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Article

China's patent promotion policies and its quality implications

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Abstract

Based on China's patent data from 1985 to 2010, we find that behind the country's patent number explosion, the overall innovation content of Chinese patents has not achieved proportional growth. An important explanation for this phenomenon is the patent promotion polices (*PPP*s), which have prompted the quantitative expansion of patent applications and approvals, but have had negative effects on average patent quality, as proxied by patent application withdrawal rate and patent renewal rate. These patterns are observed both at the provincial level and at the patent level, and they are especially pertinent to patent applications filed by firms, which are the main targets of the *PPP*s.

Key words: patent quantity; patent quality; patent promotion policies

1. Introduction

The numbers of patent applications and approvals in China have experienced drastic increases in recent years. And in 2011, China surpassed the USA and Japan to become the number one country in the quantity of patent applications. What have been driving such rapid growth? And how shall we evaluate such development? We intend to address these questions in the current study.

To preview our empirical findings, we document patterns in support of the argument that patent promotion policies (*PPPs*), which are measures adopted by various government agencies linking tax incentives and subsidies to patent ownership, have significantly contributed to the rapid growth in both patent applications and patent approvals in China. More importantly, we present evidence that the adoption of *PPP*s has led to a decline in average patent quality by multiple measures.

We make use of two databases in studying the sources and implications of patent expansion in China. The first database is the SIPO (State Intellectual Property Office) Chinese patent record database for 1985–2010 with 5.59 million patent applications, which includes rich information on both patent applications and their applicants. In addition, we manually construct the second database on the *PPP*s, using information sources including *Beida Fabao*, *Beida Fayi*, and the Compendium of Chinese Laws (from the Chinese Court Website) to collect information on government *PPPs* across regions in China.

Our study conducts two levels of investigations, where we adopt different analytical methodologies. At the provincial level, we use the differences-in-differences approach by relying on the variations in adoption time of the *PPP*s across regions to explore the impact of *PPPs* on patent quantity and quality. At the patent level, we conduct a Poisson estimation and a survival analysis, using the withdrawal decision and the renewal status of a patent, respectively, as the measure of the patent's market value or quality. Both types of patent level analysis allow more detailed patent characteristics to be controlled for. In addition, the survival analysis enables us to distinguish the quality impact from the other two effects brought about by a *PPP*'s adoption, that is, the market demand effect and the innovation capacity effect (see Section 3 for more detailed discussion).

The remainder of the article is structured as follows: Section 2 provides background information on China's patent explosion in recent years and gives a brief review of the related literature. Section 3 describes *PPPs* in China, followed by a stylized model of patent application to derive theoretical predictions of the *PPP*, as well as an overview of the patent application process to arrive at the various measures for patent quality. Data description is given in Section 4, while estimation results are offered in Section 5. Section 6 concludes with some discussion on endogeneity.

2. China's patent explosion: background and literature review

In this section, we will first provide background information on the recent patent explosion in China, and then discuss *PPPs* adopted by various government agencies. We will also review research work studying China's patent growth as well as the general literature relating innovation to government policies.

2.1 Patent growth in China

Since the 1980s, China's patent applications and approvals have experienced geometric growth. And with a growth rate substantially

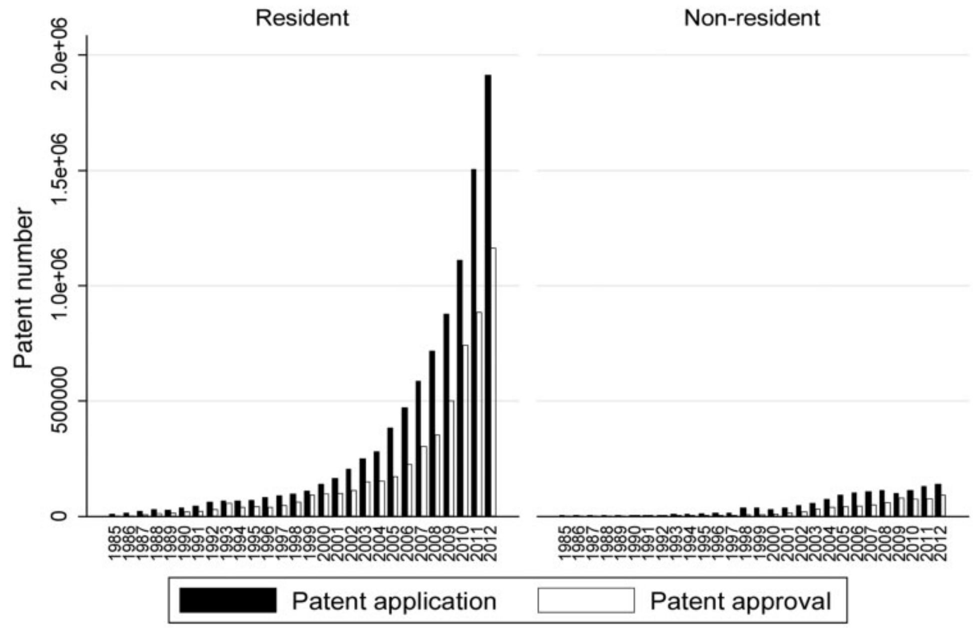

Figure 1. Patent applications and approvals in China (1985–2012): by residents and non-residents. *Source*: WIPO IP Statistics Data Center.

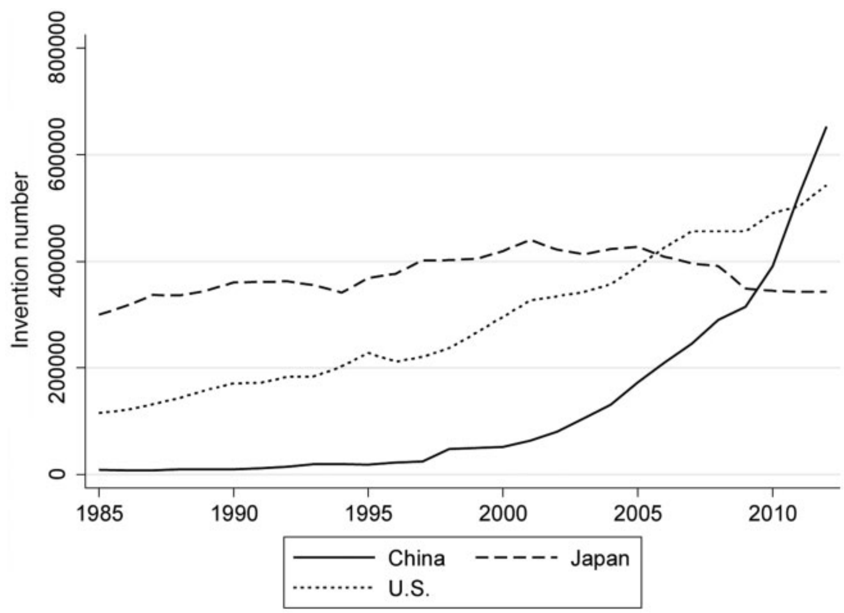

Figure 2. Comparing invention applications among China, Japan, and USA. *Source*: WIPO IP Statistics Data Center.

higher than other parts of the world, the country surpassed the USA and Japan in 2011 to become the largest patent applicant country (WIPO 2012). Figure 1 shows the number of patent applications and the number of patent approvals in China over the period of 1985–2012, while Fig. 2 compares the patent application quantities in China, Japan, and the USA. Clearly, China has witnessed a patent explosion over the past 10 years or so.

Yet along with the rapid rise in patent numbers, the average quality of patents has shown some signs of declining. Figure 3 gives the percentages of patent applications accounted for by inventions, utility models, and exterior designs in China and Japan, respectively, between 1985 and 2012. As shown in the graph, inventions make up only a small proportion of Chinese patents in most years, with the proportion falling since 2005, while the combined share of inventions and utility models among all patents has been declining throughout the period of 1985 and 2012. In contrast, the composition of different types of patents in Japan has remained largely constant since 1994, with invention percentage continuously above 80 per cent. Given that the novelty standard for patent approval in China has been lower than the international standard in most of the time period, the differences between the two countries discussed above cannot be explained away by variations in patent standards.[1]

Thus, a theory about why a patent explosion has occurred in China will need to account for both the increasing trend in patent quantity as well as the declining pattern in patent quality. We now turn to a brief review of the existing explanations for the patent explosion in China.

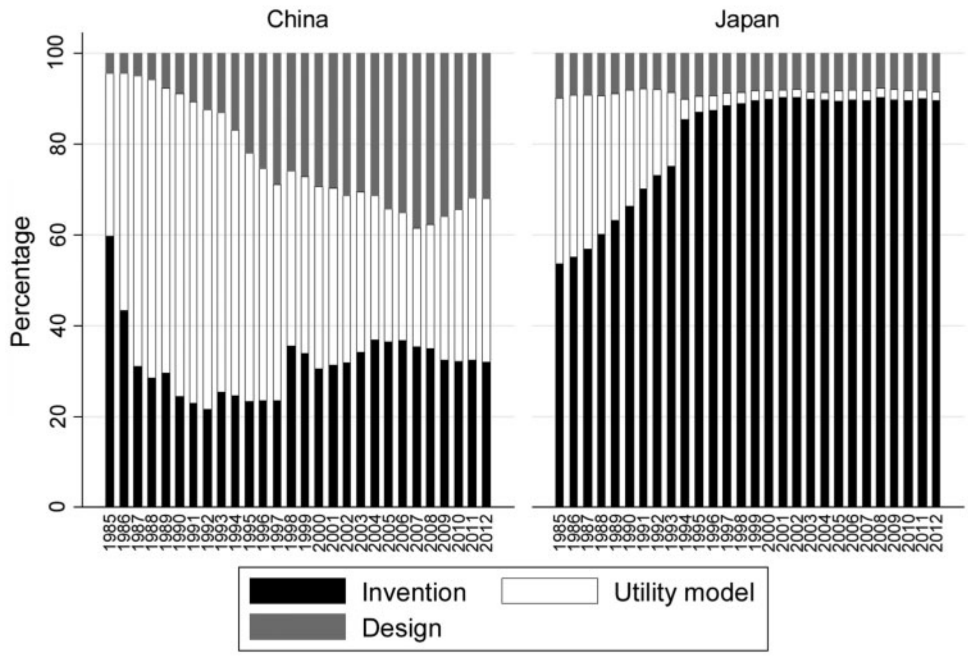

Figure 3. Composition of patent types: China versus Japan. *Source*: WIPO IP Statistics Data Center.

2.2 Literature review

While the occurrence of a patent explosion in China is beyond any doubt, academics and policy makers alike debate about what forces have been behind the rapid increase in patent applications and approvals. The answer to this question will not only shed light on the mechanisms that serve as the engine for innovation, but will also help predict the economic development consequences of the patent explosion. We now review related research work done in this area.

To summarize, the following theories contend to be the most relevant candidate for explaining why the patent explosion has occurred in China. The most optimistic argument is that China's innovation capacity has been improving rapidly, and thus the fast growth in the number of patents, which is an important indicator of a country's ability to innovate. Hu et al. (2005) and Cheung and Lin (2004), for example, take this view when they present empirical evidence showing that the levels of foreign direct investment and R&D input positively correlate with the number of patent applications.[2] A different but equally sanguine view is that the patent law revisions in 1992, 2000, and 2008 have brought about improved protection for patents, which has led to a greater willingness to apply for patents and thus the continuous growth in patent numbers. After controlling for the amount of Foreign Direct Investment (FDI) and the number of science and technical staff, Hu and Jefferson (2009) and Yueh (2009) argue that the improvements in China's Intellectual Property (IP) system have provided the important guarantee for patent growth. In particular, Hu and Jefferson (2009) provided empirical evidence that the patent law revisions of 2000 is significantly correlated with the quantity increase in patent applications.

Both views above, however, fail to address the concurrent decline in patent quality during the time period. They also neglect a big part of the government's role in China's patent explosion. In addition to attracting FDI, investing more in science and technical training, and ushering in legal reforms that provide gradually improved protection for intellectual properties including patents, various government agencies have also implemented many direct measures to encourage innovation behaviors. In particular, since the 1990 s, many provincial governments have issued policies that link tax incentives and subsidies to the possession of patents, especially for firms. These policies give direct monetary incentives to apply for patents, hence potentially constitute a major reason for the fast rise in patent numbers in the past two decades.

The main advantage of the *PPP* explanation is that it can account for both the rising number and the declining quality of patents. Besides offering an alternative explanation for the patent explosion in China, the *PPP* argument also offers a very different evaluation of the country's rapid expansion of patent accumulation. Instead of joining the celebratory chorus for the fast improvement of innovative capacity, this argument sounds a warning siren for the decreasing average quality of Chinese patents. More generally, it makes a cautious note of the unintended consequences of government intervention in the innovation market.

In addition to the papers discussed above that directly study the patent explosion in China, the current study relates to the following two lines of research in general: one is the literature on innovation, while the other is on public policy. In particular, our study relates closely to the sizable literature that explores the effects and affecting mechanisms of policies related to patents and innovation. Some studies give positive scores for the related policy initiatives, including Jaffe and Lerner (2001), who find significant improvement in per unit R&D input and patent output, controlling for patent quality, after federally-sponsored laboratories were allowed to transfer patents in commercial transactions. Fleisher and Zhou (2010) study the patent law revisions in 1993 and 2001, and they argue that the strengthened protection for intellectual property has made a significant contribution to China's Total Factor Productivity (TFP) growth. Using data on government promotion policies and firm innovation behaviors in Germany, Czarnitzki and Hussinger (2004) produce empirical evidence that government funds have positive effects on both R&D input and patent output, while Ebersberger (2004) obtains similar findings for Finnish firms. Relying on panel data and random effect model, Zhu and Xu (2003) analyze the impact of Shanghai city government's technology promotion policies on self-raised R&D input and patent output in large and medium-sized industrial firms. They find that government technology fund transfer and tax reduction both help firms raise R&D funds, yet only self-raised R&D expenditure helps increase patent output.

Other studies find effects opposite to the initial policy goals. Based on salary data for American researchers, Goolsbee (1998) finds that government funding policies mainly result in higher income for researchers, have limited impact on research activities, and at the same time crowd out private R&D investment. Sakakibara and Branstetter (2001) analyze patent data from 307 Japanese firms and conclude that the Japanese patent reform of 1988, which increased patent rights, did not bring about significant impact on either R&D input or innovation output. Similarly, Mansfield (1986) only finds limited impact of tax deductibles on industrial firms' R&D expenses.

Prud'homme (2012) argues that the various patent promoting laws and policies will not achieve the expected results, but instead may bring about negative consequences and constrain the further improvement in patent quality for China, regardless whether the policies are patent application subsidies, monetary incentives, export subsidies, or other preferential treatments targeting high-tech firms. Zhu and Zhang (2012) also claim that the flaws in *PPPs* will possibly induce a large number of rubbish patents.

To the strand of literature on innovation and public policy, our study makes the following contributions: First of all, we make use of microlevel patent data to study how government policies impact patent applications and innovative behaviors in China regarding both quantity and quality. More generally, in our exploration into the effects of policy and regulation, we find additional empirical evidence for unintended consequences in the Chinese context. In particular, the *PPP*s, which aim to promote patent production, end up having a negative impact on average patent quality. This is consistent with the message from the regulation literature, where policy and regulation often fail to achieve the initial policy goal and sometimes even produce effects opposite to the initial intentions. Thus, the current study may be able to offer lessons for the future policy making process related to innovation.

3. *PPP*s, hypotheses, and measures

In this section, we overview the *PPPs* and the patent application process in China to help derive the implications of the *PPP*s on patent quantity and quality as well as the various measures for patent quality.

3.1 *PPPs*

The importance of technological innovation has long been recognized by the Chinese government as a main source for sustainable economic growth. While the primary justification for attracting FDI into China since the late 1970s has been the absorption of advanced technology from abroad, the focus has been placed in boosting indigenous innovation capacity in recent years. While a multitude of government policies have been implemented to promote domestic innovations, the focus of the current study is *PPPs* at the provincial level, because they are the largest in number and also provide regional variations in adoption time to facilitate analysis.

Since the 1990s, close to a third of the provincial governments have adopted various *PPP*s to link monetary incentives with patent ownership, by which tax deductibles, tax refunds, or subsidies are offered to patent holders. In contrast to laws that provide substantive or procedural protection for patents, *PPP*s incur direct fiscal costs. In other words, governments make the conscious decision to sacrifice fiscal revenue in return for improved innovative capacity. It is therefore essential that we evaluate the effectiveness of these policies. Are the *PPP*s cost effective? In other words, is the benefit from increased patents sufficiently large to cover the cost?

Economic theory predicts that the monetary incentives provided in *PPPs* will induce more innovators to apply for patents, leading to a larger number of patent applications and patent approvals. But at the same time, the implications on patent quality may not be positive. Given that the approval process is not perfect, some innovations of inferior quality will inevitably be approved. Because the *PPP*s will mostly attract innovations of lower quality into the patent application pool, the percentage of such inferior innovations will likely increase, thus lowering the average quality of approved patents. To explicitly illustrate this point, the next subsection (Section 3.2) will present a simple model to describe the patent application process, which is then used to formalize two hypotheses regarding the impact of *PPP*s on patent quality. The later part of the article will empirically test the validity of these hypotheses.

Accordingly, the *PPPs* studied in the current article satisfy two conditions: first, the policy has to primarily target patents; secondly, the policy has to include monetary incentives. We focus on provincial level *PPPs*, which are each promulgated by the People's Congress standing committee in the corresponding province. Three examples of such *PPPs* include: 'Regulation of Liaoning Province for the Implementation of the Law of the People's Republic of China on Promoting the Transformation of Scientific and Technological Achievements' (passed in 1997), 'Regulation of Beijing Municipality on the Protection and Promotion of Patents' (passed in 2005), and 'Regulation of Anhui Province on the Protection and Promotion of Patents' (passed in 2006). The main clauses of these *PPP*s stipulate tax refunds, tax deductibles, or other monetary rewards for patent holders.

3.2 Hypothesis development

We now outline the decision making process for patent application and derive some straightforward theoretical predictions. Consider an innovation with quality of x, whose owner of the innovation faces the decision of whether to apply for patent protection for the innovation. Assume that the filing cost for patent application is c and the distribution of patent quality has a frequency function of $f(x)$. Further assume that the market value of a patent is an increasing function of patent quality, and without loss of generality, let the market value of the patent of quality x be x. Furthermore, when a *PPP* is implemented, a patent holder is given a monetary reward valued at A.

Let $p(x)$ be the approval probability for a patent of quality x, and we model the approval process as follows: the approval probability is a nondecreasing function of patent quality. Before the *PPP* is introduced, the owner uses the following decision rule: apply for patent if $x > x^*$, where $x^* p(x^*) - c = 0$; and do not apply otherwise. After the *PPP* is introduced, the patent owner's decision rule becomes the following: apply for patent if $x > x^{**}$, where $x^{**} p(x^{**}) + Ap(x^{**}) - c = 0$; and do not apply otherwise.

It is straightforward to show that $x^* > x^{**}$. As the quantity of innovations chosen to submit for patent application is $\int_{x^*} f(x)dx$

before the *PPP* is introduced and $\int_{x^{**}} f(x)dx$ after the *PPP* implementation, we thus have the following theoretical prediction:

Theorem 1: *The number of patent applications increases after the implementation of the PPP*

Now consider the average quality of all innovations submitted to apply for patent rights. Before the PPP implementation, it is given as $\int_{x^*} xf(x)dx$, while after the *PPP* implementation, it is given as $\int_{x^{**}} xf(x)dx$. It can be easily shown that the average quality of patent applications is lower in the presence of the *PPP*, thus the following prediction:

Theorem 2: *The average quality of patent applications decreases after the implementation of the PPP*

Now consider the average quality of all approved patents. Before the *PPP* implementation, it is given as $\int_{x^*} xp(x)f(x)dx$, while after the *PPP* implementation, it is given as $\int_{x^{**}} xp(x)f(x)dx$. As shown by the proof included in the Appendix, the average quality of approved patents after the *PPP* introduction is also lower than that before the *PPP* introduction, under the condition that *p(x)* is strictly increasing in x for $x < x^*$. In other words, we will have the following theoretical prediction:

Theorem 3: *The average quality of approved patents decreases after the implementation of the PPP*

The prediction above requires the following two assumptions: (1) the patent office approves the patent application from a higher quality innovation with a higher probability; and (2) the patent office does not enforce an absolute quality standard below x^*, above which all patent applications will be approved. Combined together, these two conditions essentially assume that the patent office is not capable of perfectly distinguishing innovations with satisfactory quality from those with inferior quality unless the quality reaches a sufficiently level (above x^*), although their probability of approving an application with higher quality is higher than that of approving a lower quality application (see the complete proof in the Appendix). The later part of the study will empirically test the hypotheses discussed above, but we need to first introduce the various measures for patent quality.

3.3 Overview of patent system and measures of patent quality

We now provide a brief description of the patent system in China to help introduce the various measures for patent quality. The patent system in modern China was not established till 1985, when the Patent Law was first passed, followed by revisions in 1992, 2000, and 2008. China's patent law defines three types of patents: inventions, utility models, and exterior designs, where inventions need both formality examination and substantive examination for approval and thus possess the highest quality, while the other two only require formality examination to get approved. The protection duration for inventions is 20 years, while that for utility models and designs is 10 years. To begin any patent application, application materials need to be prepared and submitted, which can be handled by either a patent agent or the applicant himself. The procedures then differ depending on whether the application is for an invention or for the other types of patents.

For an application involving a utility model or an exterior design, a preliminary examination regarding formality is conducted, and the application is approved if no reason is found for rejection. In contrast, a much lengthier process ensues in an invention application. The patent bureau first goes through a preliminary examination, whose successful conclusion will be followed by the publication of the patent application 18 months after its filing, where the publication of the patent application can also be accelerated at the request of the applicant. Within 3 years of the application, the patent bureau conducts the substantive examination of the application, if requested by the applicant. In the case that the request for substantive examination is not made within the 3-year period, the application is considered withdrawn. Only after the successful conclusion of the substantive examination is the patent application approved, otherwise the application is rejected.

To continue with these stages in the patent application process, various fees need to be paid. Within 2 months of the application's submission, the applicant needs to pay the application fee, and the invention publication fee and additional application fee in the case of an invention application. To request the substantive examination, a corresponding fee of RMB 2,500 is required. The applicant of an invention patent not approved for 2 years after submitting the application also needs to pay the application maintenance fee starting from the third year. And if the applicant fails to pay in full and on time any of the fees listed above, the application will be considered withdrawn. Finally, an annual fee has to be paid to maintain the patent rights, which rises substantially at 3-year intervals, and the failure to pay the annual fee will result in the termination of the patent rights.

Based on the description above, whether a patent application results in protectable patent rights or not is thus determined by both the patent examiner and the applicant. While the examiner may reject an application because it does not satisfy the patentability requirement, the applicant may also decide to terminate the application because it is costly to continue the patent application process and the expected marketability or profit from the patent (if obtained) does not warrant the cost. In other words, patents with lower quality are more likely to be rejected by the patent examiner and they are also more likely to be withdrawn by the applicants themselves. As a result, we will use *withdrawal rate* as a measure of average patent quality. Similarly, it is costly to maintain patent rights after they are obtained, thus applicants with lower valuation of expected marketability or profit from their patents are more likely to stop paying annual fees, resulting in the termination of the patent rights (Schankerman and Parks 1986). In order to avoid any confusion, it must be emphasized that there should be a positive correlation between patent value and patent quality, generally speaking, the greater the value of the patent, the higher the quality of the patent. As stated earlier, we assume that the market value of the patent equals patent quality. Hence, we will use the probability of patent renewal to measure patent quality. Between the two measures discussed thus far, renewal rate is positively correlated with patent quality, while withdrawal rate is negatively correlated with patent quality.

4. Data sources and description

In this section, we describe the data sources used in the study as well as the preliminary patterns observed in the data. The first set of data sources provides information on the *PPPs* at the provincial level in China. Using keywords including patent, award, preferential tax treatment, and subsidy, we access all provincial level legislations and regulations from *Beida Fabao*, *Beida Fayi*, and the Compendium of Chinese laws (maintained by the Chinese Court

Table 1. Regional PPP adoptions over time

Year	Province	Main policy	Policy for firm	Cover all patents
1995	Guangdong	Tax refund		
1997	Liaoning	Tax refund		
1999	Jilin, Hubei	Tax refund		
2000	Shanghai	Financial subsidy	Shanghai	Shanghai
2005	Beijing	Tax preference	Beijing	Beijing
2006	Anhui	Tax deductible	Anhui	Anhui
2010	Jiangxi	Tax preference	Jiangxi	Jiangxi
2011	Tianjin	Tax deductible	Tianjin	Tianjin

website) to locate all possible policies of interest. These three databases cover mostly the same materials but occasionally complement one another; thus, combined together they include practically all legislations, regulations, and executive orders by central and local governments throughout the history of modern China. We then read through all legislations and regulations that pass the keyword selection to verify for accuracy, that is, the legislation or regulation indeed provides monetary incentives for patent holders.

Table 1 lists the names of the provinces and the years in which the *PPPs* were first implemented. Up till 2011, nine provinces have implemented twelve qualifying *PPPs*, where both coastal regions and inland provinces are represented and the timing of the *PPP* does not seem to correlate with the level of regional development. Based on the information collected, we construct a dummy variable to indicate whether a province has a *PPP* in place in a certain year as follows: if the *PPP* has been implemented in a province before 1 June in a certain year, then the dummy variable takes the value of 1 for that year; otherwise, the dummy takes the value of 0.

The second set of data sources cover patent data, which comes from the SIPO patent application database and includes information on 5.6 million patent applications filed between 1985 and 2010. We exclude patent applications from nonresidents of China, as they do not have location information within China, resulting in a sample of close to 4.3 million patent applications. The database includes patent application number, application date, publication date, patent number if approved, the current legal status, as well as applicant name and address. Based on such preliminary information, we further construct the following variables: patent type (invention, utility model, or exterior design), location of applicant, type of applicant (individual versus firm, etc.), time of application withdrawal, time of approval, time of termination, and so on. By aggregating the variables at the provincial level, we are also able to produce the provincial level panel data for 1985–2010, including number of patent applications, patent approvals, approval rate, withdrawal rate, and renewal rate.

As discussed in Section 3.3, we will use withdrawal rate, as well as renewal rate to measure patent quality in the empirical study. To compute the withdrawal rate for a province in a year, we divide the number of patent applications filed in the year that are eventually approved by the total number of patent application withdrawals in that year. For the renewal rate, we compute separate rates for different length of duration and we compute in the sample only patents that have terminated during our sample period. For example, to obtain the renewal rate after 2 years (or the 2-year renewal rate) for a certain province in a certain year, we assign as the denominator the number of patents that are filed for application in the year, are eventually approved, and are terminated before 2010. And as the numerator, we assign the number of patents among the above that are renewed after 2 years. As a result, a higher renewal rate and a lower withdrawal rate correspond to higher average quality of patents.

Finally, we collect information on various provincial characteristics from various editions of China Statistical Yearbooks, including measures on population size, economic development, and human capital quality. Tables 2 and 3 give the descriptive statistics of the main variables used in the empirical analysis. As shown in Table 2, after the *PPP* implementation, both the per capita patent applications and the per capita patent approvals increased significantly, while both withdrawal rate and renewal rate decreased significantly, especially for firms. The changes in patent quantity and the change in renewal rate are consistent with the theoretical predictions in Section 3.2, but the change in withdrawal rate is the one opposite to the prediction. We will explore these patterns in more detail later.

Table 3 provides more information on patent quality based on their status. As discussed in Section 3.3, survival time is a good indicator for patent quality as it is costly to maintain a patent's active status. The average duration for all patents is 52.4 months, which is shorter than 4.5 years, whereas the average duration for domestic patents is even shorter at 48.4 months, about 4 years. Given that inventions have the legal protection for 20 years, whereas the other patents have it for 10 years, the difference observed above may be due to either the composition of patents or within-group quality differences. A careful look at the data suggests that compared with domestic patents, inventions account for a larger proportion of foreign patents. Furthermore, foreign patents tend to have a longer duration on average. These patterns are consistent with foreign patents having higher quality, thanks to the comparative advantage in technology and capital possessed by foreign applicants.

Among domestic patents, inventions, utility models, and exterior designs have average durations of 82.8 months, 49.4 months, and 43.4 months, respectively. Compared to the legal protection period of 240 months and 120 months, the actual patent survival time is only about a third. Across different types of applicants, patent duration decreases from research institutions, to universities, to firms, then to individuals. But again, such differences may be explained by either the composition of patents or within-group quality differences. Among patents applied by firms and individuals, which make up the largest proportion, the average duration for inventions, utility models, and exterior designs is 85.5 months, 53.6 months, and 45.1 months, respectively, for firms, and 86.2 months, 48.4 months, and 42.5 months, respectively, for individuals. The statistics above is based on the sample for which patents have already been terminated, giving us the exact termination time. There are still many patents (52.4 per cent) that did not terminate by the end of 2010, and a more careful examination will be conducted in the empirical part of the article to study these patent's termination decision. Withdrawal rate can also be used to measure patent quality, with higher rates corresponding to lower patent quality. Among different types of applicants, withdrawal rate is lowest for firms.

5. Empirical findings

In this section, we will conduct both provincial level analysis and patent level analysis to study the various impacts of *PPPs*.

5.1 Provincial level analysis

We first explore the empirical implications of *PPPs* at the provincial level by looking at how patent quantity and quality change after the

Table 2. Summary statistics for patent applications and patent approvals (province level variables)

Variables	Whole sample ($N = 692$)		Before policy ($N = 628$)		After policy ($N = 64$)		*t*-statistic
	Mean	S.D.	Mean	S.D.	Mean	S.D.	
Applications(per 10000 persons)	1.37	2.98	0.98	0.08	5.39	0.74	−13.12***
Per capita firm application	0.52	1.48	0.32	0.03	2.56	0.4	−13.47***
Per capita institute application	0.06	0.19	0.04	0.004	0.27	0.06	−9.91***
Per capita college application	0.1	0.31	0.06	0.01	0.49	0.09	−11.93***
Per capita individual application	0.56	1	0.47	0.03	1.44	0.14	−8.1***
Approvals(per 10,000 persons)	1.11	2.31	0.81	0.06	4.12	0.52	−12.64***
Per capita firm approval	0.42	1.14	0.27	0.03	1.97	0.3	−13.3***
Per capita institute approval	0.04	0.12	0.03	0.003	0.15	0.03	−8.69***
Per capita college approval	0.07	0.19	0.04	0.004	0.3	0.05	−11.55***
Per capita individual approval	0.48	0.91	0.4	0.03	1.24	0.13	−7.66***
Patent withdrawal rate	0.11	0.08	0.12	0.003	0.08	0.01	3.31***
Firm withdrawal rate	0.09	0.09	0.1	0.003	0.07	0.01	1.92**
Institute withdrawal rate	0.17	0.15	0.17	0.01	0.13	0.01	1.98**
College withdrawal rate	0.16	0.13	0.16	0.01	0.12	0.01	2.11**
Individual withdrawal rate	0.11	0.08	0.11	0.002	0.08	0.01	3.58***
Patent renewal rate (over 2 yrs)	0.73	0.18	0.73	0.01	0.69	0.03	1.81**
Firm renewal rate (over 2 yrs)	0.73	0.2	0.74	0.01	0.7	0.03	1.37*
Institute renewal rate (over 2 yrs)	0.74	0.22	0.74	0.01	0.71	0.04	1.19
College renewal rate (over 2 yrs)	0.69	0.24	0.69	0.01	0.69	0.04	−0.11
Individual renewal rate (over 2 yrs)	0.73	0.18	0.73	0.01	0.7	0.03	1.45*
Patent renewal rate (over 3 yrs)	0.41	0.17	0.42	0.01	0.35	0.03	2.84***
Firm renewal rate (over 3 yrs)	0.46	0.2	0.46	0.01	0.39	0.03	2.89***
Institute renewal rate (over 3 yrs)	0.48	0.25	0.49	0.01	0.41	0.04	2.27***
College renewal rate (over 3 yrs)	0.4	0.26	0.4	0.1	0.4	0.04	0.07
Individual renewal rate (over 3 yrs)	0.41	0.17	0.41	0.01	0.36	0.03	2.22**
Patent renewal rate (over 4 yrs)	0.19	0.11	0.2	0.004	0.17	0.02	2.07**
Firm renewal rate (over 4 yrs)	0.27	0.16	0.27	0.01	0.22	0.02	2.79***
Institute renewal rate (over 4 yrs)	0.29	0.21	0.3	0.01	0.22	0.03	2.84***
College renewal rate (over 4 yrs)	0.2	0.18	0.2	0.01	0.19	0.02	0.56
Individual renewal rate (over 4 yrs)	0.16	0.1	0.17	0.003	0.15	0.01	1
Patent renewal rate (over 5 yrs)	0.11	0.08	0.11	0.002	0.08	0.01	2.5***
Firm renewal rate (over 5 yrs)	0.17	0.13	0.18	0.005	0.13	0.02	2.78***
Institute renewal rate (over 5 yrs)	0.18	0.18	0.19	0.01	0.11	0.02	3.3***
College renewal rate (over 5 yrs)	0.1	0.13	0.11	0.01	0.07	0.01	1.91**
Individual renewal rate (over 5 yrs)	0.08	0.06	0.08	0.002	0.07	0.01	1.77**

***Significant at 1%, **at 5%, *at 10%.

Table 3. Summary statistics for patent applications and patent approvals (patent level variables, by patent types).

Variables	Obs.	Mean	SD
Duration (in months)	1,936,652	52.436	25.164
Duration (foreign)	238,849	81.302	38.494
Duration (domestic)	1,697,803	48.375	19.497
Inventions	87,216	82.826	27.200
Utility models	837,801	49.416	17.460
Designs	772,786	43.358	16.150
Firms	426,883	49.020	20.887
Research institutions	35,014	64.301	27.603
Universities	63,041	55.136	23.298
Individuals	1,049,654	46.864	17.612
Withdrawals (domestic)	4,250,838	0.064	0.245
Firms	1,581,575	0.049	0.217
Research institutions	113,113	0.136	0.342
Universities	252,896	0.109	0.312
Individuals	1,966,620	0.062	0.242

introduction of the *PPP*. To measure quantity effects, we use per capita patent applications and per capita patent approvals, while patent quality is measured by withdrawal rate and renewal rate.[3] To take into account determining factors other than the *PPP*, we control for various provincial characteristics in the following two-way fixed-effect estimation:

$$Y_{i,t} = \alpha + \beta \text{Policy}_{i,t} + \gamma \mathbf{X}_{i,t-1} + \eta_i + \mu_t + \varepsilon_{i,t}, \qquad (1)$$

where $Y_{i,t}$ is the outcome measure for province *i* in year *t*, $\text{Policy}_{i,t}$ is the corresponding *PPP* measure (=1 if the *PPP* has been in place before June 1 in year *t*;=0 otherwise), and thus β gives the effect of *PPP* on the outcome variable. A set of control variables are captured in $X_{i,t-1}$, which is a vector of provincial characteristics in the previous year, including population, per capita Gross Domestic Product (GDP), and per capita FDI (all in logs), when we use the data for the period 1985–2010. Provincial fixed effects η_i and year fixed effect μ_t are included to address other unobserved province and time variations, while $\varepsilon_{i,\,t}$ is the random error term.

5.1.1 *PPP* effects on patent quantity

The results from estimating model (1), using patent quantity as the outcome variable are shown in Tables 4 and 5, where the Table 4 show the results using application numbers, while the Table 5 use approval numbers. When using per capita applications as the outcome variable, we construct the measure using all patent applications, only firm patent applications, only non-firm applications, or three different types of patent applications. And similarly, we use six different measures for per capita patent approvals in Table 5.

As shown in Tables 4 and 5, *PPP* has a positive and significant effect on both per capita patent applications and approvals, regardless whether the patent is applied by a firm or a non-firm entity, and regardless of the type of the patent (an invention, a utility model, or a design). This is consistent with Theorem 1 in Section 3.1, and the larger effect on firm patents is in line with the fact that *PPPs* mainly target at firms.

It is worth noting that the effects on patent quantity are not only statistically significant, but also economically important. In particular, the number of patent applications increases by more than 1.7 per 10,000 residents after the *PPP*'s implementation, which is 57.45 per cent of the standard deviation of per capita patent applications. Likewise, the number of patent approvals increases by close to 1.2 per 10,000 residents after the *PPP*'s implementation, which is 50.16 per cent of the standard deviation of per capita patent approvals. If we use Year 2000 as a baseline, introducing the *PPP* will increase China's per capita patent applications and per capita patent approvals by 273.74 per cent and 170.69 per cent, respectively, which are equivalent to a rise of 347,000 patent applications and 216,000 patent approvals a year. The above results, therefore, are supportive of Theorem 1 in Section 3.1, which states that the implementation of *PPPs* helps improve patent quantity. The policy is thus effective in increasing patent quantity.

5.1.2 *PPP* effects on patent quality

As the ultimate goal of the *PPP* is to improve a region's innovative capacity, which is the key to sustainable economic growth in the long run, it is essential that the aggregate innovation content increases in step with the increase in innovation quantity. Hence, it is equally important to study the impact of *PPP* on patent quality, which we will now turn to.

In line with the discussion in Section 3.3, we will use withdrawal rate and renewal rate as the patent quality measures, and we expect withdrawal rate to be negatively correlated with patent quality, whereas renewal rate to be positively correlated with patent quality. Tables 6–8

Table 4. *PPP* effects on per capita applications (1985–2010)

Variables	Per capita applications	Per capita applications (firms)	Per capita applications (others)	Per capita invention	Per capita utility model	Per capita design
PPP	1.711***	0.998***	0.166***	0.889***	0.441***	0.392***
	(0.294)	(0.159)	(0.046)	(0.124)	(0.100)	(0.136)
ln(population)	20.40***	11.15***	2.013***	8.339***	5.733***	6.379***
	(1.228)	(0.663)	(0.192)	(0.518)	(0.417)	(0.568)
ln(percapit_gdp)	3.218***	1.197***	0.682***	1.084***	0.617***	1.523***
	(0.582)	(0.314)	(0.091)	(0.246)	(0.198)	(0.270)
ln(percapit_FDI)	0.119	0.063	0.0134	0.014	0.045	0.064
	(0.088)	(0.048)	(0.014)	(0.037)	(0.030)	(0.041)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	778	778	778	778	778	778
R^2	0.742	0.695	0.713	0.706	0.757	0.563

Note: Standard errors are in parentheses.
***Significant at 1%, **at 5%, *at 10%.

Table 5. *PPP* effects on per capita approvals (1985–2010)

Variables	Per capita approvals	Per capita approvals (firms)	Per capita approvals (others)	Per capita invention	Per capita utility model	Per capita design
PPP	1.157***	0.713***	0.105**	0.318***	0.450***	0.396***
	(0.238)	(0.124)	(0.042)	(0.057)	(0.101)	(0.137)
ln(population)	14.64***	8.243***	1.371***	2.499***	5.816***	6.408***
	(0.996)	(0.516)	(0.174)	(0.238)	(0.420)	(0.569)
ln(percapit_gdp)	2.855***	0.980***	0.636***	0.683***	0.641***	1.527***
	(0.472)	(0.245)	(0.082)	(0.113)	(0.199)	(0.270)
ln(percapit_FDI)	0.101	0.059	0.010	−0.004	0.044	0.065
	(0.072)	(0.037)	(0.013)	(0.017)	(0.030)	(0.041)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	778	778	778	778	778	778
R^2	0.717	0.687	0.655	0.630	0.753	0.562

Note: Standard errors are in parentheses.
***Significant at 1%, **at 5%, *at 10%.

give the results from estimating model (1), with withdrawal rate and various renewal rates as the outcome variable, respectively.

Table 6 shows that the implementation of a *PPP* is positively and significantly correlated with the withdrawal rate for patents filed by firm applicants, which are the main targets of the *PPP*s. The finding is consistent with the predictions of Theorem 2. In other words, the average quality of patent applications (proxied by the withdrawal rate) has declined at the presence of the *PPP* and the patterns are particularly relevant for firms.

Tables 7 and 8 use the renewal rate over 3 years and that over 5 years to measure patent quality. The results show that the presence of a *PPP* is negatively and significantly correlated with the renewal rates of patent applications, in support of the prediction of Theorem 3. In other words, the average quality of approved patents (proxied by the renewal rates) has declined in the presence of the *PPP*. To further explore the influences of *PPPs* on different types of patents in the last three columns, we only observe a negative and significant coefficient for utility models, which means that the negative influences of *PPPs* on renewal rate are mainly directed at utility models.

To summarize the results from the provincial level analyses above, we have observed an increase in quantity but a decline in average quality of patent applications and approvals, in response to the passage and implementation of *PPPs*. The decline in average quality may mainly be due to the utility models, which only need formality examination. We will move on to the patent level analysis next, which will allow us to control for more additional factors to further substantiate our empirical findings.

Table 6. *PPP* Effects on patent withdrawal rate (1985–2010)

Variables	Withdrawal rate	Withdrawal rate (firms)	Withdrawal rate (firm invention)	Withdrawal rate (others)
PPP	0.005	0.022*	0.013	−0.0003
	(0.010)	(0.013)	(0.011)	(0.009)
ln(population)	0.089**	0.073	−0.049	0.100**
	(0.040)	(0.054)	(0.116)	(0.040)
ln(percapit_gdp)	−0.020	0.003	−0.027	−0.035*
	(0.019)	(0.025)	(0.055)	(0.019)
ln(percapit_FDI)	−0.003	−0.005	−0.001	−0.0003
	(0.003)	(0.004)	(0.008)	(0.003)
Year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Obs.	778	769	769	778
R^2	0.459	0.377	0.573	0.452

Note: Standard errors are in parentheses.
***Significant at 1%, **at 5%, *at 10%.

Table 7. *PPP* effects on patent renewal rate over 3 years (1985–2010)

Variables	Renewal over 3 yrs	Renewal over 3 yrs (firms)	Renewal over 3 yrs (others)	Renewal over 3 yrs (invention)	Renewal over 3 yrs (utility)	Renewal over 3 yrs (design)
PPP	−0.0444***	−0.0387*	−0.0351***	−0.011	−0.039***	−0.035
	(0.0120)	(0.0207)	(0.0119)	(0.023)	(0.013)	(0.025)
ln(population)	−0.321***	−0.331***	−0.237***	0.003	−0.057	−0.117
	(0.0538)	(0.0954)	(0.0533)	(0.106)	(0.058)	(0.112)
ln(percapit_gdp)	−0.0542**	−0.0974**	−0.0602**	−0.021	−0.057**	−0.173***
	(0.0236)	(0.0411)	(0.0234)	(0.045)	(0.026)	(0.051)
ln(percapit_FDI)	−0.00703**	0.00700	−0.00821**	0.004	−0.003	0.002
	(0.00354)	(0.00616)	(0.00350)	(0.007)	(0.004)	(0.008)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	746	739	746	710	746	737
R^2	0.878	0.729	0.879	0.756	0.872	0.608

Note: Standard errors are in parentheses.
***Significant at 1%, **at 5%, *at 10%.

Table 8. *PPP* effects on patent renewal rate over 5 years (1985–2010)

Variables	Renewal over 5 yrs	Renewal over 5 yrs (firms)	Renewal over 5 yrs (others)	Renewal over 5 yrs (invention)	Renewal over 5 yrs (utility)	Renewal over 5 yrs (design)
PPP	−0.0171***	−0.0277*	−0.0127**	−0.013	−0.002**	−0.004
	(0.00626)	(0.0148)	(0.00569)	(0.018)	(0.001)	(0.014)
ln(population)	−0.163***	−0.202***	−0.111***	−0.063	−0.022	−0.136**
	(0.0281)	(0.0682)	(0.0256)	(0.083)	(0.023)	(0.060)
ln(percapit_gdp)	0.0111	−0.0469	0.00514	0.024	0.036***	−0.031
	(0.0124)	(0.0294)	(0.0112)	(0.035)	(0.010)	(0.027)
ln(percapit_FDI)	0.00236	0.00562	0.00113	0.007	−0.004**	0.008**
	(0.00185)	(0.00441)	(0.00168)	(0.005)	(0.002)	(0.004)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	746	739	746	710	746	737
R^2	0.828	0.678	0.804	0.572	0.853	0.467

Note: Standard errors are in parentheses.
***Significant at 1%, **at 5%, *at 10%.

Table 9. *PPP* effects on withdrawal probability

Incidence rate ratio	Whole sample	Firms	Firms invention	Non-firms
Apply after policy	1.091**	1.426***	1.279***	0.942*
(PPP)	(0.047)	(0.107)	(0.087)	(0.033)
ln(percapit_gdp)	1.692***	2.785***	2.247***	1.113
	(0.192)	(0.610)	(0.445)	(0.099)
ln(population)	0.958***	0.383**	0.399***	1.587***
	(0.178)	(0.147)	(0.121)	(0.239)
ln(percapit_FDI)	0.988	0.911*	0.932*	1.020
	(0.020)	(0.043)	(0.037)	(0.016)
Applicant type	Yes	No	No	No
Applicant year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Field FE	Yes	Yes	Yes	Yes
Log pdlikelihood	−772,975.5	−223,436.8	−166,788.4	−545,936.0
Obs.	2791964	1009142	386016	1782822

Note: Standard errors are in parentheses.
***Significant at 1%, **at 5%, *at 10%.

5.2 Patent level analysis

This section will make use of patent level data to further explore the quality implications of the *PPPs*. We will begin with the study of how the *PPP* influences the probability of withdrawal for invention applications, followed by a detailed survival analysis of the renewal decision faced by the patent holder, which is the focus of this section.

Poisson estimation of withdrawal probability

We use the following Poisson regression model to estimate the effects of *PPP* on the probability of withdrawal for invention applications:

$$\mathrm{Prob}\left(y_{i,t}\right) = \frac{e^{-\lambda_{i,t}}\lambda_{i,t}}{y_{i,t}!} \tag{2}$$

$$\begin{aligned}\ln(\lambda_{i,t}) &= \sum_{i=0}^{K} \beta_i X_{i,t} \\ &= \beta_0 + \beta_1\, \textit{apply after policy}_{i,t} + \cdots + \beta_k X_{i,t} + \varepsilon_{i,t}\end{aligned} \tag{3}$$

where $y_{i,t}$ is the count variable for the number of withdrawals that have occurred in province i up to year t, $\lambda_{i,t}$ is the expectation parameter corresponding to the Poisson distribution, which is further defined as a function of the various patent level characteristics, $X_{i,t}$, as well as the policy variable *apply after policy*, indicating that the patent is applied after the implementation of the *PPP*. Thus, the dummy, *apply after policy*, gives the *PPP*'s patent level effect, corresponding to the provincial effect of the dummy *PPP*.

The results from the Poisson estimation are presented in Table 9. As the coefficients shown are the estimated incidence rate ratios, the effect of the corresponding variable on the withdrawal probability is positive when the estimated coefficient is larger than 1, and the effect on withdrawal probability is negative when the estimate is smaller than 1. It is thus clear from the table that, for patent applications and invention applications filed by firms,[4] the probability of withdrawal becomes higher after the *PPP* is implemented. But for patent applications from non-firms, the withdrawal probability does not show a clear pattern with regard to the *PPP* implementation. As the *PPP*'s main focus is on firms, the results are again in line with Theorem 2, which predicts lower average quality of patent applications in response to the *PPP*.

Then, we take into account the possibility that firms responding to the *PPP* by increasing their R&D input and thus improving their innovative capacity over time, in other words, patent quality will improve and withdrawal rate will decrease over time. Note that this is probably the government's presumption when implementing the *PPPs*. Thus, we include the length of time after the *PPP* is implemented in the following estimation.

$$\begin{aligned}\ln(\lambda_{i,t}) &= \sum_{i=0}^{K} \beta_i X_{i,t} \\ &= \beta_0 + \beta_1\, \textit{apply after policy}_{i,t} + \beta_2\, \textit{year after policy} \ldots \\ &\quad + \beta_k X_{i,t} + \varepsilon_{i,t}\end{aligned} \tag{4}$$

Table 10 presents the results with *years after policy* included. As seen in the result table, for all the patent and invention applications filed by firms, the effect of length of time after *PPP* on withdrawal probability is negative since the estimate is smaller than 1 and significant. It indicates the probability of withdrawal tends to be reduced over time.

Survival analysis of renewal probability

The patent level analysis can fully utilize the detailed information available for each patent, thus allowing us to present a richer picture based on more reliable exploration. The survival analysis provides an additional advantage: when using provincial level data, the renewal rate cannot be computed for patents until they are terminated, thus a large proportion of patent information is lost, which can be recovered in the survival analysis (Zeebroeck 2007; Xie and Giles 2011).

But the survival analysis also poses some additional challenges. Section 3.2 discusses the *PPP* effect on patent quality and predicts that the average quality of approved patents will be lower if they are applied after the *PPP*'s implementation (see Theorem 3). When we use renewal probability to measure patent quality, this implies that these patents will be renewed with a lower likelihood at any given time after controlling for other factors. In the survival analysis, however, a patent owner with the decision to make on whether to renew a patent also considers the market demand in each year, which is influenced by the presence or absence of the *PPP*. If there exists *PPPs* in the province, then the patent owner can expect a higher likelihood of his patent finding a buyer, who either aims to secure

Table 10. *PPP* effects on withdrawal probability (including year after policy)

Incidence rate ratio	Whole sample	Firms	Firms invention	Non-firms
Apply after policy (PPP)	1.009	1.316***	1.256***	0.926*
	(0.045)	(0.105)	(0.087)	(0.038)
Year after policy	0.980***	0.957***	0.940***	0.995
	(0.006)	(0.011)	(0.010)	(0.006)
ln(percapit_gdp)	1.378***	2.079***	1.376	1.048
	(0.147)	(0.484)	(0.275)	(0.096)
ln(population)	1.162	0.458*	0.486**	1.698***
	(0.218)	(0.193)	(0.155)	(0.255)
ln(percapit_FDI)	0.979	0.874***	0.892***	1.019
	(0.019)	(0.042)	(0.036)	(0.016)
Applicant type	Yes	No	No	No
Applicant year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Field FE	Yes	Yes	Yes	Yes
Log-likelihood	−772,925.4	−223,499.2	−166,705.4	−545,914.5
Obs.	2,791,964	1,009,142	386,016	1,782,822

Note: Standard errors are in parentheses.
***Significant at 1%, **at 5%, *at 10%.

monetary rewards from the government directly using the purchased patents or plans to use the bought patent to help develop new patents. The first scenario may apply when firms purchase patents from individual owners as the *PPP* may only apply to corporations, while the second scenario applies more generally.

As a result, while the *PPP* effect discussed in Section 3.2 predicts a lower average renewal probability due to the selection of more inferior innovations into the patent application process, the impact of *PPPs* on market demand discussed above implies a higher renewal probability. Henceforth, we will refer to the quality effect discussed in Section 3.2 as the *selection effect* and the effect on the availability of potential buyers for existing patents as the *market demand effect*. It is thus crucial to distinguish the *selection effect* and the *market demand effect*, and we use the following Cox proportional hazards model (Cox 1972) to estimate these two effects separately:

$$h(t/X) = h_0(t)\exp(\beta_1 \textit{apply after policy} + \beta_2 \textit{policy} + \cdots \beta_p X_p), \tag{5}$$

where $h(t/X)$ is the hazard function of a patent in year t, that is, the conditional probability that the patent will not be renewed, given that it has been renewed until time year t. The two variables of interest to us include: *apply after policy*, an indicator for whether the patent was filed after the *PPP* is implemented, and *policy*, the PPP dummy indicating whether a *PPP* is present in that year in the province where the patent is located. Thus, β_1 and β_2 measure separately the selection effect and the market demand effect of the *PPP*. As the hazard function model the nonrenewal decision, a positive β_1 will provide supporting evidence for the selection effect, while a negative β_2 will substantiate the market demand effect. In addition, we include various patent level characteristics such as patent applicant information, province information, field information, and the year of approval.

Finally, we take into account the effect of length of time after an implemented *PPP*. We refer to this beneficial effect of the *PPP* as the *R&D capacity effect*, since the increasing of R&D input could likely improve patent quality, and a plausible assumption regarding this effect is that it increases over time. Thus we include the length of time after the *PPP* is implemented in the following estimation to capture the *R&D capacity effect*.

$$h(t/\mathbf{X}) = h_0(t)\ \exp(\beta_1 \textit{apply after policy} + \beta_2 \textit{policy} + \beta_3 \textit{year after policy} + \cdots + \beta p X p). \tag{6}$$

Table 11 gives the estimation results based on model (5), while Table 12 gives results from estimating model (6). In each table, the first column presents the effects on patent hazard ratio using the whole sample of data, the second and the third columns present results using the subsamples of patents applied by firms and those applied by non-firms, respectively, while the last three columns study the subsamples of invention, utility model, and design patents, respectively.

As the coefficients shown in the tables are the estimated effects on the hazard ratio, a number larger than unity implies a positive effect on the hazard ratio and thus a negative effect on the patent getting renewed. Therefore, the results in Table 11 show that the *apply after policy* dummy, which captures the *selection effect* of *PPPs*, consistently reduces the renewal likelihood of a patent, regardless whether the patent is applied by a firm or a non-firm entity, and regardless of the type of the patent (an invention, a utility model, or a design). The *market demand effect*, captured by the *policy* dummy, on the other hand, varies across patent applicant types and patent types. While the presence of a *PPP* seems to increase market demand for non-firm patent applicants and inventions and utility models (as evidenced by effects on hazard ratio lower than 1), it tends to reduce market demand slightly for firms and design patents.

Table 12 presents the results with *years after policy* included to capture the *R&D capacity effect*. As seen in the result table, the significant and negative selection effect on patent quality largely remains, while the market demand effect continues to be ambiguous. In addition, there is evidence that the presence of *PPP* may have a small but positive effect on the R&D capacity of the local firms and residents, as evidenced by the smaller than unity and mostly significant effect of *years after policy* on the hazard ratio for patent.

6. Discussion and conclusion

Using provincial and patent level data, we have found evidence showing the effects of *PPPs*. In terms of patent quantity, the results show that the implementation of the *PPPs* has unambiguously increased the numbers of patent applications and patent approvals,

Table 11. *PPP* effects on patent hazard ratio (by applicant type and patent type, 1985–2010)

Variables	Whole sample	Firms	Non-firm	Invention	Utility model	Design
Apply after policy	1.513***	1.485***	1.546***	1.315***	1.205***	1.652***
(*PPP*)	(0.006)	(0.011)	(0.007)	(0.022)	(0.006)	(0.010)
Policy	1.018***	1.188***	0.953***	0.911***	0.924***	1.140***
	(0.003)	(0.007)	(0.003)	(0.011)	(0.004)	(0.005)
Utility	3.848***	4.323***	3.862***			
	(0.018)	(0.048)	(0.019)			
Design	6.044***	9.248***	5.348***			
	(0.029)	(0.105)	(0.027)			
ln(percapit_gdp)	1.824***	1.322***	2.221***	4.292***	1.475***	2.140***
	(0.014)	(0.023)	(0.020)	(0.104)	(0.017)	(0.033)
ln(population)	0.389***	0.743***	0.293***	0.291***	0.360***	0.631***
	(0.007)	(0.027)	(0.006)	(0.023)	(0.009)	(0.021)
ln(percapit_FDI)	0.977***	0.968***	0.961***	0.961***	0.999	1.021***
	(0.002)	(0.004)	(0.002)	(0.007)	(0.003)	(0.004)
Applicant type	Yes	No	No	Yes	Yes	Yes
Approval year FE	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Field FE	No	No	No	Yes	Yes	No
Obs.	4,517,930	1,640,786	2,877,144	535,237	2,179,174	1,813,958
Log-likelihood	−23,122,077	−5,320,077.2	−16,847,426	−954,682.2	−10,826,753	−9,927,307.2
Prob > χ^2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Note: Standard errors are in parentheses.
***Significant at 1%, **at 5%, *at 10%.

Table 12. *PPP* effects on patent hazard ratio (including R&D capacity effect, 1985–2010)

Variables	Whole sample	Firms	Non-Firm	Invention	Utility mode	Design
Apply after policy	1.590***	1.524***	1.614***	1.327***	1.220***	1.645***
(*PPP*)	(0.006)	(0.012)	(0.003)	(0.026)	(0.007)	(0.010)
Policy	0.953***	1.080***	0.911***	0.909***	0.916***	0.997
	(0.003)	(0.007)	(0.003)	(0.011)	(0.004)	(0.005)
Year after policy	0.970***	0.960***	0.979***	0.997	0.996***	0.945***
	(0.0006)	(0.001)	(0.001)	(0.004)	(0.001)	(0.001)
Utility	3.957***	4.474***	3.937***			
	(0.018)	(0.051)	(0.019)			
Design	6.213***	9.549***	5.455***			
	(0.030)	(0.109)	(0.028)			
ln(percapit_gdp)	1.798***	1.344***	2.190***	4.300***	1.466***	2.355***
	(0.014)	(0.023)	(0.020)	(0.105)	(0.017)	(0.036)
ln(population)	0.502***	1.250***	0.339***	0.292***	0.367***	1.479***
	(0.010)	(0.049)	(0.008)	(0.023)	(0.009)	(0.055)
ln(percapit_FDI)	0.956***	0.922***	0.948***	0.960***	0.997	0.936***
	(0.002)	(0.004)	(0.002)	(0.007)	(0.003)	(0.004)
Applicant type	Yes	No	No	Yes	Yes	Yes
Approve year FE	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Field FE	No	No	No	Yes	Yes	No
Obs.	4517930	1640786	2877144	533484	2169664	1813958
Log-likelihood	−23,120,882	−5,319,562	−16,846,984	−954,681.9	−10,801,213	−9,925,957.1
Prob > χ^2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Note: Standard errors are in parentheses.
***Significant at 1%, **at 5%, *at 10%.

largely explaining China's patent explosion in recent years. But in terms of patent quality, the empirical findings suggest that the incentives provided by the *PPPs* and the resultant larger numbers of patent applications and patent approvals are accompanied by a decline in both the average quality of patent applications and the average quality of approved patents. While the withdrawal rate among patent applications has increased in response to the *PPP*, the renewal rate among approved patents has decreased.

A cautious reader may be concerned with the potential issue of endogeneity related to our findings. Specifically, provinces that have adopted the *PPP* may have certain other characteristics that will account for the patent quantity hike and the patent quality decline.

Thus, the observed correlation between *PPP* adoption and changes in patent quantity and quality should not be interpreted as causal. To this concern, we provide the following responses. First of all, as shown in Table 1, there are no clear patterns in terms of economic development level or geographic locations between regions that have adopted the *PPP* and those that have not. But in future research, we will continue to explore other dimensions of regional variations to better rule out the possibility of different underlying trends regarding innovation capacity.

Secondly, even if the provincial government was to predict future trends and to make *PPPs* accordingly, it would be extremely difficult to forecast both the quantity change and the quality change in patent applications and approved patents, since patent approvals are made by the Patent Office at the national level. To the extent that the provincial government is able to influence the approval decisions made by the Patent Office, a provincial government that has adopted a *PPP* would have the incentive to convince the Patent Office to lower the approval standard for patent applications filed from its own region. This will result in a potential downward bias on the selection effect estimated in our analysis, thus further strengthening our results.

We also conduct additional robustness checks, including using separate policy indicators for invention/utility versus designs, separating policy indicators for those targeting only firms versus those aiming at all patent owners, excluding years 2005–10 or years 2001–10 from the provincial level analysis, including both approval year FEs and application year FEs, as well as controlling for additional provincial-year characteristics for the later period of 1998–2010. Across all specifications, our main results remain.

In conclusion, we have produced a substantial amount of empirical evidence that the adoption of *PPPs* at the provincial level has a positive impact on patent quantity but a negative impact on patent quality. In addition, we found that there is potentially a small positive effect on the R&D capacity in the region with the *PPP*. While the positive impact may be supportive of the main justification for the government to adopt the policy, our findings highlight the unintended consequences on patent quality of government policies regarding innovation.

Notes

1. Until 2009, the novelty standard in China was *relative novelty*, which required the patent application to show its novelty relative to other domestic entities. The third revision to the Patent Law changed the relative novelty requirement to the absolute novelty standard, which requires the patent application to show its *absolute novelty*, that is, novelty around the world.
2. For similar empirical evidence from other countries, see Bound *et al*. (1984), Jaffe (1986), and Javorcik (2002).
3. We also use the approval rate as the quality measure, which obtains the predicted negative effect, but the estimated coefficient is not statistically significant.
4. Since utility models and exterior designs only require formality examination, very few utility models (0.04 per cent) and exterior designs (0.00 per cent) withdrawn after application submitted. Therefore, we only have the results of effects on inventions.

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Appendix

Proof for Theorem 3

Assume X≥0 with pdf $f(x)$, show that $E(x|x > c)$ is increasing with c.

Proof. Let $h(c) = E(x|x > c)$, we want to show that $h'(c) > 0$, then $h(c)$ is increasing function of c.

$$h(c) = E(X|X > c) = \frac{\int_c^\infty xf(x)dx}{\int_c^\infty f(x)dx}$$

Then

$$\frac{\partial h(c)}{\partial c} = \frac{-cf(c)\int_c^\infty f(x)dx + \int_c^\infty xf(x)dxf(c)^2}{\left[\int_c^\infty f(x)dx\right]}$$
$$= \frac{f(c)\int_c^\infty (x-c)f(x)dx^2}{\left[\int_c^\infty f(x)dx\right]} \geq 0$$

For any nonnegative monotonically increasing function $g(X)$, we can show that $\frac{\partial E(g(X)|X>c)}{\partial c} \geq 0$ by the same method, the last formula is

$$\frac{f(c)\int_c^\infty (g(x)-g(c))f(x)dx^2}{\left[\int_c^\infty f(x)dx\right]} \geq 0$$