China's Patent Subsidy Policy and its Impacts on Invention and Patent Quality *

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Abstract

In this paper we assess the quality of Chinese invention patents and study the impacts of patent subsidy programs implemented by each provincial region. We compile a comprehensive set of quality indicators to show that the technological and economic quality of Chinese patents did not decline with the recent jump of Chinese patents. Based on Chinese provincial panel data from 1995 to 2010, we find that the effect of patent subsidy policies on the technological quality of patents was significantly positive. However, the effect of patent subsidy policies on the economic quality of Chinese patents was insignificant. Our results also show that the effect of patent subsidy policies on the technological quality of Chinese patents depends on the growth rate of well-established or experienced innovators in patenting, rather than the growth rate of entrants or marginal innovators, suggesting that much more attention should be paid to the experienced innovators instead of marginal innovators in the design of public policy for the developing countries.

JEL classification: O31 O34 O38.

Keywords: Patent quality; Patent subsidy policy; Well-established innovator

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1 Introduction

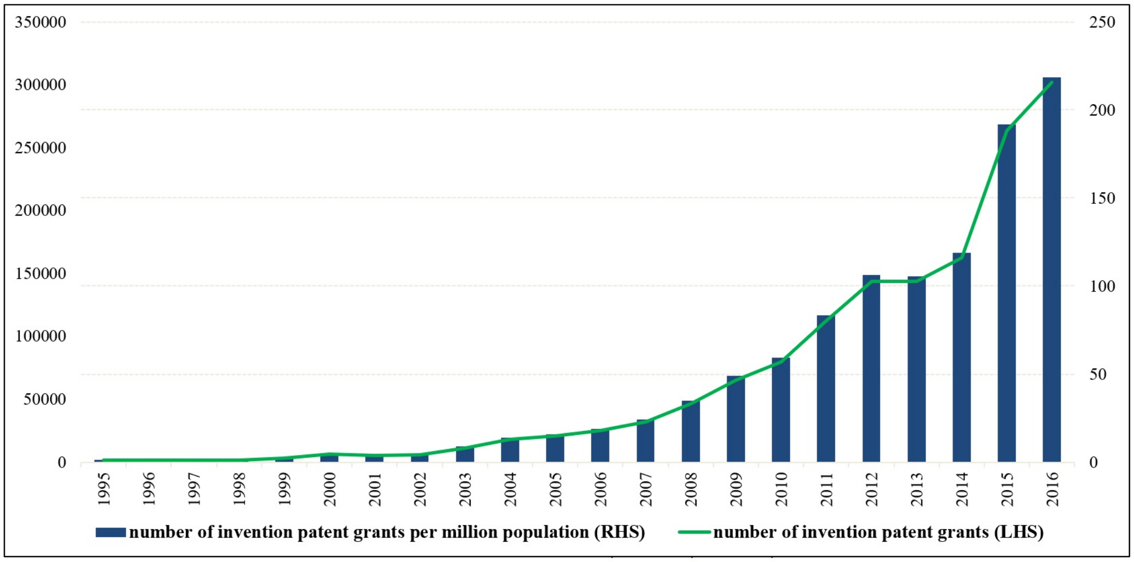
This paper is motivated by the unprecedented surge of patenting in China [1]. Grants for Chinese invention patents began to rise in the year 1999 (in either absolute or rate terms). The number of residential granted invention patent per million population in China grew by almost 47 fold from 1995 to 2010 (Figure 1). The annual growth rate of China's invention patent grants between 1995 and 1998 was around 0.35% per year, but jumped to 42% per year between 1998 and 2010. In 2011, China ranked first in patenting, which made an outstanding contribution to the global patent growth. It is interesting to note that around the time of the patent surge, China was going through a series of important institutional transitions. The Chinese government started highlighting the role of the patent system in promoting technology innovation in 1997. Shanghai started launching a patent subsidy program in 1999, which was quickly followed by other local governments. These observations prompted the natural question of whether the quality of Chinese patents suffered from this explosive growth. We are interested in studying whether the extraordinary growth of patenting in China brought a decline of Chinese invention patent quality. Since the patent subsidy policies seem to have played an important role in the growth of Chinese patenting, we are also interested in the impact of those policies on patent quality. Moreover, we examine what patent subsidy policy is conducive to raise patent quality.

Why do we care about Chinese patent quality problem? First, the quality of patents is a better metric of invention outputs. Patent quality can help reveal research efficiency, and provide more insight than quantity of patents for innovation capacity, technological change and productivity growth. By now, it has become the consensus that a sustainable development of the Chinese economy should be driven by its innovation capacity. Therefore, if the quality of Chinese patents has kept pace with the increase of its volume, then it is possible that China transformed itself from a technological follower to a technological leader and is achieving its goal of catching-up with developed countries. Second, some assert that although China is ramping up its patent applications, their value is questionable. As a matter of fact, unlike the patent offices in the developed countries which have well-documented data on patent qualities, SIPO (State Intellectual Property Office of China) releases very limited information for the quality of its patents. If these data drawbacks can be solved, then the question over Chinese patent quality can be answered. Third, it is obvious that innovators have to confront much higher uncertainty and use more research input to produce patents of good quality. Therefore, to reduce the market failure in innovation, more incentives should be given to the quality of patents, rather than the quantity of patents. From the perspective of public policy, if the impact of subsidy polices on the quality of patents can be estimated accurately, then it will be much more useful for the policy makers to understand the effectiveness of the policies and

[1] There are three types of patent in China: invention patent, utility model patent and design patent. Because of the technological importance of inventions, this paper will focus on granted invention patents. Unless specified otherwise, all patents in this study refer to inventions.

design ones that raise the quality of patents and nurture creativity.

Figure 1: The surge of Chinese invention patents



Data source: National Bureau of Statistics

Our goal in this paper is to comprehensively estimate the quality of Chinese patents based on a unique and comprehensive database, and then to evaluate the impact of patent subsidy policies on the quality of Chinese patents. We then discuss how patent subsidy policies could stimulate the rise of patent quality. By linking Chinese patent database (released by SIPO, 1985- 2012) with Google Patents database containing forward citations and claims, we obtain a unique database of Chinese patent quality. Our unique database not only overcomes the shortcoming of SIPO data, but also allows us to analyze the technological quality and economic quality of Chinese inventions. The statistical results show that the technological and economic quality of Chinese invention patents does not decline with the jump in quantity. Moreover, based on provincial panel data from 1995 to 2010, we find that the effect of patent subsidy policies on the technological quality of Chinese patents was significantly positive. However, the effect of patent subsidy policies on the economic quality of Chinese patents was insignificant. Finally, we find that the effect of patent subsidy policies on the technological quality of patents depends on the growth rate of well-established or experienced innovators in patenting, other than the growth rate of entrants.

We contribute to the stream of research on the quality of Chinese patents. Since Chinese patent data have no commonly used indicators of patent quality such as forward citation and patent claim information, several attempts have been made to reflect the quality characteristics of Chinese patents. Li (2012) used patent grant rate to show the dynamic changes of Chinese invention patent quality from 1998 to 2006, while Dang and Motohashi (2015) analyzed the invention patent quality of Chinese industrial enterprises using the number of nouns in patent claims. Some studies were based on patent renewal period data to track the economic value of Chinese expired invention patents, such as Zhang and Chen (2012) and Zhang et al. (2014). Recently, more attention has been paid to the indicator of forward citations, which is obtained from PATSTAT database (Patent Statistical Database by EPO). Fisch et. al. (2016) used the number of forward citations received by 155 Chinese leading universities from 1991 to 2009, and Fisch et al. (2017) used citation lag of a small stratified sample of China's invention patents with priority years between 2000 and 2010. However, a simple quality indicator of patents and a selected patent sample are not enough to reflect precisely the overall quality features of inventions in China. To reduce the measured variance in quality and overcome the drawback of Chinese patent data, we collect the information of patent claims and forward citations from Google Patents, and use multiple indicators, including the number of inventors, withdrawal rate and renewal rate, to analyze aggregate and dynamic quality feature of Chinese invention.

We also contribute to another stream of literature focusing on the drivers for the explosive surge of patents in China. Previous studies have found that the explosion of patent filings at SIPO was driven by factors other than underlying innovative behavior, including government subsidies that encourage patent filings directly (Eberhardt et al., 2017)). Li (2012) also found that patent subsidy programs played an important role in the growth of Chinese invention patenting at the provincial level. Similar results were found using Chinese industrial enterprise patenting data (Dang and Motohashi, 2015). Furthermore, it is found that subsidy programs promoting research excellence is a significant driver of patent quantity and quality at the top 155 universities in China (Fisch et. al., 2016). Unlike the prior studies which have largely focused on the impact of patent subsidy program on the rise of patenting, this paper is to investigate whether and how the patent subsidy policies influence the quality of aggregate innovations in China. Thus, we fill in the gap in the literature by examining the quality aspects of policy effects.

The rest of the paper is organized as follows. Section 2 reviews the measurement of patent quality and shows the summary statistics of the quality features of aggregate invention patents in China. Section 3 presents the implementation and evaluation of patent subsidy program. Section 4 shows the data and empirical results. Section 5 demonstrates the results of a number of robustness tests and the influence mechanism of patent subsidy program on technological quality. Section 6 concludes.

2 Quality for invention patent

It is well known that patents vary enormously in their importance or value. Since patents are seldom marketed, their actual value is in general unobserved. Therefore, various indicators have been used to adjust for variation in the quality of patents (Lanjouw and Schankerman, 2004; Arora et. al., 2004; Trajtenberg, 1990). One of the widely used indicators is the number of forward citations, which is the number of times the patent in question is cited by subsequent patents, and thus reflects the technological and economic importance of the patent. Other important indicators that have been used include the number of claims in the patent application (Tong and Frame, 1994), the number of inventors (Gambardella et al., 2004), rate of withdrawal and invalidation or cessation (Long and Wang, 2014; and Dan Prud'homme, 2012), and patent value based on patent renewal fee (Zhang et.al., 2016).

2.1 Chinese Patent Quality Dataset

The discussion of Chinese invention patent quality is based on SIPO database[2] and Google Patents. The SIPO database provides a rich description of all patent applications that have been filed at SIPO since 1985 and offers some patenting information on provincial level. However, the shortcoming of this database is that it includes no commonly used patent quality measures such as patent forward citations and the number of claims. Google Patents, fortunately, provides these two measures for all Chinese patent applications and we thus link it with SIPO database[3]. Specifically, Google Patents records patent information based on the publication number, and each webpage records one patent application[4]. It should be noted that according to Chinese invention patent publication number system, one invention patent may have two types of publication number: unexamined patent publication (ends with "A") and granted patent publication (ends with "B"). Thus, if the invention patent is granted, there could be cases where one patent has two webpages in Google Patents, where the claims information can be recorded differently.[5]. In order to obtain full information of patent citation and claims, the webpages of both publication numbers are crawled and cleaned.

For the invention patents issued before 1989 and issued between July 2007 and August 2016, we match Google Patents with SIPO database using the publication number. However, for applications published between 1990 and July 2007, SIPO database only records unexamined patent publication number. We fix the problem by crawling the entire Chinese invention patent during this period on Google Patents to obtain full information of patent citation, claims and application number. Since almost all of the invention patents in the SIPO database are found in Google Patents, we can use

[2]In accordance with the restructuring plan approved by the 13th National People's Congress, SIPO was renamed CNIPA (China National Intellectual Property Administration) on August 29, 2018. CNIPA will not subordinate to the State Council, but under the supervision of the newly established State Administration of Market Supervision and Administration.

[3]This database is cleaned and constructed by our team in August 2016, and the linking python program is compiled by Zhen Sun (Assistance professor at Institute of Economic Research of Tsinghua University).

[4]For instance, see https://www.google.com/patents/CN101728830Bwhich has a total of 3 claims and 2 backward citations.

[5]For example, application CN200910114583 was published as CN101728830A (https://www.google.com/patents/CN101728830A) first, and then given a granted patent publication number CN101728830B (https://www.google.com/patents/CN101728830B) after it was granted. Moreover, there are fewer claims on the granted patent number page, which is probably narrowed down because of the substantial examination.

the patent application number to get a perfect match.

This is a novel database, some of the working papers that are using this database include Sun et. al. (2019), Sun et. al.(2018) and Howell et. al. (2018). However, we are the first to examine the effect of provincial patent subsidy program on patent quality using this database.

2.2 Indices for Quality of Chinese Invention Patent

We classify commonly used patent quality indicators into two groups in order to reveal two distinguishing dimensions of patent quality: the technological quality and economic quality. The former can be measured by the number of forward citations, number of patent claims, and number of inventors; while the latter can be captured by withdrawal rate, cessation ratio, and renewal rate.

2.2.1 Patent Claims

The claims in the patent specification delineate the property rights protected by the patent. The principal claims define the essential novel features of the invention and subordinate claims describe detailed features of the innovation (Lanjouw and Schankerman, 2004). Thus more claim number means more technology contributions and solutions for the technical difficulties. Both number of principal and subordinate claims are available on Google Patent.

Figure 2 shows the average number of claims for the invention patents between 1985 and 2010. We can see from Figure 2 that the number of claims for an average invention shows a significant rising trend, from 4.2 in 1993 to 6.2 in 2010, although there are still some gaps between Chinese patents (6 claims per patent) and international patents (22 claims per patent)[6].

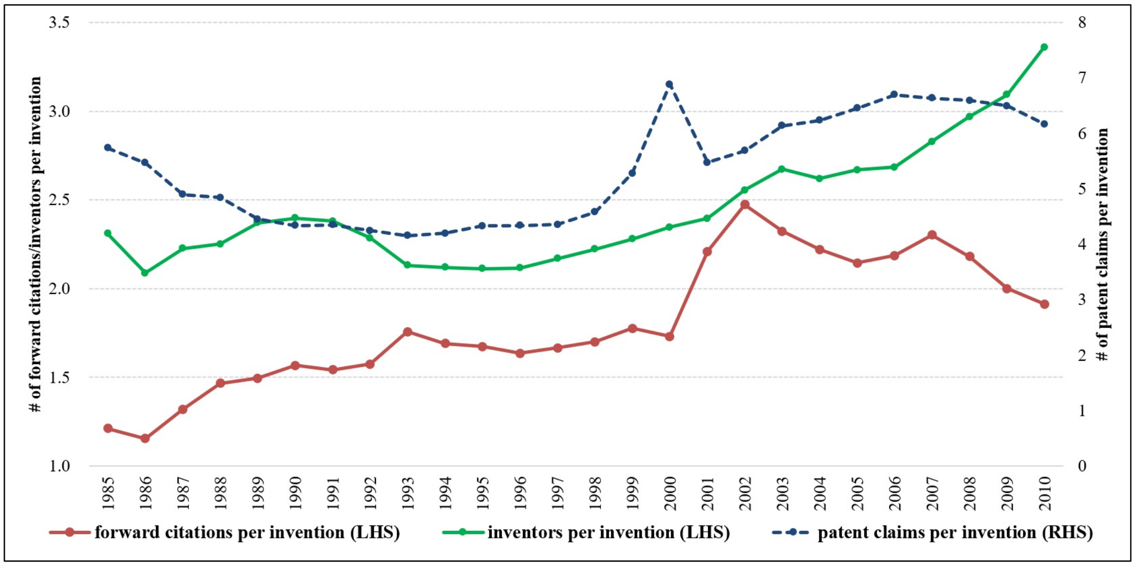
2.2.2 Forward citation

The number of forward citations reflects the technological value and importance of the patent. For technological progress is cumulative, the inventors stand on the shoulders of giants' prior art for further progress. In this sense, a large number of forward citations indicates that the patent is fundamental to many subsequent innovations. Therefore, a larger number of forward citations is often associated with the patent having higher quality, which is theoretically and empirically confirmed by Trajtenberg (1990), Albert et al. (1991), Henderson et al. (1993), Jaffe et al. (2002) and Gvilivhes (1990).

Considering that more than 50% of forward citations of an invention patent occur within the first 5 years (Nagaoka et al., 2010), we choose patents filed between 1985 and 2010 so that even a patent applied in 2010 can have almost all of the forward citations in its entire life. This helps to largely reduce the problems of underestimation for younger patents due to the truncation of forward citations problem.

[6]See Song and Li (2014)

Figure 2: Technological Quality of Invention Patents in China



Data source: Authors' calculation based on data of SIPO and Google Patents

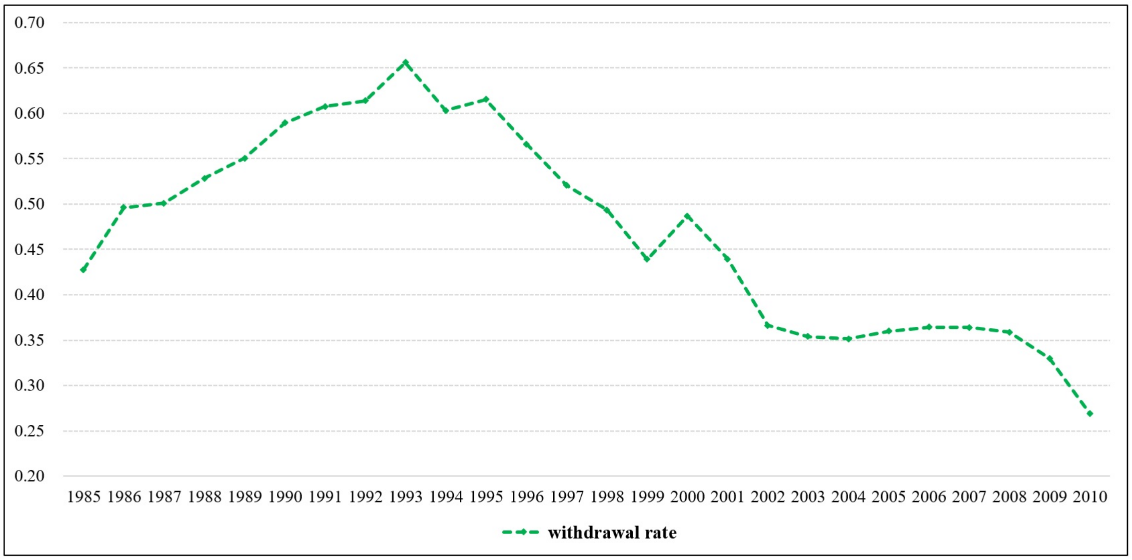
Figure 2 demonstrates the average number of forward citations received by an invention patent in China from 1985 to 2010. In Figure 2, there is a clear increasing trend for the average forward citations in China over the past 25 years. The average number of forward citations rose from 1.2 pieces in 1986 to 2.5 pieces in 2002, indicating a progress of technological quality of Chinese invention. Even for most recent years, such as 2010, for an average invention, there are 1.9 pieces of forward citation although its forward citations can only be observed within five years, compared to thirty years for the inventions filing in 1985. In other words, the increasing trend will be more obvious if all inventions have the same length of citation span.

This finding is consistent with Fisch et. al. (2016). They found that there has been a dramatic increase in forward citations of top 155 universities invention from 2000 to 2004, with annual growth rate of 52%. Hu and Mathews (2008) used Chinese invention patenting records at the USPTO (United States Patent and Trademark Office) and demonstrated that the significant increase in forward citations is particularly to be noted since the year 2001.

2.2.3 Inventors

The number of inventors in the patenting is an important determinant of the technological value of patent. Compared to individual inventor, multiple inventors can bring greater collective knowledge and effort for the innovation, especially in technological areas of high complexity and difficulty. Based on a comprehensive analysis of 2.1 million patents, Wuchty et al. (2007) found that the process of knowledge creation has fundamentally changed, shifting from individual-based model of scientific advance to a teamwork model. In addition, they found that teams produce more highly cited and high impact research than individuals (solo inventors) do and this advantage is increasing over time. Similar pattern is observed in China. It can be seen from Figure 2 that the average number of inventors was 2.1 in 1995 and increased to 3.4 in 2010.

Figure 3: Withdrawal Rate of Invention Patents in China



Data source: Authors' calculation based on data of SIPO and Google Patents

2.2.4 Patent withdrawal

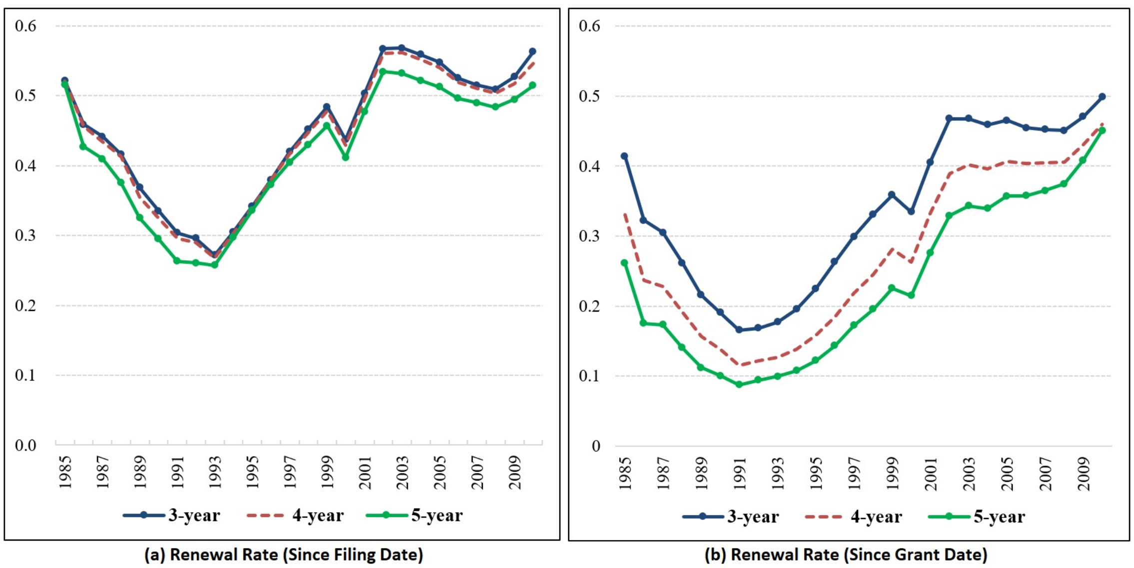
There are three kinds of patent application results: granted, rejected and withdrawal. The former two results are based on whether the patent satisfies the patentability requirements, and the last result depends on the tradeoff between the cost of application and expected profit from the patent (if approved). The applicant will terminate the application if the expected marketability from the patent is less than application cost. In other words, patents with lower economic value are more likely to be withdrawn by the applicants themselves.

Figure 3 presents the average probability of patent withdrawal rate (withdrawal rate) between 1985 and 2010. The withdrawal rate exhibits a significant decreasing trend since 1993, indicating that the expected economic quality of patent applications is rising. This argument can be supported by the increasing grant rate from 0.27 in 1993 to 0.56 in 2010.

2.2.5 Patent renewal

In most countries a patentee has to pay an annual renewal fee to keep her patent rights in force. Rational pantentees make renewal decisions based on the value of the patent right obtained by renewal (Schankerman and Pakes, 1986). If the patent have little or no value, and as such, patentee will cease to renew them. Moreover, the patent renewal fee in most of countries increases over time after the date of grant. For example, SIPO charge tiered prices for the renewal of patent rights and increase the renewal fee every three years [7]. Therefore, the longer a patent right is kept, the greater its economic value/quality. It should be noted that only a small number of valuable patents are kept until the patent expiration date, which provides us a way to observe the variation of economic quality among patents. Several studies (Zhang and Chen, 2012; Zhang et al., 2014) have attempted to estimate the value of invention patents in China using renewal payment model based on expired invention patent data of SIPO (1985-2009) and found that patent value from Chinese owners is much lower than that of overseas owners (from U.S., Japan, European countries).

Figure 4: Renewal Rate of Invention Patents in China



Data source: Authors' calculation based on data of SIPO and Google Patents

In this paper, we use cessation information [8] to identify those patents which are in force for different lengths of duration and then calculate separate rates of renewal. For example, to obtain 3-year renewal rate (Chart (a) in Figure 4), the number of patents filed for application in the given year, which are eventually approved and whose durations between application date and cessation date are larger than 3 years, is assigned as the numerator and the number of application in the given year is assigned as the denominator. Likewise, we have Chart (b) in Figure 4 if we change the

[7]900 yuan will be charged each year for the first three years, and then 1200 yuan, 2000 yuan, 4000 yuan, 6000 yuan, 8000 yuan each year for the 4-6 year, 7-9 year, 10-12 year, 13-15 year, and 16-20 year respectively.

[8]There are mainly three types of patent cessation: "non-payment", "abandoned", and "expiry"; with two other minor groups of "patent invalidation" and "avoid re-grant".

application date into grant date and recalculate the numerator. It can be easily inferred that the second renewal rate will be smaller than the first one for the approbations of patents takes times. Figure 4 shows that the longer duration the lower the renewal rate and the renewal rates have a marked rise since early 1990s, indicating that the economic quality for an average invention patent is rising in the recent years. Since cessation rate and renewal rate are two sides of the same coin, we choose to only use renewal rate in our model to represent one of the dimensions of economic quality.

3 Patent Subsidy Policy and Invention Patent Quality

3.1 The implementation of Patent Subsidy Policy in China

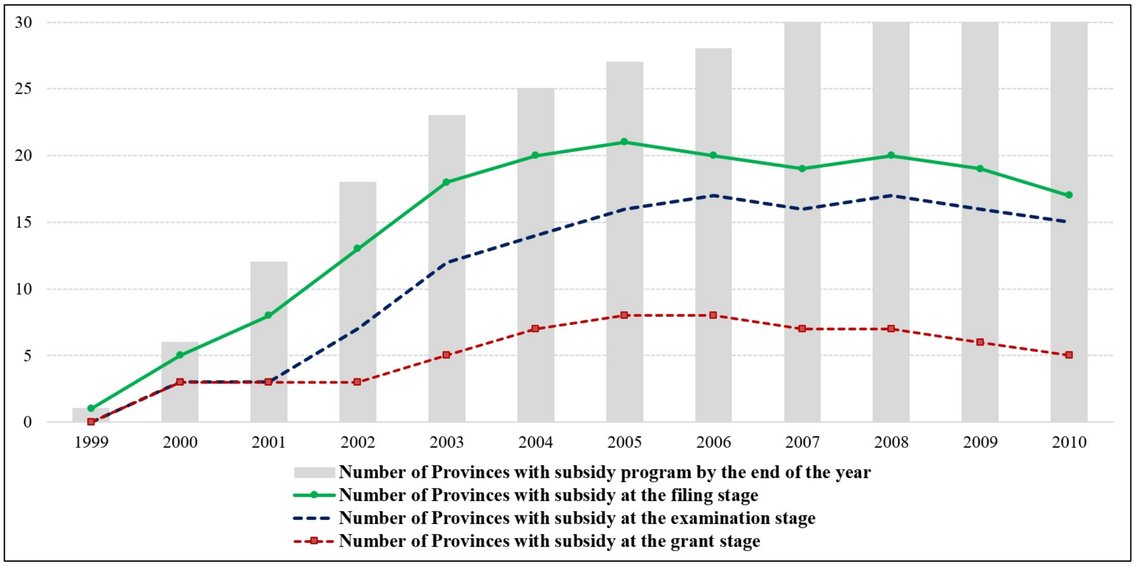
To implement the strategy of developing the country through science and education and the strategy of sustainable development put forward by the 15th National Congress of the CPC in 1997, the central government developed the "Tenth Five-year Plan" for National Patent Work to give full play to the role of patent system in promoting technology innovation. During the period of the Tenth Five-year Plan, one of the expected targets of National Patent Work was to increase the average annual growth rate of patent application to around 14% and that of invention patents to around 18% in 2005. The Plan also aimed to have invention patents accounting for more than 25% of the three patent applications in 2005. Moreover, both the amount of invention patent applications in high and new technology fields and that of foreign patent applications should be greatly improved.

To be consistent with the national patent development strategy and complete the above goal of patent work, local governments initiated the implementation of patent subsidies to motivate and help inventors to fully utilize technological research results. The programs aimed to increase both the quantity and quality of patent applications by cultivating the strength of inventors in science and technology to achieve self-dependent intellectual property. A batch of patent subsidy measures were made to procure more patent rights legally, from domestic patents to overseas patents. Shanghai was the first to launch patent subsidy program in 1999 to promote invention and creation in its jurisdiction. Beijing, Tianjin, Guangdong, Jiangsu and Chongqing quickly followed to set up their own funds for subsidizing patent filings from firms, universities and public research institutes, and residents in their jurisdiction. By the end of 2007, 30 provincial level government had launched a patent subsidy program with subsidies at one of, or all stages of patent application (Figure 5). It is worthwhile to note that although the local governments usually review and revise their patent subsidy programs on a regular basis, most provinces continued to subsidize patenting year after year. The incentive provided by these subsidies is therefore not one-off.

After studying the patent subsidy policies including revised ones[9] (94 documents in total), we

[9]The policy documents were mainly collected from www.pkulaw.cn, www.lawyee.net and government official websites.

Figure 5: Patent subsidy programs among Chinese provincial regions



Data source: Authors' calculation based on government public documents

found that the invention patents have priority over the other two types of patents, exhibiting a higher probability of being sponsored. Some provinces[10] issued patent subsidy documents stipulating that only payments made during the application, grant and/or maintenance stages of invention patents can be reimbursed. Moreover, invention patents were given higher amounts of reimbursement compared with the actual payment for patent application processing and related attorney fees. Take Shanghai for example, 80% of the actual payment during application of domestic invention patent were reimbursed while only 50% and 60% of actual payments during the application of domestic utility and design patent were reimbursed. In Beijing, the reimbursement standard for each domestic invention patent is no more than 950 yuan for application fee and 1200 yuan for substantial examination fee, while the reimbursement standard for each domestic utility and design patent is no more than 150 yuan. It is the same for the overseas invention patent. For instance, the reimbursement amount of each foreign invention patent in Shanghai can be up to 30,000 yuan per country (less than 5 countries for the invention patent applied in multiple countries) while that of foreign utility patent will be less than 3000 yuan per country (less than 3 countries for the utility patent applied in multiple countries). In addition, there was a rising trend in the amount of reimbursement for the invention patent. For domestic invention and utility patent, the compensation was 2000 yuan and 400 yuan respectively in 2004, and the former's compensation increased to 3000 yuan while the latter remained the same in 2010.

It is noticeable that not all of the fee items were compensated. Thus it is impossible for the patent

[10] Such as Zhejiang, Guangdong, Hebei, Hainan, Inner Mongolia, and Anhui.

applicant to obtain extra benefits exceeding its costs through government subsidies. Over 70% of provinces treated filing fees and substantial examination fees (only eligible for the invention patent) as the funding target, leaving the applicants to make payments such as annual fees, surcharge for claims, pages in excess of specified number, and agent fee. In most cases, applicants can only apply for the reimbursement of filing fee after SIPO has accepted the patent application and filing fee has already incurred. However, in some provinces, such as Zhejiang, Shandong, Yunnan, Hebei, Anhui and Hubei, only after the patent was granted by SIPO, can the filing fee and (or) substantial examination fee incurred be partly reimbursed. This kind of provision largely narrowed down the funding target and effectively decreased the production of low-quality patent since the average rate of being granted is 21%, which increasingly became the common practices in the patent subsidy programs.

It is obvious that patent subsidy programs adopted the principle of giving priority to excellence. All units and individuals were encouraged to procure patent rights for their inventions and creations that meet the patent application requirements. However, constrained by limited funds and pressure of completing the task set by the central government, not all patent holders in the jurisdiction were eligible for applying the reimbursement. The most common funding form is to set higher funding standards for the big enterprises and business groups who have self-dependent intellectual property, like Patent Pilot Enterprise, Patent Demonstration Enterprise, and core enterprises in emerging industries of strategic importance and high-tech industries. On the other hand, set lower funding standards for the ordinary patent applicants. Patent Pilot Enterprise and Patent Demonstration Enterprise were carefully selected through the process of experts review, discussion and consultation. Only those with outstanding performances in technology innovation and creation can be authorized and become the nurture and development focal of the provincial-level patent work. Besides, some provinces set up funding to reward the patent award receiver both at central and provincial level to inspire inventors to produce important patents.

3.2 The evaluation of patent subsidy policy on invention patent quality

Public support for innovation-related activities has been justified in several ways. The first justification for government subsidies is that the government is responsible for providing basic knowledge and general-purpose technologies to the society, and its task is to support the development, diffusion and implementation of innovations directly or indirectly. The second reason for government subsidies is to correct for market failures resulting from under investment in innovation activities (Arrow, 1962). Owing to positive externalities due to the difficulty of appropriating all the returns to an innovation and uncertainty of its success, it is argued that private sector invests less in innovation than is socially desirable. Therefore, government needs to provide incentives to private sector to compensate for the gap between the private and social returns to innovation in order to ensure the social optimal supply of research and development.

Patent subsidy programs aim at lowering the cost of seeking patent protection and promoting invention and creation. However, the influence of patent subsidy programs on patent quality is unclear. On the one hand, patent subsidy programs may enable innovators to reduce the externality of innovation and increase returns from their R&D investment, which strengthens incentives to invest in significant but risky technology development. The patent subsidy program in favor of Small and Medium Enterprises (SMEs), which are treated in some cases as the drivers of advanced technologies and breakthrough innovation, may also strengthen the incentives of innovators lacking access to financial resources to convert R&D results into patents by lowering costs. On the other hand, patent subsidy programs may discourage the quality of invention patents if the low entry threshold to patenting activity absorbs the (potential) low quality innovators and weakens incentives to develop brand-new technology, thus resulting in below history level aggregate quality of invention patent applications.

To test whether patent subsidy program increases or decreases the quality of invention patents in China, we first compare changes in the quality of invention patents at provincial level before and after patent subsidy programs. Table 1 below presents the descriptive statistics of invention patent quality. As shown in the table, it is apparent that both the number of patent applications and grants increase significantly after the patent subsidy programs. Moreover, the patent technological quality measured by the number of patent citations, patent claims, and inventors also increases significantly after the patent subsidy programs. In addition, the patent economic quality measured by withdrawal rate and renewal rate has been greatly improved since the launch of the patent subsidy program, which can be expressed as the decline of patent withdrawal rate and the rise of patent renewal rate.

Table 1: Descriptive Statistics

variable	Full sample (N=494)		Without subsidy (N=238)		With subsidy (N=256)		t-test	
	mean	stdev	mean	stdev	mean	stdev	t	P-value
# of applications	2169	4484	507	711	3715	5782	-8.5	0
# of grants	1147	2478	246	406	1985	3202	-8.32	0
# of citations	4559	9461	996	1604	7872	12158	-8.65	0
# of claims	13728	34639	2415	3902	24246	45553	-7.37	0
# of inventors	6258	13157	1324	2441	10846	16891	-8.61	0
grant rate	0.48	0.11	0.44	0.11	0.52	0.09	-8.97	0
withdrawal rate	0.43	0.12	0.5	0.12	0.38	0.1	12.25	0
3-year renewal rate	0.76	0.12	0.7	0.11	0.83	0.09	-14.33	0
4-year renewal rate	0.62	0.16	0.52	0.14	0.71	0.11	-18.16	0
5-year renewal rate	0.52	0.18	0.4	0.14	0.63	0.13	-18.55	0

A critical research question is whether the changes of invention patent quality are affected by the patent subsidy program. Considering that the effect of patent subsidy program in the short run is different from that in the long run, we follow Li (2012) and use two variables to measure the effect of patent subsidy programs. A binary variable (*patsub*) is used to identify persistent effect or long-run effect of patent subsidy program (β_ℓ), which takes a value of 1 after the province launches its patent subsidy program and 0 otherwise. The second variable (*patsub2*) is used to identify immediate effect or short-run effect (β_s), which takes the value of $-1/(t - t_0 + 1)$ after the province launches its patent subsidy program and 0 otherwise, where t_0 is the year when the province first launches the program. Therefore, the impact of patent subsidy programs on invention patent quality in year t can be expressed as $\exp(\beta_\ell - \beta_s/(t - t_0 + 1))$.

Regarding model specifications, we took the quality outcome of invention patent applications as the dependent variable and employed the knowledge production function as the underlying theoretical framework. We used the two-way fixed effect panel regression and specified the model as following:

$$\text{Patent Quality}_{it} = \alpha_0 + \beta_\ell\left(\text{patsub}_{it}\right) + \beta_s\left(\text{patsub2}_{it}\right) + \lambda X_{it} + \eta_i + \mu_t + \varepsilon_{it} \quad (1)$$

Patent Quality_{it} is the outcome variable of interest for province i in year t. we construct each of the five indicators introduced in Section 2.2 in the following way. When estimating the impact of patent subsidy program on technological quality of invention patents, we take the logarithm of the quality indicators. More specifically, for patent claims, we take the logarithm of the total number of claims of the applied invention patents in year t of province i, and denote by *lnclaims*. For forward citation, we take the logarithm of the total number of citations of the applied invention patents in year t of province i, and denote by *lnciting*. For the number of inventors, we take the logarithm of the total number of inventors of the applied invention patents in year t of province i, and denote by *lninventors*. In the case of estimating the impact of patent subsidy program on economic quality of invention patent, we use the ratio as the dependent variables. We measure the withdrawal rate by taking the ratio of "the total number of withdrawals of the applied invention patents in year t of province i" to "the total number of applied invention patents in year t of province i". This index is denoted by *Rwithdrawal*. We measure the 3-year renewal rate by taking the ratio of "the total number of granted invention patents in year t of province i that are active 3 years of longer" to "the total number of granted invention patents in year t of province i". This index is denoted by *Rrenewal3*. Let us make the definition clearer by a simple example. Suppose Patent A applied in year 2000 and was granted, then subsequently terminated the patent in year 2005. Patent A would be classified as being active for 5 years. Take one step further, if a province in year 2000 had 500 patent applications that were granted, among the 500 patents, 50 of them remained active for 1 year, 100 remained active for 2 years, 150 remained active for 3 years, and 200 remained active for 4 years. Then, *Rrenewal3* for this province in year 2000 is $\frac{350}{500} = 70\%$.

X_{it} is a vector of 3 control variables. First is real R&D expenditure, we use the one year lag and take the logarithm (denoted by *L.trd*). Pro-patent legal change variable (*ipenv*) is constructed like Li (2012). Last is the stock of inflow foreign direct investment (FDI), [11] we take its logarithm and denote by *lgfdi*. η_i and μ_t indicate the province fixed effect and year fixed effect respectively. ε_{it} is the error term. The control variables represent alternative explanations of China's patent surge. R&D expenditure is one of the most important factors of generating patents. However, literature has found that the elasticity of the number of patents with respect to R&D investment is less than 1 (Cincera, 1997; Hausman et al., 1984; Hu and Jefferson, 2004, 2009; Li, 2006, 2008; and Hu, Zhang and Zhao, 2017). Thus, R&D expenditure alone would not be able to explain the whole story of the dramatic increase in patents. Following the econometric literature on estimating the relationship between R&D and patents (Hausam et. al, 1984; Crepon and Duguet, 1997; Li, 2008, 2012; and Dang and Motohashi, 2015), we use lagged R&D expenditure as controls for the effect of R&D. In order to avoid the loss of too many observations, we use only one year lag. As noted in the institutional change that coincided with the patent surge, we acknowledge the change in the Chinese legal environment as another force that helped foster the patent surge. Kortum and Lerner (1999) argues that if China has a favorable legal environment for inventors, both Chinese and foreign inventors should find patenting in China increasingly attractive, when compared to elsewhere. However, Li (2012) finds that though the legal environment change is important, it cannot give a complete explanation to the patent surge. Hu and Jefferson (2009) instead argue that FDI inflow stock can increase technological opportunities for domestic firms to imitate and innovate. Zhang and Rogers (2009) also consider FDI as a factor contributing to firms' innovative performance.

4 Estimation and results

4.1 Data

The estimate is based on a comprehensive dataset constructed from multiple official sources. Specifically, the exact launch year for patent subsidy programs for each province was gleaned from the series of annuals of Chinese Intellectual Property Rights which record important policies and practices of intellectual property management every year for each local government. Patent information[12] was collected from Chinese SIPO and Google Patents. Information on R&D expenditure was gathered from the series of Chinese Science & Technology Statistical Yearbooks[13]. The remaining data were collected from Chinese Statistical Yearbooks which provide rich information on country-level export

[11] Following Hall and Mairesee(1995), the depreciation rate of FDI was set at 15%, and interest rate was set at 5%.

[12] Foreign residential patent application information was collected from WIPO.

[13] China started the statistics of Research and Development expenditure at the provincial level in 1999. Consequently, we use the internal expenditure of scientific and technological activities to represent the innovation input at the provincial level from 1995 to 1998.

and direct investment in China to construct FDI stock and pro-patent legal changes.

4.2 Pre-treated trend test

To assess the credibility of our empirical specification, a test between the treated and the control are used to see whether there is any significant difference in pre-treatment trend. If the pre-treated trend between the treated group and the control group is parallel, then it is valid to consider β_s and β_ℓ as the immediate and persistent effect of patent subsidy program. We use the sub-sample before the launching of patent subsidy programs as our test base, i.e. 84 observations in total from 1995 to 1998. The test equation is:

$$\text{Patent Quality}_{it} = \alpha_0 + \alpha_1\,(\text{trend}_t) + \alpha_2\,(\text{trend}_t \times \text{treated}_i) + \lambda X_{it} + \eta_i + \varepsilon_{it} \tag{2}$$

where trend_t is the time trend item that equals to $t - 1994$, treated_i is a dummy variable of being treated or not, X_{it} is the set of controls, η_i is the treated province fixed effect, ε_{it} is the error term.

Table 2: Pre-treated Trends Test

	(1) lnclaims	(2) lnciting	(3) lninventors	(4) Rwithdrawal	(5) Rrenewal3
L.trd	-0.121	-0.229	-0.105	-0.092	-0.029
	[0.204]	[0.329]	[0.220]	[0.062]	[0.083]
lgfdi	0.216	0.489	0.500**	-0.006	0.260***
	[0.210]	[0.339]	[0.227]	[0.064]	[0.085]
trend	0.077**	0.124**	0.105***	-0.037***	0.024*
	[0.035]	[0.057]	[0.038]	[0.011]	[0.014]
trend ×	0.021	-0.041	-0.006	-0.007	0.025
treated	[0.047]	[0.076]	[0.051]	[0.014]	[0.019]
Province	Yes	Yes	Yes	Yes	Yes
Observations	84	84	84	84	84
adj. R^2	-0.206	-0.351	-0.178	-0.078	-0.114

Robust standard errors are in brackets.
$^*p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

To guarantee the variation of treated_i and the distribution of sample, we set the provinces which launched patent subsidy program before 2001 as the treated group. That is to say, treated_i equals to 1 if the province was treated before 2001 (6 treated provinces in total) and 0 otherwise. When the coefficient of the interactive term ($\text{trend}_t \times \text{treated}_i$) is insignificant, it means that the marginal effect of trend_t on invention patent quality is independent of whether the province launch the patent subsidy program.

Table 2 shows the coefficient of the interaction is insignificant, no matter what kind of invention patent quality measures is used, indicating that there is no systematic difference in pre-trends across treated and control provinces. The results are robust across different definitions for treated_i. We performed the pre-treated trends test for (a) treated_i equals to 1 if the province was treated before 2002 (12 treated provinces in total) and 0 otherwise, (b) treated_i equals to 1 if the province was treated before 2003 (18 treated provinces in total) and 0 otherwise, and (c) treated_i equals to 1 if the province was treated before 2004 (23 treated provinces in total) and 0 otherwise. The results were almost the same as Table 2 shown.

4.3 Empirical results

The results from the estimation model, using the quality of invention patents as the outcome variable, are shown in Table 3. Regression results reveal a high and statistically significant positive correlation between patent subsidy program and technological quality of invention patents, based on the number of invention patent claims, forward citations and inventors. Coefficients of patsub2_{it} stay highly significant at the 1% level in columns (1)-(3), which indicate that implementing a patent subsidy program has an immediate impact on the number of invention patent claims, forward citations and inventors. The persistent effects of patent subsidy program on the technological quality of invention patents are mixed, although coefficients of patsub_{it} are consistently positive. Moreover, it is clear that the impact of patent subsidy programs on the technological quality of invention patents declines as time elapses ($\beta_s > \beta_\ell$). According to our estimates, the effects of patent subsidy policies on the number of patent claims, forward citations and inventors are 63% (=exp(0.487)-1), 79% (=exp(0.582)-1) and 70% (=exp(0.531)-1) higher for the provinces implementing patent subsidy policies than for those without policies in the short term.

Table 3 column (4)-(5) reports estimated coefficients of patent subsidy program on the economic quality of invention patents. The coefficients of both patsub2_{it} and patsub_{it} on the ratio of withdrawal and renewal are statistically insignificant. The results suggest that whether a patent subsidy program was implemented is uncorrelated with the economic quality of invention patents. It is likely that the patent applicant has its rational judgment on the economic or market value of the invention patents, which is not easy to be influenced by the government's patent subsidy program.

The contribution of lagged one year R&D expenditure ($L.trd$) to the quality of invention patent is mixed. According to column (1)-(3) of Table 3, it can be seen clearly that coefficients of R&D are statistically significant, indicating that more innovation input will produce larger number of patent claims, forward citations, and attract more inventors to attend patenting activities. Moreover, as shown in column (4), the coefficient of R&D on the ratio of patent withdrawal becomes statistically

Table 3: Empirical Results

	Technological Quality			Economic Quality	
	(1)	(2)	(3)	(4)	(5)
	lnclaims	lnciting	lninventors	Rwithdrawal	Rrenewal3
patsub2	0.487**	0.582***	0.530***	-0.006	-0.018
	[0.200]	[0.194]	[0.192]	[0.037]	[0.020]
patsub	0.350	0.377**	0.363*	-0.005	0.009
	[0.220]	[0.178]	[0.200]	[0.037]	[0.023]
L.trd	0.481**	0.480**	0.418**	-0.058**	0.003
	[0.185]	[0.187]	[0.170]	[0.025]	[0.022]
lgfdi	-0.227*	-0.182	-0.184*	0.016	0.017
	[0.121]	[0.116]	[0.101]	[0.022]	[0.014]
ipenv	0.906***	0.877***	1.031***	-0.100***	0.077***
	[0.067]	[0.065]	[0.067]	[0.012]	[0.008]
Year	Yes	Yes	Yes	Yes	Yes
Province	Yes	Yes	Yes	Yes	Yes
Observations	421	421	421	421	421
adj. R^2	0.906	0.919	0.938	0.593	0.602

Robust standard errors are in brackets.

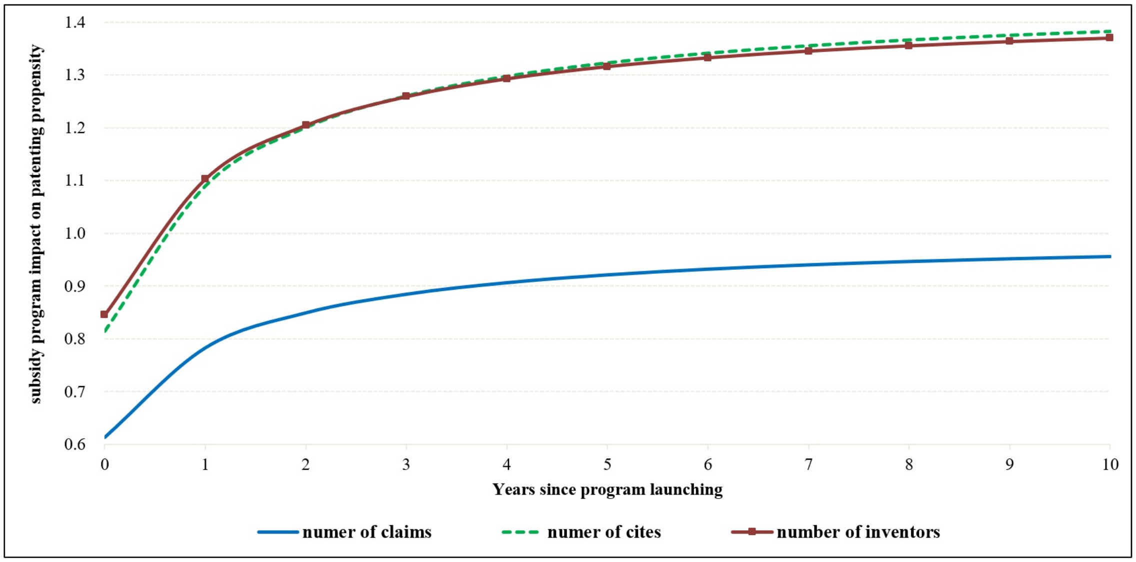
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

negative significant, implying that the invention patents with larger amount of R&D input have better economic quality and the patentees will have lower possibility to withdraw their applications. However, whether the patentees renew their invention patents after grant through paying the annual fee is independent of prior R&D input. As shown clearly in the table, the elasticity of patent quality with respect to R&D expenditure is less than 1 in all cases. This result is in line with the literature.

In terms of the impact of FDI stock (*lgfdi*), it is found to be statistically significant negative at the 10% level only for the number of patent claims and patent inventors, whereas insignificant for the remaining three indicators of patent quality. These findings demonstrate that the inflow of FDI is likely to compete for the technological dominance and resources (such as new ideas and inventors) with the domestic innovator and produce negative impact on the number of patent claims and patent inventors.

It is worth noting that the impact of the pro-patent legal changes variable (*ipenv*) on the technological quality of invention patents is consistently significant and positive. Columns (1)-(3) of Table 3 reveal that coefficients of pro-patent legal change variable on the number of patent claims, citation, and inventors are all significantly positive. The impact on the economic quality also paints the same story: significant and negative effect on the withdrawal rate, and significant and positive effect on the renewal rate. Therefore, the overall legal environment in China, especially positive changes in patent law has made a positive effect on the technological and economic qualities of patents.

Figure 6: Impact of subsidy program on patent propensity



Note: The vertical axis represents predicted multipliers of patent propensity.
Data source: Authors' calculation based on empirical results

In Figure 6, we calculate the total impact of patent subsidy program on patent propensity $exp[\beta_\ell - \beta_s/(t-t_0+1)]$ using the estimated coefficients β_ℓ and β_s from Table 3. Since the persistent effect of patent subsidy programs on the number of claims is insignificant, we only consider the transient effect for number of claims. For number of forward citations and inventors, we consider both the persistent and transient effects. The difference in effects may be due to the way the patent subsidy programs were designed. In most issued policies, there are clear incentives for applicants to have more forward citations and number of inventors, whereas we see less policies concerning the number of claims. We see that the first year multiplier on patent propensity is less than 1, suggesting a lagged effect from program launch.

5 Robustness Check and Discussion

5.1 Placebo test and randomized policy check

One potential problem in our empirical results is whether the above empirical design identifies the exact effect of patent subsidy program. In order to validate the identification of the treatment effect, we have conducted the placebo test as follows: First, we generate one year lead value of the patent subsidy programs ($F.\text{patsub}_{(i,t)} = \text{patsub}_{(i,t+1)}$). Based on the sample without a real patent subsidy program or treatment, we regress the outcome variables on pseudo patent subsidies variable ($F.\text{patsub}_{(i,t)}$) and other controls as Table 3. If coefficients of $F.\text{patsub}_{(i,t)}$ are statistically insignificant, it can be inferred that only the truly happened patent subsidy program can have a significant impact on the patent quality. Second, to be consistent with the baseline model, we generate two year lead value of the patent subsidy programs ($F2.\text{patsub}_{(i,t)} = \text{patsub}_{(i,t+2)}$ and $F2.\text{patsub2}_{(i,t)} = \text{patsub2}_{(i,t+2)}$) and replicate the above process again to further test the effect of patent subsidy program. Third, we also try the three year lead value of the patent subsidy programs.

Table 4: Placebo Test

	(1) lnclaims	(2) lnciting	(3) lninventors	(4) Rwithdrawal	(5) Rrenewal3
Panel A: 1 year lead (N=191)					
F.patsub	0.052	-0.048	-0.012	-0.011	0.001
	[0.068]	[0.059]	[0.059]	[0.016]	[0.021]
Panel B: 2 year lead (N=189)					
F2.patsub	0.101	-0.098	-0.028	-0.021	0.003
	[0.136]	[0.117]	[0.114]	[0.031]	[0.043]
F2.patsub2	0.155	-0.042	0.083	-0.019	-0.018
	[0.106]	[0.097]	[0.085]	[0.029]	[0.039]
Panel C: 3 year lead (N=187)					
F3.patsub	-0.048	-0.163	-0.250	-0.020	0.046
	[0.194]	[0.161]	[0.166]	[0.045]	[0.050]
F3.patsub2	0.081	-0.078	-0.265	-0.053	0.039
	[0.329]	[0.268]	[0.254]	[0.073]	[0.088]

Robust standard errors are in brackets.

Table 4 reports the results of the placebo test. The estimated coefficients of the pseudo patent subsidy programs are found to be statistically insignificant on all of the outcomes of invention patent qualities. These findings demonstrate that the effect of patent subsidy programs does not exist in the sample without the true treatment, which can inversely justify that our basic model specification captures the impacts of patent subsidy program on patent quality estimated in Table 3.

Another potential problem is whether there is endogeneity issue of the patent subsidy programs. We examine this by conducting a randomized policy test. When policy is randomized and exogenous, then there is no endogeneity problem. One way to test whether policies are random and exogenous is by checking the results with or without controlled variables. If the estimated impact of subsidy policies on patent quality (β_ℓ and β_s) exhibit similar magnitudes and statistical significance, then we can conclude that the policies are indeed randomized and exogenous. As we can see from Table 5, the coefficients tell the same story as Table 3.

Table 5: Randomized Policy Check

	(1)	(2)	(3)	(4)	(5)
	lnclaims	lnciting	lninventors	Rwithdrawal	Rrenewal3
patsub2	0.673***	0.650***	0.693***	0.005	0.019
	[0.236]	[0.194]	[0.224]	[0.038]	[0.044]
patsub	0.488**	0.445**	0.464**	0.006	0.033
	[0.225]	[0.180]	[0.200]	[0.035]	[0.031]
Year	Yes	Yes	Yes	Yes	Yes
Province	Yes	Yes	Yes	Yes	Yes
Observations	494	494	494	494	494
adj. R^2	0.885	0.909	0.919	0.589	0.475

Robust standard errors are in brackets.
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

5.2 Patent Subsidy Program Robustness Check

In our model, we used *patsub* to capture the persistent effects of the patent subsidy programs, and *patsub2* to capture the transient effects. In order to check whether the constructed variables *patsub* and *patsub2* account for all the possible time lag between policy stimulus and effects on patent quality, we conduct additional robustness check. The dummy variables for policy effect in Table 6 are constructed as follows: "Dummy of i^{th} year" takes a value of 1 if it is the i^{th} year of the patent subsidy program being launched, otherwise, the dummy is set to 0. Note that Shanghai is the only provincial government that has a patent subsidy program in place for 12 years, the sample size of "Dummy of 12^{th} year= 1" is limited, and therefore would affect the statistical significance of the estimate. Hence, we only include dummy variables up to the 11^{th} year. From Table 6 we can see that the estimated policy effect is very similar to that of Table 3, therefore we conclude that our construction of the subsidy effects is robust.

Table 6: Policy Stimulus and Lagged Effect

	(1) lnclaims	(2) lnciting	(3) lninventors	(4) Rwithdrawal	(5) Rrenewal3
Dummy of 1st year	0.062	0.029	0.061	-0.008	0.013
	[0.058]	[0.086]	[0.062]	[0.013]	[0.009]
Dummy of 2nd year	0.227**	0.170	0.243***	0.017	0.008
	[0.109]	[0.108]	[0.069]	[0.027]	[0.014]
Dummy of 3rd year	0.288**	0.341***	0.356***	-0.007	0.017
	[0.117]	[0.122]	[0.099]	[0.024]	[0.020]
Dummy of 4th year	0.437**	0.500***	0.530***	-0.011	0.010
	[0.159]	[0.154]	[0.137]	[0.029]	[0.026]
Dummy of 5th year	0.601***	0.660***	0.705***	-0.021	-0.015
	[0.197]	[0.186]	[0.165]	[0.031]	[0.029]
Dummy of 6th year	0.764***	0.843***	0.863***	-0.014	-0.015
	[0.219]	[0.213]	[0.184]	[0.039]	[0.028]
Dummy of 7th year	0.950***	1.020***	0.997***	-0.010	-0.009
	[0.237]	[0.248]	[0.206]	[0.043]	[0.028]
Dummy of 8th year	1.144***	1.200***	1.197***	-0.009	-0.013
	[0.269]	[0.285]	[0.241]	[0.049]	[0.031]
Dummy of 9th year	1.264***	1.272***	1.278***	-0.008	-0.015
	[0.296]	[0.325]	[0.272]	[0.053]	[0.034]
Dummy of 10th year	1.501***	1.522***	1.502***	-0.002	-0.021
	[0.339]	[0.365]	[0.311]	[0.058]	[0.039]
Dummy of 11th year	1.554***	1.608***	1.490***	0.035	-0.023
	[0.370]	[0.427]	[0.362]	[0.053]	[0.042]
L.trd	0.399**	0.412**	0.362**	-0.055**	-0.003
	[0.155]	[0.166]	[0.145]	[0.026]	[0.021]
lgfdi	-0.148	-0.106	-0.116	0.022	0.018
	[0.117]	[0.128]	[0.111]	[0.022]	[0.014]
ipenv	0.585***	0.541***	0.695***	-0.101***	0.090***
	[0.129]	[0.144]	[0.116]	[0.016]	[0.011]
Year	Yes	Yes	Yes	Yes	Yes
Province	Yes	Yes	Yes	Yes	Yes
Observations	391	391	391	391	391
adj. R^2	0.917	0.930	0.948	0.588	0.612

Robust standard errors are in brackets.

$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

5.3 Well-established Innovators

China is not the only country to implement patent subsidy program. In Japan, about one third, or even half of the patent filing fees and annual fees incurred in SMEs are reimbursed. In France and German, the rates of reimbursement for SMEs are almost the same as Japan, about 50%. Lithuania, Spain, Belgium and Hungary provide more generous funding for SMEs, with the rates higher than 50%, and even up to 90%. However, unlike these developed countries with patent subsidy programs that give priority to patent work of SMEs, the funding targets of patent subsidy programs in China are innovators who have the ability to complete independent innovation, like Patent Pilot Enterprise, Patent Demonstration Enterprise or large enterprises with core technology.

It is plausible that those well-established innovators are much more preferred by Chinese policy makers, rather than SMEs. It is acknowledged that China began developing economically and technologically later than forerunner nations and the intellectual property rights landscape in many high-tech industries is dominated by developed countries. As the Latecomer theory implies, proactive policy intervention in technology and innovation may seem like an attractive tool to help domestic inventors to obtain core indigenous IP rights and nurture its catchup ability. In this context, it is more effective and efficient for the Chinese provincial government to implement discriminatory policies and support well-established innovators, which not only can help them finish the patent development tasks assigned by the central government, but also avoid the critique of junk patents and achieve the catch-up goal.

We conduct a further empirical analysis of policy effects to test whether the government strictly implements such a discriminatory patent subsidy program as its document demonstrates[14], and evaluate its impact on the technological quality[15] of China's invention patents. Intuitively, if the well-established innovators are the biggest beneficiaries from patent subsidies, then these selective patent subsidies can produce a positive feedback mechanism. By reducing the cost of patent filings, it increases the incentive of growth of great innovators in the long run, thus finally produce more high quality inventions. In most cases, those who insist on patenting activities are more likely to be great innovators, which is more obvious especially in the developing countries who are still at the stage of technology accumulation and learning.

To verify the above hypothesis, we separate the patentees into *entrants* (normally SMEs) and *incumbents* (normally well-established innovators) based on whether the patentee insists on patenting activities. Empirically, we define the patentee who can be observed only in year t as an entrant and the patentees who can be observed both in year $t-1$ and year t as incumbents. We use incumbents

[14] For example, Beijing issued preferential patent subsidy policies during 2000-2002 for institutions and individuals that have filed a substantial amount of patent applications. During 2007-2010, the policies further specified that when the applicant has filed more than 100 invention patent applications in a given year, an additional 1000 yuan will be subsidized for each application, and 1500 yuan for each granted application.

[15] We focus only on technological quality in this section since the impact of patent subsidy on economic quality as found to be statistically insignificant in Section 4.3.

to indicate well-established innovator. In the following specification, we add four variables on the basis of the basic regression model: the growth rate of entrants (Renter_{it}) and its interaction term with patent subsidy program ($\text{patsub}_{it} \times \text{Renter}_{it}$), the growth rate of incumbents (Rincumb_{it}), and its interaction term with patent subsidy program ($\text{patsub}_{it} \times \text{Rincumb}_{it}$).

$$
\begin{aligned}
\text{Patent Quality}_{it} = \alpha_0 &+ \beta_\ell \text{patsub}_{it} + \beta_s \text{patsub2}_{it} + \alpha_1 \text{Renter}_{it} \\
&+ \alpha_2 \text{Rincumb}_{it} + \alpha_3 \text{patsub}_{it} \times \text{Renter}_{it} \\
&+ \alpha_4 \text{patsub}_{it} \times \text{Rincumb}_{it} + \lambda X_{it} + \eta_i + \mu_t + \varepsilon_{it}
\end{aligned} \tag{3}
$$

If the coefficients of $\text{patsub}_{it} \times \text{Rincumb}_{it}$ are statistically significant and the coefficients of $\text{patsub}_{it} \times \text{Renter}_{it}$ are statistically insignificant, then it is plausible that the positive persistent effect of patent subsidy program on the technological quality of invention patents depends on the growth rate of incumbents or well-established innovator, rather than the growth rate of entrants or SMEs. In other words, the mechanism through which patent subsidies improve the technological quality of invention patents is because patent subsidies help well-established innovators survive and prosper.

Table 7 presents the estimation results of the above model specification. As shown in Table 7, both Renter_{it} and Rincumb_{it} have positive impacts on the technological quality of invention patent (statistically significant at the 1% level), indicating that the surge of patentees, both well-established innovators and new innovators, has a noticeable impact on the technological quality of China's invention patents. Specifically, when there is no persistent impact of patent subsidy programs, the growth of well-established innovators lead to 12.8%, 18.2% and 10.5% higher number of patent claims, forward citations and inventors, and the growth of new innovators lead to 23%, 52.2% and 35.2% higher number of patent claims, forward citations and inventors.

Moreover, the estimated coefficients of $\text{patsub}_{it} \times \text{Rincumb}_{it}$ are significant and positive, whereas the coefficients of $\text{patsub}_{it} \times \text{Renter}_{it}$ are insignificant. From Table 7, we can see that the persistent effects of patent subsidy programs on the number of patent claims, forward citations and inventors are not affected by the growth rate of new innovators, but by the growth rate of well-established innovators. It can be inferred that the difference of invention patents technological quality between the treated group (with patent subsidy programs) and the controlled group (without patent subsidy programs) will increase with the rise of the growth rate of incumbent patentees. In other words, the relationship between the technological quality of China's invention patents and the persistent impact of patent subsidy program varies as a function of the growth rate of well-established innovators.

Note that the coefficient of patsub_{it} become insignificant after the inclusion of $\text{patsub}_{it} \times \text{Rincumb}_{it}$ and $\text{patsub}_{it} \times \text{Renter}_{it}$. It indicates that there is no technological quality difference in the long term between the treated group and the control group when the growth rate of well-established innovators is held constant at zero. This suggests that only those programs which lead to

Table 7: Mechanism: The Role of Incumbents

	(1) lnclaims	(2) lnciting	(3) lninventors
patsub2	0.474**	0.569***	0.514***
	[0.193]	[0.177]	[0.177]
patsub	0.217	0.255	0.226
	[0.219]	[0.182]	[0.197]
Rentrant	0.234*	0.522***	0.350***
	[0.117]	[0.129]	[0.085]
Rincumbent	0.127***	0.182**	0.104**
	[0.044]	[0.068]	[0.045]
patsub × Renter	0.193	-0.012	0.094
	[0.306]	[0.205]	[0.224]
patsub × Rincumb	0.476**	0.468***	0.525***
	[0.173]	[0.166]	[0.162]
L.trd	0.461**	0.475**	0.402**
	[0.181]	[0.179]	[0.166]
lgfdi	-0.223*	-0.183	-0.182*
	[0.121]	[0.116]	[0.101]
ipenv	0.967***	0.940***	1.096***
	[0.078]	[0.073]	[0.074]
Province	Yes	Yes	Yes
Year	Yes	Yes	Yes
Observations	421	421	421
adj. R^2	0.911	0.927	0.943

Robust standard errors are in brackets.
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

the growth of well-established innovators can exert a persistent impact on the technological quality of Chinas invention patents.

6 Conclusions

China has aimed to transform its growth model from ”high speed” to ”high quality”, and from factor driven to innovation driven. The contribution from inventions and innovation capability have become increasingly important. Since patents are the most commonly used indicator of the invention output and technological change, one may wonder whether such a dramatic rise of China's invention patents signals the increase of innovation quality and the development of innovation ability. We try to answer this question by linking SIPO data with Google Patents data and analyze a comprehensive set of quality indicators for invention patents. Following Lanjouw and Schankerman (2004), we use the number of forward citations, the number of patent claims and the number of patent inventors as the proxies of technological quality of inventions patents, and withdrawal rate and renewal rate as the proxies of economic quality of inventions patents. The statistical results present that both technological and economic quality of Chinas invention patents did not decline with the jump of China's invention patents.

To better understand the policy drivers behind the patent surge, our second goal in this paper is to evaluate the impact of patent subsidy policies on Chinas invention. Unlike most of the literature, we look at the effect of patent subsidy on the quality of inventions, encompassing technological and economic quality, rather than the quantity of inventions. By regression estimation, we find a positive impact of patent subsidy policies on the technological quality of Chinas invention patents. The effect turns out to be consistent across different technological quality measures, including the number of forward citations, patent claims and patent inventors. According to our estimates, the effects of patent subsidy policies on the number of patent claims, forward citations and inventors are 63%, 79% and 70% higher for the provinces that implemented patent subsidy policies than for those without policies in the short term. We also find that the overall impact of patent subsidy policies on technological quality of invention patents changes as time elapses, which indicates that the positive impact of patent subsidy policies on the technological quality of China's invention patents is not instantaneous. Further empirical analysis show that the persistent effect of the policies is smaller than the temporary effect.

Moreover, we show that patent subsidy policies have an insignificant effect on the economic quality of China's invention patents. First, the ratio of patent withdrawal is not affected by patent subsidy policies. As a matter of fact, the withdrawal decision during the application of patenting is often viewed as rational choices of patentees, which reflects the tradeoff between potential economic benefits of excluding others from exploiting an invention and the costs of preparing, filing and maintaining the invention patent. In our study, this argument is supported and validated by the insignificant coefficient of patent subsidy policies on the ratio of patent withdrawal. Second, the situation of patent subsidy on the ratio of renewal (three years after filing) has a similar situation. Again, assuming that renewal decisions are based on economic criteria, patentees will renew their patents only if the value of holding them an additional year exceeds the cost of renewal. We also find that patent subsidy policies did not influence the rationale of the patentees.

The above results are robust to the placebo test. We examined a variety of lead years for patent subsidy policies as the dependent variables and found the coefficients of falsified patent subsidy policies insignificant. These results imply that the quality of invention patent can only be affected if subsidy policies were implemented. Moreover, when we add the two interaction terms— one is between the policy variables and the growth rate of well-established innovators, the other is between the policy variable and the growth rate of new innovators— the estimation results suggest that the persistent effect of patent subsidy policies on the technological quality of invention patents depends on the growth rate of well-established or experienced innovators in patenting, other than the growth rate of entrants. With the growth of well-established innovators, patent subsidy polices shows a multiplier effect on the technological quality of invention patents. This implies that the well-established innovators are more active and effective in producing important inventions, and the government can build its innovation capacity through them.

This research contributes to at least two lines of research. On the one hand, it presents the quality of China's invention patents as fully as possible based on the comprehensive patent information and enriches our understanding of its dynamic features. On the other hand, it contributes to the studies on the evaluation of the impact of patent subsidy program on the patent quality. As far as we know, no other paper examines the relationship between patent subsidy programs and the quality of regional inventions, although lots of advanced countries have implemented similar programs as China.

This paper also raises important issues for public policy related to patents, asking what types of patent subsidy policy can facilitate invention and patent quality more. We show that patent subsidy programs in favor of well-established innovators have given a great impetus to the technological quality of regional inventions. It demonstrates that in the implementation of patent subsidy programs, the local government was consistent with its documents and the policy takes effect. Moreover, the selection of patent funding targets is important to seek catch-up opportunity for the developing countries. Giving a priority to well-established innovators and allocating more funding to them seems to be a good way to achieve Pareto improvement of scarce public research resource. By doing so, government can not only help nurture experienced innovators with independent innovation capacity, but also improve the quality of innovation and promote the development of technology and the construction of national innovation system.

Finally, it should be noted that China's patent quality problem still exists. Our paper shows that the quality of China's invention patent does not decline, which does not mean that there is no patent quality problem in China. Actually, China still has a long way to go before it can establish itself as a dominant player in intellectual property and technology leadership. Some studies indicate that the average quality of China's patent is declining, mainly due to low quality of utility model and design patent (Gao et.al., 2011; Dong and He, 2015). Moreover, there is still a patent quality gap between China's invention patent and foreign invention patent (Boeing, 2016). To be sure, it is clear that China possesses great innovation potential. However, China still lags behind many developed countries in terms of innovation, let alone breakthrough innovation and highest quality patents. In addition, China's patent quality problem is systemic: it goes far beyond the often cited reasons of patent (filing) subsidies and occasional tax incentives, having roots in a wide range of policies and other measures, as well as administrative and enforcement approaches. These issues do not seem to be effectively addressed at present, nor no course to be effectively addressed, and in some cases are not even discussed at all. Therefore, the patent quality is worthy of further exploration in future research with more detailed and comprehensive data.

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