty of the life of newly granted patents. A widely used patent value indicator is the number of forward citations (Harhoff et al., 2003; Nagaoka et al., 2010; Trajtenberg, 1990). Trajtenberg (1990) provides a theoretic foundation of using citation data for patent value, arguing that a patent receives more citations when "it opens a new technologically successful line of innovation," just like highly cited academic papers often open a new research topic. The correlation between citation and patent value are empirically confirmed in terms of technological importance (Albert et al., 1991), renewal fees paid (Harhoff, Narin, Scherer, & Vopel, 1999), social value (Trajtenberg, 1990), and market value (B. Hall, Jaffe, & Trajtenberg, 2005). Studies also use citation-weighted patent counts as a more precise indicator of innovation output (Bloom & Van Reenen, 2002; B. H. Hall, Thoma, & Torrisi, 2007; Trajtenberg, 1990). Unfortunately, SIPO does not document citation information. An alternative approach is to quantify the breadth of patent claims by counting either the number of claims (Lanjouw & Schankerman, 2004) or the length of the primary independent claim. Although the number of claims is more widely used in the literature, it has not been well documented in the Chinese context, making it inappropriate for research with large datasets. Malackowski and Barney (2008) propose patent claim length (count of words) as a rough measurement of claim breadth and state the logic as follows:

While claim breadth cannot be precisely measured mechanically or statistically, counting the average number of words per independent claim in an issued patent can serve as rough proxy if taken from a sufficiently large, statistically relevant sample. That is because each word in a claim introduces a further legal limitation upon its scope.

Meeks and Eldering (2010) also propose that claim length can serve as an initial measurement in determining the scope of claims. Because this method is free of the untimeliness limitation, we apply it to Chinese patent statistics to track the impact of patent subsidy programs on the patent quality.

2.2 Patent subsidy programs and their impact on patent-based innovation indicators

Patent subsidy programs were launched at the end of the 1990s in response to a strong governmental concern about domestic firms' technological competiveness after China became a WTO member. To strengthen the awareness of intellectual property rights and encourage domestic firms' "endogenous innovation," the central government issued policy guidelines titled "Strengthen Technology Innovation, Develop High-Tech Industries, and Promote Industrialization [of Inventions]." In response to these guidelines, relatively developed regions such as Shanghai, started promoting patenting activities of local enterprises in 1999. Other provinces followed, and 29 of 30 provinces launched similar programs by 2007 (Li, 2012).

Although the goals are the same, policy design varies across regions, and several governments have made considerable revisions to their policies. Li (2012) describes differences in budget constraints and subsidy amounts between regions. A more subtle difference is the timing and condition of subsidies for invention patents, which are more highly valued and are considered a better indicator of technological capabilities. Subsidy amounts for invention patents are significantly higher than for utility models or design patents.

Applying for an invention patent includes three steps: filing, requesting examination, and examination by the patent office (Liang & Xue, 2010; Yang, 2008). The examination request can be submitted within three years after filing. However, an early request is encouraged as applicants must otherwise pay an application maintenance fee each year for two years after filing. Renewal fees are charged to maintain a granted patent's validity. Figure 2 illustrates the filing and granting procedure for invention patents and relative costs.

(Figure 2)

Figure 2 depicts a typical case, and costs may vary slightly. For example, if a patent has more than 10 claims, the fee includes an additional 150 yuan for each extra claim. However, the examination and registration fees do not change with the number of claims.

Local governments differ in their detailed subsidy conditions. Some governments subsidize only granted patents, intending to promote applications with a good probability of passing the examination. However, such programs may not provide strong incentives for patent filing because three to four years elapse between the filing for and the granting of patents, and the examination results are uncertain. Therefore, some governments provide subsidies during the filing and examination stages, allowing the applicants to obtain subsidies immediately after a patent filing or examination request. Applicants are not required to return the subsidies if the applications are rejected by examiners. The amount of the subsidies also differs. Some governments fully subsidize the filing and/or examination fee, whereas others provide subsidies covering only 50%–80% of the fees. Grant-contingent rewards can vary from 500 yuan (Hebei) to 15,000 yuan (Tibet). Some provinces set no firm amount and provide subsidies on a case-by-case basis. Li (2012) first collected information on regional patent subsidy programs and identified the starting year of those programs.

On the basis of this information, as summarized in Appendix 1, we checked the policy details in official documents published on local government websites and news reports or by telephone interviews of local officials and categorized the types and amounts of subsidies. A description of the provincial and time distribution of subsidy programs is provided in Appendix 2. By 2008, 80 percent of the provinces in mainland China had initiated filing fee subsidies, while about half of the provinces gave examining fee subsidies and grant-contingent rewards. The subsidy programs have been revised in several provinces, e.g. replacing filing fee subsidies with grant-contingent rewards.

The effect of subsidy programs on the quality of patent applications can be analyzed from two perspectives--patent grant rate (number of granted patents divided by number of total filed applications) and the value of granted patents. An application may not be granted in two cases: 1) the applicant does not request an examination within three years after filing, or 2) the invention does not meet the criteria of patentability, including utility, novelty, and non-obviousness. Therefore, a low patent grant rate may result from a lower rate of examination requests after filing and a higher probability of patent denial by examiners. For simplicity, we define the patent grant rate as the number of granted patents divided by the number of filed patents. Thus, patent grant rate = examination request rate × patent allowance rate. Correspondingly, for one application, the probability of grant = probability of examination request × probability of allowance.

The effect of filing fee subsidies should be the simplest to determine as they reduce patenting costs from the outset. One may attempt to patent a technology with a lower patentability when subsidies are available. Such applications have a higher probability of being rejected by the examiner, resulting in a decreased rate of patent grants. Moreover, filing fee subsidies may encourage filings of inventions with great market uncertainties. After filing, the applicant may drop the filed applications before requesting examination if it is clear that the economic value of the patent is lower than the subsequent costs for examination and registration. Thus, filing fee subsidies can result in a lower examination request rate and consequently a lower patent grant rate.

The effect of examination fee subsidies can be complex. On one hand, it decreases the total patenting cost and increases the patenting propensity, which may decrease the patent grant rate as more low-quality patent applications may be filed. On the other hand, examination fee subsidies may encourage applicants to request examination for patents that would have been abandoned because of low patentability or low economic value, resulting in a higher examination request rate. The total effect depends on which effect is dominant.

Grant-contingent rewards give patent assignees economic benefits in addition to exclusive rights. Similar to filing fee and examination fee subsidies, they can increase the trend of patent filing, but will not encourage filing inventions with low patentability as the reward is contingent on patent grants. Therefore, grant-contingent rewards should not affect the patent granting rate. However, grant-contingent rewards can encourage applicants to submit examination requests for inventions with good patentability but low value. Although applicants may not benefit greatly from the exclusive rights of patents, they can benefit from the subsidy programs. The increased examination request rate results in a higher grant rate. One characteristic of low-value patents is a narrow independent claim because competitors can easily bypass the protected scope and develop similar products. If grant-contingent rewards encourage the filing of low-value patents, we observe narrowed claims.

As described by Li (2012), individuals, universities, research institutes, and businesses receive essentially the same support. The subsidy programs make no explicit discrimination between different types of businesses, except for Anhui province, which prohibits foreign-owned and foreign-controlled companies from receiving subsidies. However, subsidy programs' implicit barriers may exclude foreign-funded businesses because recent Chinese government science and technology development policies emphasize promoting "endogenous innovation" or "self-dependent innovation" (Liu, Simon, Sun, & Cao, 2011). Further, patenting by FFEs is more likely to be determined by their headquarters' R&D output and marketing strategies rather than local policy incentives.

3 Data and variables

3.1 Data

This study uses a combined dataset of patent information from SIPO and industrial survey data.

<u>Chinese patent data</u>

Patent data in China is available on the SIPO website (http://www.sipo.gov.cn/). It provides formatted data (only with a subscription) covering all patent applications since 1985, when China established its patent system, and provides the following information (Motohashi, 2008):

(1) Patent application information of invention patents, utility models, and design patents, including application number, application date, IPC classification, patent number of priority applications, applicants' names and addresses, inventors' names, and the name and address of each patent's attorney. For invention patents and utility models, the title, abstract, and primary independent claim are available; for design patents, the title and a short description are provided. There is a time lag of 18 months between the filing and publication of patent applications.

(2) Examination information of invention patents, including examination request date and issue date of granted patents. Because patent examination generally takes three to four years after filing, there is a time lag in obtaining the result of the final examination decision.

(3) Patent renewal information indicating whether a patent has expired because of unpaid maintenance fees. If the applicant pays past-due maintenance and late fees within six months, the terminated patent rights can be revived and the revival records are also available.

The main drawback of China's patent data is inadequate citation information--a widely used patent quality indicator. Another limitation is that full claim information and patent descriptions are not currently available for automatic processing.

This study uses domestic invention applications from 1998 to 2008 as the base dataset. We limit our research to invention patents because they represent innovations of high quality. No substantial examination is required for the other two types of patents, utility models and design patents. Thus, it is difficult to determine whether they have novelty and value. Also, invention patents represent the major investment target of all regions' patent subsidy programs, whereas some regions, such as Zhejiang and Anhui provinces, do not subsidize utility models and design patents. We truncate old applications before 1998 to match firm data, which is available only from 1998 onward. Patents requested after 2008 are also truncated because their examination information was not available by the end of 2012. The time span is suitable for testing the subsidy programs as those programs were initiated between 1999 and 2007.

Industrial survey data

Industrial survey data is based on annual investigations by the National Bureau of Statistics of China. The data is also called "Industrial survey data on Large and Medium Size Firms" or "Industrial survey data on manufacturing firms." It has been used in economic studies on several topics: SOE privatization and ownership reform

(Jefferson, Hu, Guan, & Yu, 2003; Tong, 2009); foreign direct investment (Xu & Sheng, 2012); corporate governance (Cai & Liu, 2009); R&D and firm innovation (Hu & Jefferson, 2009; Li, 2012; Motohashi & Yun, 2007), for example. The data covers roughly 150,000 businesses from 1998 to 2002. More businesses were then added, and since 2009, it has covered roughly 380,000 businesses. It includes firm profiles, such as name, ownership, location, established year, and industry, and financial information on assets, revenue, profit, and cash flow. The data covers 31 provinces in Mainland China. Shares of covered businesses in each province are proportional to their shares in China's GDP. Thus, the data does not have a severe regional bias.

A major limitation of this data is that information on R&D expenditures is absent for a large number of companies, especially in the years before 2005. Availability of R&D information is unlikely a random selection as larger firms tend to record R&D costs more precisely and report it in surveys. Therefore, we use two datasets in this study: 1) a small group of companies with R&D information, which allows us to estimate the patent-R&D expenditure elasticity; and 2) a large dataset without R&D information, which allows us to specifically evaluate the effects of different kinds of patent subsidies on patent quality and to provide more general results.

The first dataset covers a time span of 10 years from 1998 to 2007, during which R&D data is available for about 20,000 businesses each year, or 10% of the total industrial survey data. However, the R&D expenditure statistics are noisy, with several types of mistakes for some observations. First, R&D expenditure is set at zero for many observations, but we cannot tell whether that means the firm does not engage in R&D or whether the data is just missing; we thus exclude those observations. Second, some observations have R&D expenditures less than 10,000 yuan, which are very likely mistaken inputs because it is unrealistic for a firm to engage in R&D with such a small amount of money. These observations are excluded from our sample. Third, some firms have abnormal figures for R&D expenditures in the year 2005 compared to their values in other years. We dropped observations if a particular R&D expenditure grew tenfold or decreased by 90 percent from 2005 to 2006. We also exclude firms with one or two years' R&D expenditure information during the ten-year span as it is difficult to verify whether the data is reliable. After cleaning, we get an average of 6,267 observations per year for 10 years, which includes 9,969 firms.

<u>Merging industrial survey data with patent data</u>

We match the sampled firms in the industrial survey data with the Chinese patent database by their names. As there is a time lag between R&D input and the final output of applications, we use the patent data from 1999 to 2008. We find that 1,419 firms (14.2% of all the sampled firms) have filed at least one invention patent during the ten-year time span. Therefore, we get unbalanced panel data (Dataset A), which is summarized in Table 1.

(Table 1)

The industrial survey questionnaire also has columns asking the number of patents and invention patents a firm applied for in the surveyed year; these numbers are used in studies by Hu (2009) and Li (2012). By comparison, we find two types of noise in these numbers: (1) mistakenly input total number of patents owned rather than applied for in a year; and (2) mistakenly counted utility patents or design patents in the number of invention patents. Merging patent data with survey data can give more accurate results. Moreover, the merged dataset allows us to determine the number of granted patents, which cannot be covered by annual surveys. Merging patent data with survey data has a weakness: some private firms apply for patents in their owners' names instead of the firms' names, which means they cannot be counted. This kind of problem is generally observed in small enterprises whose technologies are mainly developed by the founding members.

To evaluate the policy impacts in detail, we compose a second dataset without requiring R&D information. Matching all the observations in the industrial survey data with patent data by names of companies, we get a dataset of 126,386 applications from 12,208 businesses, which accounts for 44.6% of domestic businesses' invention applications filed from 1998 to 2008. However, those applications are highly concentrated, with the top ten applicants contributing 46.4% of the total applications. Those applicants include Huawei and ZTE, which are known as aggressive global patent applicants. To use detailed information of each patent, such as patent classifications and claims, we have to perform the estimations at the patent level, not at the firm level. Including the top applicants' large portfolio of patents in the estimations may bring bias to the results. For example, Huawei and ZTE filed some high-quality patents in the 2000s, which have been accepted as "essential patents" in mobile communication standardization (Kang, Huo, & Motohashi, 2014). The government of Guangdong province, where the two companies are located, also initiated patent subsidy programs in 2000. Thus, subsidies could have a "correlation" with "high quality," but not have causality. This kind of noise can be significant because of the two firms' large share of patent applications. Thus, we exclude applications from the 12 largest applicants, meaning those that have portfolios of more than 1,000 patents, which results in a dataset of 60,244 applications from 12,197 businesses (Dataset B). We divide those applications according to the ownership of applicants: SOEs, POEs, and FFEs (including Hongkong-Macau-Taiwan invested businesses).

3.2 Methodology and variables

(1) Estimation of patent production function

We use Dataset A to estimate a patent production function suggested in various literature (Griliches, 1998; Hu & Jefferson, 2009; Li, 2012; Pakes & Griliches, 1984):

$$log(P_{i,t}) = \alpha log(R\&D_{i,t-1}) + \beta S_{i,t} + \gamma X_{i,t} + Constant$$

$P_{i,t}$ is the number of applications or granted patents applied for by firm *i* in year *t*; $R\&D_{i,t-1}$ is the real R&D expenditure in year t-1; $S_{i,t}$ stands for patent subsidies firm *i* received in year t; $X_{i,t}$ stands for other control variables. Literature has suggested that there is a lag effect in relationships between R&D and patent applications, but only a one-year lag is consistently significant in different models (Wang & Hagedoorn, 2014). After several experimental estimations, we find that a one-year lag of R&D expenditures is more significant than either contemporaneous or longer lagged values. Also, using more lagged variables will decrease our sample significantly. Therefore, we only include one-year lag R&D expenditures as an explanatory variable. A firm may not apply for any patents in a particular year, resulting in $P_{i,t}$ as zero. To calculate $log(P_{i,t})$, we follow the approach of Pakes and Griliches (1984) to add a small number (1/3) to $P_{i,t}$ for all the observations. Thus, we have the following dependent variables:

log(Applications): log (number of applications in year *t* + 1/3);
log(Grants): log (number of patents applied for in year *t* and granted within 4 years after filing + 1/6).

Patent granting takes 3.87 years on average after filing with the SIPO. The examination process may last longer for some patents because of delays on the sides of both the applicant and examiner. For a recently filed patent, we cannot obtain accurate information as to whether it will be granted. Thus, we use a time window of four years after filing; 83% of domestic applications have received decisions within that time. Since the chance that an application will be granted is about 50%, we add 1/3 to the number of applications, but 1/6 to the number of grants.

We define several category variables to indicate the subsidies received by each firm in year *t*.

FilingSub: category variable; 1 if the filing fee is fully subsidized in the province where the applicant is located in year *t*, 0.5 if partly, 0 if not.

ExamSub: category variable; 1 if the examination fee is fully subsidized, 0.5 if partly, subsidized 0 if not subsidized.
GrantSub: category variable; 1 if grant-contingent rewards are no less than 2000 yuan, 0.5 if less than 2000 yuan, 0 if no rewards are made.
Since filing fee subsidies and examination fee subsidies are provided instantaneously in many regions, the two variables have a high correlation in the small Dataset A. To avoid multicollinearity problems, we create another variable, *ApplSub* = *FilingSub* + *ExamSub*, to indicate the subsidies which are not conditioned on grants.

We use *log(Employee)* to control for size effect and include 2-digit NBS industrial code dummies in our patent production estimation models.

(2) Estimation of subsidy policy impacts on patent quality

We use three steps to estimate the effect of patent subsidy programs using Dataset B. First, we use a probit model to estimate the aggregate effects of filing fee subsidies, examination fee subsidies, and grant-contingent rewards on the patent grant rate. We assume that before filing, the applicants have considered all available subsidies provided by local governments, including grant-contingent rewards. Second, we test whether grant-contingent rewards affect the claim breadth using ordinary least squares (OLS) estimations. Finally, we use the Heckman two-step model to analyze whether the effect of grant-contingent rewards is reflected in the allowance rate. Dependent variables are defined as follows.
Granted: dummy variable; equals 1 if an application is granted within four years of filing.
Examined: dummy variable; equals 1 if the applicant files an examination request for a patent application.
ClaimScope: inverse of logarithm of noun counts in a patent's primary independent claim. We use the inverse because a larger number of nouns indicate a narrower claim scope.

Our measurement of claim breadth is based on Malackowski and Barney (2012), but with modifications. We count only the number of nouns rather than all the words in the claims, because nouns represent more substantial technology factors and are a better proxy of "legal limitation." As the Chinese language does not use spaces to separate words in a sentence, we use the ICTCLAS Chinese lexical analysis program developed by the China Academy of Science to separate and tag nouns. We separate process and usage patents from device patents by text mining abstracts and control for this in our regressions because the two types of patents have significantly different conventions in claim drafting.

Our independent variables include *FilingSub, ExamSub* and *GrantSub*, which are defined above. The following variables are included as controls:

Non-device: dummy; 1 if the application is for a product or a device, 0 if it is about a method, process, or new usage.

Experience: years between the current application and the applicant's first application. The literature suggests that experienced applicants may be skilled in assessing the patentability of technologies, drafting strong application documents, and communicating with examiners (Thoma, 2013). Thus, we use this as a control in our models. The models include technology and year dummies. Technology dummies are generated from the NBER patent classifications based on the IPC, which includes 33 categories. Moreover, we include five regional dummies that indicate whether the applicants are located in Guangdong, Beijing, Shanghai, Jiangsu, or Zhejiang. These top five regions contributed 59% of domestic applications from 1998 to 2008. We use the logarithm of the number of employees to control for firm size effect.

3.3 Descriptive trends

(1) Patents examination request rate

(Figure 3)

Figure 3 illustrates the trend of the patent examination request rate. Besides domestic enterprises, which are the target of our analysis, we also plot the numbers of other types of applicants for comparison. Both domestic and foreign applications have exhibited a higher examination request rate since 2001. Foreign applicants and domestic non-business organizations (NBOs) have requested examination for most of their filed patents in recent years, whereas individuals more often let their filed applications lapse without requesting examination, reflecting their budget constraints.

(2) Patent allowance rate

(Figure 4)

Figure 4 depicts the allowance rate of examined patents. Except for the year effect of the patent law amendment in 2000, the patent allowance rate has been generally steady in recent years. The allowance rate of patent applications from NBOs has been decreasing gradually in recent years.

4 Empirical results

4.1 Patents production function and the effectiveness of patent statistics

Table 2 reports the estimations of the patent applications production function using OLS and fixed effects linear models.[2] In Model (2) and Model (4), cross-product terms are added to test interaction effects between R&D expenditure and subsidies. To make the results with interaction effects more interpretable, *log(R&D)* is centered to its mean in all the models (Afshartous & Preston, 2011). The results in Model (1) and Model (3) show that *log(R&D)* is positively significant, even when size effects are controlled. Thus, patent growth is at least partly driven by investment in R&D of Chinese firms. *ApplSub* is positively significant, confirming that patent applications are increased by filing and examination fee subsidies. A more interesting result is that *GrantSub* is also strongly significant, showing that applicants also consider rewards contingent on grants when deciding whether to patent.

The cross term of *log(R&D)* and *GrantSub* shows a positive significance only in the fixed effects model (Model (4)). It can be said that rewards contingent on grants will have a stronger impact when a firm invests more in R&D as they are more confident that their applications can pass examination and they can obtain the rewards after the grants. However, this interaction effect is not significant in OLS models, suggesting no significant difference in the effectiveness of grant-contingent subsidies among firms with large or small R&D expenditures.

(Table 2)

Table 3 reports the estimations results of granted patents. The result is similar to what we get from estimations on patent applications. The significant positive effects of subsidies show that a significant part of those applications stimulated by policy incentives also passed examination eventually and resulted in a boosted number of patent grants. However, the cross-production term of *log(R&D)* and *GrantSub* is not significant in fixed effects estimations.

(Table 3)

To better understand how patent growth is driven by R&D expenditures and policy incentives, we construct a simulation based on the estimation results. We choose 86 firms from the total 1,419 firms with R&D expenditure data available for ten years, and predict their applications and grants with/without subsidies. Figure 5 shows the

[2] For our dataset, the Hausman specification test supports using a fixed effects model rather than a random effects model, and thus, random effects estimation results are not reported here.

result of the "average" simulated numbers. Since the numbers of applications/grants are highly skewed, the sample mean does not reflect a "typical" firm's outcome (Hu & Jefferson, 2009). Thus, we first calculate the mean of predicted *log(Applications)* and *log(Grants)* respectively, and plot the number of applications and grants calculated from the mean of logarithms in Figure 5.

(Figure 5)

Figure 5 illustrates the contribution of patent subsidies programs in both applications and grants. The gap between predicted numbers with/without subsidies grows as more and more provinces gradually adopted patent subsidy programs. After 2006, the gap becomes stable as nearly all provinces had adopted those kinds of programs. In 2008, the number of patent applications was increased by 23%, while patent grants were increased by 26%. The result is surprising, because one would expect that low-quality patent applications filed under policy incentives may have a higher chance of being rejected in examination and the granted number of patents would not be increased on the same scale as applications. The result is contrary: the grant ratio is higher under subsidies than the simulated number without subsidies. It is necessary to take a more detailed look at how the detailed policy designs affect patenting behavior and quality of granted patents. Nevertheless, even without patent subsidies, we see quick growth in both applications and grants, which is driven by growth in R&D.

(Table 4)

From the input view, we find no significant difference in patent statistics based on applications and grants data as they both are increased by subsidies. Then, we test whether one is better than the other from an output view: are the two types of statistics useful in predicting the performance of businesses? We make a preliminary estimation of return on asset (*ROA*) using Dataset A and report the results in Table 4. The explanatory variables include one-year lagged R&D expenditure and logarithms of applications/grants. In OLS models, both lagged *log(Applications)* and *log(Grants)* are significant when *log(R&D)* are controlled. In fixed effects models, only *log(Grants)* is slightly significant. The results suggest that patent statistics have value more than as merely a proxy for investment in R&D, and are especially valuable in making cross-firm comparisons. This can be theoretically explained in two ways: 1) patent counts can partly reflect the R&D efficiency as they provide an indicator of R&D output; 2) formal intellectual property protection can help a firm capture more rents through a market monopoly. A strict test of casualties between financial performance and patenting activities needs more solid theory and model specifications, which is beyond the scope of this paper. However, the result provides preliminary clues indicating that patent statistics are meaningful for measuring "real" innovations from an output view.

4.2 Effect of patent subsidy programs on probability of patent granting

Using *Granted* as the dependent variable, we estimate the effects of three kinds of subsidies on the granting probability with probit models. Table 5 shows that *FilingSub* is negatively significant whereas *ExamSub* and *GrantSub* are positively significant in the estimations with the entire Dataset B. The positive significance of *ExamSub* reveals that the effect of examination fee subsidies on increasing the trend for requesting examination is more significant than its effect on encouraging low-quality applications. Grant-contingent rewards have a similar effect on increasing the examination rate. However, the positive significance of *GrantSub* may also result from its effect on increasing the probability of allowance. Table 5 reports a negative significance of *ClaimScope*, suggesting that applications with a narrower claim scope are more likely to be granted. In Section 4.3, we test whether grant-contingent rewards encourage applicants to file applications with a narrow claims scope to more easily obtain patent grants.

(Table 5)

In estimations using sub-datasets, the effects of examination fee subsidies and grant-contingent rewards vary across the categories of applicants. *ExamSub* significantly increased the probability of grants for applications filed by POEs, but decreased it for SOEs and FFEs, suggesting that the effect of examination fee subsidies on increasing the propensity of requesting examination is less significant than its effect on encouraging low-quality applications from SOEs and FFEs. *GrantSub* is positively significant for POEs, but is not significant for SOEs and FFEs, suggesting that grant-contingent rewards may increase the propensity of examination requests for POEs, but not for SOEs and FFEs.

4.3 Effect of grant-contingent rewards on breadth of patent claims

Using OLS models, we estimate whether grant-contingent rewards encourage applicants to file patents with narrower claims. The dependent variable is *ClaimScope*. Table 6 reports that *GrantSub* is negatively significant. The result suggests that grant-contingent rewards encourage more patents with a narrow claim scope and thus lower economic value.

(Table 6)

In estimations using the sub-dataset of different types of enterprises, though *GrantSub* is not significant for SOEs and POEs, the coefficient is negative. *GrantSub* is significantly negative in estimations using applications from FFEs, suggesting that FFEs are also affected by patent subsidy programs.

4. 4 Effects of patent subsidies on probability of patent allowance

Our probit estimation results in Section 4.2 demonstrate that grant-contingent rewards increase the probability of patent granting. However, it is unclear whether the effect results only from a similar effect to that of examination subsidies on increasing the propensity of examination requests, or whether grant-contingent rewards also increase the probability of patent allowance in the examination process. Results in Section 4.3 demonstrate that grant-contingent rewards encourage the filing of patent applications with a narrow claim scope, which may result from a strategy to increase the probability of allowance.

There is a self-selection problem with a direct estimation of the probability of patent allowance with examined patent applications (Heckman, 1979): applicants are more likely to select patents with higher grant probability. The allowance rate of examined applications does not provide a good estimation of the allowance rate of applications dropped before examination if those applications have been examined. Bias can be significant because filing and examination fee subsidies can affect the decision to request examination. To test whether grant-contingent rewards increase the probability of patent allowance, we use Heckman's two-step selection models. We use all applications as observations rather than using only examined patents, and control for the selection effect in examination requests. Cross production terms between *GrantSub* and *ClaimScope* are included to test the interaction effects.

(Table 7)

Table 7 reports the results. *GrantSub* is positively significant in estimations without cross-production terms between *GrantSub* and *ClaimScope*, suggesting that *GrantSub* generally increases the probability of patent allowance when the selection effect in examination requests is controlled. An institutional perspective is that patent examination results are not affected by any types of subsidy programs because examiners make the decision to approve or reject. However, the applicant's actions can affect the outcome of examination. First, applicants may make greater efforts in drafting better patent descriptions and responding to Office action (a document of reasons for possible rejection) from examiners if grant-contingent rewards exist. Second, applicants may narrow the breadth of claims to more easily obtain a patent grant. Our results in Section 4.3 suggest greater probability for the second scenario. The cross-production terms show a slightly negative significance, suggesting that grant-contingent rewards may encourage some businesses to strategically narrow patent claim scope to more easily obtain the patent.

In estimations with data subsets, the results vary across different types of applicants. *GrantSub* is positively significant for POEs, suggesting that grant-contingent rewards increase the allowance rate of patent applications from POEs. However, *GrantSub* is not significant for SOEs and FFEs, suggesting that SOEs and FFEs are less interested in rewards contingent on grants.

4.5 Robustness check

There is a potential endogeneity problem in this study: whether patent subsidy policy variables are perfectly "exogenous," as the decisions made by a local government may reflect the innovation capabilities of firms, universities, and individuals in that region as well as its budget constraints. To address this problem, we use per capita GDP, lagged patenting intensity (number of patents/GDP), and averaged patent quality indicators (claim scope) as explanatory variables for provincial policy differences. We find a consistent positive significant effect of per capita GDP in launching subsidies at the application stage, suggesting that budget constraints explain part of the provincial variations, as provinces with higher per capita GDP, such as Beijing and Shanghai, are more developed and have higher budgets. However, for subsidies contingent on grants, per capita GDP is not significant, suggesting that it is not simply a budget issue, but rather, more complex considerations are included in policy decisions. We did not find significant effects of lagged patenting intensities or averaged patent quality indicators in policy decisions. Thus, our study does not suffer from serious endogeneity problems.

We made several treatments to the dataset, including adding a small number (1/3 or 1/6) to make *log(Applications)* or *log(Grants)* meaningful. We perform a robust check of this treatment by using negative binomial models with/without fixed effects to estimate the patent production function (Appendices 3 and 4). The results are generally consistent. However, the interaction terms of *log(R&D)* and *ApplSub* or *GrantSub* show a negative significance despite insignificant results in the OLS estimation. The interpretation is that firms with lower R&D expenditure are more likely to be motivated by subsidies. Compared to Li (2012)'s finding of a 60% increase in patent applications driven by patent subsidies using provincial level data, our simulation result is more modest. One possible reason is that firms reporting R&D are generally large firms, and our estimation may have a downward bias. When fixed effects are included, the interaction term between *log(R&D)* and *GrantSub* is still negatively significant. There is an argument that a fixed effects negative binominal model is not a true fixed effects method (Allison & Waterman, 2002). Therefore, the interpretation of the interaction effects in Table 2 and Table 3 should be made cautiously.

The two datasets used in our sample have their respective limitations: Dataset A with R&D expenditure data only covers 10% of firms that are covered in the industrial survey and have patent applications; Dataset B does not allow a control for R&D intensity in estimations. We checked the estimation result of patent quality by controlling for R&D intensity (R&D/Sales) using a small dataset of patents applied by firms with R&D data available and report results in Appendix 5. Higher R&D intensity increases the likelihood of patent grants and the breadth of patent claims, and thus indicates higher quality. The estimated coefficients for *GrantSub* and *ApplSub* are consistent with the results in Table 5 and Table 6. However, *ExamSub* shows a negative significance, demonstrating that its effect in encouraging low-quality filing outweighs an increasing examination request rate. This occurs because firms reporting R&D expenditures generally are larger firms which seldom abandon filed applications before examination (96% applications entered the examination process). The benefits of examination fee subsidies are considered in the decision of whether to file, rather than whether to request an examination.

We also tested the estimation result without excluding patents of the top applicants. The results are generally consistent with what we found by excluding them, except that the interaction term between *GrantSub* and *ClaimScope* becomes insignificant in Heckman's two-stage estimations. The reason could be that those top applicants are less likely to sacrifice claim breadth simply for the sake of grant contingent rewards.

In general, our results are robust, though for special datasets, the interpretation of some variables should be made cautiously.

5 Discussion

5.1 Patent statistics as an innovation indicator

By merging patent data with industrial survey data, we test whether patent statistics are a reliable indicator of innovations in China from different perspectives. The results do not lead to a straightforward conclusion, but reveal a need for careful interpretation.

Both patent applications and patent grants have a strong correlation with R&D expenditures. Our simulation results show that patent growth reflects a growth of R&D expenditures of enterprises even without subsidies stimulation. Thus, patent statistics can serve as an indicator of inventive activities in China. Based on a variety of empirical studies, Griliches (1998) concludes that patent counts can be a good proxy for R&D expenditures when R&D expenditures are not available. Though the elasticity of patent-R&D of Chinese firms is not as strong as observed in other countries, the correlation allows it to be considered as a non-perfect, but useful measure of investment in innovation. From an output view, we also find that patent statistics are predictive of financial performance measured by ROA. Though further studies are needed to confirm the underlying causatives, the results draw possibilities of including innovation measurement in financial analysis of Chinese firms.

However, policy impacts cannot be neglected as they create significant bias to patent statistics. In quantity, subsidies have increased patent counts by more than 20 percent. Because patent policies are initiated at the local government level and are not harmonized, it is necessary to make adjustments to compare regional innovation performance. An unfortunate fact is that statistics based on patent grants are not closer to the "real numbers" than application statistics. A more implicit bias lies in the quality of granted patents. Our results reveal that applicants strategically file patents with narrow claim scopes to obtain patents more easily after examination. The quality bias between patents filed with/without grant-contingent rewards makes patent counts unreliable. Although adjusting patent statistics using citation data is highly recommended in the literature, it is not practical for Chinese patents where citation data is not available. Patent count weighted by claim scope presents another practical option.

Nevertheless, patent statistics are a useful and valuable measure of innovation in China, as in other countries. It just requires more careful control and interpretation due to the complex policy incentives.

5.2 Toward a better subsidy policy design

Patent subsidy programs enacted by local governments have contributed to the surge of patenting in China. These programs have had a positive influence in promoting recognition of intellectual property (IP) value, easing financially constrained SMEs' burden of obtaining patents, and encouraging inventions. These influences have significant meaning in a weak intellectual property environment such as China, which is attempting to transform from "imitation" to "innovation." However, our empirical study confirms a general concern that patent subsidies have side effects in that they encourage applications of lower quality.

Policy makers should consider these side effects and consider the differentiated policy incentive designs in different regions. The variety of practices allows us to analyze their effects and suggests implications for future policy modifications.

The first question is whether subsidies should be contingent on grants. Our study provides evidence that patent subsidies before grants decrease the patent allowance rate, indicating that these subsidies encourage filing of inventions lacking novelty or that are obvious. From the perspective of policy efficiency, grant-contingent subsidies or rewards are better choices for increasing granted patents, which is a policy target as many provinces treat the number of granted patents as an assessment of local innovative capability. Our results demonstrate that grant-contingent rewards improve the grant rate as well as the allowance rate.

However, grant-contingent rewards are not perfect. They can prevent applicants from filing patents of low patentability, but cannot prevent them from filing patents of low value. Our empirical results reveal that grant-contingent rewards encourage the filing of patents with a narrow claim scope, which is a sign of lower economic value. Firms have incentive to increase grant probability by sacrificing broad claims. This reaction is implicit and difficult to identify.

A more complex issue is whether the examination fee should be subsidized. Examination fee subsidies have the same function as filing fee subsidies in encouraging more patent filings. They also have a similar effect to that of grant-contingent rewards in increasing the examination request rate and grant rate, as our empirical results demonstrate. However, they disable the filtering effect of the examination fee system. The examination fee requires an applicant to reconsider the patentability and economic value of its application after filing. For example, an applicant may discover prior art making the patent unlikely to be granted, or he may become less optimistic about appropriation potential after filing. Requesting examination would not be economically beneficial in these cases. Dropped applications before examination can decrease patent examiner workload, but subsidizing the examination fee may weaken the motivation to make a careful assessment before requesting examination.

Although a complete economic assessment of patent subsidy programs is beyond the scope of this study, our results provide empirical evidence of "strategic patenting" driven by various subsidies, which may represent an undesirable policy effect, thus necessitating continuing policy modification.

6 Conclusions

Patent data has been widely used in economic studies in various aspects. However, studies using Chinese patent data have been limited due to the shortcomings of patent data itself and a lack of linkage with financial data of enterprises. The shortcomings of Chinese patent data are reflected in the lack of citations and well-documented claims, as well as policy stimulated noises. This paper attempts to clarify and solve those problems.

First, we merge patent data with widely used industrial survey data by firm names. Patent applications by matched 12,208 businesses account for almost half of the total applications, providing a very representative dataset of innovation activities in China. The merged dataset makes it possible to investigate the relationship between financial performance and innovation activities. Though R&D information is limited to 10% of all the businesses, a large dataset can be created by using patent count as a rough proxy for R&D expenditure.

Second, with the merged dataset, we make a bibliometric analysis of patenting activities of Chinese LMEs and test whether patent statistics based on applications and grants are a good indicator of innovation in China. Our empirical results show that patent count is correlated with R&D input and financial output, which suggests that patent statistics are an informative indicator of innovations in China. However, policy impact is also significant. By simulation, we find a more than 20% increase of patent counts driven by policy, and more importantly, deteriorated patent quality in narrower claims. We emphasize the necessity of adjustments and provide a novel method of using the number of nouns in claims to quantify claim scope, thus overcoming the shortcomings of Chinese patent data that have no citations or lack well-documented patent claim information.

Third, we extend prior studies on patent subsidies programs in two aspects: 1) detailed clarification of policy designs and their impacts; and 2) evaluation of policy impacts on both quantity and quality. We provide solid evidence that subsidizing the filing fee generates applications of lower quality. More local governments seem to have identified this problem recently as we observe that certain governments, such as Zhejiang and Hunan, have suspended the filing fee and examination fee subsidy and replaced it with grant-contingent rewards. However, the policy shift cannot prevent applicants from strategically filing low-value patents, which waste the government budget for promoting innovations. We observe a more complex effect for examination fee subsidies. Although these subsidies have increased the patent grant rate, the increase results from more examination requests for low-quality or low-value patents. That is, the subsidies hindered the filtering effect of examination fees and generated an excessive workload for patent examiners.

Further research is needed to identify how these subsidy programs have affected R&D activities and intellectual property management, and whether they have achieved the goal of promoting "real" innovation output. Increases in patenting are beneficial to society in that more disclosure of inventions prevents potential duplication of research among players and increases the technology market. However, excessive patents generate complexity in the technology landscape and a "patent thicket" that stifles subsequent innovation. Understanding such social impacts of patenting is important for interpreting patent statistics as an innovation indicator.

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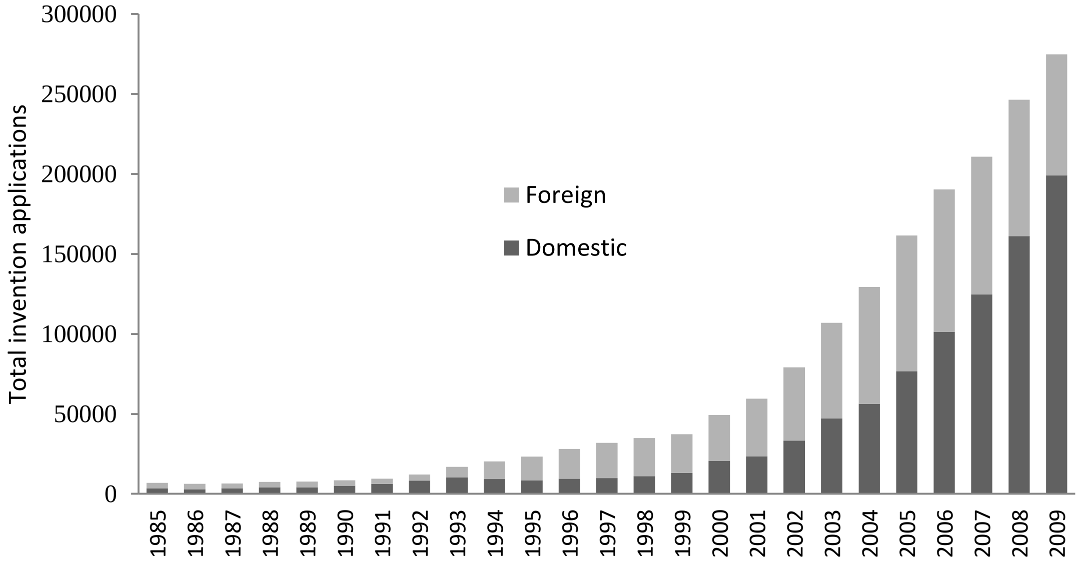

Figure.1 Growth of invention patent applications in SIPO (1985~2009)

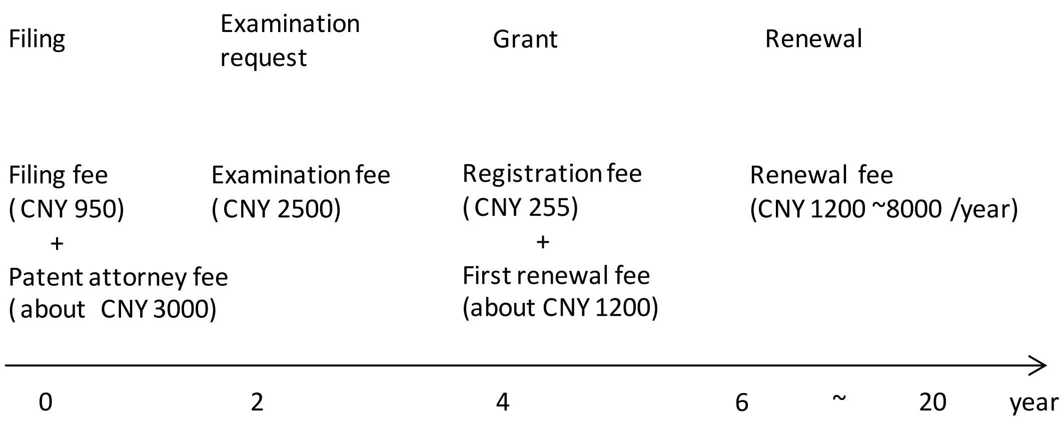

Figure.2 Filing and granting procedure for invention patents and relative costs in SIPO

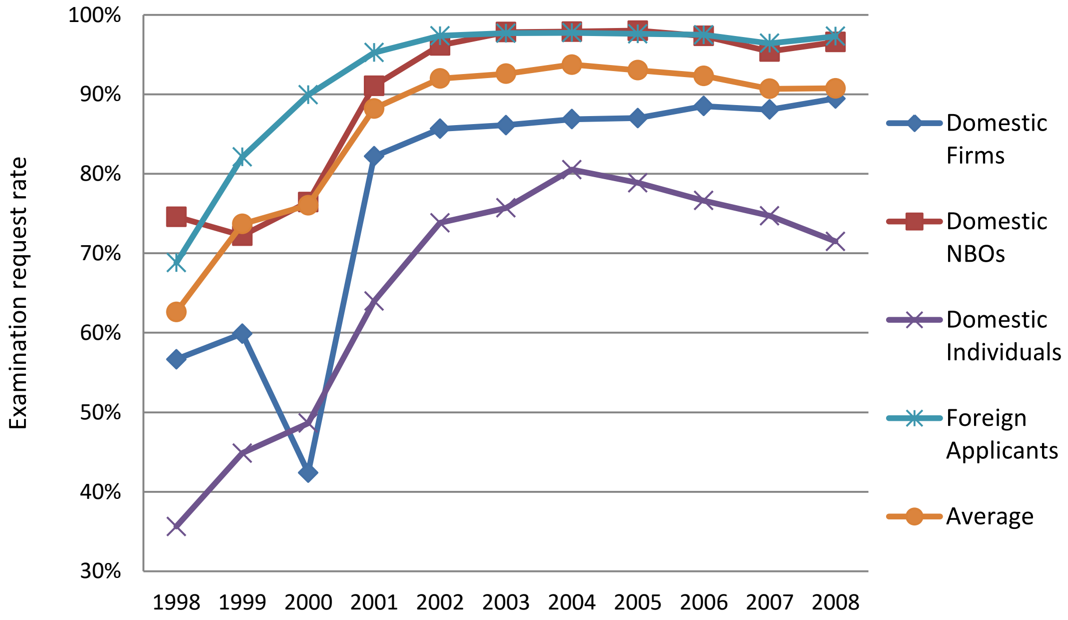

Figure. 3 Examination request rate of invention applications in SIPO (1998~2008)

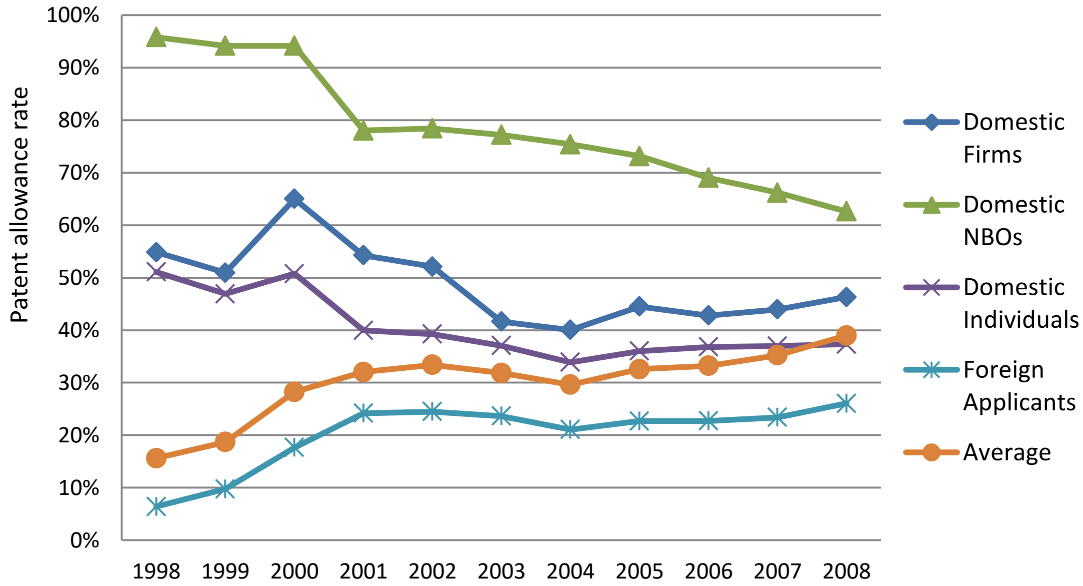

Figure. 4 Allowance rate of examined invention applications in SIPO (1998~2008)

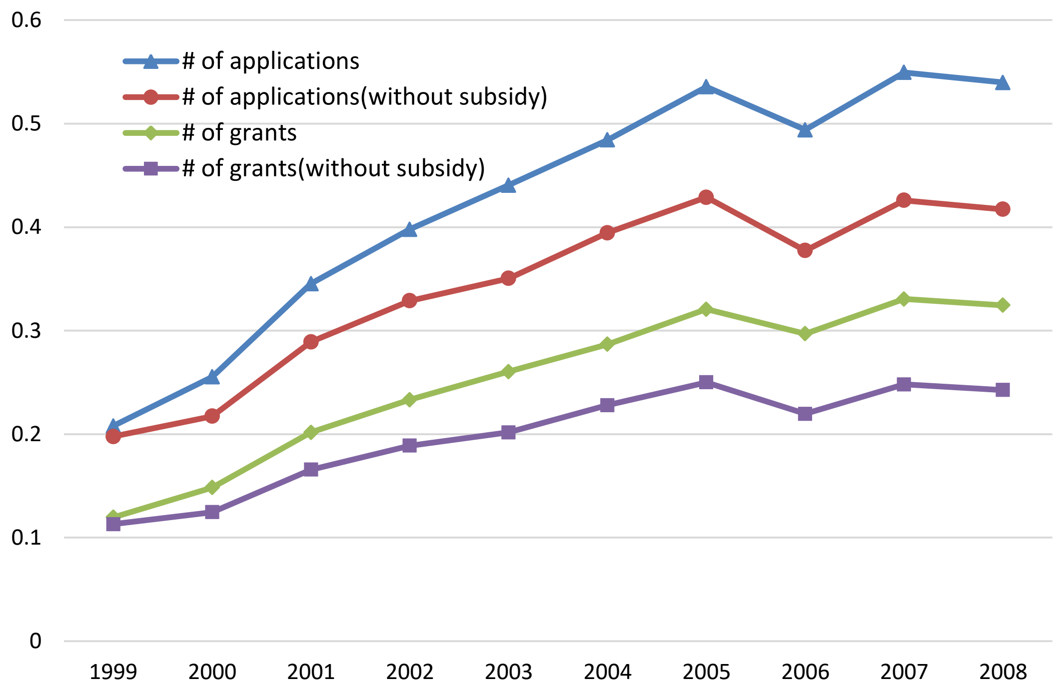

Figure. 5 Simulation of patent subsidies impacts on patent growth

Table 1. Summary statistics of Dataset A

Application year	Frequency	Percentage	Cumulative Distribution
1999	336	4.44%	4.44%
2000	399	5.27%	9.71%
2001	466	6.16%	15.86%
2002	565	7.46%	23.33%
2003	491	6.49%	29.81%
2004	791	10.45%	40.26%
2005	934	12.34%	52.60%
2006	1,117	14.75%	67.35%
2007	1,223	16.15%	83.50%
2008	1,249	16.50%	100.00%
Observations: 7, 571			
Number of firms: 1, 419			
	Min	Mean	Max
Observations per firm:	3	5.3	10
Real R&D expenditure(Unit: 1000 yuan)*	18,707	5	5,297,906
Number of applications per year	0	5.6	4,040
Number of grants per year	0	3.6	2,539

*R&D expenditure is adjusted by GDP deflator with its value of 1998 as base.

Table 2. Patent production function estimation: applications

	OLS		Fixed effects	
	(1)	(2)	(3)	(4)
	log(Applications)	*log(Applications)*	*log(Applications)*	*log(Applications)*
log(R&D)	0.159***	0.163***	0.0795***	0.0550***
	(0.00784)	(0.0125)	(0.00959)	(0.0140)
ApplSub	0.0324***	0.0323***	0.0678***	0.0700***
	(0.00789)	(0.00791)	(0.0122)	(0.0122)
GrantSub	0.115***	0.115***	0.225***	0.224***
	(0.0142)	(0.0142)	(0.0209)	(0.0209)
log(R&D) × ApplSub		-0.00199		0.0143
		(0.00933)		(0.0108)
log(R&D) × GrantSub		-0.0109		0.0459**
		(0.0171)		(0.0203)
log(Employee)	0.143***	0.143***	0.186***	0.183***
	(0.0135)	(0.0135)	(0.0363)	(0.0363)
SOE	-0.138***	-0.138***	-0.107***	-0.109***
	(0.0138)	(0.0138)	(0.0222)	(0.0222)
FFE	0.0761***	0.0767***	0.0133	0.0123
	(0.0224)	(0.0224)	(0.0432)	(0.0432)
Constant	-0.682***	-0.683***	-0.826***	-0.819***
	(0.0463)	(0.0463)	(0.116)	(0.116)
Industry dummies	Yes	Yes	Yes	Yes
Observations	7571	7571	7571	7571
Adjusted R2	0.156	0.155		
LogLik	-5163.5	-5163.3	-2784.2	-2779.3

Standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

ApplSub: subsidies of filing fee or examination fee;

GrantSub: reward contingent on patent grants.

Table 3. Patent production function estimation: grants

	OLS		Fixed effects	
	log(Grants)	*log(Grants)*	*log(Grants)*	*log(Grants)*
log(R&D)	0.168***	0.174***	0.0922***	0.0644***
	(0.00917)	(0.0146)	(0.0118)	(0.0173)
ApplSub	0.0365***	0.0366***	0.0800***	0.0829***
	(0.00923)	(0.00925)	(0.0150)	(0.0151)
GrantSub	0.145***	0.145***	0.281***	0.281***
	(0.0166)	(0.0166)	(0.0258)	(0.0258)
log(R&D) × ApplSub		-0.000882		0.0210
		(0.0109)		(0.0134)
log(R&D) × GrantSub		-0.0190		0.0358
		(0.0201)		(0.0250)
log(Employee)	0.150***	0.150***	0.201***	0.198***
	(0.0158)	(0.0158)	(0.0448)	(0.0448)
SOE	-0.153***	-0.153***	-0.126***	-0.128***
	(0.0161)	(0.0161)	(0.0274)	(0.0274)
FFE	0.0725***	0.0733***	0.0283	0.0271
	(0.0262)	(0.0262)	(0.0533)	(0.0533)
Constant	-0.967***	-0.967***	-1.146***	-1.138***
	(0.0541)	(0.0541)	(0.143)	(0.143)
Industry dummies	Yes	Yes	Yes	Yes
Observations	7571	7571	7571	7571
Adjusted R2	0.134	0.134		
LogLik	-6353.0	-6352.6	-4378.1	-4374.8

Standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
ApplSub: subsidies of filing fee or examination fee;
GrantSub: reward contingent on patent grants.

Table 4. Estimation of ROA using patent statistics

	OLS		Fixed effects	
	ROA	*ROA*	*ROA*	*ROA*
log(R&D)	0.0151***	0.0149***	0.0100***	0.00997***
	(7.56)	(7.49)	(4.98)	(4.96)
log(Applications)	0.00743***		0.00383	
	(2.64)		(1.44)	
log(Grants)		0.00840***		0.00402*
		(3.42)		(1.83)
log(Employee)	-0.0237***	-0.0239***	-0.00176	-0.00156
	(-7.23)	(-7.33)	(-0.23)	(-0.20)
SOE	-0.0260***	-0.0260***	-0.00900**	-0.00905**
	(-8.08)	(-8.07)	(-2.06)	(-2.08)
FFE	0.00697	0.00697	0.0106	0.0107
	(1.23)	(1.24)	(1.18)	(1.19)
Constant	0.106***	0.109***	0.0360	0.0365
	(9.95)	(10.21)	(1.31)	(1.33)
Year dummies	Yes	Yes	Yes	Yes
Industry dummies	Yes	Yes	Yes	Yes
Observations	4400	4400	4400	4400
Adjusted R2	0.0663	0.0673		
LogLik	4598.4	4600.7	7078.0	7078.8

t statistics in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 5. Probit estimations of determinants of patent grants

	All		SOEs		POEs		FFEs	
Dependent var: *Granted*								
FilingSub	-0.303***	(0.0227)	-0.110*	(0.0640)	-0.301***	(0.0254)	-0.422***	(0.154)
ExamSub	0.0848***	(0.0246)	-0.259***	(0.0780)	0.195***	(0.0277)	-0.319***	(0.102)
GrantSub	0.224***	(0.0213)	-0.0189	(0.0662)	0.277***	(0.0238)	0.0554	(0.0950)
ClaimScope	-0.271***	(0.00797)	-0.219***	(0.0238)	-0.276***	(0.00923)	-0.327***	(0.0224)
SOE	0.0775***	(0.0190)						
FFE	0.0550***	(0.0157)						
Non-device	0.0750***	(0.0115)	-0.0420	(0.0356)	0.0903***	(0.0136)	0.0517*	(0.0297)
Experience	0.00807***	(0.00208)	0.00864**	(0.00367)	0.0145***	(0.00299)	-0.0375***	(0.00819)
log(Employee)	0.0132***	(0.00349)	0.00186	(0.0101)	0.0102**	(0.00417)	0.0288***	(0.00974)
Constant	-1.617***	(0.525)	-5.975	(147.9)	-1.548*	(0.912)	-1.273	(0.829)
Year dummies	Yes		Yes		Yes		Yes	
Region dummies	Yes		Yes		Yes		Yes	
Technology dummies	Yes		Yes		Yes		Yes	
Observations	59429		6097		43176		10147	
LogLik	-39379.0		-4019.9		-28525.7		-6539.4	
chi-squared	3336.3		389.1		2522.8		878.5	

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Granted: dummy variable; equals 1 if an application is granted within four years of filing; FilingSub: subsidies of filing fee; ExamSub: subsidies of examination fee; GrantSub: reward contingent on patent grants; ClaimScope: breadth of claims; Non-device: dummy indicating whether a patent is a non-device (process or usage) patent.

Table 6. OLS estimations of the determinants of patent claim breadth

	All		SOEs		POEs		FFEs	
Dependent var: *ClaimScope*								
GrantSub	-0.0203*	(0.0104)	-0.0390	(0.0300)	-0.0123	(0.0120)	-0.173***	(0.0354)
SOE	-0.0712***	(0.00989)						
FFE	0.0891***	(0.00816)						
Non-device	-0.0921***	(0.00598)	-0.118***	(0.0194)	-0.104***	(0.00713)	-0.0396***	(0.0136)
Experience	0.000291	(0.00108)	0.00661***	(0.00195)	-0.00217	(0.00157)	0.00890**	(0.00371)
log(Employee)	0.0162***	(0.00182)	0.000413	(0.00553)	0.0160***	(0.00220)	0.0292***	(0.00444)
Constant	-3.794***	(0.276)	-3.792***	(0.705)	-3.242***	(0.482)	-4.004***	(0.369)
Year dummies	Yes		Yes		Yes		Yes	
Region dummies	Yes		Yes		Yes		Yes	
Technology dummies	Yes		Yes		Yes		Yes	
Observations	59429		6097		43176		10156	
Adj R-squared	0.0747		0.104		0.0783		0.0693	

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
ClaimScope: breadth of claims; Granted: dummy variable; equals 1 if an application is granted within four years of filing; FilingSub: subsidies of filing fee; ExamSub: subsidies of examination fee; GrantSub: reward contingent on patent grants; Non-device: dummy indicating whether a patent is a non-device (process or usage) patent.

Table 7. Heckman probit estimations of determinants of patent grants

	All		SOEs		POEs		FFEs	
Granted								
GrantSub	0.103***	0.00288	-0.0672	-0.239	0.150***	0.0812	0.0195	-0.153
ClaimScope	-0.256***	-0.246***	-0.209***	-0.192***	-0.251***	-0.245***	-0.326***	-0.305***
GrantSub × ClaimScope		-0.0302*		-0.0502		-0.0207		-0.0539
SOE	0.0460**	0.0460**						
FFE	0.0209	0.0203						
Non-device	0.0518***	0.0520***	-0.0745**	-0.0744**	0.0662***	0.0663***	0.0343	0.0349
Experience	0.00447**	0.00443**	0.0110***	0.0109***	0.00744**	0.00741**	-0.0443***	-0.0448***
log(Employee)	0.00289	0.00287	-0.0142	-0.0147	-0.00154	-0.00150	0.0193*	0.0188*
Constant	-0.621	-0.589	-5.279	-5.239	-0.484	-0.459	-1.706***	-0.645
Examined								
FilingSub	-0.662***	-0.662***	-0.180*	-0.180*	-0.728***	-0.728***	-0.440**	-0.396*
ExamSub	0.546***	0.546***	-0.0124	-0.0124	0.651***	0.651***	-0.165	-0.217
SOE	0.215***	0.215***						
FFE	0.239***	0.239***						
Experience	0.0323***	0.0323***	0.0203**	0.0203**	0.0276***	0.0276***	0.0672***	0.0689***
Log(Employee)	0.0467***	0.0467***	0.106***	0.106***	0.0421***	0.0421***	0.0617***	0.0608***
Constant	-0.703	-0.703	3.320	3.327	3.440	3.440	-0.197	-0.531
Constant	-0.394***	-0.395***	-0.246	-0.249	-0.644***	-0.644***	-0.578*	-0.635*
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Technology dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	60244	60244	6139	6139	43901	43901	10204	10204
LogLik	-51912.3	-51910.9	-4863.9	-4863.5	-38618.7	-38618.3	-7826.1	-7818.9
chi-squared	2331.2	2333.0	325.8	326.6	1679.0	1680.0	623.4	626.2

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Granted: dummy variable; equals 1 if an application is granted within four years of filing; FilingSub: subsidies of filing fee; ExamSub: subsidies of examination fee; GrantSub: reward contingent on patent grants; ClaimScope: breadth of claims; Non-device: dummy indicating whether a patent is a non-device (process or usage) patent.

Appendix 1. Summary of patent subsidy programs

Province	Start year	Filing fee subsidies	Examination fee subsidies	Grant-contingent rewards
Beijing	2000	Fully	Partly	No
Tianjin	2000	Fully	No	No
Hebei	2005	Partly	No	Low
Shanxi	2003	Fully	Fully	No
Inner Mongolia	2002	Fully	Fully	No
Liaoning	2006	Fully	No	High
Jilin	2004	Partly	Partly	Low
Heilongjiang	2001	Fully	No	Low
Shanghai	1999	Fully	Fully	High
Jiangsu	2000	Fully	Fully	No
Zhejiang	2001 - 2005 2006 ~	No No	Fully No	No High
Anhui	2003	No No	No	High
Fujian	2002 - 2005 2006 ~	Fully Fully	Fully Fully	No High
Jiangxi	2002	Partly	Partly	No
Shandong	2003	Partly	Partly	High
Henan	2002	Partly	Partly	Low
Hubei	2007	No	No	Low
Hunan	2004 - 2006 2007 ~	Partly No	Partly No	No High
Guangdong	2000	Partly	Partly	No
Guangxi	2001	Fully	Partly	High
Chongqing	2000	Fully	No	Low
Sichuan	2001	Partly	Partly	No
Guizhou	2002	Fully	Partly	No
Yunnan	2003 2004 ~	Partly Partly	Partly No	Low Low
Tibet	2004	Fully	Fully	High
Shaanxi	2003	Fully	No	High
Qinghai	2006	Fully	Partly	No
Xinjiang	2002	Partly	No	High
Hainan	2001	Partly	No	No

Data source: the authors' collection from official documents published on local government websites and news reports or telephone interviews of local officials.
Filing and examination fee subsidy as “Fully” if the amount is equal to the fees charged by SIPO, and “Partly” if the amount is unclear or less than the fee charged. Grant-contingent reward is classified as “High” if the amount is no less than 2000 yuan, and “Low” if unclear or less than 2000 yuan.

Appendix 2. Number of provinces administered subsidy programs

Year	Filing fee subsidy #	(Percentage)	Examination fee subsidy #	(Percentage)	Grant-contingent rewards #	(Percentage)
1998	0	(0.0%)	0	(0.0%)	0	(0.0%)
1999	1	(3.2%)	1	(3.2%)	1	(3.2%)
2000	6	(19.4%)	4	(12.9%)	2	(6.5%)
2001	10	(32.3%)	7	(22.6%)	4	(12.9%)
2002	16	(51.6%)	12	(38.7%)	6	(19.4%)
2003	20	(64.5%)	15	(48.4%)	10	(32.3%)
2004	23	(74.2%)	17	(54.8%)	12	(38.7%)
2005	24	(77.4%)	17	(54.8%)	13	(41.9%)
2006	26	(83.9%)	17	(54.8%)	16	(51.6%)
2007	25	(80.6%)	16	(51.6%)	17	(54.8%)
2008	25	(80.6%)	16	(51.6%)	18	(58.1%)

The percentage is calculated by dividing number of provinces administered subsidy programs by 31, which is the total number of provinces of mainland China since Chongqing became a municipality in 1997.

Appendix 3. Negative binominal estimation of patent production function: applications

	Negative binominal model		Negative binominal model with fixed effects	
	Applications	*Applications*	*Applications*	*Applications*
log(R&D)	0.711***	0.986***	0.376***	0.475***
	(0.0327)	(0.0614)	(0.0390)	(0.0648)
ApplSub	0.193***	0.903***	0.301***	0.511***
	(0.0442)	(0.177)	(0.0501)	(0.179)
GrantSub	0.329***	1.673***	0.980***	1.447***
	(0.0732)	(0.286)	(0.0798)	(0.291)
log(R&D) × ApplSub		-0.197***		-0.0575
		(0.0489)		(0.0466)
log(R&D) × GrantSub		-0.371***		-0.125*
		(0.0767)		(0.0741)
Size	1.159***	1.152***	0.364***	0.352***
	(0.0626)	(0.0623)	(0.0847)	(0.0850)
SOE	-1.000***	-1.003***	-0.667***	-0.663***
	(0.0739)	(0.0737)	(0.0890)	(0.0891)
FFE	0.120	0.197*	0.158	0.161
	(0.105)	(0.106)	(0.116)	(0.116)
Constant	-6.299***	-7.304***	-3.550***	-3.876***
	(0.204)	(0.276)	(0.291)	(0.339)
lnalpha				
Constant	1.467***	1.458***		
	(0.0277)	(0.0277)		
Industry dummies	Yes	Yes	Yes	Yes
Observations	7571	7571	7090	7090
LogLik	-10215.3	-10196.2	-5639.1	-5636.8
chi-squared	3173.2	3211.3	501.1	494.8

Standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
ApplSub: subsidies of filing fee or examination fee;
GrantSub: reward contingent on patent grants.

Appendix 4. Negative binominal estimation of patent production function: grants

	Negative binominal model		Negative binominal model with fixed effects	
	Grants	*Grants*	*Grants*	*Grants*
log(R&D)	0.679***	0.897***	0.365***	0.440***
	(0.0335)	(0.0616)	(0.0408)	(0.0681)
ApplSub	0.206***	0.743***	0.321***	0.421**
	(0.0439)	(0.175)	(0.0537)	(0.188)
GrantSub	0.437***	1.541***	0.993***	1.520***
	(0.0732)	(0.281)	(0.0846)	(0.305)
log(R&D) × *ApplSub*		-0.148***		-0.0283
		(0.0478)		(0.0490)
log(R&D) × *GrantSub*		-0.304***		-0.141*
		(0.0751)		(0.0779)
Size	1.093***	1.090***	0.416***	0.404***
	(0.0617)	(0.0616)	(0.0893)	(0.0896)
SOE	-0.890***	-0.892***	-0.682***	-0.679***
	(0.0739)	(0.0739)	(0.0937)	(0.0938)
FFE	0.0941	0.179*	0.240*	0.245**
	(0.106)	(0.109)	(0.125)	(0.125)
Constant	-6.236***	-7.038***	-3.825***	-4.064***
	(0.202)	(0.275)	(0.308)	(0.358)
lnalpha				
Constant	1.444***	1.439***		
	(0.0298)	(0.0298)		
Industry dummies	Yes	Yes	Yes	Yes
Observations	7571	7571	6904	6904
LogLik	-9357.8	-9345.6	-5110.0	-5108.1
chi-squared	2796.7	2821.1	466.5	461.7

Standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
ApplSub: subsidies of filing fee or examination fee;
GrantSub: reward contingent on patent grants.

Appendix 5 Estimations of determinants of patent grants and claim breadth controlling R&D intensity

	Probit estimation		OLS estimation	
	Granted		*ClaimScope*	
R&D/Sales	0.570**	(0.286)	0.329**	(0.139)
FilingSub	-0.275***	(0.0548)		
ExamSub	-0.150***	(0.0582)		
GrantSub	0.179***	(0.0516)	-0.0399*	(0.0239)
ClaimScope	-0.253***	(0.0168)		
SOE	0.0975***	(0.0378)	-0.102***	(0.0186)
FFE	0.00797	(0.0321)	0.116***	(0.0158)
NonDevice	0.000159	(0.0244)	-0.104***	(0.0121)
Experience	-0.00218	(0.00359)	0.00142	(0.00177)
log(Employee)	0.0123	(0.0103)	0.0271***	(0.00510)
Constant	-5.521	(138.5)	-3.996***	(0.641)
Year dummies	Yes		Yes	
Region dummies	Yes		Yes	
Technology dummies	Yes		Yes	
Observations	14553		14555	
Adjusted R2			0.0939	
LogLik	-9408.9			
chi-squared	1337.2			

Standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

ClaimScope: breadth of claims; Granted: dummy variable; equals 1 if an application is granted within four years of filing; FilingSub: subsidies of filing fee; ExamSub: subsidies of examination fee; GrantSub: reward contingent on patent grants; Non-device: dummy indicating whether a patent is a non-device (process or usage) patent.