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Patent length and innovation: Novel evidence from China

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ABSTRACT

Patent length is a fundamental design of the patent system, indicating the duration of the legal monopoly granted by patents. The fast-tracking patent applications (FPA) policy is found to bring about an exogenous variation in patent length, which can be regarded as a quasi-natural experiment to study the impact of patent length extension on corporate innovation. By exploiting a difference-in-differences approach, the patent length extension brought about by FPA is found to have a significant positive impact on corporate innovation, resulting in a 30 % increase in patent applications. The effects are more reflected in firms with more political resources, firms belonging to industries with higher patent propensities, and firms facing fiercer market competition. Furthermore, the patent length extension also facilitates technology disclosure and knowledge spillover, as evidenced by a 4.8 % increase in average forward citations per patent. Overall, this study casts fresh light on patent length and fills up the gap in the empirical research on the impact of patent length extension. The findings can help optimize patent system design to achieve the dual fundamental goals of innovation incentives and technology disclosure.

1. Introduction

Innovation amounts to knowledge production. However, knowledge is considered as a non-competitive and non-exclusive public good, resulting in insufficient incentives to innovate. Thus, the actual R&D investment often falls below the optimal level that maximizes social welfare (Arrow, 1962). With the development of the patent system for hundreds of years (Machlup and Penrose, 1950), it is widely accepted that a strong patent system is likely to encourage innovation for the benefit of economic growth. However, the patent system rewards patentees by granting monopoly right, which causes social welfare loss. Patents create static distortions corresponding to the classical deadweight loss caused by inefficient monopoly pricing. Not all consumers valuing goods above their marginal cost can buy patented products (Encaoua et al., 2006). Monopoly also gives rise to dynamic distortions evidenced by the increased cost of follow-on innovation. In this context, there is much debate about patent policies, which focus on the trade-offs between the benefits and costs in terms of innovation and competition (Hall and Harhoff, 2011). Among the debate, a critical factor in the design of the patent system is patent length, as it plays a pivotal role in shaping innovation incentives. A well-determined patent length can strike a balance between providing adequate rewards to inventors and promoting technology disclosure for the benefit of society. Therefore, optimal patent length has been the focus of discussion.

Patent length denotes the duration of legal monopoly granted by patents. And the earliest discussion on patent length can be traced back to the groundbreaking contribution of Nordhaus (1969, 1972), and the geometric interpretation of the Nordhaus model (Scherer, 1972). In these early models, an important assumption is that R&D investment always leads to innovation, the size of which depends on the investment undertaken. Within this analytical framework, an optimal patent should have a finite term but result in an absolute positive benefit, which means that the total social benefit derived from a patent should be greater than its total social cost (Corinne and GianCarlo, 2002). Nordhaus clarifies the relationship more quantitatively and precisely, but significant limitations remain (Scherer, 2015). After that, a series of theoretical studies are conducted based on the Nordhaus model (Mohamed, 2018a).

The existing research has discussed optimal patent length in great detail from multiple perspectives (Chang, 1995; Denicolo, 1996; La Manna, 1992; Li, 2001; Matutes et al., 1996; O'Donoghue et al., 1998). However, the relationship between patent length and innovation remains controversial. First, previous theoretical research fails to reach a consensus on whether patent length extension is conducive to innovation. For example, Gallini (1992) defines patent length based on the cost

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of imitation, suggesting that a shorter patent duration discourages imitation and is therefore optimal. However, the findings of Gilbert and Shapiro (1990) and Klemperer (1990) contradict this view. Gilbert and Shapiro (1990) provide a definition of patent length as any factor that amplifies innovators' profit stream during post-grant period. And Klemperer (1990) defines patent length as the space of differentiated products covered by granted patents. They argue that a narrow but infinitely long patent is optimal, as extending patent length may provide additional rewards to patentees with market power. Therefore, patent length is served as a beneficial mechanism to stimulate innovation. Thus, the socially cost-effective way to achieve a given reward for innovators is to have patents with infinite life, with the minimum market power required to achieve the desired level of reward. Wright (1999) validates the two opinions and puts forward that it depends on the assumed market structure and the properties of demand function. Second, there is clearly a dearth of empirical evidence on the relationship between patent length and innovation (Budish et al., 2016; Williams, 2016). Two empirical studies attempt to investigate whether stronger patents induce additional research investments or innovation (Lerner, 2009; Sakakibara and Branstetter, 1999). However, both of them do not directly focus on specific patent length.

To fill up this gap, we exploit an exogenous variation in patent substantive review delay to study the causal relationship between patent length and innovation. In 2012, the State Intellectual Property Office of China, which was renamed in 2018 to China National Intellectual Property Administration (CNIPA), formally implemented the fast-tracking patent applications (FPA) system. Where CNIPA agrees to conduct fast-tracking, a first notice should be issued within thirty days, and the case should be settled within one year. Thus, FPA policy shortens the review period for qualified patent applications. We show that an exogenous reduction in pre-grant period leads to a longer post-grant period, which implies longer patent length. Based on the policy background and theoretical analysis, we explore empirically whether patent length extension incentivizes corporate innovation using a difference-in-differences (DID) approach, accompanied by a discussion of robustness checks and heterogeneous analysis. Moreover, we further examine whether patent length extension contributes to technology disclosure, which is another major goal of the patent system.

There are three main empirical findings. First, we show that the patent length extension brought about by FPA significantly stimulates corporate innovation, leading to a 30 % increase in patent applications on average. This finding is robust to a wide variety of alternative specifications. Second, we find that the positive impact of patent length extension on innovation is highly heterogeneous, which is mainly concentrated on enterprises with more political resources, enterprises belonging to industries with higher patent propensities, and enterprises facing greater market competition. Third, besides incenticing innovation, patent length extension also contributes to technology disclosure and knowledge spillover. Taken together, our findings show that patent length extension facilitates innovation incentives and technology disclosure, illustrating that government policies should be targeted at reducing patent review delay.

The contributions of this paper are mainly manifested in the following aspects. First, this paper provides the basis for a subsequent empirical study of patent length by establishing a link to patent substantive review. Second, this paper adopts a novel identification strategy to estimate the possible subsequent impact of patent length extension on innovation, providing empirical evidence for a large number of existing theoretical studies. Third, this paper comprehensively considers the characteristics of firms' institutional environment in determining the innovation incentive performance of patent length extension, which sheds light on the way of effective subsequent policy implementation. Finally, we put the two fundamental objectives of the patent system under one framework, including innovation incentives and technology disclosure, and provide empirical evidence that the patent length extension can help to achieve these two goals at the same time.

We organize the remainder of this paper as follows. Section 2 provides a brief policy background, analyzes how the acceleration in substantive review prolongs patent length and affects corporate innovation, and then presents the research hypothesis. Section 3 introduces the identification strategy, including data description and empirical design. Section 4 presents empirical results, robustness checks, and heterogeneity analysis. Section 5 provides further analysis of technology disclosure. Section 6 concludes the paper with a discussion of policy implications.

2. Policy background and theoretical analysis

2.1. Policy background

To promote innovation, an efficient patent system design is often beneficial (Bloom et al., 2019). On June 19th, 2012, the CNIPA promulgated the Administrative Measures for the Fast-tacking Patent Applications (AMFPA), which became completely effective on August 1st, 2012. This policy is set to promote the optimization and upgrading of industrial structure, giving priority review to specific patent applications.[1] The article 4 of AMFPA specifies that patent applications in strategic emerging industries, such as energy saving and environmental protection, information technology, biotechnology, and green technology, can undergo fast-tracking review. Furthermore, the article 5 of AMFPA states that the number of patents actually fast-tracked for review is determined by CNIPA based on various factors, including the examination capacity of different technical fields, the number of patents granted in previous year, and the number of pending examinations in current year. This indicates that for AMFPA-eligible patents, the outcome of whether or not they ultimately get accelerated examinations is relatively exogenous to applicants.

For patent applications that successfully enter the FPA process, CNIPA will give a first notification within thirty days, and the case should be settled within one year. Fig. 1 illustrates the three stages that patent applications go through to grant, including formal review, publication, and substantive review, regardless of whether they follow the general process or the FPA process. It is worth mentioning that formal review and substantive review are different. Formal review is a quick and preliminary review that only focuses on the most basic formal elements to ascertain whether applications comply with the provisions of the Patent Law regarding formal requirements. Substantive review, however, is an exhaustive examination of the patentability of applications to determine whether their novelty, inventiveness, and practicability meet the requirements of the Patent Law. The applicants' requests for FPA occur only at the substantive review stage and have no bearing on formal review. As shown in Fig. 1, the immediate effect of FPA is to accelerate substantive review and bring early grants.

In addition, FPA is not only practiced in China. Other countries implementing FPA include the United Kingdom (May 12th, 2009), Australia (September 15th, 2009), South Korea (October 1st, 2009), Japan (November 1st, 2009), the United States (December 8th, 2009), Israel (December 27th, 2009), Canada (March 3rd, 2011) and Brazil (April 17th, 2012).[2] While the FPA in these countries mainly focuses on green technologies, China's FPA also includes emerging technologies in multiple fields. There is some theoretical research on the FPA system (Lu, 2013), mainly focusing on the justification of this policy. Besides, Antoine (2013) empirically studies the patents requesting accelerated review globally, and finds that FPA can indeed help technology spread earlier. However, existing studies do not address the possible

[1] In China, patents are divided into three categories, namely inventions, utilities and designs. The FPA only covers invention patents, and all patents mentioned in this paper are invention patents unless otherwise specified.

[2] Refer to https://www.wipo.int/wipo_magazine/en/2013/03/article_0002.html, last accessed on April 27th, 2023.

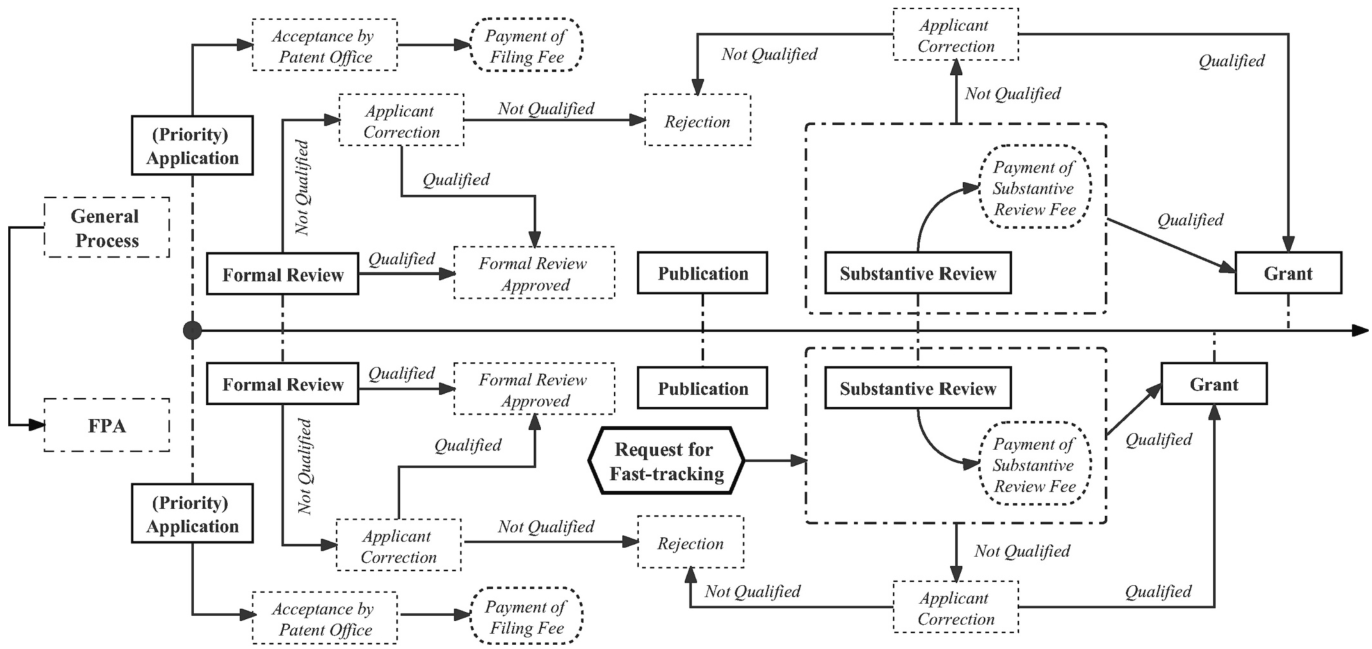

Fig. 1. FPA accelerates substantive review and brings early grants.

relationship between FPA and patent length, and FPA's subsequent impact on innovation.

2.2. Definition of patent length

Before discussing the relationship between FPA and patent length, it is necessary to clarify the duration covered by the alleged patent length in this study.

Let's start by discussing the suitable starting point for patent length, which we believe should be the grant date. The topic of patent length often revolves around the design of the patent system. It examines the extent to which the patent system should offer eligible subjects with an extension of exclusive rights within a defined timeframe. And it is important to note that the grant date signifies the actual commencement of these rights. This aligns with Article 39 of the Patent Law of the People's Republic of China, which states that patent rights become effective upon the announcement of their grant. In addition, relevant studies consistently consider the grant date as the appropriate reference for determining patent length (Chu, 2010; Serrano, 2010).

Besides, as shown in Fig. 1, there are other important time points before patent grant, such as the filing date and the publication date. We also would like to explain why they are not the appropriate starting point for patent length. First, patent applications do not naturally confer monopoly rights when they are filed, which still need a subsequent substantive review. According to China's judicial interpretation,[3] during the period between patent filing and publication, the Patent Law does not provide exclusive protection for the filed invention. Therefore, if another individual independently develops and implements a similar invention during this period, they cannot be held liable for patent infringement. This principle is also followed in Chinese judicial practice.[4] Second, although the patent system is designed to incentivize inventors to disclose their technology in exchange for monopoly rights, these rights are not established at the time of patent publication. The primary purpose of the patent system placing publication before grant is to promote technology disclosure, which is an important social objective of the patent system (Hall and Harhoff, 2011). To protect applicants from potential losses due to pre-grant publication, the patent system provides a provisional protection period. Specifically, according to Article 13 of the Patent Law of the People's Republic of China, if someone commercially utilizes patented technologies during the provisional protection period, patentees could seek reasonable compensation to cover any damages incurred. It is worth emphasizing that the provisional protection period is contingent on the eventual successful grant of a patent, and the level of protection for applicants' interests during this period is considerably lower than that after the grant. In summary, we argue that the grant date should be deemed the appropriate initial reference for determining the duration of a patent, as opposed to the filing date or the publication date.

Having clarified the starting point of patent length, let's move on to its ending point. To the best of our knowledge, there are two slightly different understandings of that. In Nordhaus (1969) model, the termination of patent length is considered as an exogenous factor, which is static and statutory. Another understanding incorporates the consideration regarding patent maintenance. Not all patents are maintained to the statutory termination due to the cost of maintenance fees. In this context, the maintenance decision of patentees determines the effective life of patents, thus the termination of patent length is endogenous (Mohamed, 2018b). The definition of exogenous and endogenous patent length is shown in Fig. 2. Next, we try to argue how FPA extends patent length based on these two understandings.

2.3. Patent length and FPA

2.3.1. Exogenous patent length and FPA

For the first understanding, patent length is exogenous to patentees. It specifically refers to the time from patent grant to the statutory expiration. It is important to emphasize that although patentees in the modern patent system do not necessarily maintain their patents to the statutory expiration, the interpretation of Nordhaus (1969) model regarding exogenous patent length is still valuable. While patentees do not know when the costs of maintaining a patent outweigh the benefits, longer exogenous patent length always means a greater likelihood of revenue. As we can see from Fig. 3, the pre-grant period of patents

[3] Gazette of the Supreme People's Court of the People's Republic of China (1993). Answers of the Supreme People's Court on Several Questions on the Trial of Patent Disputes, 26–27.

[4] Zhilin Zhu v. Hangzhou Qiandao Lake Tianhong Organic Food Co. (2006), Hangzhou Intermediate People's Court No. 142, 15 December.

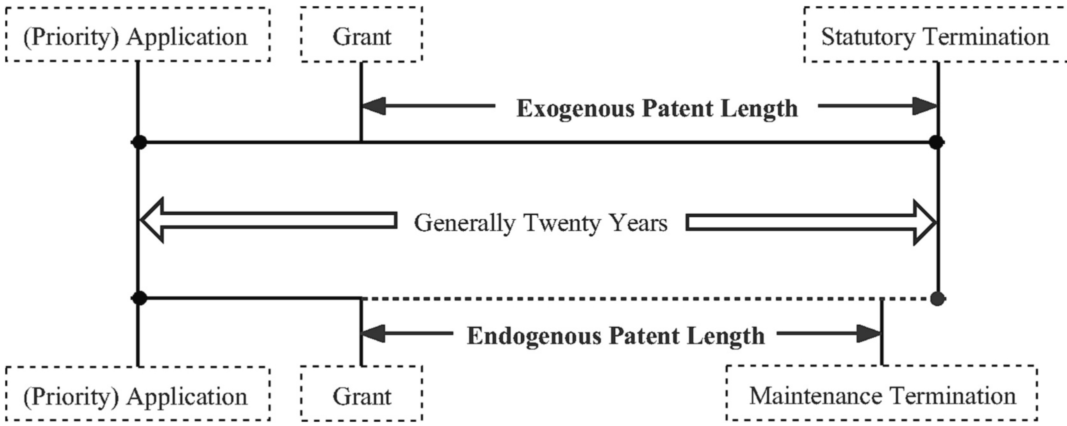

Fig. 2. Definition of the exogenous and endogenous patent length.

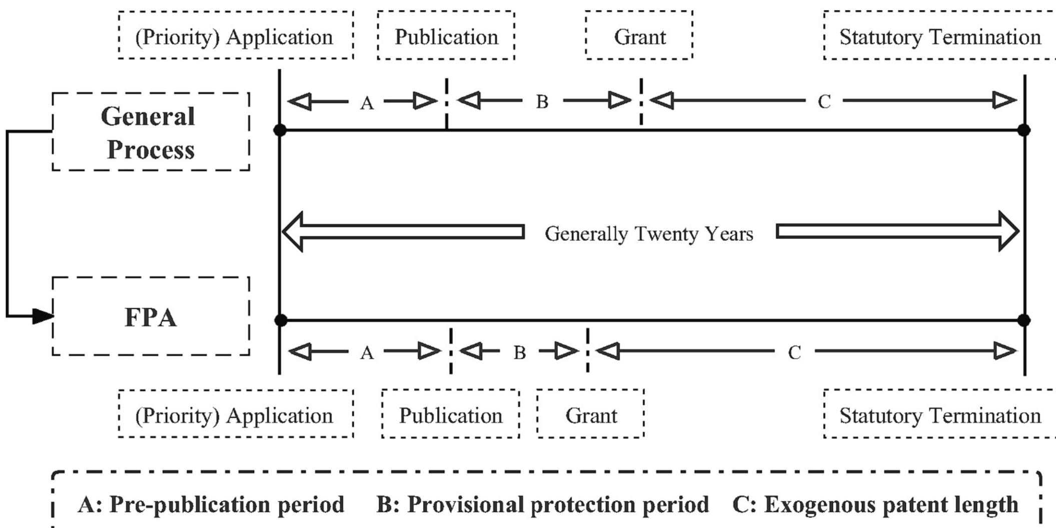

Fig. 3. FPA brings longer exogenous patent length.

consists of a pre-publication period and a provisional protection period. The FPA enables patents to be granted earlier through accelerated substantive review, which means longer exogenous patent length.

2.3.2. Endogenous patent length and FPA

For the second understanding, patent length is endogenous to patentees. Patents do not necessarily end at the statutory termination, but rather when patentees voluntarily end patent maintenance. In such a context, FPA may affect patentees' maintenance decisions, and therefore have an impact on endogenous patent length. In this section, we try to propose an analytical framework that cooperates patent costs and benefits under the general process and FPA.

Consider that a patentee chooses a lifespan for his/her patent to maximize the expected discounted value of net return. Let $c(t)$ denotes the annual maintenance fee for a patent in year t, and $r(t)$ denotes the appropriable revenues for a patent in year t. Based on the fact that the annual maintenance fee grows at a certain rate,[5] $c(t)$ is an increasing function with respect to t. The property of $c(t)$ is determined as follows:

$$c(t+1) \geq c(t)$$
$$\frac{\partial c(t)}{\partial t} \geq 0. \tag{1}$$

Referring to the related classical literature (Pakes and Schankerman, 1984; Schankerman and Pakes, 1986), the appropriable revenues decline at rate δ, making $r(t)$ a decreasing function with respect to t. Then $r(t)$ can be written as:

$$r(t) = r(0)e^{-\delta t}$$
$$\frac{\partial r(t)}{\partial t} = -r(0)e^{-\delta t} < 0. \tag{2}$$

Using cost-benefit analysis, the net profit of a patent in year t is $f(t)$, which is a strictly decreasing function with respect to t.

$$f(t) = r(t) - c(t),$$
$$\frac{\partial f(t)}{\partial t} = \frac{\partial r(t)}{\partial t} - \frac{\partial c(t)}{\partial t} < 0. \tag{3}$$

Thus, the discounted value of expected return accruing to a patent from grant date to date T is given by:

[5] Refer to *The Standard of Patent and Integrated Circuit Layout Design Fees* from https://www.cnipa.gov.cn/col/col1518/index.html, last accessed on April 27th, 2023.

$$EV(T) = \int_{g}^{T} f(t)e^{-it}dt \tag{4}$$

where i is the discount rate, g is the grant date of a patent, $T \in [g, a+c]$,[6] a is the filing date of a patent.

The function of the probability of patent maintenance is usually based on a comparison between the benefits and costs of patentees. It can be expressed as:

$$Pr(t) = h(EV) \tag{5}$$

Patentees are more likely to maintain patents when the expected discounted value of net return is higher, thus $Pr(t)$ is a monotonically increasing function with respect to EV. Collating the relevant variables, we can obtain the expected patent return with the general process and FPA:

$$EV(T_{general}) = \int_{g_{general}}^{T} f(t)e^{-it}dt \tag{6}$$

$$EV(T_{FPA}) = \int_{g_{FPA}}^{T} f(t)e^{-it}dt \tag{7}$$

As discussed in the above institutional background (as shown in Fig. 1), FPA accelerates substantive review for qualified patent applications, thus the grant date of patents undergoing the FPA process is earlier than that undergoing the general process:

$$g_{general} > g_{FPA} \tag{8}$$

By the nature of the integral and Eq. (3), we can obtain:

$$EV(T_{FPA}) > EV(T_{general}) \tag{9}$$

Eq. (9) implies that FPA results in higher expected benefits accruing to patents from grant date to date T. The patentee's decision to maintain his/her patent at date T depends on the expected discounted value of the patent's net return, $EV(T)$. The greater the expected return from patents at date T, the higher the probability of patent maintenance. That is:

$$Pr(T_{FPA}) > Pr(T_{general}) \tag{10}$$

For any $T \in [g, a+c]$, the increase in expected return induced by FPA increases the probability of maintenance. Therefore, FPA extends endogenous patent length from the perspective of patentees' maintenance probability.

It should be further noted that the theoretical model only considers the cost-benefit analysis of patentees in post-grant phase. The reasons are specifically twofold. First, there exists a significant difference in the cost and benefit of patents before and after their grant. During pre-grant phase, the costs consist mainly of filing fees and substantive review fees, regardless of whether patent applications follow the general process or the FPA process. In contrast, maintenance costs are only incurred after the grant. Admittedly, there are cases where a patent generates profits before it is granted, such as pre-grant licenses or transfers. However, some empirical studies suggest that this is not common, due to an uncertainty of whether applications ultimately acquire monopoly rights. For example, Ma et al. (2021) find that pre-grant licenses occurred in only 2313 out of the 5,627,136 patents filed in China from 2001 to 2015. Furthermore, according to the 2016 China Patent Survey Data Report,[7] the effective patent transfer rate is only 5.4 %, and pre-grant patent transfers (actually the transfer of patent application rights in the legal sense) are even rare (Fan, 2018). In other words, most of the profits from patents come after grants. Second, the cost-benefit analysis in pre-grant and post-grant phase differs from the perspective of applicants. During pre-grant phase, applicants primarily bear costs without reaping any immediate benefits. At this stage, the incurred costs are mainly aimed at obtaining future monopoly rights. The expected benefits following the grant, rather than before it, serve as the motivation for applicants to bear these costs. In contrast, during post-grant phase, the granted monopoly rights can generate profits, and costs come in the form of stepped-up maintenance fees. The cost-benefit analysis formally emerges each time a patentee decides whether to renew a patent. In summary, the benefit function of most patents arises only after grant, and so does the cost-benefit analysis based on maintenance decisions. As a result, the theoretical model in this study only considers applicants' cost-benefit situation in post-grant period.

To further support the above analysis, we also attempt to provide stylized empirical evidence to show that FPA indeed extends the maintenance time of granted patents. We first divide the enterprises into two groups, A and B, according to whether they are in strategic emerging industries or not. That is, enterprises in Group A are affected by the FPA policy shock, while enterprises in Group B are not affected. Referring to the indicator construction method of Long and Wang (2019), we then calculate the average patent maintenance rate of the two groups from 2007 to 2016, respectively. It is worth noting that although FPA started in 2012, the enterprises affected by FPA existed before its implementation. Our aim is to compare the changes in patent maintenance rates in the two groups before and after the implementation of FPA. This comparison allows us to demonstrate whether FPA empirically leads to longer endogenous patent length.

The specific calculation process is as follows. First, we limit the sample to patents that have been granted and expired,[8] which have a clear grant date and termination date. Second, we calculate the number of granted patents among the patent applications by the two groups each year as the denominator. Third, we calculate the number of patents filed in the two groups each year that have been maintained for at least 4 years[9] as the numerator. Finally, the ratio of the two is the proportion of patents maintained for >4 years in Group A and Group B, i.e. the average maintenance rate. The results are shown in Fig. 4.

As illustrated in Fig. 4, before the implementation of FPA, the patent maintenance rates in the two groups are similar. And the patent maintenance rates in Group B are even higher than those in Group A. In contrast, after the implementation of FPA, the situation is significantly reversed. It indicates that the enterprises affected by FPA are more inclined to engage in patent maintenance compared to those not affected by FPA, which provides empirical support for the results in the above theoretical analysis. It should be noted that this empirical evidence is preliminary and limited, as the sample must be restricted to expired patents. However, it is the most relevant evidence based on the currently available data which may be used as a reasonable approach.

2.4. Research hypotheses

As discussed earlier, FPA extends patent length based on the two different interpretations. Here, we pull innovation into our discussion, stating theoretically how patent length extension affects innovation. For a specific patent application, longer patent length denotes a longer full-

[6] c is the statutory period of patent rights since application, generally 20 years.

[7] Refer to *2016 China Patent Survey Data Report* from China National Intellectual Property Administration via https://www.gov.cn/xinwen/2017-07/01/5207170/files/0d83016749434af3aeffe3db92343ad9.pdf

[8] As the FPA policy was implemented in 2012, many of the patents filed during that time have not yet reached the end of patent maintenance and remain in an indefinite state. Therefore, our attempt to offer initial empirical evidence for the theoretical model is restricted to the sample of these expired patents.

[9] The observation date for patent data is the end of 2022 and the average length of a patent from filing to grant is 2–3 years. Due to the truncation issues in patent data, we set the maintenance period at 4 years to ensure a fair comparison between patents with different application years.

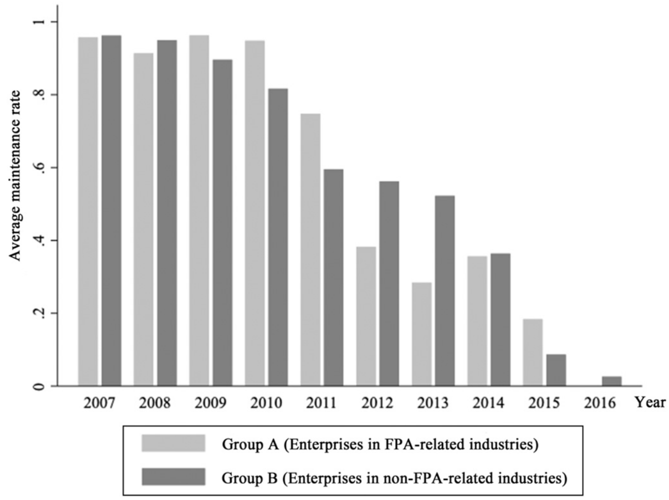

Fig. 4. FPA brings longer endogenous patent length.

protection period, which is an incentive for innovators to reap more benefits during the monopoly period from the following aspects. First, there is an ex-ante preventive effect against potential infringements for patentees with a full-protection right. Second, after a patent infringement has occurred, patentees are more likely to receive desired compensation in court with a full-protection right. Third, a full protection right makes high-priced patent licenses and transactions more likely. Thus, we argue that the increase in expected revenue from longer patent length leads to an increase in corporate innovation.

However, considering that the expected benefits of patentees are not only related to the monopoly right but also closely related to the behaviors of follow-on innovators, patent length extension may have the potential to undermine subsequent innovation. First, as proposed by Gallini (1992), in the case of high-cost imitation, the rivals' decision to imitate depends on the duration of the monopoly right granted to patentees. The longer the patent length, the longer the technology be in the private sector. As a result, competitors are more likely to invent around patented products, rendering the original patent obsolete and eroding its commercial return. Second, the development of innovation is often a continuous and cumulative process, with subsequent innovation building on the existing innovation. A strong patent system brings dynamic distortions corresponding to the hindering effects caused by the increased cost of follow-on innovation. For example, a new technology built on the underlying patented technology may also be granted if it meets the patentability requirements, but the implementation of this subsequent patented technology often requires licenses to the underlying technology as well, which significantly increases the costs of commercializing new technology. In this context, patent length extension means higher costs for using subsequent patented technology, which may not be conducive to subsequent innovation. As mentioned above, we propose competitive hypothesis 1a and 1b.

H1a. Patent length extension promotes innovation incentives.

H1b. Patent length extension undermines innovation incentives.

Since the potential impact of patent length extension on innovation is closely related to the institutional environment in which firms operate, we further consider the heterogeneity of the relationship between patent length extension and innovation in three aspects: political resources, industry patent propensities, and market competition.

First, corporate innovation activity is a trade-off between monopoly gains and R&D costs. Firms with more political resources are more likely to have access to favorable policies and financial support, tend to face fewer financing constraints, and therefore have different innovation preferences. Due to soft budget constraints, governments usually provide them with additional funds, cut their taxes, and provide other compensation when losses occur (Lin and Tan, 1999). In addition, they have a clear credit financing advantage (Acharya et al., 2014; Borisova et al., 2015; Huang et al., 2017), and therefore have access to more working capital to support long-cycle innovation. According to existing research, firms with more political resources invest more in R&D, hold more patents (Wei et al., 2017), and are better placed to undertake substantive innovation (Gu et al., 2018; Fang et al., 2020). In this context, the innovation incentive effect of patent length extension on firms with more political resources may be more pronounced. Thus, we propose hypothesis 2a.

H2a. Patent length extension is more effective in stimulating innovation for enterprises with more political resources.

Second, patent propensities vary across industries and play an important role in the relationship between patent length and firm innovation. Compared to industries with low patent propensities, industries with high patent propensities are more competitive (Hall and Ziedonis, 2001; Blazsek and Escribano, 2016), more R&D intensive (Cohen et al., 2000; Hall et al., 2001), and have more technology diffusion (Bloom et al., 2013). In this case, firms in industries with high propensities attach more necessity and importance to engaging in innovation, especially substantive innovation, to maintain their market position and competitive advantage. Patent length extension may help firms better protect and exploit their innovation, and provide firms with more opportunities to capture the appropriable revenue, thus offering greater incentives to innovate. And the positive effects of patent length extension are more attractive for firms in industries with high patent propensities, thus leading to more investment in innovation among these firms. Therefore, we propose hypothesis 2b.

H2b. Patent length extension is more effective in stimulating innovation for enterprises belonging to industries with higher patent propensities.

Third, the market competition faced by enterprises may also have an impact on innovative behavior. In particular, the monopolistic nature of patents makes them often appear as a competitive tool in fierce market competition, giving rise to patent races between companies (Thompson and Kuhn, 2020). For one thing, in a market with fierce technology competition, the patent thicket is likely to emerge, which is a dense network of overlapping patents owned by different companies (Gatkowski et al., 2020). The surge of patent applications is a driving force behind the emergence of patent thickets, which in turn acts as a competitive strategy for companies and provides an incentive for subsequent patent applications. For another thing, in a market with fierce product competition, the proliferation of new products requires adequate patents as an important safeguard against infringement. Overall, for companies facing greater market competition, the benefits of longer patent length include more bargaining power with other enterprises, bringing a better actual incentive to innovate. As discussed above, we propose hypothesis 2c.

H2c. Patent length extension is more effective in stimulating innovation for enterprises facing greater market competition.

In addition to innovation incentives, technology disclosure is another fundamental goal of the patent system (Hall and Harhoff, 2011), which facilitates knowledge spillover (Hegde et al., 2022), reduces follow-up research costs (Harhoff, 2011) and duplicative R&D (Luck et al., 2020). In this study, the patent length extension is brought about by an accelerated substantive review process. In China, substantive review can only begin after patent publication. According to Article 34 of the Patent Law of the People's Republic of China, patent applicants may request for early publication, in addition to the statutory publication after 18 months from the filing date. Thus, those applicants, who want to obtain timely substantive review by FPA, are more likely to request an early publication of patents. According to existing studies, publication delay means that the information disclosed in a patent document is outdated by the time it becomes available (Hall and Harhoff, 2011), which may impede inventors' ability to learn about state-of-the-art technologies (Ouellette, 2012, 2017). Based on a quasi-natural experiment with the implementation of the American Inventors Protection Act, Baruffaldi and Simeth (2020) find that early publication of patents can facilitate knowledge spillover. As mentioned above, we propose hypothesis 3, and the research framework is shown in Fig. 5.

H3. Patent length extension promotes technology disclosure and knowledge spillover.

3. Model construction and variable definition

We consider the implementation of FPA as a quasi-natural experiment and construct a DID model by dividing the sample into treatment and control groups based on whether the firms belong to FPA-required industries, i.e., strategic emerging industries. The causal effect of patent length extension on innovation output is explored by comparing the difference in the number of patent applications between the two groups before and after the implementation of FPA. The benchmark regression model is set as follows.

$$Patent_{e,t} = \alpha + \beta_1 treat_e \times post_t + \gamma controls_{e,t} + \delta_e + \lambda_{p,t} + \varepsilon_{e,t} \quad (11)$$

where the subscript e denotes an enterprise, the subscript t denotes a year, and the subscript p denotes a province. $Patent_{e,t}$ refers to the number of patent applications corresponding to enterprise e in year t. In the process of setting the interaction term, $treat_e$ is a dummy variable with a value of 1 for the enterprises in the strategic emerging industries and 0 for the others. And $post_t$ is a time dummy variable with a value of 0 for the year before FPA's implementation (2007–2011) and 1 for the year after that (2012–2016). $controls_{c,t}$ is the matrix of control variables of the model. Considering the availability of data and relevant research, the control variables include enterprise assets (*size*), the age of enterprise (*lnage*), the return on assets (*roa*), profit margin (*profit*), enterprise value (*tobin*), and concentration ratio (*hhi*). Except for the ratio variables, the variable of *Patent* is treated by adding one and taking natural logarithm, and the variable of *size and lnage* is treated by taking natural logarithm to eliminate potential heteroskedasticity problems. The variable description is shown in Table 1(a), and the descriptive statistics are shown in Table 1(b). All the financial data are collected and compiled from China Stock Market & Accounting Research Database (https://cn.gtadata.com). Patent-related data including the date of application, the date of publication, the date of grant, the date of citing, and the number of forward citations is manually obtained from the CNIPA Patent Search Platform. In addition, to control for unobservable and time-invariant factors from the enterprise level, such as enterprise culture, we include firm-fixed effects (δ_e) in the model. To control for changes in the province-year level such as the level of economic development, human capital, and legal environment, we include province × year fixed effects ($\lambda_{p,t}$) in the model. The standard error is robust and clustered at the firm level.

The estimated coefficient β_1 of the interaction term $treat_e \times post_t$ is the causal effect of FPA that is the focus of this paper: $\beta_1 < 0$ indicates that patent length extension undermines enterprise innovation output, $\beta_1 > 0$ indicates that patent length extension stimulates enterprise innovation output, and $\beta_1 = 0$ indicates that patent length extension does not affect enterprise innovation output.

Table 1
Variable description and descriptive statistics (a).

Variables	Definition	Description
Patent	Patent applications	The number of patent applications
did2	Interaction term	The interaction term of policy shock dummy variable and time dummy variable
size	Enterprise assets	The enterprise's total assets
lnage	Enterprise age	The number of years since the enterprise establishment
roa	Return on assets	The ratio of net profits to total assets
profit	Profit margin	The ratio of profits to sales
tobin	Market value	The ratio of market cap to total assets
hhi	Concentration ratio	The concentration of market structure across the industry

Data description and descriptive statistics (b)

Variables	Count	Mean	S.D.	Min	Median	Max
Patent	15,558	1.562	1.462	0	1.386	8.620
did2	15,558	0.382	0.486	0	0	1
size	15,558	21.999	1.301	19.046	21.789	28.509
lnage	15,558	2.646	0.415	0	2.708	3.912
roa	15,558	0.048	0.048	−0.523	0.042	0.482
profit	15,558	0.108	0.310	−14.386	0.081	23.054
tobin	15,558	2.092	1.369	0.699	1.678	31.400
hhi	15,558	0.052	0.146	0	0.008	1

4. Empirical results

4.1. Benchmark regression results

To examine the impact of patent length extension on innovation, a sample of Chinese listed companies from 2007 to 2016 is included in the model with standard errors clustered at the firm level. The benchmark regression results are shown in Table 2.

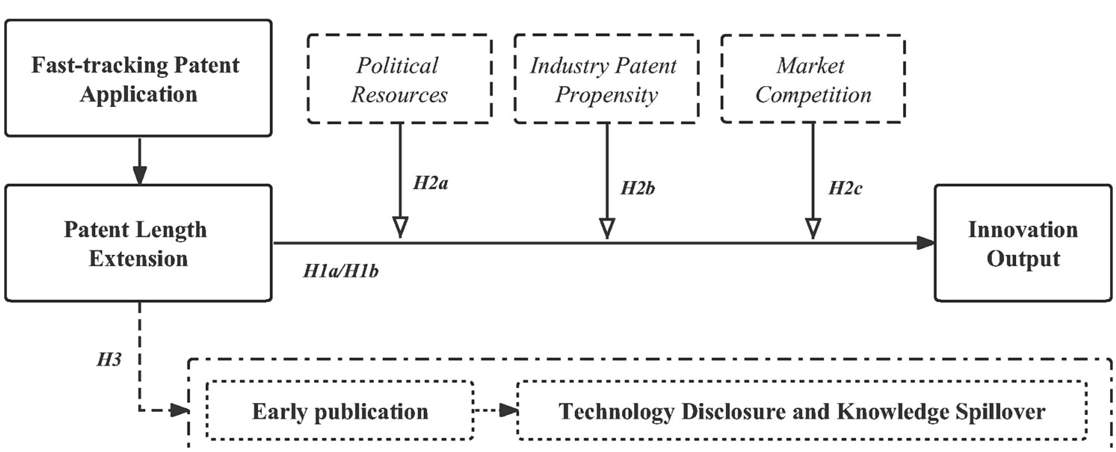

Fig. 5. Research framework.

Table 2
The result of benchmark regression.

Variables	(1) Patent	(2) Patent	(3) Patent
did2	0.248***	0.332***	0.311***
	(0.030)	(0.037)	(0.038)
size		0.271***	0.268***
		(0.032)	(0.032)
lnage		0.412***	0.351***
		(0.108)	(0.111)
roa		0.265	0.247
		(0.240)	(0.238)
profit		0.005	0.005
		(0.013)	(0.013)
tobin		0.007	0.011
		(0.009)	(0.008)
hhi		0.025	−0.017
		(0.102)	(0.101)
Observations	19,798	15,558	15,558
Firm-FE	Yes	Yes	Yes
Year-FE	Yes	Yes	No
Province * Year-FE	No	No	Yes
Adjusted R^2	0.731	0.775	0.779
Clustvar	Firm	Firm	Firm
N_cluster	2751	2144	2144

Cluster standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Column (1) controls the firm-fixed effect (Firm-FE) and year-fixed effect (Year-FE). The coefficient of the interaction term in column (1) is 0.248, which is significant at the 1 % level, showing that the patent length extension increases patent applications. With the control of Firm-FE and Year-FE, column (2) includes the control variables, and the estimated coefficient indicates that the significant positive effect remains almost the same. To further ensure the robustness of the results, we replace Year-FE with Province × Year-FE in column (3). In general, the model has a corrected coefficient of determination of 0.779, indicating that the model is meaningful and explains over 70 % of the variation in enterprise innovation output. The estimated coefficient of the interaction term is 0.311 at the 1 % statistically significant level. In terms of economic significance, patent applications in the treatment group significantly increase by approximately 31.1 % after the implementation of FPA compared to those in the control group. This result supports H1a.

Before discussing the findings in further depth, we acknowledge a potential concern, namely, since FPA brings about both a reduction of pre-grant phase and an extension of post-grant phase, why do we attribute these empirical results to the latter? Let us first briefly discuss the relationship between these two factors. Based on the understanding of exogenous patent length, it is intuitive that since the time from filing to statutory termination is fixed, a reduction in pre-grant phase necessarily implies an extension of post-grant phase. In addition, considering endogenous patent length, the theoretical model shows an earlier patent grant (a shorter pre-grant phase) leads to higher expected revenue. Consequently, this higher expected revenue implies a higher probability of maintaining patents, resulting in a longer post-grant phase.

Based on this discussion, patent length extension and pre-grant phase shortening are interconnected and simultaneous events. That is, the occurrence of one inevitably implies the occurrence of the other. These two aspects can be likened to two sides of one coin. It is important to recognize that the coin as a whole brings innovation incentives. Our objective is to determine which side of the coin better elucidates the whole story. In other words, when the implementation of FPA provides patent applicants with a coin that offers innovation incentives, we need to consider which side better represents the essence of the matter. Specifically, should the innovation incentives for applicants be attributed to patent length extension or the more favorable examination in the shortened pre-grant phase? We believe that this is contingent upon the fundamental rationale of the patent system in promoting incentives for innovation.

It is crucial to acknowledge that the patent system is designed to incentivize innovation by granting statutory monopolicies. Admittedly, a more favorable examination can satisfy applicants. However, we need to note that the underlying intention behind this favorable examination is still to extend the period of monopoly rights. This is the main source of the expected benefits for patentees. The objective should not be to reach a quick conclusion to the examination, but rather to ensure longer patent length. In summary, we think that the innovation incentive effects observed in the benchmark regression results should be attributed to the extension of patent length, rather than the reduction of pre-grant phase.

4.2. Robustness checks

4.2.1. Dynamic effects test

The benchmark regression results indicate that the patent length extension significantly stimulates Chinese corporate innovation. However, we cannot catch the trend of the treatment group and the control group before and after the policy in the benchmark regression. And it cannot explain whether the parallel trend assumption is satisfied, which is the basic assumption for the adoption of DID. The parallel trend assumption means without the implementation of FPA, enterprise innovation output in the two groups should maintain the same trend. To test this assumption, we extend the benchmark regression model to the following dynamic model in Eq. (12), in which the dummy variable $post_t$ in Eq. (11) is replaced by the dummy variable representing several years before and after the implementation of FPA, and other variables remain unchanged. The dynamic model is as follows, and the results are shown in Fig. 6:

$$Patent_{e,t} = \beta_k \sum_{k=-4}^{4} \mathrm{treat}_e \times \mathrm{post}_{2012+k} + \gamma controls_{e,t} + \delta_e + \lambda_{p,t} + \epsilon_{e,t} \tag{12}$$

As illustrated in Fig. 6, the estimated coefficients of the interaction terms are all insignificant and around the value of zero in the ex-ante years. This indicates that controlling for other factors, the trends in enterprise innovation output in the two groups are essentially the same before the implementation of FPA, satisfying the assumption of parallel trends required by the DID model. In contrast, after the implementation of FPA, the coefficients of the interaction terms are significantly positive in three years, which indicates the enterprise innovation output of the two groups shows different trends. It demonstrates a significant increase in the innovation output of enterprises in the strategic emerging industries.

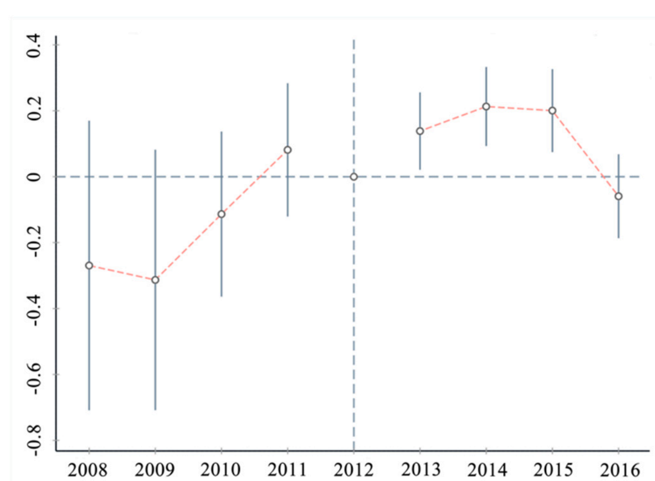

Fig. 6. Dynamic effects.

4.2.2. Placebo tests

The results of the dynamic effects test ensure that the parallel trends assumption is satisfied. However, another reasonable challenge to the benchmark regression results is that the econometric model fails to control for some unobservable and time-varying firm-level differences. Based on the practice of Li et al. (2016), we conduct a placebo test. We take the estimated coefficient $\widehat{\beta}_1^{random}$ as the following formula to indirectly test whether there is such a potential unobservable factor:

$$\widehat{\beta}_1^{random} = \beta_1 + \alpha \times \frac{cov\left(treat_e \times post_t, \varepsilon_{e,t} \mid C\right)}{var\left(treat_e \times post_t \mid C\right)} \tag{13}$$

where C includes the control variable matrix and the fixed effect, and α represents the influence of potential unobservable factors on the explained variable. If the test supports $\alpha = 0$, it indicates that potential unobservable factors do not affect the estimated results. More specifically, we randomly assign enterprises to the treatment group or control group, and then estimate using the benchmark regression model. Theoretically, there should be $\beta_1 = 0$. On this basis, if the value of the regression coefficient obtained by random group assignment is zero ($\widehat{\beta}_1^{random}$=0), it can be inferred that $\alpha = 0$. The above process is repeated 500 times to obtain the corresponding random estimated coefficient $\widehat{\beta}_1^{random}$. The results are shown in Fig. 7. The random estimated coefficient results follow a normal distribution, and the mean value is close to 0, which is much smaller than the true value of 0.311. The results of the placebo test support $\alpha = 0$, and potential unobservable factors do not affect the conclusions of this study.

In addition to constructing spurious explanatory variables by randomly assigning enterprises to the control and treatment groups, we also construct spurious explained variables for the placebo test. In China, patents are divided into three categories, namely invention, utility, and design. The type of patents involved in FPA, as well as the explained variables in the benchmark regression, is the invention patents. This allows us to construct another placebo test. Therefore, we further explore the robustness of the benchmark regression results by replacing the explanatory variable with other types of patents, and the results are shown in Table 3. Column (1) replaces the explained variable with utility applications. The coefficient of the interaction term in column (1) is −0.123 with a significance at 5 % level. We then take design applications as the explained variable, and the result shown in column (2) is insignificant. In column (3), we take non-invention applications, which is the sum of utility applications and design applications as the explained variable, and the result is negatively significant. As we can see, the interaction term coefficients obtained by constructing spurious explained variables are inconsistent with the benchmark regression results, which further confirm the robustness.

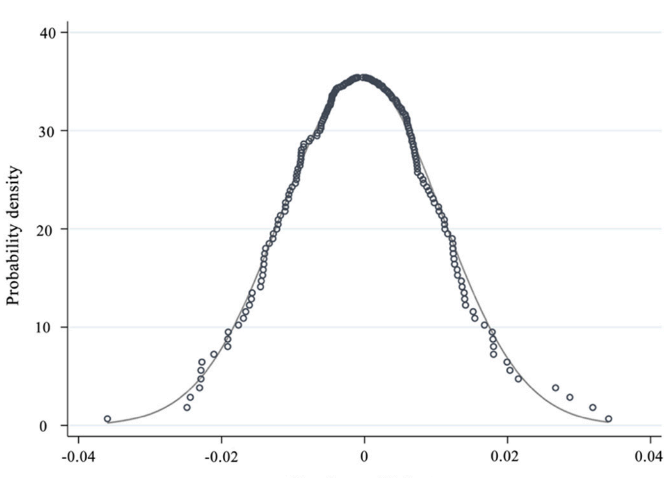

Fig. 7. Placebo test with a spurious *treat*.

Table 3
Placebo test with spurious explained variables.

Variables	(1) *lnappli_uti*	(2) *lnappli_des*	(3) *lnappli_noninv*
did2	−0.123**	−0.032	−0.111**
	(0.051)	(0.044)	(0.055)
Controls	Yes	Yes	Yes
Observations	15,558	15,558	15,558
Firm-FE	Yes	Yes	Yes
Year-FE	No	No	No
Province * Year-FE	Yes	Yes	Yes
Adjusted R^2	0.892	0.762	0.896
Clustvar	Firm	Firm	Firm
N_cluster	2144	2144	2144

Cluster standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

4.2.3. Propensity score matching

Although the factors affecting firm innovation are controlled and the parallel trend assumption is satisfied in the above analysis, we cannot fully avoid possible systematic differences in the level of innovation between the two groups because the grouping is based on whether firms are in the strategic emerging industries. To alleviate this concern, we exploit the propensity score matching (PSM) method to characterize the two groups as similar as possible.

Given the PSM method in panel data and data availability, we use three separate matching approaches to enhance the robustness and reliability of the results as much as possible. First, we perform year-by-year matching using the control variables in the benchmark regressions as matching variables. The method has the advantage of making the PSM-DID control variables consistent with the benchmark regression model as well as having an adequate sample size. However, it may neglect firms' innovation and technology capabilities. Further, we include firms' R&D ratios (the ratio of R&D expenses to revenues) in the matching variables for year-by-year matching, and the results remain robust. Nonetheless, the sample size is compromised due to the missing R&D data. Lastly, we also implement the base-period matching. In addition to selecting the aforementioned control variables for matching, we also consider firms' innovation quality in 2007, as an additional measure of firms' innovation capabilities. This includes variables such as the average number of independent claims per patent, the average number of inventors per patent, the average number of patent citations received in 3 years, and the average number of patent citations received in 5 years. For each of the three approaches mentioned above, we employ various matching methods, including neighbor matching, caliper matching, radius matching, and kernel matching. These methods aim to match the treatment group firms with the most similar control group firms in order to minimize the potential influence of systematic differences in firm innovation levels on the estimation results.

The balance test results show no significant difference between all variables after matching, which indicate that this method is valid. Table 4 reports the PSM-DID estimation results based on year-by-year matching and base-period matching. The results are similar to the benchmark regression, further verifying that patent length extension promotes innovation incentives.

4.3. Heterogeneity analysis

Based on the verification of H1a, we further try to clarify the internal logic behind the innovation effect of patent length extension, to expand the policy support role of the research. Therefore, we conduct heterogeneity analysis based on the institutional environment in which firms operate. Specifically, three aspects are considered, including political resources, industry patent propensities, and market competition. The results are shown in Table 5.

Table 4
PSM-DID.

Variables	(1)	(2)	(3)	(4)	(5)
	1–1 neighbor	1–4 neighbor	Caliper	Radius	Kernel
Panel A year by year matching					
did2	0.334***	0.326***	0.322***	0.312***	0.312***
	(0.057)	(0.039)	(0.040)	(0.038)	(0.038)
Controls	Yes	Yes	Yes	Yes	Yes
Observations	5186	12,317	11,640	15,484	15,484
Firm-FE	Yes	Yes	Yes	Yes	Yes
Province * Year-FE	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.805	0.791	0.792	0.778	0.778
Clustvar	Firm	Firm	Firm	Firm	Firm
N_cluster	1194	1981	1942	2144	2144
Panel B year by year matching (R&D ratio included)					
did2	0.175***	0171***	0.167***	0.170***	0.170***
	(0.059)	(0.062)	(0.064)	(0.059)	(0.059)
Controls	Yes	Yes	Yes	Yes	Yes
Observations	1773	4023	4473	9711	9711
Firm-FE	Yes	Yes	Yes	Yes	Yes
Province * Year-FE	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.750	0.767	0.768	0.762	0.762
Clustvar	Firm	Firm	Firm	Firm	Firm
N_cluster	521	1096	1190	1820	1820
Panel C base-period matching					
did2	0.302**	0.357***	0.348***	0.358***	0.358***
	(0.132)	(0.105)	(0.047)	(0.046)	(0.046)
Controls	Yes	Yes	Yes	Yes	Yes
Observations	2001	4130	9899	10,513	10,513
Firm-FE	Yes	Yes	Yes	Yes	Yes
Province * Year-FE	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.746	0.734	0.781	0.787	0.787
Clustvar	Firm	Firm	Firm	Firm	Firm
N_cluster	227	469	1078	1144	1144

Notes: 1. Controls in *Panel A*: enterprise assets, the age of enterprise, the return on assets, profit margin, enterprise value, and concentration ratio; Controls in *Panel B*: enterprise assets, the age of enterprise, the return on assets, profit margin, enterprise value, concentration ratio, and R&D ratio; Controls in *Panel C*: enterprise assets, the age of enterprise, the return on assets, profit margin, enterprise value, and concentration ratio. 2. Cluster standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

First, depending on the political resources held by enterprises in China, they can be categorized into state-owned enterprises (SOEs) and non-SOEs. Based on this classification, we explore the impact of political resources on the innovation effect of patent length extension. As we can see, the innovation effect of patent length extension on SOEs (column 1, $\beta_1 = 0.365, p < 0.001$) is higher than that on non-SOEs (column 2, $\beta_1 = 0.249$, $p < 0.001$). As discussed before, enterprises with more political resources are in a better position to make substantive innovations, which may lead to the heterogeneity of the innovation effect of patent length extension. The results verify H2a.

Second, industry patent propensities reflect the variability in patent applications in different industries. We measure industry patent propensities by the number of patent applications. By calculating the patent propensities in each industry in the base period, we classify industries into those with below-median patent propensities and those with above-median patent propensities. Based on this classification, we explore the heterogeneous impact of patent length extension on enterprise innovation across industries with different patent propensities. As illustrated in Table 5, the innovation effect of patent length extension on enterprises in high patent propensities industries (column 4, $\beta_1 = 0.451, p < 0.001$)

Table 5
Heterogeneity analysis.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	SOE	Non_SOE	L_PP	H_PP	L_Thickets	H_Thickets	L_Share	H_Share
	Patent	Patent	Patent	Patent	Patent	Patent	Patent	Patent
did2	0.365***	0.249***	0.242***	0.451***	0.191***	0.279***	0.287***	0.492***
	(0.055)	(0.054)	(0.042)	(0.149)	(0.060)	(0.060)	(0.064)	(0.073)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6845	8508	10,168	5285	6282	7287	5444	4954
Firm-FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-FE	No	No	No	No	No	No	No	No
Province * Year-FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.836	0.712	0.748	0.785	0.696	0.807	0.783	0.781
Clustvar	Firm	Firm	Firm	Firm	Firm	Firm	Firm	Firm
N_cluster	800	1392	1441	809	1326	1473	588	527

Cluster standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

is higher than that in low patent propensities industries (column 3, $\beta_1 = 0.242$, $p < 0.001$). The H2b is verified.

Third, the patent thicket is selected as an indicator to explore the impact of technology market competition on the innovation effect of patent length extension. Referring to Long and Zhang (2019), patent thickets faced by a company reflect the transaction cost of commercializing new technology, including the cost of negotiating with multiple patent owners, the cost of searching for IP risks, and the cost of licensing. The average density of patent thickets faced by a company is derived by taking the proportion of patent stocks in each technology field as the weight and weighting the average according to the number of triangular obstacles in the corresponding technology field. The detailed calculation formula is as follows:

$$thickets_{i,t} = \frac{1}{n}\sum_{j=1}^{n}\frac{stock_{i,j,t}}{stock_{i,t}} \times triples_{j,t} \quad (14)$$

in which the $triples_{j,t}$ represents the number of triangular barriers per thousand patent applications in technology field *j* in year *t*. Based on the method proposed by von Graevenitz et al. (2011), we use the Chinese Patent Data to identify the triangular barriers (triples) and calculate the number of triples in each technology field based on the citation-cited relationship between patent owners. $stock_{i,j,t}/stock_{i,t}$ denotes the shares of enterprises in each technology field, where the numerator is the number of patents owned by firm *i* in technology field *j* in year *t*, and the denominator is the number of patents owned by firm *i* in year *t*. The patent stock is depreciated by 20 %. *n* denotes the number of technology fields involved by firm *i*. The larger the value of $thickets_{i,t}$, the higher the transaction cost paid by a firm to commercialize new technologies and the more intensive the patent thickets faced by a firm. We divide enterprises into two parts based on whether they face patent thickets larger than the median and explore its impact on the innovation effect of patent length extension. As illustrated in Table 5, the innovation effect of patent length extension on enterprises facing weaker patent thickets (column 5, $\beta_1 = 0.191$, $p < 0.001$) is lower than that on enterprises facing greater patent thickets (column 6, $\beta_1 = 0.279$, $p < 0.001$). For enterprises facing greater patent thickets, they need their patents to obtain longer patent length to get enough bargaining chips in fierce market competition.

Patent thickets reflect the level of competition and innovation in a particular technology field, and give insight into the level of investment and R&D effort being put into that field. Additionally, a high density of patent thickets can often lead to patent disputes and legal battles between enterprises, which may be regarded as evidence of the level of market competition. It can be seen that the density of patent thickets faced by enterprises captures more of the degree of competition in technology market. However, the degree of competition in product market is under-focused. Thus, we measure the degree of competition in product market using the proportion of market shares of enterprises in their industries in the base period. The sample is divided into enterprises facing low and high competition based on the median market share for sub-sample regression. As illustrated in Table 5, the innovation effect of patent length extension on enterprises facing weaker product market competition (column 7, $\beta_1 = 0.287$, $p < 0.001$) is lower than that on enterprises facing greater product market competition (column 8, $\beta_1 = 0.492$, $p < 0.001$). The heterogeneity analysis results based on technology and product market competition both confirm H2c of this study.

Table 6
Further analysis.

Variables	(1)	(2)	(3)	(4)
	App-pub_time	All sample	Spill-out	Spill-in
	lnm_lagap_m	*lnm_citedin3*	*lnm_citedin3*	*lnm_citedin3*
did2	−0.198***	0.048**	0.075**	0.007
	(0.033)	(0.023)	(0.029)	(0.043)
Controls	Yes	Yes	Yes	Yes
Observations	15,558	15,558	9126	5793
Firm-FE	Yes	Yes	Yes	Yes
Year-FE	No	No	No	No
Province * Year-FE	Yes	Yes	Yes	Yes
Adjusted R^2	0.531	0.479	0.488	0.411
Clustvar	Firm	Firm	Firm	Firm
N_cluster	2144	2144	1188	705

Cluster standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

5. Further analysis

After identifying the innovation incentive effect of patent length extension, which means stronger monopoly power, another issue of concern is whether it hinders subsequent innovation as we discussed before. Thus, we further explore its impact on technology disclosure, which is another fundamental goal of the patent system. According to the theoretical derivation of H3, we speculate that the applicants who try to extend patent length through FPA are likely to prefer early publication, which may result in knowledge spillover. To test our conjecture, we conduct a series of exploratory analysis, and the results are shown in Table 6.

We first examine whether patent length extension promotes technology disclosure. The time lag from patent filing to publication is used as a proxy variable. As shown in Table 6, the average time lag from patent filing to publication significantly decreases after the implementation of FPA. The estimated coefficient of the interaction term is −0.198, which is significant at the 1 % level. The result indicates that the patent publication delay is reduced by about 20 %, which is about 3.6 months. According to Baruffaldi and Simeth (2020), a one-year decrease in patent publication delay increases the number of citations from priority by 13 %, from disclosure by 19 %, and from grant by 11 %. Thus, the next question is whether the earlier technology disclosure brought about by patent length extension leads to further knowledge spillover. We then examine FPA's impact on the number of citations for patents within three years of application, and the results shown in column (2) confirm the knowledge spillover effect of patent length extension. Further, we explore whether there is firm heterogeneity in the knowledge spillover effect from patent length extension. More specifically, are companies that originally preferred technology disclosure more affected by FPA? Considering that technology disclosure is a costly act, enterprises that already prefer early disclosure pay less for the patent length extension brought about by FPA. Therefore, we suppose that the knowledge spillover effect may be more pronounced for them. We divide enterprises into two parts based on whether the average application-publication time lag of enterprises before FPA implementation is greater than that of the enterprise's industry. The results are shown in columns (3) and column (4), which verify the hypothesis.

6. Conclusion

To better achieve the innovation incentives and technology disclosure goals of the patent system, it is necessary to find empirical evidence to argue for the role played by patent length. Notably, improvements in patent review efficiency can lead to patent length extension. Based on the data of listed companies in China, this paper takes the FPA policy in 2012 as a quasi-natural experiment and adopts DID method to investigate the effect of patent length extension on innovation incentives and technology disclosure. Using the number of patent applications as a measure of corporate innovation output, we find that the patent length extension brought about by FPA increases corporate patent applications significantly by approximately 30 %. The results are confirmed by the dynamic effects test and the placebo test. Moreover, the innovation incentive effect of patent length extension is heterogeneous, depending on the characteristics of the institutional environment. Specifically, the innovation incentive effect is more reflected in firms with more political resources, firms belonging to industries with higher patent propensities, and firms facing fiercer market competition. Further analysis illustrates that patent length extension facilitates technology disclosure and knowledge spillover. In conclusion, the patent length extension induced by FPA has a positive impact on innovation incentives as well as technology disclosure, contributing to the two fundamental goals of the patent system.

In light of this, our results lead to a better understanding of the effects of patent length extension. Accordingly, this paper offers the following policy recommendations. First, it is important to take substantive review as a possible approach to regulate patent length. Improving the efficiency of substantive review under the premise of ensuring its quality is a good way to extend patent length, which is beneficial to patentees and the whole society. Second, when extending patent length by accelerating substantive review, corresponding supporting measures should be formulated according to the heterogeneity of innovation incentive effects. For firms with fewer political resources, firms in industries with lower patent propensities, and firms facing lower market competition, patent offices can offer a more preferential review schedule to better achieve the goal. Third, considering that the patent length extension based on improved review efficiency can help stimulate applicants to disclose patented technologies earlier, the approach of bringing knowledge spillover through policy guidance deserves the governments' attention.

Given the limitations of the dataset, namely the truncation problem, we do not have direct access to the maintenance years of patents, especially for patents applied after 2012 (the implementation of FPA). Further research could take a look at how the design of the patent system affects the economic performance of firms or their subsequent industry organization outcomes. In the future, these lines of research may deepen our understanding of the optimal design of the patent system and its evolution in response to changes in the institutional environment, such as identifying adjustments to the degree of IPP with respect to regions or industries.

Ethical approval

This is an original article that did not use other information that requires ethical approval.

Consent to participate

All authors participated in this article.

Consent to publish

All authors have given consent to the publication of this article.

CRediT authorship contribution statement

Meiyang Zhang: Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing – review & editing. **Xuezhong Zhu:** Validation, Funding acquisition, Supervision. **Rui Liu:** Conceptualization, Formal analysis, Writing – original draft, Writing – review & editing, Visualization, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data presented in this study are available on request from the corresponding author.

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