Patent Litigation, Patent Value and the Direction of Innovation: Evidence from China *

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Abstract

This paper investigates the role of patent enforcement in the private value of patents valuation and firm patenting strategy. I take China as the institutional context and examine how its damage awards doctrine and patent remedy enhancement efforts impact the private value of patents and the direction of firm innovative activities. To estimate the private value of patent protection, I construct a finite-horizon stochastic dynamic model and recover key parameters of firms' patenting and litigation processes. The structural estimates and counterfactual simulations show that strengthening patent enforcement by promoting damage awards significantly boosts the private value of utility models- the type of patents that do not go through rigorous examination- while leaving the private value of invention patents- the type of patents that go through examination and describe more substantive inventions- almost unchanged. To explore the implications for firm strategy, I run a series of difference-in-differences analyses on a comprehensive sample of Chinese patenting firms. I find that firms with higher litigation exposure tend to patent more utility models when patent reform enhances damage awards. This tendency of filing more utility models is more pronounced among financially constrained firms. The "treated" firms are more likely to switch from low-quality invention patents to utility models, which leads to deterioration of the overall quality of innovation outputs. Policy simulations suggest that differentiating damage awards for invention patents and utility models might be a feasible solution to adjust the distortion in patent

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valuation and firms' innovation choices.

Keywords— patent litigation, patent value, direction of innovation, weak intellectual property right regimes, China

1 Introduction

Patent protection is crucial to the effective functioning of the innovation system (Arora et al., 2004; Branstetter and Sakakibara, 2002; Hall and Ziedonis, 2001; Klemperer, 1990; Lerner, 2009; Moser, 2005; Nordhaus, 1969; Qian, 2007. Real patent protection requires effective patent enforcement by courts. (Agarwal et al., 2009; Ganco et al., 2015; Lanjouw and Schankerman, 2001; Lemley and Shapiro, 2005; Shapiro, 2016; Somaya, 2012). Though patent litigation is usually a "rare" event, the way patent litigation is handled in court is closely watched by innovators, policy makers and even potential imitators. Strengthening patent enforcement has long been advocated as the right direction for innovation policy, especially in weak IPR regimes.

Though a strain of studies estimate the private value of patents using structural modeling approach (Bloom and Van Reenen, 2002; Lanjouw et al., 1998; Marco, 2005; Pakes, 1984), there is limited evidence on how the effectiveness of patent enforcement in court impacts firms' value capture mechanisms via the channel of private value of patents. Furthermore, if strengthening IPR enforcement makes certain types of patents more valuable and appealing, firms will likely react by switching to the more valuable type. Specifically, which types of firms are most likely to shift towards the more valuable type of patents? How does the shift in patent strategy affect the quality of innovations and firm performance?

This paper intends to explore these questions by estimating the private value of patent litigation and examining how changes in the option value impact firms' patent strategy and performance. I choose China as the institutional context because it provides sufficient variations in both the patent litigation and patent type. First, despite its relatively short history of the modern patent system, China launched four rounds of patent reforms, and strengthening patent enforcement is at the heart of almost all the reforms. Unlike Western countries, China's dominant doctrine of compensating infringement loss is the statutory damage awards doctrine , which sets a fixed range for the damage awards instead of awarding the actual loss. This feature dramatically facilitates quantifying the strength of patent enforcement over time. Second, China's patent office grants two types of patents: invention patents- the type of patents analogous to utility patents granted in the U.S.- and utility models- patents whose grants are not contingent on rigorous examination and thus are inferior to the invention patents. The bifurcation in the types of patents provides variations that could facilitate the evaluation of the effect of patent enforcement on patent value.

I start with a structural model of patent litigation. I consider a stochastic finite-horizon dynamic model and structurally estimate critical parameters of the model. Specifically, the patent owner has two choices- renewal and litigation- at each period during the entire patent life cycle. The patent owner could stop paying the patent renewal fees; as a result, the patent will expire, and its value becomes zero at the focal period. If the patent owner decides to renew the patent, she faces the second decision: whether to launch a patent litigation lawsuit if she detects infringement. The decision-making is based on two state variables that the patent owner observes at the beginning of each period: 1) per-period profit flow of the patented technology, which depreciates at a known rate over time; 2) whether infringement occurs, whose likelihood is also known. I assume the patent owner is rational in the sense that she anticipates all possible outcomes in the future given her knowledge (maybe limited) at each period and she will choose the option to optimize her expected profits from the current and all the future periods.

I then fit the dynamic finite-horizon model with China's patent litigation data and recover key parameters: technology depreciation rate, infringement hazards, the distribution of initial patent value, exogenous shocks to the patent value, and the share of market profits the patent owner receives if she tolerates the infringement. As expected, the structural estimation illustrates that invention patents are much more valuable than utility models. On average, invention patents are around 18 times as large as utility models in terms of the first-period valuation. Furthermore, I investigate the effect of strengthening patent enforcement on patent valuation by simulating the scenario of the 2009 patent reform, which greatly enhanced the range of damage awards. While the extent to which damage awards are lifted is the same for invention patents and utility models, I document a significantly larger boosting effect of damage awards enhancement on the value of utility models than invention patents, suggesting an over-compensation potential impact of the 2009 patent reform for utility models. This indicates that increasing damage awards without differentiating the heterogeneity of patents might lead to the over-valuation of patents with relatively low value. The back-of-the-envelope calculation illustrates that the 2009 patent reform might significantly reduce the gap in the valuation between invention patents and utility models- from 18 times (the ratio of invention value over utility models) to around 6. The over-valuation of low-value patents will potentially lead to a switch of firm innovation strategy from invention patents to utility models.

To examine whether and to what extent this strategy shift occurs, I compile a comprehensive data set containing all invention patents and utility models filed by domestic Chinese firms from 2005 to 2012. I focus on the firms that filed both types of patents during the period and measure their exposures to patent litigation hazards before 2009. Using a difference-in-differences framework, I find that firms with higher litigation exposure tend to increase the ratio of utility models in their patent portfolio after the 2009 patent reform compared to firms with lower litigation exposure. This tendency of filing more utility models is more pronounced among financially constrained firms such as private firms and non-state-owned firms relative to publicly traded firms and state-owned firms. Furthermore, I explore the implication of the shift from invention patents toward utility models on the quality of invention patents. I find that "treated" firms with high litigation exposure tend to switch low-quality invention patents to utility models, leading to a deterioration of the overall quality of innovative outputs.

This paper contributes to several strains of studies on firm innovation strategy and patent policy. First, this study contributes to an arising literature highlighting the downside of strong patent protection. Strong upstream patent rights might increase the costs and risks for downstream innovations and thus hinder the inventive activities (Budish et al., 2013; Galasso and Schankerman, 2015; Murray and Stern, 2007; Scotchmer, 1991). Furthermore, well-established patent rights might exacerbate the inertia of incumbent innovators in making breakthrough innovations due to the replacement effect (Arrow, 1962; Parra, 2019). In practice, the patent enforcement system is not always effective even in Western countries (Lemley and Shapiro, 2005). Noisy enforcement and uncertain and fuzzy boundaries of patent rights might encourage speculative patenting and frivolous litigation, which potentially damage innovation ecosystems and economic growth (Bessen and Meurer, 2008; Feng and Jaravel, 2020; Lemley and Feldman, 2016; Mezzanotti, 2021). My study contributes to this line of research by identifying the potential inefficiency of strengthening patent protection in the weak IPR regimes. The extant studies on innovation strategy in weak IPR regimes mostly focus on the downside of weak patent protection and thus implicitly suggest the strengthening patent protection would be a public good (Belderbos et al., 2021; Beukel and Zhao, 2018; Lamin and Ramos, 2016; Paik and Zhu, 2016; Zhao, 2006). This paper reveals the caveats of strengthening IP protection in weak IPR regimes.

The paper also closely relates to the literature of structural estimation of patent values (Lanjouw et al., 1998; Pakes, 1984; Schankerman and Pakes, 1985; Serrano, 2018). This line of research attempts to estimate patent value via patent owners' renewal decisions, assuming that the patent owner stops renewing the patent when its expected profit flow falls below zero. Based on Schankerman and Pakes, 1985's seminal work, later studies add up more features to the original model. For instance, Lanjouw, 1998 and Marco, 2005 consider patent litigation as another key option for the patent owner. Serrano, 2018 introduces patent transaction as an option, exploring how selling out a patent impacts patent valuation. My paper extends this line of research in the following aspects. First, instead of assuming infringement happens at each time period, my model considers infringement as a stochastic event, making it possible to recover the overall infringement hazards. Second, to the best of my knowledge, this paper is the first to evaluate the effect of patent enforcement on patent valuation by comparing two types of patents. Utility model patents, though not as popular as invention patents, play an important role in many countries like Germany, Japan and South Korea. The study of utility models, however, is scarce and this paper helps to improve our understanding of this type of patents.

Finally, this paper contributes to the theoretical discussion on the potential impact of damage awards doctrines on innovation incentives (Anton and Yao, 2007; Y. Chen and Sappington, 2018; Choi, 2009; Henry and Turner, 2010; Schankerman and Scotchmer, 2001). Prior studies mostly focus on doctrines of unjust enrichment or lost profit, the types of doctrines prevalent in the U.S. or Europe. This paper examines the effect of statutory damage awards doctrine- the dominant damage awards doctrine in China which leads to "homogeneous" damage awards for patents with different values. I show that the statutory damage awards doctrine might be responsible for "crowding out" valuable patents from pursuing patent remedies in court. Furthermore, lifting the damage awards under such doctrine might narrow the gap of patents with different values and thus potentially drive the explosion in low-value patents observed in recent years in China.

2 Institutional background

2.1 China's two types of patents

China is a latecomer to the modern patent regime. The current patent system was first established in 1985 and revised four times in 1992, 2000, 2009, and 2021. Each revision made significant changes to improve the efficiency and efficacy of the regime. The patent law's initial version was mainly "imported" from Japan and Germany. As a result, China "inherited" the utility model patenting system from the two countries. Utility models are usually viewed as "moderate improvement" compared to invention patents because their inventive steps are generally smaller. Though utility models are rarely considered equivalent to invention patents in Germany and Japan, they are widely filed in China, usually as substitutes, instead of complementary options, for invention patents.

Table 1 summarizes significant differences between invention patents and utility models in China. Invention patents provide a longer protection term- 20 years since the patent filing date- than utility models, which only offer 10-year protection at the most. More extended protection is based on rigorous examination: invention patents usually undergo a relatively rigorous examination process, taking around 400 days in China on average, from when the first request for examination is issued to the grant decision date. In contrast, the examination of utility models is usually reduced to a formality check which typically takes less than one year. Aside from prolonging the examination cycle, rigorous examination for invention patents usually shoots down around 20% of applications[1], whereas utility models are almost sure to be granted.

[1]Self-calculated from patent data provided by IncoPat.

Withstanding the relatively higher cost of filing an invention patent compared to utility models, the expected benefits of the invention patents are typically higher than utility models. Apart from the more extended protection term an invention patent could have, invention patents usually serve as signals of the innovation capacity of the patent owner. The signaling function could sometimes be more beneficial for the owner than the profit extracted from the patent per se. For instance, China's central and local governments implement a battery of patent subsidy programs- usually direct cash transfers- to encourage patent filings. Besides, firms with valid patents are also eligible for a variety of policy benefits ranging from substantial corporate tax cuts (e.g., InnoCom policy) to a higher chance of being listed in the tech stock market or being funded by state institutions. For all these "patent-contingent" resources, inventions usually prove to be more beneficial than utility models [2].

Last, invention patents and utility models are set to protect different types of technologies. Invention patents are eligible for all technological innovations fulfilling the three criteria: novelty, non-obviousness, and usefulness. On the other hand, utility models cover fewer types of innovations: only inventions with solid structures or shapes could be applied to utility models. For instance, pharmaceutical products, process improvement, or method innovation are only eligible for invention patents because they lack concrete structures or shapes.

However, unlike in Germany and Japan, where utility models are considered quite different from invention patents, utility models are taken as substitutes for invention patents in China. According to my informal interviews with several Chinese patent attorneys and scholars studying the European patent system, several factors might cause the similarity. First, these two types of patents share the same set of patent classifications (namely the IPCs), suggesting similar technological coverage of the two types of patents. More importantly, China's patent office officially recognized the "double patenting" practice in the 2009 patent reform: patent applicants are allowed to file one invention patent and one utility model for the same innovation on the same day. Still, at any single time point, only one of these two patent rights could be reserved. The "double patenting" practice further narrows the difference between two types of patents in inventive step and protection scope because patent applicants usually submit one filing document for the two types of patents. Finally, utility models yield similar or even more significant judicial benefits than invention patents in patent infringement lawsuits. Apart from the equal amounts of damage awards compensated for these two types of patents, infringement on utility models are usually easier to be proved because features of inventions with solid shape or structure are typically easier to be identified, whereas, for certain types of invention patents, especially method inventions or process improvement, evidence on infringement could be more challenging to collect and

[2]For instance, the InnoCom policy stipulates that owning six utility models will be evaluated as earning the same score as holding one invention patent grant.

confirm.

In sum, utility models offer quicker but weaker protection options compared with invention patents. Some studies show (Cao et al., 2014; Cohen et al., 2000), utility models tend to be more prevalent in industries where technologies advance rapidly. That said, for owners of precious inventions who seek effective patent protection, invention patents could be a better choice if the examination process is not too long and the patent could be effectively defended in court. But Chinese innovators tend to treat these two types of patents as similar substitutes. I will discuss the implication of these features in later parts of the paper.

2.2 Doctrines of damage awards for patent infringement lawsuits

As an established member of the World Intellectual Property Organization (WIPO), China has adopted the "unjust enrichment" (UE) and "lost profit and reasonable royalty" doctrines (LP)- two rules that are commonly applied when deciding the damage awards compensated for the patent owner (Schankerman and Scotchmer, 2001). Besides, China's patent judges could compensate the prevailing patent owners according to the third doctrine- the "statutory damages award doctrine." The 2001 Chinese patent law stipulated the statutory damages to be no less than 5000 RMB ($ 725) but no more than 300,000 RMB ($ 46,590). This range was enhanced by the 2009 patent law revision to the level from 10,000 RMB ($ 1553) to 1,000,000 RMB ($ 155,300) [3].

China's patent law sequences these damage awards doctrines and places the statutory damage awards after the 'unjust enrichment' and 'lost profits and reasonable royalty' doctrines, meaning the statutory damage doctrine applies only when the plaintiff could not provide valid evidence on the amount of infringement loss. In practice, however, adopting the UE or LP doctrines is a rare case: 98% of all infringement lawsuits in which patent owners prevailed followed the statutory damage awards doctrine, according to CIELA's patent infringement data[4]. The popularity of the statutory damage awards doctrine in China is mainly driven by the difficulty of evidence collection and pressure for judges to close cases as quickly as possible. Lack of 'evidence discovery' doctrine, it usually takes enormous time and resources for patent owners to collect evidence of infringement. Moreover, as lawsuit process time is a key performance measure for Chinese judges, they are inclined to employ an easy and quick way, such as the statutory damage awards doctrine, as the compensation decision rule.

I will discuss the implication of the dominance of statutory damage doctrine in later parts

[3] In 2021, China conducted the fourth patent reform, which further lifted the statutory damage awards to the range of 30,000 RMB to 5 million RMB ($4660 to $776,700).

[4] https://www.ciela.cn/en/analysis/patents.

of this paper. For now, it is intuitive to see that if the statutory damage awards are too low compared with what the UE or LP doctrines could offer, patent owners might be reluctant to defend their patented inventions via judicial lawsuits; as a result, the valuation of patents might be discounted as well. This also implies that if the statutory damages are too big, infringed patents tend to be over-compensated, and patent rights will be unnecessarily strengthened, which probably will lead to inefficiency, such as amplifying monopoly market power or blocking follow-on innovations.

3 The model

In this section, I establish a finite-horizon stochastic dynamic model to capture key features of the patent life cycle. Like other types of assets with real options, patent owners face various decisions during the entire patent life. Before the patent expires, patent owners must decide whether to renew it, sell it out, license it to others for royalty profits, or launch a litigation lawsuit in court when infringement occurs. Each option affects the profit flows of the current period and the following periods. Litigation, despite its rareness, could potentially affect patent valuation via other venues. Thus, in this model, I attempt to single out the effect of litigation decisions and explore how institutions related to patent litigation, such as compensation doctrines and infringement hazards, influence patent valuation, litigation, and renewal likelihoods.

3.1 Model Set-up

Consider a granted patent with maximum periods of validity, T. That said, the patent owner could keep the patent for a maximum of T periods, as long as she pays the patent renewal fees at the beginning of each period. Or, she could simply stop paying the renewal fees at t (where $t \leq T$); the patent will expire in that period. In China, T is 20 years for invention patents and ten years for utility model patents from the filing date.

In each period t, the patent owner has three options. The first is to sue the alleged infringer in court. This option implicitly assumes that the patent is renewed at that time periodortantly; I assume the litigation option is only available when infringement occurs and is detected by the patent owner. Prior studies (Lanjouw, 1998; Marco, 2005) mostly assume infringement occurs at *each* time period. My mo Instead, my model allows for the stochastic occurrence of infringement, which is not only a closer mimic to reality lso helpful in estimating the overall infringement hazards. The second option the patent owner could choose is to renew the patent but not launch litigation lawsuits in court. This choice is available whether or not infringement is detected. If infringement occurs but the patent owner decides to tolerate the infringement, she will only receive a portion of the profit flow of the patent, and the portion is denoted as θ, $\theta \in (0, 1)$. Finally, if the patent is considered useless, or formally, with negative value, the owner could choose the third option-stop renewing the patent. The patent, after that, will expire and join the realm of public knowledge, meaning that anyone could use the patented technology free of charge.

The scheme of patent renewal fees plays an essential role in this dynamic decision-making process. Whether the patent is litigated or not, the patent owner needs to compare the current-period patent valuation with the renewal fee. The patent will only be renewed if the valuation exceeds renewal fees at t. Different from the U.S. or Europe, China's patent office requires the renewal fees to be paid annually since the patent application was submitted. As Table A1 shows, the amount of patent fees increases as the patent ages, implying that the cost of keeping the patent valid increases over time. Renewal fees for invention patents are typically higher than those for utility models, reflecting the widely held belief that the valuation of inventions should be higher than that of utility models.

At each period, patent owners decide which option to choose based on two state variables they observe at the beginning of the period (but might not be observed by other people). One state variable is the current-period profit flow of the patent, x_t [5]. This state variable covers all expected profits from patent options other than litigation, such as licensing, transaction, or signaling [6]. I assume the evolution of x_t follows a Markov process:

$$x_t = \gamma x_{t-1} + u_t \tag{1}$$

Equation 1 assumes that x_t only depends on the profit flow from the previous period and an exogenous shock u_t, which is subject to a normal distribution $\mathcal{N}(0, \sigma^2)$. σ is known by the patent owner, which captures the stochastic component of the patent's profit flows, such as unexpected policy changes, technological shocks (or opportunities), or market turbulence. Aside from these exogenous shocks, the per-period patent profit flow is assumed to decrease over time. This could be driven by a patent (technology) race in a highly competitive industry or by technological obsolescence. γ models the depreciation rate, $\gamma \in (0, 1)$.

[5] x_t could be closely related to the profit flows the patent owner expects to receive from enforcing the patent. For instance, if the court enforcement is too weak to deter infringement, it is likely that the patent owner cannot negotiate a profitable license agreement or transaction contract with potential downstream users. But this type of association usually occurs at a general level, namely that x_t will be affected by the patent enforcement effectiveness of the whole system (i.e., the overall distribution of realized damage awards, not the specific amount of damage awards the patent owner expects to get for the focal patent. Therefore, in the baseline model, I assume the per-period profit flows of these two options- enforce or not enforce- are not related.

[6] In China, patents usually serve as important signals of innovation capacities to resource providers, usually the government. For instance, firms with valid patent grants are more likely to win government subsidies for innovative enterprises. The subsidies, sometimes, could be substantial. For example, the InnoCom program provides qualified firms with income tax reductions by 10 percentage points (i.e., from 25% to 15%). Only firms with valid patent grants are eligible to win the InnoCom certificate.

The initial value of x_t is set as x_0. As mentioned in section 2, invention patents are usually more valuable than utility models. To model this difference, I assume that at period 1, x_0 is randomly drawn from a known right-skewed Gamma distribution. This distribution set-up captures the feature that most patents are of relatively low values, whereas merely a tiny portion of patents- the outliers- is highly valuable. To simplify the model without losing generality, I fixate the scale parameters of Gamma distributions of both utility models and invention patents to be $50,000$ RMB [7]. The only difference between these two distributions is the shape parameter, α. To visualize how α affects the Gamma distribution, I plot two Gamma distributions with $\alpha = 2$ and $\alpha = 4$ (Figure A.1); β is fixated at 5. The distribution with smaller α is employed to describe the distribution of utility models' initial values. As expected, invention patents are more valuable than utility models (higher mean), and the portion of high-value invention patents is significantly larger than that of high-value utility models (fatter tails).

The other state variable that the patent owner observes at the beginning of each period is whether the infringement occurs [8]. I use a dummy variable $L_t \in \{0, 1\}$ to denote the infringement occurrence. I assume the infringement occurrence reaches its peak when the patent is formally granted. Before the patent grant, patent applications were also subject to infringement, but the infringement hazards might not be high because of the uncertainty of the patent right (if the patent was not granted yet, its value for firms other than the patent owner would be uncertain). I also assume the infringement occurrence in the last period of the patent becomes zero since there will be no value left even if the infringement is not held accountable. Therefore, from the year the patent was granted (normally the second year of the utility models and the fifth year of the invention patents) to the last year, I assume the infringement hazard l_t decreases constantly. Finally, I assume the first-year infringement occurrence for invention patents to be zero because the invention patents will not be published after 18 months since the patent filing date [9] Finally, note that before time period t, the patent owner (and others) will know that the likelihood for infringement to happen in time t is l_t. But whether the infringement occurs at time, t is uncertain. Therefore, I assume that there is no stochastic component in the evolution of infringement hazards, simplifying the model without losing generality.

If the infringement is detected at time t, the patent owner could litigate against the infringer in court or tolerate the infringement. As stated previously, if the infringement is tolerated, the patent owner will only receive θx_t from the patent in that period. On the other hand,

[7] This figure comes from estimates of another two papers on the valuation of Chinese patents (Gupeng and Xiangdong, 2012; Zhang et al., 2014). $50,000$ RMB is around the median value of invention patents at the first period in their papers.

[8] In the case that infringement happens but is not detected by the patent owner, the infringement is considered as not occurring.

[9] Though the patent owner could request the publication of the patent document before the end of the 18th month, most patents remain unknown by other parties at least during the first year.

if the patent owner decides to litigate in court, it is not guaranteed that her loss will be compensated. For instance, a common counter-strategy of the defendant (infringer) is to challenge the validity of the disputed patent; even if the patent passes the validity challenge, it is likely for the patent owner to lose the lawsuit due to a variety of reasons. Therefore, I use $p \in (0, 1)$ to capture the win rate of the patent owner in an infringement lawsuit, which is conditional on the fact that the patent has already passed validity challenges. If the patent owner prevails, she will receive $z > 0$- the damage awards- as compensation for her infringement loss. Litigation lawsuits are usually costly, even in China. Patent attorney fees, administrative payments to the court, and opportunity costs from the time and resources the patent owner could have allocated to other activities all contribute to a non-trivial litigation cost, denoted in the model as $c > 0$.

3.2 Dynamic decisions

The current-period profits of the patent owner are thus clear. Formally, the reward function of time t could be written as:

$$f(t) = L_t[\ (pz - c)a_t + (1 - a_t)x_t\theta]\ + (1 - L_t)x_t - Rc_t \tag{2}$$

L_t is a dummy variable taking value 1 if the patent owner detects infringement at time t. a_t is a choice variable, taking value 1 if the patent owner decides to sue the infringer. Rc_t is the renewal cost at time t, usually increasing as t gets bigger. The first term of Equation 2 is the expected profits if the infringement occurs. The second term is the expected profits if the infringement does not occur. Whether infringement happens, the renewal fees will be paid; so the last term is the subtraction of patent renewal fees.

It is not sufficient for the patent owner to only calculate the current-period profits to make decisions. She also needs to calculate the expected profit flows of all future periods and discount and incorporate them together with $f(t)$. This is the Bellman equation:

$$V(x_t, L_t) = \max_{a_t}[\ 0, f(t) + \delta E_{u,l} V(x_{t+1}, L_{t+1})] \tag{3}$$

Where $V(x, L)$ is the per-period valuation of the focal patent, accommodating all future profits. The value function V is a function of the state variables x_t and L_t, the optimal choice a_t (litigate or not) the patent owner makes at the period. It also involves stochastic components u and l, the exogenous shock to patent value, and infringement hazards, which govern the evolution process of x_t and infringement occurrence L_t. δ is the discount factor. The Bellman equation states that at each period t, the patent owner will calculate and discount all the future profits, adding it together with the current-period profit $f(t)$ in

Equation 2. The second term inside the maximization operator calculates the optimal value if the patent owner does not give up the patent. Thus the final step would be to compare it with 0, the profit the patent owner will get if she decides not to renew the patent.

3.3 Numerical solutions and likelihoods

This is a finite-horizon dynamic programming problem that does not have a closed-form solution. Following the literature (Lanjouw, 1998; Miranda and Fackler, 2004; Pakes, 1984; Schankerman and Pakes, 1985), I solve the model numerically using backward induction. The algorithm assumes the value of the patent at the $T+1$ period to be zero and infers the value function and optimal choices for each period, backwardly, from period T to 1.

Several features of this dynamic model could be solved numerically. Aside from per-period patent value V_t, the model also identifies per-period thresholds for renewal and litigation decisions, $\bar{x}_{rt}$ and $\bar{x}_{lt}$, as well as the optimal action set $\Omega_t = \{a_t, k_t\}$. a_t and k_t are the indicators for litigation or renewal, which take value one when the patent owner decides to litigate or renew the patent at the focal period. In the real-world data, however, I observe neither x_t (or their thresholds for litigation and renewal) nor the patent value V_t. The only observable element is Ω_t, patent owners' choices. This feature motivates a maximum likelihood method for the structural estimation, for which I will introduce details in the next section. Here I specify the likelihoods needed for the maximum likelihood estimation. Specifically, the litigation likelihood at time t is:

$$Pr(a_t = 1) = l_t\{\Phi(\frac{\bar{x}_{lt} - \mu_x(t)}{\sigma_x(t)}) - \Phi(\frac{\bar{x}_{rt} - \mu_x(t)}{\sigma_x(t)})\} \tag{4}$$

And the renewal likelihood is:

$$Pr(k_t = 1) = 1 - \Phi(\frac{\bar{x}_{rt} - \mu_x(t)}{\sigma_x(t)}) \tag{5}$$

Where σ_x and μ_x are standard variances and means of the distribution of x_t, and Φ denotes the *cdf* of a normal distribution. According to Equation 1, x_t follows a normal distribution because of the distribution assumption made for u_t, given that x_0 is already drawn and known by the patent owner. Formally, $x_t \sim \mathcal{N}(\mu_x(t), \sigma_x(t)^2)$, where:

$$\mu_x(t) = \gamma^{t-1} x_0 \tag{6}$$

$$\sigma_x(t)^2 = \gamma^{2(t-1)} x_0 + \frac{1-\gamma^{2(t-1)}}{1-\gamma^2}\sigma^2 \tag{7}$$

It is straightforward to see that the patent will be renewed if x_t exceeds the threshold $\bar{x}_{rt}$, which motivates Equation 5. However, for the litigation decision, it is more complicated. Under the current setting, the damage awards are a fixed amount; patents will be litigated only if x_t is lower than the threshold $\bar{x}_{lt}$. The intuition is as the following. When the per-period profit flow is lower than the expected infringement compensation, the patent owner will decide to litigate. The upper bound of damage awards also imposes an upper bound on the expected profits the patent owner could get from litigation. This implies that patent owners who consider their patents more valuable than this "upper bound" will choose to tolerate the infringement because litigation is a less profitable choice. Formally, this could be summarized as:

Proposition 1 If the damage awards are capped by an upper bound $\bar{z}$, the patent will be litigated against the infringement only when its value is below $\bar{x}_{lt}$, where

$$\bar{x}_{lt} \leq \frac{p\bar{z} - c}{\theta} \tag{8}$$

It is easy to see that the threshold $\bar{x}_{lt}$ increases in the expected damage awards pz and decreases in litigation cost c and the market share of the patent owner θ if the infringement is tolerated. However, the implication does not seem straightforward when it comes to the renewal threshold $\bar{x}_{rt}$. Unlike $\bar{x}_{lt}$, there is no closed-form solution for $\bar{x}_{rt}$, meaning the renewal likelihood depends on almost all parameters identified in this model.

4 Structural estimates and counterfactual analysis

In this section, I first introduce the data and maximum likelihood estimation method I use for structural estimation. Then I present the parameters estimated from the maximum likelihood estimation method. Using the estimated parameters, I recover the distribution of patent value and aggregate litigation and renewal rates. Finally, I present two counterfactual analyses that explore the changes in patent valuation before and after 2009.

4.1 Empirical approach

4.1.1 Data

The primary challenge of calibrating the model is the rarity of patent litigation. The ratio of patents being litigated among all patents issued is usually very low. In the U.S., this ratio is higher than in other Western jurisdictions- around 1% on average (Bessen and Meurer, 2005). In China, however, the litigation rate is extremely low- around 0.17%. The low occurrence of litigation events among all patents poses a challenge for structural modeling. If the theoretical model is fitted with a "sparse" data set- a dataset with more than 99% zeros, in this case, model convergence could be challenging to achieve.

To solve this problem, I focus on a sample of litigated inventions and utility model patents and a group of similar non-litigated patents. First, I select all invention patents and utility models involved in infringement lawsuits in mainland China. In 2009, China revised the patent law, making several changes to the legal practice of patent enforcement. To ensure a relatively stable regulatory environment, I focus on patents for which the infringement lawsuits were decided before 2009. Moreover, there are several types of patent infringement lawsuits, such as in-court settlements, disputes over court jurisdiction, and judicial judgment on infringements. I select the last type- judicial determination on infringements- because in-court settlements are closer to the scenario in which the patent owner decides not to sue. The jurisdiction disputes usually serve as a combatant strategy of the defendants and thus an integral part of cases with judicial judgment. Finally, to reduce the dependence among observations in my sample to the lowest, I reserve the first patent that has been litigated by patent owners who have multiple patents being litigated. Similarly, for the non-litigated patents, I pick up one single patent from each patent owner. If there are numerous non-litigated patents by the same owner linked to one litigated patent, I randomly pick up one. In the final sample, each patent is owned by one single owner.

The restrictions in sampling lead to a sample containing 377 litigated patents with 115 invention patents and 262 utility models. To select a "control" group that shares similar features- so that the litigation hazards are similar, I match the litigated patents with all patents filed on the same day as the litigated patent and in the same technological areas (measured by 3-digital IPC assignment) [10], following prior literature (Allison et al., 2003; Lanjouw and Schankerman, 2001). As a result, I match a group of 2247 "control" patents (726 invention patents, 1521 utility models) for the sampled litigated patents. Together with the litigated patents, the final sample contains 2624 patents with 841 invention patents and 1783 utility models.

The detailed summary statistics of the data are laid out in Appendix E. Here I briefly summarize the general pattern. First, invention patents tend to be more valuable than utility models if we focus on variables usually considered proxies for patent value- the number of claims, foreign destinations of family patents, and the number of inventors (Allison et al., 2003; Lanjouw et al., 1998; Lanjouw and Schankerman, 1997). However, if we compare litigated and non-litigated patents within each type of patents, the pattern differs from what prior studies have documented (Table A2). Indeed, valuable patents are less likely to be

[10] Some litigated patents do not have patents registered in the same day and the same tech area. I extend the search to 7 days before and after filing for these patents.

litigated for invention patents, whereas for utility models, the pattern is reversed- valuable utility model patents are more likely to be litigated. These patterns are further corroborated by the distribution of patent renewal terms (Figure A.3). The summary statistics confirm proposition one derived from the theoretical model. It implies that as the patent value decreases (e.g., from invention patents to utility models), the "adverse selection" pattern- namely that the valuable patents will be "crowded out" from litigation practice- might be lessened.

4.1.2 Maximum likelihood estimation

The empirical strategy is mainly motivated by the feature of the data. I use maximum likelihood estimation instead of the simulated moment method, which has been widely employed by prior studies in this strain of research (Lanjouw, 1998; Pakes, 1984; Schankerman and Pakes, 1985; Serrano, 2018) for several reasons. First, the data of my sample is available at the individual patent level, which allows the maximum likelihood method at such a granular level. As a comparison, estimation by the simulated moment method is usually at the aggregate level- in this case, the aggregate litigation and renewal rates-which might neglect functional patterns at the micro level. Second, though the model does not produce closed-form solutions, it does explicitly yield litigation and renewal likelihoods at the individual level (though not in the closed form either), potentially enabling the maximum likelihood estimation. Finally, unlike most Western countries, patents in China are renewed yearly, potentially providing sufficient moments for the MLE method.

To start with, I calculate the litigation and renewal likelihoods using Equation 4 and 5 and get the possibility of not renewal by subtracting the litigation and renewal likelihoods from 1. For each "cell" (each individual patent at each period), I thus obtain its likelihood based on the real-world choice [11]. After taking the logarithm of each likelihood, I sum up all the log likelihoods and maximize the sum. Formally, the log-likelihood function could be written as:

$$\max_{\gamma,\sigma,\alpha,\theta,l_0} \sum_{i=1}^{N} \sum_{t=1}^{T} Log\left(A_{it}P^i_{litigate}(t) + K_{it}P^i_{renew}(t) + (1 - A_{it} - K_{it})\left(1 - P^i_{litigate}(t) - P^i_{renew}(t)\right)\right) \tag{9}$$

Where i denotes patent, i and t denotes patent term t. A_{it} and K_{it} are litigation and renewal decisions from the real-world data. N is the size of the sample. $P^i_{litigate}(t)$ and $P^i_{renew}(t)$ could be derived from Equation 4 and 5. In other words, I'm seeking the set of

[11] For example, if the patent owner stops renewing the patent at the current period, I will assign the likelihood of stop restoring to that cell.

parameters that maximize the likelihood of the formal model being supported by the data.

Next, I calibrate several parameters with values from the literature or directly estimated from the data. The interest rate r is set to be 0.1, following the literature (Lanjouw, 1998; Pakes, 1984; Schankerman and Pakes, 1985; Serrano, 2018). Annual renewal costs Rc are obtained directly from the official payment schedule published by China's Patent Office (Table A1). Patent terms, T, are stipulated by the law, which is 20 years for invention patents, and ten years for utility models[12].

For the gamma distribution of x_0, two parameters- α, the shape parameter, and β, the position parameter- are unknown. Both parameters determine the distribution, but if two gamma distributions are similar- in our case, the invention patents and utility models could be substitutes for each other- fixating one parameter could significantly reduce computation loads without losing generality. Thus, I fix the position parameter, β, to be 50,000 RMB for both types of patents, which is around the median level of monetary values of patents estimated by prior studies (Gupeng and Xiangdong, 2012; Zhang et al., 2014). This leaves α as the only unknown parameter of the distribution of initial patent values.

The rest parameters are the ones associated with infringement lawsuits: litigation costs, c, damage awards, z, and win rate p. In the sample, this information is only available for litigated patents that prevail in the infringement lawsuits. However, the seeming lack of data points does not pose a severe challenge here because patent owners make decisions based on *expected* values of litigation cost, damage awards, and win rate, instead of their real values. Therefore, it is reasonable to assume that the patent owner obtains the knowledge of the empirical distribution of damage awards, litigation costs, and win rate by observing closed and published lawsuits (i.e., the data I have collected). Thereby, I estimate the empirical distribution using all available data points on litigation costs [13] and damage awards before 2009. Usually, damage awards and litigation costs tend to increase in the patent value because the patent owner is willing to make more efforts in court to defend their valuable innovation. Therefore, I assume the damage awards and litigation cost will be at the same "position" in their empirical distributions as the patent's initial value. Specifically, I

[12]The annual renewal fees are charged from the patent filing date. Here I assign the maximum patent life term to 20 years and ten years, assuming that infringement might occur before the patent is officially granted. The infringement could be even more severe before the patent is granted because patents are not officially under patent protection during the examination process.

[13]Some of the disclosed patent infringement lawsuits reveal the litigation costs claimed by the patent owner (i.e., plaintiffs). I use this information to estimate the empirical distribution of litigation costs. Though it is possible that the revealed litigation costs might not be representative of the population, empirical distribution inferred from this information is still reliable because these are precisely the information the patent owner could get access to when making litigation decisions. Thus, the empirical distribution derived from the disclosed litigation costs should be close to the patent owner's information set.

calculate the percentile of the initial value x_0 for each observation and locate the damage awards and litigation cost at the same percentile in their empirical distributions. I use the aggregate win rate 0.7 as the value of the win rate. Prior studies show that patent owners will adjust their expectation of win rate based on the aggregate average (Bessen and Meurer, 2005; Lanjouw, 1998). Informal interviews with several Chinese patent attorneys also confirm that it is not uncommon that infringement lawsuit plaintiffs will be informed by the average damage awards and litigation costs of similar cases and make litigation decisions accordingly.

Apart from parameters whose values are calibrated, there are five parameters to be estimated: technology depreciation rate γ, the shape parameter, α, of the gamma distribution of initial patent value, and the standard deviation of the random shock to per-period patent profit flows, σ, the share of profits the patent owner is supposed to extract from the patent if the patent owner does not litigate against the detected infringement, θ, as well as the peak value of the infringement hazards, l_0.

Though there are no closed-form solutions for each period's litigation or renewal likelihoods, I provide a heuristic description of how these likelihoods could identify the five key parameters. γ, the technology depreciation rate, could be identified through the distribution of per-period patent flow x_t. From Equation 6 and 7, it is clear that γ governs the values of $\mu_x(t)$ and $\sigma_x(t)$. Similarly, σ could be identified through changes in $\sigma_x(t)$; but different from γ, it has no effect on $\mu_x(t)$. Furthermore, α governs the distribution of x_0, which affects $\mu_x(t)$ and $\sigma_x(t)$, as shown in Equation 6 and 7. The way θ is identified is mainly through the litigation threshold $\bar{x}_{lt}$, as stated in Equation 8. A larger θ leads to a smaller litigation threshold and thus a lower litigation likelihood if the renewal threshold is held constant. Moreover, the peak infringement hazards l_0 could be identified by l_t, the per-period infringement hazards, mainly shown in the litigation likelihood (Equation 4). Finally, due to the lack of closed-form solutions, I determine these thresholds numerically via the decisions observed from the simulated data. Therefore, the five parameters might all take part, implicitly or explicitly, in the governance of the litigation threshold $\bar{x}_{lt}$ and renewal threshold $\bar{x}_{rt}$, which are key components of the litigation and renewal likelihoods shown in Equation 4 and 5.

4.2 Estimates on key parameters

Table 2 shows point estimates of key parameters and their confidential intervals (CIs) at the 95% level. [14] To start with, the technology depreciation rate, γ, of invention patents

[14] Bootstrapping confidential intervals such as BC_a or ABC methods are widely used in the literature (DiCiccio and Efron, 1996). Motivated by these methods, I estimate the CIs using the 97.5 and 2.5 percentile of all the point estimates I obtained. The MLE procedure runs for 100 rounds, a process similar to the bootstrapping of BC_a or ABC methods.

(γ=0.75) is larger than that of utility models (γ=0.65), reflecting the fact that compared to invention patents, utility models have shorter patent terms. They are more likely to be used in fast-moving, highly competitive industries where technologies quickly become obsolescent (Cao et al., 2014). But the variation of per-period profit flows of invention patents ($\sigma = 20089$) is larger than that of utility models ($\sigma = 5007$), indicating that extremely valuable patents are more likely to be found among invention patents than among utility models. As expected, invention patents (α=4.52) have a much larger α than utility models (α=0.34), meaning that invention patents are generally much more valuable than utility models.

However, parameters related to the infringement process do not significantly differ between these two types of patents. Specifically, the owners of invention patents are expected to receive a slightly larger share of the profits from patented technology ($\theta = 0.32$) than the owners of utility models ($\theta = 0.24$) if they tolerate the infringement. The pattern might be driven by the difficulties in imitating certain invention patents, such as massive infrastructure investment, organizational routines, tacit knowledge, and skill endowment embedded within firms' specific human resources. These obstacles could be more pronounced among invention patents than utility models. Finally, the peak infringement hazards, l_0, are similar for these two types of patents. The similarity reflects the trade-off of infringing valuable invention patents: on the one hand, the gains will be magnificent if they succeed; on the other hand, however, the cost and risk of imitating valuable patents might be proportionally (or even disproportionately) higher. The large magnitude of infringement hazards-40%- is also consistent with the widely-held impression of the prevalence of infringement in China. The peak infringement hazard, however, is strikingly high compared to the litigation rate in China- namely, the ratio of patents being litigated in court over all patents filed during the same time (much lower than 1%), suggesting that the patent enforcement might be too weak to incentivize patent owners to defend their infringed patents in court.

Next, I examine the aggregate litigation and renewal rates across the entire patent life cycle and compare them with the rates calculated from the real-world data. Figure 1 shows the results of invention patents. While I do not target the per-period aggregate litigation or renewal rates when running MLE estimation [15], the estimated rates (solid lines) turn out to be reasonably close to the real-world rates (dash lines). The same pattern applies to utility models, shown in Figure 2. These patterns further corroborate the robustness of the MLE estimates. The aggregate renewal rates of both types of patents keep declining, reflecting that the patent value decreases over time, regardless of the patent type. Specifically, around 80% of sampled invention patents are kept valid for at least ten years, and around 20% of invention patents are renewed until the end of the maximum term (i.e., 20 years). Though the proportion of utility models which are kept valid till the end of the maximum term is

[15] Prior studies usually target these two aggregate rates using the simulated moment method (Lanjouw et al., 1998; Pakes, 1984; Schankerman and Pakes, 1985).

similar to that of invention patents (i.e., 20%), only 60% of utility models are renewed for half of the maximum time (equivalent to 10 years for invention patents), lower than that of invention patents. This might be driven by the higher depreciation rate utility models have relative to invention patents.

Figure A.4 shows the evolution of patent value over the entire patent life, simulated using the MLE estimates. The left panel reports the valuation of invention patents, with the solid line in the middle showing the median and two dash lines showing the values at 90 and 10 percentiles. The value of invention patents decreases over time, consistent with the pattern of renewal rates in Figure 1 and Figure 2. More details are revealed if we look at the patent value in the first period, which is the sum of the first-period value and expected values from the following periods (Table 3) [16]. The first-period value of invention patents is much higher than that of utility models- almost 60 times larger at the median (Table 3). But the gap seems to narrow as we move up the distribution. For instance, the maximum value of invention patents in the first period is roughly twice that of utility models. This pattern is also exhibited by the larger gap of first-period value between the 90 percentile and median of utility models relative to the 90%-median gap of invention patents (Figure A.4). This might partly be driven by the fact that these two types of patents share the same range of statutory damage awards.

4.3 Robustness checks

The maximum likelihood estimation method is particularly vulnerable to two problems (Struben et al., 2015). The first is the violation of the MLE's key assumption-observations independent in terms of the likelihood. It is difficult to directly test the independence of litigation and renewal likelihoods among all observations because closed-form solutions are unavailable. But it is still possible to reduce the dependence to a low level. The patent owner makes litigation and renewal decisions; therefore, the most significant dependence of these likelihoods comes from the common patent ownership. For instance, if one patent has already been litigated, the owner might refuse to litigate another due to the cost. Similarly, paying renewal fees for one of the critical patents might reduce the patent owner's incentive to renew another one, especially when the latter is less important. Therefore, I reserve one patent from the same patent owner in the sample. For litigated patents, I keep the first litigated one by the same patent owner; for non-litigated patents, I randomly pick one from the group of control patents owned by the same patentee. If the same patent owner holds litigated and non-litigated patents, I keep the litigated one.

The other concern of the MLE method regards its sensitivity to the initial guess of the parameters. To alleviate this concern, I generate the initial guess using a global search

[16] As for each type of patents, the value decreases at a relatively stable rate. Therefore, the patent value in the first period is representative of patent values in the following periods.

algorithm (e.g., the "annealing" algorithm in MATLAB). The advantage of the global search algorithm is that it leaps through the entire parameter space to search for the optimal solution, thus reducing the possibility of parameter estimates being "trapped" within a local optimum.

After the initial guess is generated, the next robustness check ensures that MLE estimation is close to "true" parameters. This could be done by running a trial simulation. Specifically, I generate two data sets- 1000 utility models and 1000 inventions- using the theoretical model introduced in section 3. I employ the same MLE algorithm I plan to apply to the actual data to recover the parameters. Since I know the actual parameters of the simulated data sets, I could compare the estimated parameters with their true values. To control for the stochastic component of the model, I run the MLE estimation for 50 rounds. It turns out that the median value of each parameter is very close to the "true" parameters I use to generate the data. This robustness check exercise confirms the reliability of the MLE estimates and helps me identify the statistics I could use as the final estimates. Appendix B lays out the details of this robustness check.

One might also be concerned that the specific setting of the model and estimation strategy (e.g., parameter calibration) drive the particular pattern we observed. To alleviate this concern, I employ an alternative estimation strategy to: 1) reduce the influence of stochastic components on the estimation; 2) extend the set of parameters for estimation to test the robustness of the current point estimation. To this end, I set the litigation cost c and the shape parameter of the gamma distribution of initial patent value β as parameters for estimation and construct a "seven-parameter" model. As Table A8 and Table A9 show, the estimates yielded by this alternative model are mainly consistent with the main results. See Appendix D for details of this robustness check.

4.4 Counterfactual analysis

To answer the major inquiry of this paper, I perform two counterfactual analyses. One is to explore how the patent value, litigation, and renewal rates change if the damage awards equal the actual infringement loss, the ideal scenario I use as the benchmark. The second counterfactual exercise examines how the patent value, litigation, and renewal rates react to lifted damage awards, such as the enhancement enacted by the 2009 patent reform.

4.4.1 The benchmark: damage awards doctrines compensating the real loss

To further evaluate the efficiency of patent enforcement under the "statutory damage awards doctrine," I estimate the evolution of patent value and the aggregate litigation and renewal rates of the sampled patents by running a counterfactual exercise assuming that damage awards will equal the actual loss from infringement. The "unjust enrichment" or "lost profits and reasonable royalty" doctrines (UE and LP doctrines) and damage awards doctrines widely adopted by Western countries are close to this scenario. This generates a benchmark for evaluating the statutory damage awards doctrine and the damage awards range it has imposed.

Formally, I revise the model by substituting z, the lump-sum statutory damage awards, with x_t, the per-period patent profit flow at time t. Other parameters, including those estimated in section 5.1, remain the same as the baseline model. The reward function at time t is re-written as:

$$f(t) = L_t[\ (px_t - c)a_t + (1 - a_t)x_t\theta]\ + (1 - L_t)x_t - Rc_t \tag{10}$$

Figure A.5 shows the evolution of patent value for invention patents (the left panel) and utility models (the right panel) in the benchmark scenario. Surprisingly, the estimates of patent value are very close to those estimates from the baseline model. Table 3 reports the first-period patent value in the benchmark scenario. First-period patent values estimated from the baseline model and the benchmark scenario are similar across the entire distribution. This evidence seems to suggest that the damage awards range imposed by the statutory damage awards doctrine before 2009 is appropriate in the sense that it generates similar distributions of patent value as the benchmark.

The benchmark scenario, however, does differ significantly from the statutory damage awards doctrine in one aspect. Table A3 reports the aggregate litigation and renewal rates estimated from these two scenarios. The aggregate renewal rates of the benchmark are pretty similar to those under the statutory damage awards doctrine, reflecting the similarity mentioned above in patent valuation. Nevertheless, aggregate litigation rates differ significantly across the two scenarios. For invention patents, the aggregate litigation rates of the benchmark are much larger than those of the statutory damage awards doctrine (Panel A of Table A3). The gap, however, seems to decline sharply as the patent ages. This pattern does not hold among utility models. Panel B of Table A3 shows that the aggregate litigation rates of utility models before 2009 (the baseline model) are larger than those estimated in the benchmark scenario.

This indicates that the pre-2009 level of damage awards might already over-compensate utility models because it seems to encourage more utility models to be litigated in court. The extremely low litigation rate in invention patents before 2009 reveals the potential inefficiency of the statutory damage awards doctrine. Patent owners, especially those with valuable patents, might be reluctant to defend their patents in litigation court because of the cap imposed on the expected amount of damage awards by the doctrine. This is consistent with proposition one and the empirical pattern revealed by the summary statistics in section 4.2 that litigated invention patents seem not to be more valuable than non-litigated counterparts. Though the general distribution of patent value seems not to be directly affected by the damage awards doctrine, the extremely low litigation rate implies the potential welfare loss of owners with extremely valuable patents.

4.4.2 The effect of lifting statutory damage awards: China's patent reform in 2009

Finally, I examine how the enhancement in damage awards- the key component of the 2009 patent reform- affects the patent valuation and aggregate rates of litigation and renewal. According to the 2009 patent law, the range of damage awards increased from 5000 RMB ($725) to 300,000 RMB ($46,590) before 2009 to the range of 10,000 RMB ($1553) to 1,000,000 RMB ($155,300) after that. The expected amount of damage awards, especially the upper bound, was promoted more than three times.

As expected, the valuation of the two types of patents increases after the enhancement in damage awards, shown by Figure A.6 (compared to Figure A.4). Specifically, for invention patents, the lines of the median, ten percentile, and 90 percentile all move slightly- compared to the invention panel in Figure A.4. The improvement in the valuation of utility models turns out to be more evident: the medians of patent value before the 2009 patent reform stay below 10,000 RMB for all periods (the solid line in the utility model panel of Figure A.4) whereas the median line only goes below 10,000 RMB after period seven after the reform (the solid line in the utility model panel of Figure A.6). The 10 and 90 percentiles exhibit similar patterns. Additionally, the first-period patent values across the entire distribution illustrate the different patterns of invention patents and utility models (Table 3). The enhancement in damage awards improves the patent value for invention patents, but not much. At the 90 percentile, median, and ten percentile, the increases in first-period patent value are merely 4%, 5%, and 6.5% relative to their pre-reform levels, respectively. In contrast, the increases in the value of utility models at the 90 percentile, median, and ten percentile of the distribution, are 155%, 289%, and 605% relative to the pre-reform levels. These patterns seem to persist through the entire life cycle of most patents.

These patterns imply that the promotion in damage awards by the 2009 patent reform bears boosting effect on both types of patents. Still, the result is much more significant on utility models than on invention patents. More importantly, the post-reform valuation of utility models is much larger than the "benchmark" patent value estimated in the previous section. In contrast, the post-reform valuation of invention patents is similar- or even slightly smaller- compared to the benchmark valuation. These patterns suggest that the 2009 patent reform might lead to the overvaluation of utility models while leaving the valuation of invention patents almost unchanged. This seems corroborated by the dramatic spike in utility model patenting and a relatively moderate increase in invention patenting in China since 2009.

4.4.3 Asymmetric effects of boosting damage awards

The enhancement of the damage awards by the 2009 patent reform might significantly narrow the valuation gap between invention patents and utility models. This will shift firms' patenting strategy in favor of utility models- the type of inventions featuring "baby steps"- and away from invention patents- the type of inventions that are more likely to generate "quantum leaps" and thus make significant economic contributions. This is largely because, as illustrated in section 2.1, creating a utility model typically involves much lower costs and uncertainty than invention patents.

A back-of-the-envelope calculation helps to clarify this argument. Table A4 reports the ratio of the valuation of invention patents over utility models, adjusted by the patent grant rates across the entire distribution [17]. Evidently, the valuation gap between invention patents and utility models significantly shrinks after 2009 across the entire distribution. On average, the valuation of invention patents is around 18 times as large as that of utility models before the 2009 patent reform; the former is merely six times as large as the latter after 2009. That said, after 2009, one invention patent is roughly equivalent to six utility models in terms of the expected value. This estimate is surprisingly close to the "rule-of-thumb" estimate provided by Chinese officials. For instance, the Chinese authority stipulates that six utility models are equivalent to one invention patent when evaluating firms' high-tech innovation capacity (e.g., InnoCom policy, Z. Chen et al., 2021; Wei et al., 2021). Moreover, Table 3 illustrates that patents from the lower end of the distribution might be affected by the enhancement in damage awards to a larger extent than their counterparts from the upper end. Indeed, changes in the ratio among patents from the upper end of the distribution (i.e., above the median or 75%) are much smaller than changes among patents from the lower end of the distribution. For example, the ratio of values of inventions relative to utility models among patents in the bottom 1% goes down from 88 before 2009 to merely ten after 2009, while the ratio of patents from the top 99% moves from 4.3 to 1.6. Considering that the sample of patents I examine in this paper tend to be patents with relatively higher values among the entire population of Chinese patents, the overall effect of the 2009 patent reform on the population might be larger than the estimates reported in Table A4.

5 The effect on innovation direction

The structural estimation and simulation show that the enhancement in damage awards by the 2009 patent reform asymmetrically impacts the valuation of invention patents and utility models. It significantly promotes the valuation of the low-value type- utility models- while leaving the valuation of invention patents almost unchanged. A direct consequence of this asymmetric influence could be a shift from utility model patenting to invention patenting

[17] The patent grant rate is the ratio of invention patents that are eventually granted over the cohort of invention applications. See Appendix C for details on the grant rate.

by innovating firms. In this section, I employ a series of firm-level difference-in-differences analyses to explore the extent to which the shift occurs and its implication on the quality of innovation output and firm heterogeneity.

5.1 Data and methodology

I compile a comprehensive panel data set of all Chinese patenting firms from 2001 to 2012. Specifically, I searched the IncoPat data- a private data provider widely used by scholars and China's patent examiners- for all firm patenting records within mainland China by domestic Chinese firms from 2005 to 2012. I tease out institutional patent owners whose identities could not be uniquely confirmed [18]. I also drop foreign patent owners because they might face different regulatory and innovation environments when filing patents [19]. This yields 219166 unique firm patent owners. Furthermore, I drop firms that only patent one type of patents because I do not observe a switch between the two types of patents for these firms. The final data set comprises 30018 patenting firms. These firms filed 156379 invention patents and 337613 utility models during the period.

Begin with the "treatment" measure. In principle, the 2009 patent reform affected all firms in my sample, but the extent to which they were affected could be heterogeneous across firms. Thus, I leverage this firm heterogeneity in exposure to the litigation-related changes to identify the effect on firm innovation strategy. Specifically, I assume that firms exposed to more patent litigation hazards before the reform will potentially be more reactive to litigation-related policy changes. Following the procedure proposed by Mezzanotti, 2021, I construct a measure for firms' exposure to patent litigation:

$$\eta_i = \sum_{q=1}^{N} \zeta_{iq} r_q \tag{11}$$

η_i is the measure for patent litigation exposure of firm i. ζ_{iq} is the ratio of patents filed in area q (e.g., IPC classes) by firm i over the number of all patents filed by firm i, measuring the relative importance of each technological area in the patent portfolio of the focal firm. r_q is the ratio of the number of patents being litigated in area q over the number of all patents being litigated, measuring the litigation hazards of area q. Put together, η_i proxies the weighted patent litigation exposure that varies across firms and time windows. In the main analysis, I use two-digit industry codes to define the area and calculate the total litigation exposure of sampled firms from 2005 to 2008. The summary statistics of major

[18] The IncoPat database standardized all institutional patent owners according to their history of patent records. I utilize this function and drop out patent owners that are not standardized.

[19] Most patents registered to China's patent office by foreign patent owners are family patents to original inventions made in foreign countries.

variables used in this section are shown in Table A11.

5.2 The ratio of invention patenting over utility model patenting

The major outcome variable of interest is firms' choices over invention patenting vis-a-vis utility model patents. Specifically, I intend to quantify how the over-compensation of utility models by the 2009 patent reform impacts firms' choices between the two types of patents. Formally, I estimate:

$$Y_{it} = \beta_0 + \beta_1 H_i * Post_t + Post_t + X_{it} + \delta_i + \theta_{jt} + \psi_{lt} + \epsilon_{it} \tag{12}$$

Y_{it} is the ratio of the utility model applications over all patent applications filed by firm i in year t, measuring the firms' patenting choice between the two types of patents. H_i is a dummy variable that takes value one if the litigation exposure of firm i, η_i, is positive from 2005 to 2008. $Post_t$ is a dummy variable that takes one after the patent reform year (2009, including). X_{it} are a battery of control variables, teasing out impacts from potential contributors to the dependent variable. Specifically, I use the number of patents registered in foreign countries to measure firms' foreign patenting activities. Hu and Jefferson, 2009 points out firms' exposure to foreign investment and trade plays a vital role in their patenting strategy. Furthermore, it is well acknowledged by the literature that a firm's R&D spending is closely associated with its patenting strategy. While I do not directly observe R&D spending from the data, I use the size of firms' patent portfolio- the number of firms' valid patents in year t- as a proxy for firms' R&D efforts and absorptive capacities. Finally, the literature also points out the extent of competitiveness of the industry (or tech area) in which the firm operates could affect its choice over invention patents and utility models (Cao et al., 2014). Thus, I compute the industry-level (or technological-area-level) herfindahl-hirschman index (HHI) of patenting at year t as another control variable.

Next, I insert fixed effects at a variety of levels. δ_i are firm fixed effects, controlling for unobserved firm-level time-invariant factors. θ_{jt} is the yearly trend of technology-area fixed effects (IPC classes), absorbing time-changing industry-level factors, such as changes in industry policies or market demands. ψ_{lt} is the yearly trend of firm location fixed effects, absorbing time-changing province-level factors. This could be particularly relevant in China's context due to its patent subsidy programs which typically offer more significant rewards for invention patents than utility models (Dang and Motohashi, 2015). I identify the technological areas (i.e., IPC classes) firms mainly patent in [20] and their major locations

[20] I consider the IPC classes in which the focal firm filed the highest number of patents (invention patents and utility models) from 2005 to 2008 as its major technological area. For firms with more

using the industries or provinces where the focal firm registers the majority of patents in year t. Though theoretically, the way I construct these measures allows them to change over time, most firms in my sample patented in a limited number of years across the entire observation window, resulting in low variations. I multiply the tech-area and location-fixed effects with the time trend.

The major coefficient of interest is β_1, which, according to my structural estimation, is expected to be positive. The DID estimation confirms this. Table 4 reports the results estimated using Equation 12. Column 1 indicates that the utility model ratio of high-exposure firms increases 8.1 percentage points after the patent reform relative to their low-exposure counterparts. The difference is statistically significant at conventional levels. To fully utilize the variation of the measure on litigation exposure, I use the litigation exposure (i.e., η_i in 11) as the treatment variable in column 2. It suggests that one standard deviation increase (around 0.0237) in the litigation exposure of a firm before 2009 will increase the ratio of utility model patenting by 0.87 percentage points. This effect is statistically significant at conventional levels. One might concern that the large size of the "treatment" group- 417 firms with positive litigation exposure- relative to the size of the "control" group- 29664 firms with zero exposure- might bias the estimation. To address this concern, I perform a one-to-one matching for firms in the treatment group using coarsened exact matching (Blackwell et al., 2009). The matching is based on the total number of invention applications and utility model applications from 2005 to 2008. Column 3 shows the results estimated on the matched sample, which contains 413 treatment firms and 413 control firms. The effect of patent reform on the utility model patenting ratio turns out to be stronger- the utility model ratio of high-exposure firms increases by 13.2 percentage points relative to the low-exposure firms after the reform. But the effect is only significant at the 10% level, which could be attributed to the relatively small sample size.

Furthermore, from columns 4 and 5, we can see that the increase in utility model ratio by firms with higher litigation exposure is mainly driven by significant increases in utility model patenting and, to a much smaller extent, decreases in the invention patenting. After the reform, the number of utility model applications filed by high-exposure firms increased by 10.6 percentage points relative to the low-exposure firms (column 4). In contrast, the number of invention patent applications filed by high-exposure firms decreased by nine percentage points. While the increase in utility model patenting is statistically significant at conventional levels, the decrease in invention patenting is merely significant at the 10% level. Moreover, the coefficients of $Post_t$ in columns 4 and 5 indicate that both types of patents filed by the low-exposure firms increase after the patent reform; and combined with the coefficients of DID estimators, the high-exposure firms also increase patenting in both types of patents. This pattern is consistent with the prediction of the structural

than one IPC class as their major technological areas, I randomly pick one.

estimation- namely, that both types of patents are expected to be incentivized due to the overall enhancement in damage awards. However, the incentives for utility model patenting are more prominent.

Next, I examine the evolution of the patenting in both types of patents by the high-exposure and low-exposure firms. Figure 3 shows the annual average number of invention applications (the left panel) and utility model applications (the right panel) by the two groups of firms. It is evident that for both types of firms, the patenting in both types of patents significantly increased after the reform, and the increase of patents filed by high-exposure firms is relatively bigger than those filed by low-exposure firms. Taking a more rigorous approach, I estimate the treatment effect by year. Specifically, I substitute the $Post_t$ in Equation 12 with a series of year dummies and plot the coefficients of the interaction terms $Litigation\_exposure_i * Year_t$, shown in the Figure 4. The jump in DID estimators after 2009 is evident, and the positive effect on the utility model ratio persists and even increases over time. Furthermore, the pre-shock trends of the two groups of firms are parallel, and the difference is indistinguishable from zero before 2009, confirming the key assumption underlying the validity of the DID analysis.

Alternative mechanisms and robustness checks. The observed increase in utility model ratio by firms with high litigation exposure might be driven by other factors or contemporaneous policy changes. The most probable are other policy changes introduced by the 2009 patent reform. One could be the official recognition of the "double patenting" practice by the 2009 patent law. According to the 2009 patent law, patent applicants are allowed to apply one invention patent and one utility model for the same invention on the same day; at any time point later, though, the patent applicant could only preserve one of the two patent rights if the patent office approves both. Informal interviews with Chinese patent attorneys suggest that the 2009 patent reform does increase "double patenting" in practice and might, to some extent, encourage utility model patents. To alleviate this concern, I have removed all registered patents as double patenting from the main analysis.

Moreover, the 2009 patent reform also enhances the criteria for granting invention patents. After 2009, Chinese patent examiners will compare invention patent applications with prior art- existing public knowledge related to the application- around the world; previously, the prior art was defined as general knowledge within mainland China. This change in the scope of prior art makes the examination of invention patents (not utility models) more rigorous. It thus could potentially lead to a shift from invention patenting to utility model patenting. One piece of evidence contrasting this argument is that invention patenting increases after 2009 in the total sample, indicated by the coefficients of $Post_t$ in Table 4. The fact that both groups of firms increase the patenting in invention patents is not consistent with the potential; effect of the improving examination criteria on invention applications.

One might also be concern about the impact of policy changes other than the 2009 patent reform, such as the InnoCom policy (Z. Chen et al., 2021; Wei et al., 2021). As mentioned before, an implicit rule of evaluating the two types of patents by the InnoCom program is that one invention patent is equivalent to six utility models. Due to the large corporate tax cut (25% to 15% after 2008) enjoyed by the certificated firms, the incentive to quickly acquire the InnoCom certification could be nontrivial. Utility models appear to be a better choice than invention patents for firms to acquire to win the certificate because they are much easier and quicker. Therefore, the utility model ratio increase could be due to the incentives to win certificates or other government subsidies in the same fashion. Several checks are ready to alleviate this concern. First, I include a yearly trend of province-fixed effects in the DID specification (Equation 12), which could control the confounding effects of province-level patent subsidy programs over time. Second, the InnoCom policy took into effect in 2008, which, if truly at work, will predict an uptake in the utility model ratio in 2008. This is inconsistent with the pattern shown in Figure 4. The dynamic DID estimators start to rise around 2009, one year after the InnoCom policy took effect.

Finally, for all the aforementioned alternative mechanisms, it is unclear how firms with high litigation exposure will increase their utility model patenting relative to firms with low exposure if the mechanisms were at work. Indeed, these mechanisms might even work in the opposite direction. For instance, studies suggest that patenting might be more proactive in areas where patent litigation does not commonly occur due to infringement concerns (Paik and Zhu, 2016). If this was the case, we might expect firms with low litigation exposure tend to react to the alternative mechanisms - the flourishing double patenting practice, tightened invention examination criteria, and patent subsidy programs such as the InnoCom policy- more actively because they are likely to face fewer infringement hazards.

Table A12 reports other robustness checks I perform. The main results are shown to be robust to: 1) measuring the litigation exposure by technological areas (IPC classes); 2) using the yearly changing measurement of litigation exposure (by IPC classes); 3) using measurement based on the litigation exposure from 2001 to 2004; 4) winsorizing the top 1% observations by year in terms of invention applications and utility models; 5) using the sample excluding the observations with zero invention applications and the ones with zero utility models.

5.3 Quality of innovation outputs

According to the structural model, the mechanism behind the increase in utility model ratio is the asymmetric effects on utility models and invention patents by enhancing damage awards by the 2009 patent reform. If this mechanism is at work, we should expect to observe the following changes in the quality of invention patents. For firms with high litigation exposure, low-quality invention patents in their patent portfolio are likely to be as valuable as some utility models as these firms increase utility model patenting. As a result, the group of invention patents whose value and quality resemble utility models will be dropped. Therefore, we expect firms with relatively high litigation exposure to reduce low-quality invention patenting, relative to firms with low litigation exposure.

To examine this prediction, I construct measures for the quality of invention patents made by sampled firms and substitute Y_{it} in Equation 12 with the quality measure. Specifically, following the literature, I calculate the number of invention patents filed in year t by the focal firm whose forward citations are among 1 percent, five percentage, ten percentage, 25 percent, and 50 percent (median) of all invention patents filed within the same industry in year t. This measurement has several advantages: first, by comparing the forward citations among patent cohorts, this measurement alleviates truncation bias which tends to undervalue the importance of patents filed in later years during the observation window; second, by constructing a comparison with other Chinese invention patents, the measure also alleviates the concern on reliability of the citation data released by China's patent office if we assume the data bias, if any, is randomly distributed across areas and over time.

Table 5 reports the results. Columns 1-4 show estimates of the number of invention patents within the top 1, 5, 10, and 25 percentages among their cohorts from the same industry. The coefficients of interaction terms $High\_litigation\_exposure_i * Post_t$ are positive but statistically insignificant at conventional levels (columns 1-4), suggesting that firms with high litigation exposure tend to have more top-quality patenting relative to firms with low litigation exposure, but the differences are not significant. Column 5 reports the estimated changes in the patenting of inventions whose qualities are below the median [21]. As expected, firms with high litigation exposure reduce low-quality invention patents relative to firms with low exposure. In contrast, firms with no litigation exposure before 2009 increased patenting in inventions of below-median quality (the estimate of $Post_t$ in column 5).

Finally, I plot the dynamic difference-in-differences estimators (i.e., the estimates by substituting the $Post_t$ dummy with a series of year dummies in Equation 12) on the number of invention patents whose qualities are below the median (Figure A.7). The dynamic DID estimators not only confirm the parallel pre-shock trend- the critical assumption of the DID analysis- but also visualize the sudden decline in the number of high-quality invention patents within the patent portfolio of firms with high litigation exposure relative to firms with low exposure.

[21] I use the median as the threshold to measure low-quality patents because the non-trivial number of invention patents does not have any forward citations. This makes the measures to be the same if I use the bottom 1, 5, 10, or 25 percentile as the measure for low-quality patents.

5.4 Firm heterogeneity

The mechanism revealed in the previous section- that the "treated" firms are more likely to switch low-quality invention patents to utility models- has an implication. From the perspective of R&D cost, this "switch" might mainly be driven by limited R&D resources of innovative firms and, therefore, will be more pronounced among firms with financial constraints. In this section, I investigate this implication by exploring firm heterogeneity in the propensity to make utility models.

To begin with, I examine whether the reactions of publicly traded companies and private firms to the changes in damage awards are different. Specifically, I split the entire sample into one sample containing publicly traded firms and another one containing the rest of private firms [22]. Then I run the difference-in-differences estimation specified in Equation 12 on the two sub-samples separately. Columns 1- 2 of Table 6 report the results. Consistent with the prediction, publicly traded firms with high litigation exposure do not significantly increase their proportion of utility model patenting relative to publicly traded firms with low exposure after 2009. On the other hand, private firms, which, compared with publicly traded firms, usually face more difficulties in raising funding, exhibit the opposite pattern: private firms whose pre-shock litigation exposures are high tend to have higher utility model ratios relative to private firms whose exposures are low. The DID estimator is statistically significant at conventional levels.

Furthermore, I triangulate the implication by comparing the reactions of the state-owned firms (SOEs) with the rest firms (non-SOEs). To this end, I use the information on the ownership type of sampled firms. SOEs are defined as firms whose ownership is labeled as state-owned. Columns 3 and 4 of Table 6 report the results. As expected, among SOE firms (column 3), firms with high litigation exposure tend to be inactive to the patent reform- the DID estimator is not statistically significant at any conventional level. By contrast, among non-SOE firms (column 4), the pattern is the opposite: firms with high litigation exposure significantly increase the utility model ratio relative to firms with low exposure. This indicates that compared with SOE firms, non-SOE firms are more likely to be constrained by financial deficiency and thus exhibit the switch from low-quality invention patents to utility models.

6 Policy suggestions

Given the asymmetric effects of lifting damage awards on invention patents and utility models and its consequences, a direct policy suggestion would be to revise the damage awards doctrine to suit different types of patents. I briefly discuss feasibility of several

[22] I identify publicly traded firms by year because some firms were listed only for several years of the entire observation window.

options of revisions in this part.

The most effective doctrine, relatively to the statutory damage awards doctrine, should be doctrines that compensate the patent owner with the real infringement loss such as the "unjust enrichment" (UE) or "lost profit and reasonable loyalty" doctrines (LP). While UE or LP doctrines have already been stipulated by China's patent law for almost two decades and been adopted in few cases in practice, they are apparently less efficient than statutory damage awards doctrine in terms of providing a quick legal remedy because determining the real loss is usually a time-consuming process, which could be a daunting task in China where there is no evidence discovery doctrine in court. Therefore, adopting a UE or LP doctrine might result in slow protection; in quickly-evolving industries, slow legal remedy could almost equal to no protection. In addition, an overall shift to the UE or LP doctrine might require a battery of experienced IP judges and other professional experts such as judicial authenticators, which might be heavily under-supplied in many areas. Thus, fully adopting UE or LP doctrine could be considered as the ultimate goal in the long run.

In the short run, small revisions to the current statutory damage awards doctrine might achieve desirable effects as well. One feasible approach is to differentiate the damage awards ranges for invention patents and utility models. Intuitively, to match the values of these two types of patents, invention patents should be bestowed with higher damage awards than utility models. Specifically, given that the range of damage awards for utility models before 2009 seems to generate a distribution of patent value similar to that generated in the benchmark scenario (see Table A3), we could leave the damage awards doctrine to its pre-2009 level for utility models, namely a range of 5000 RMB ($ 725) to 300,000 RMB ($ 46,590). Meanwhile, for invention patents, the range of damage awards needs to be enhanced from its pre-2009 level. Though the pre-2009 damage awards range generates patent value distributed in a similar way as the benchmark scenario, the aggregate litigation rate is much lower under the pre-2009 statutory damage awards doctrine than the benchmark scenario (Table A3).

Therefore, enhancing the pre-2009 damage awards range for invention patents while leaving that for utility models to its pre-2009 level could be a feasible policy approach to adjust the inefficiency in China's patent litigation system. Naturally, the next question should be how to enhance the damage awards range, e.g. to what extent. It is far-reaching to derive specific numbers for the ideal range for damage awards from my current model because models are only abstract of the reality no matter how delicate they are. However, simulation exercises like the ones in section 5.2 and 5.3 could provide useful clues on the general direction of the enhancement.

To start with, I explore lifting which bound- the upper bound or the lower bound- could be more efficient. Table A6 and Table A7 in Appendix A report four simulation exercises

I run to this end. Specifically, I extend the upper bound of the post-2009 damage awards range to 1.1 million RMB and 1.3 million RMB for the first two exercises, leaving the lower bounds unchanged, which is 0.01 million RMB; in a similar vein, I extend the lower bound of the post-2009 damage awards range to 0.1 million RMB and 0.3 million RMB for the third and fourth exercises, leaving the upper bound unchanged, which is 1 million RMB. The baseline is the results of the 2009 patent reform presented in Table A3 and Table 3. It is evident that, as expected, the patent value increases when either bounds of the damage awards range increases. Plus, the extent to which the patent value increases is proportional to the extent to which the damage awards range is lifted. For instance, lifting the upper bound to 1.3 million RMB exerts larger boosting effect on the patent value than lifting it to 1.1 million RMB. However, what is unexpected is the asymmetric effects of lifting the upper bound and lower bound. It turns out that the enhancement in the lower bound exerts a significantly larger effect on the patent value than lifting the upper bound. This effect is pervasive across the overall distribution of the first-period patent value and also applies to aggregate litigation rates (Table A7). Intuitively, the reason could be that a lower bound above zero provides a "guaranteed" bottom line of expected profits from winning the infringement lawsuits while the upper bound, however large it is, represents the best scenario which might merely happen at a very low chance, especially for innovators whose patents are of relatively low value. The asymmetry in the effect of upper bound and lower bound of the damage awards range on the patent value indicates that policy makers might need to lift the lower bound, rather than the upper bound, if they aspire to achieve a strong, positive effect of strengthening patent protection.

7 Conclusions

This paper explores the impact of the effectiveness of patent enforcement in court on the real options value of patents and the implication for patent strategy and innovation outcome. I start with estimating the real options model of the private value of patents and obtain structural estimates on the technology depreciation rate, peak litigation hazards, the distribution of initial patent values, and the share of profits the patent owner is expected to receive if the infringement is tolerated. The structural estimation and counterfactual simulation suggest that strengthening the patent enforcement by promoting damage awards exerts a much larger boosting effect on utility models than on invention patents. As a result, China's 2009 patent reform, which greatly enhanced the general level of damage awards, might overcompensate utility models- the inferior type of patents rather than inventions, by offering an inflated level of damage awards. I perform a series of difference-in-differences analyses on firms' patenting strategies and innovation outcomes. The firm-level analysis confirms that firms with high litigation exposure (and thus will be more affected by changes in patent enforcement) tend to file more utility models after the patent reform relative to firms with low exposure. This tendency is more pronounced among non-SOE and private firms relative to state-owned firms and publicly traded companies. The ”treated“ firms are more likely to reduce low-quality invention patenting while increasing utility model patenting.

Several limitations of this study could become potential venues for further exploration. First, I fit the theoretical model with a subgroup of the population of Chinese patents-though the subgroup that might potentially face the highest infringement hazards. Future studies could apply the model developed in this paper to a more comprehensive sample of Chinese patents to examine the generality of major findings among the patent population. Second, an international comparison with the evolution of utility model patents in other countries which grant utility models, such as Germany and Japan, could be handy in investigating whether the patterns exhibited by China's patent litigation practice apply to other jurisdictions.

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Tables

Table 1: Main differences between inventions and utility models

	Inventions	Utility models
Protection term	20 years	10 years
Rigorous examination	yes	no
Benefit/cost	high/high	low/low
Coverage	any invention novel non-obvious and useful	invention with solid structures or shapes

Table 2: Estimates on key parameters

	Inventions		Utility models	
	Estimates	95% CIs	Estimates	95% CIs
γ	0.748	[0.661,0.899]	0.65	[0.25,0.9]
σ	20089	[1329.321,20940.65]	5007	[1020.033,12888.44]
α	4.52	[3.792,9.983]	0.34	[0.003,1.996]
θ	0.318	[0.1,0.541]	0.243	[0.1,0.9]
l_0	0.615	[0.187,0.789]	0.61	[0.12,0.9]

Table 3: First-period patent values (in local currency, RMB)

	Inventions			Utility models		
	Before patent reform	benchmark	After patent reform	Before patent reform	Benchmark	After patent reform
Min	91166.65	104081.2	71955.01	1701.959	1786.091	13826.35
1%	175084.02	198033.7	184064.4	1725.304	1791.785	14373.17
5%	257578.63	282879.3	266990	1996.978	1962.515	16001.12
10%	310026.12	340927.7	330291.8	2460.487	2485.377	17337.78
25%	422566	450566.6	448672.6	3485.939	3368.353	24362.73
50%	590150.45	615177.6	620956	8295.944	8282.796	32245.29
75%	796095.15	830541.6	837942.2	29234.87	30212.99	79940.51
90%	1023914	1053769	1065213	73939.41	74849.56	188679.1
95%	1167655.6	1226054	1235460	116487.4	119587.2	294240.1
99%	1506869.4	1528511	1600449	305429.1	308864.4	767502.8
Max	3840061	4314056	3778141	1390615	1178542	1866687
Mean	636389.41	667373.9	670652.6	29571.3	29837.09	81728.44
SD	294561.1	303152.3	307199.7	64918.16	62930.43	134407.4
#obs	10000	10000	10000	10000	10000	10000

Table 4: The effect on the ratio of utility model patents

	(1) utility model ratio	(2) utility model ratio	(3) utility model ratio	(4) log(utility models)	(5) log(invention patents)
High_litigation_exposure*Post	0.0815***		0.132*	0.106***	-0.0898*
	(0.0183)		(0.0708)	(0.0409)	(0.0462)
Litigation_exposure*Post		0.00870***			
		(0.00240)			
Post	-0.0324***	-0.0243***	-0.0776	0.538***	0.223***
	(0.00933)	(0.00876)	(0.0717)	(0.0152)	(0.0159)
Log(family patents)	-0.216***	-0.217***	-0.242***	0.0266	0.764***
	(0.0110)	(0.0109)	(0.0424)	(0.0209)	(0.0344)
Log(patent portfolio)	0.273***	0.273***	0.184***	1.022***	0.0296***
	(0.00303)	(0.00303)	(0.0156)	(0.00521)	(0.00651)
HHI	-0.786***	-0.795***	-0.840	-1.279***	0.585*
	(0.220)	(0.222)	(0.616)	(0.296)	(0.350)
Constant	0.300***	0.293***	0.370***	-0.960***	0.298***
	(0.0109)	(0.0105)	(0.0423)	(0.0181)	(0.0202)
Firm FEs	Y	Y	Y	Y	Y
Industry FEs	Y	Y	Y	Y	Y
Province FEs	Y	Y	Y	Y	Y
Matched	N	N	Y	N	N
Observations	77,976	77,976	2,950	77,976	77,976
R-squared	0.641	0.641	0.627	0.824	0.623
#Firms	30081	30081	826	30081	30081

Note: All specifications use the OLS model. *Litigation_exposure* is measured at the firm level from 2005 to 2008. *High_litigation_exposure* is a dummy variable taking 1 if *Litigation_exposure* is positive. *Post* takes one if the year is after 2009 (including). Family patents and patent portfolios are counted at the firm level at year t. HHI is the Herfindahl–Hirschman index computed yearly at the 2-digit industry code level. The dependent variables for columns 1-3 are the ratio of utility model applications over all patent applications taken by the focal firm at year t. The dependent variables for columns 4 and 5 are the logarithm of the number of utility models and invention applications taken by the focal firm at year t. Column 3 uses the sample obtained from CEM k to k matching. All logarithm transformation is taken after adding one to the original value for all observations. Robust standard errors are clustered at the firm level, shown in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 5: The effect on the quality of invention patents

Dependent variables	(1) log (top 1 inventions)	(2) log (top 5 inventions)	(3) log (top 10 inventions)	(4) log (top 25 inventions)	(5) log(below-median inventions)
High_litigation_exposure*Post	0.0178	0.0279	0.00878	-0.0338	-0.210***
	(0.0149)	(0.0230)	(0.0262)	(0.0316)	(0.0345)
Post	0.00134	0.00617	0.00980	0.0197**	0.0808***
	(0.00223)	(0.00473)	(0.00645)	(0.00963)	(0.0105)
Log(family patents)	0.104***	0.205***	0.271***	0.390***	0.232***
	(0.0281)	(0.0380)	(0.0399)	(0.0406)	(0.0454)
Log(patent portfolio)	0.00585***	0.0210***	0.0339***	0.0581***	0.0303***
	(0.00136)	(0.00256)	(0.00330)	(0.00456)	(0.00450)
HHI	0.127	0.0635	-0.0210	0.192	0.396
	(0.176)	(0.248)	(0.280)	(0.315)	(0.347)
Constant	-0.00288	0.00308	0.0177*	0.0684***	-0.0201
	(0.00391)	(0.00726)	(0.00941)	(0.0133)	(0.0141)
Firm FEs	Y	Y	Y	Y	Y
Industry FEs	Y	Y	Y	Y	Y
Province FEs	Y	Y	Y	Y	Y
Observations	77,976	77,976	77,976	77,976	77,976
R-squared	0.482	0.538	0.554	0.580	0.386
#Firms	30081	30081	30081	30081	30081

Note: All specifications use the OLS model. All dependent variables are the number of invention patents specified within a certain quality range filed by the focal firm in year t. $High\_litigation\_exposure$ is a dummy variable taking one if the litigation measure of the focal firm is positive from 2005 to 2008. $Post$ takes one if the year is after 2009 (including). Family patents and patent portfolios are counted at the firm level at year t. HHI is the Herfindahl–Hirschman index computed yearly at the 2-digit industry code level. All logarithm transformation is taken after adding one to the original value for all observations. Robust standard errors are clustered at the firm level, shown in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 6: Firm heterogeneity on utility model ratio

Dependent variable	utility model ratio			
	(1)	(2)	(3)	(4)
Samples	publicly traded firms	private firms	SOE	non-SOE
High_litigation_exposure*Post	0.0783	0.0596***	0.0269	0.0812***
	(0.0691)	(0.0191)	(0.0915)	(0.0184)
Post	0.0965*	-0.0374***	-0.0312	-0.0315***
	(0.0575)	(0.00967)	(0.0472)	(0.00954)
Log(family patents)	-0.137***	-0.234***	-0.252***	-0.213***
	(0.0208)	(0.0114)	(0.0330)	(0.0116)
Log(patent portfolio)	0.273***	0.270***	0.247***	0.274***
	(0.0114)	(0.00321)	(0.0153)	(0.00310)
HHI	-1.340***	-0.684***	-2.566**	-0.749***
	(0.413)	(0.232)	(1.172)	(0.221)
Constant	0.0478	0.319***	0.317***	0.299***
	(0.0595)	(0.0114)	(0.0549)	(0.0112)
Firm FEs	Y	Y	Y	Y
Industry FEs	Y	Y	Y	Y
Province FEs	Y	Y	Y	Y
Observations	4,871	69,903	2,955	74,741
R-squared	0.721	0.638	0.692	0.642
#Firms	1897	27365	1089	28928

Note: All specifications use the OLS model. *High_litigation_exposure* is a dummy variable taking one if the litigation measure of the focal firm is positive from 2005 to 2008. *Post* takes one if the year is after 2009 (including). Family patents and patent portfolios are counted at the firm level at year t. HHI is the Herfindahl–Hirschman index computed yearly at the 2-digit industry code level. All logarithm transformation is taken after adding one to the original value for all observations. Robust standard errors are clustered at the firm level, shown in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Figures

Figure 1: Aggregate litigation and renewal rates of invention patents

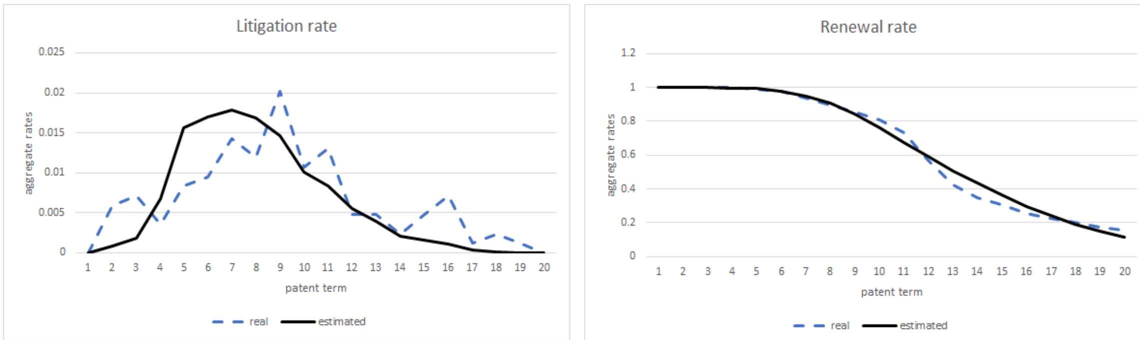


Figure 2: Aggregate rates of litigation and renewal of utility models

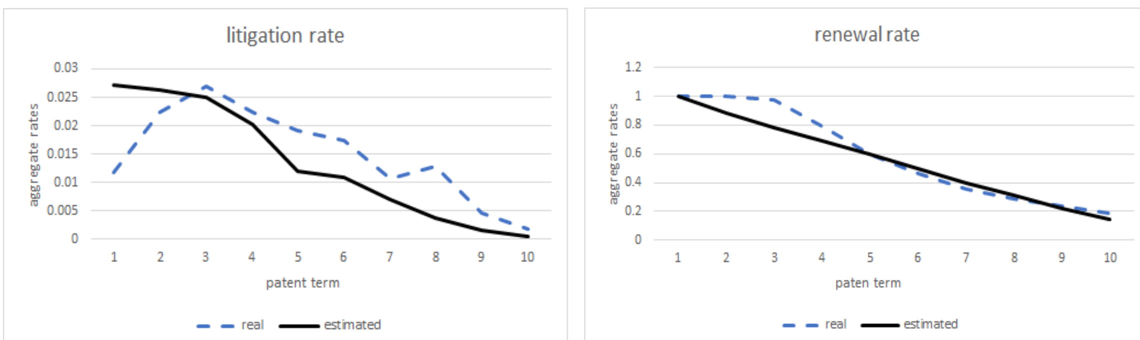
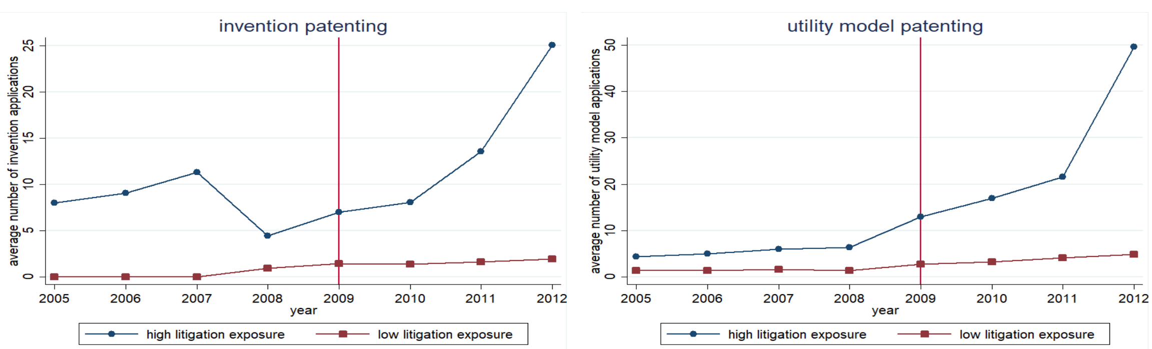
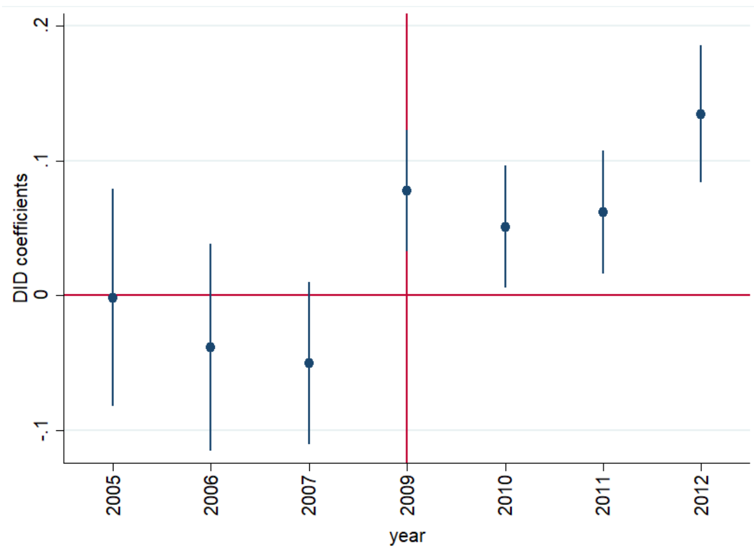


Figure 3: The annual average of invention and utility model patent filings)



Note: The x-axis shows the year; Y-axis shows the annual average number of patents filed by the focal group of firms.

Figure 4: The effect on firms' utility model ratio (dynamic diff-in-diff)



Note: The x-axis shows the year; Y-axis shows the coefficients of the dynamic difference-in-differences estimation. The treated group is the group of firms whose litigation exposure was positive from 2005 to 2008. The dependent variable is the ratio of the number of utility model applications over the number of invention patent applications at year t of industry i. 2008 is set as the baseline year, thus omitted. Vertical lines show the 95% confidence intervals for point estimates.

Appendices

A Appendix tables and figures

Table A1: Patent renewal fee scheme in China

Years	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Inventions	144	144	144	192	192	192	320	320	320	640	640	640	960	960	960	1280	1280	1280	1280	1280
Utility models	96	96	96	144	144	192	192	192	320	320										

Note: Chinese Yuan is exchanged into USD according to recent market currency price: 1 RMB=0.16 USD

Table A2: Summary statistics of sampled inventions and utility models

	#Obs	Mean	Std. Dev.	Min	Max
Panel A Litigated invention patents					
#claims	115	13.31	17.75	1	107
#foreign destinations of family patents	115	16.79	37.56	1	241
#IPC	115	1.94	1.13	1	6
#applicants	115	1.01	0.09	1	2
#inventors	115	1.97	1.55	1	8
transaction	115	0.33	0.47	0	1
invalidation	115	0.57	0.50	0	1
Panel B non-litigated invention patents					
#claims	726	23.54	22.68	1	223
#foreign destinations of family patents	726	26.56	37.00	1	241
#IPC	726	2.41	1.92	1	18
#applicants	726	1.04	0.23	1	3
#inventors	726	2.10	1.90	1	14
transaction	726	0.45	0.50	0	1
invalidation	726	0.01	0.11	0	1
Panel C litigated utility models					
#claims	262	4.47	2.88	1	23
#foreign destinations of family patents	262	1.16	1.19	1	16
#IPC	262	1.40	0.70	1	5
#applicants	262	1.08	0.50	1	8
#inventors	262	1.41	1.16	1	13
transaction	262	0.16	0.37	0	1
invalidation	262	0.53	0.50	0	1
Panel D non-litigated utility models					
#claims	1,521	4.30	3.17	1	29
#foreign destinations of family patents	1,521	1.03	0.34	1	9
#IPC	1,521	1.54	0.82	1	7
#applicants	1,521	1.13	0.42	1	4
#inventors	1,521	1.76	1.77	1	27
transaction	1,521	0.04	0.19	0	1
invalidation	1,521	0.00	0.07	0	1

Table A3: Aggregate litigation and renewal rates of simulated data

Panel A Inventions						
	Before patent reform		Benchmark		After patent reform	
Term	litigate rate	renew rate	litigate rate	renew rate	litigate rate	renew rate
1	0	1	0	1	0	1
2	0.0008	0.9999	0.0801	0.9998	0.0382	0.9998
3	0.0018	0.9987	0.1217	0.9992	0.14	0.9991
4	0.0068	0.9966	0.1218	0.9967	0.2472	0.9982
5	0.0156	0.9925	0.1129	0.9899	0.3491	0.9973
6	0.017	0.9777	0.0762	0.9757	0.3365	0.9935
7	0.0179	0.9482	0.0582	0.9474	0.319	0.9816
8	0.0169	0.9041	0.0437	0.9007	0.2967	0.9606
9	0.0147	0.8454	0.0378	0.8438	0.2749	0.9238
10	0.0101	0.7594	0.0292	0.7626	0.2392	0.8642
11	0.0084	0.6758	0.0231	0.6756	0.2139	0.7958
12	0.0055	0.5941	0.0186	0.5946	0.1727	0.7203
13	0.0039	0.5059	0.0143	0.5116	0.1432	0.6349
14	0.0021	0.4361	0.0102	0.441	0.1137	0.554
15	0.0016	0.3665	0.0072	0.3746	0.086	0.4709
16	0.0011	0.2982	0.0041	0.3071	0.0601	0.3889
17	0.0003	0.2439	0.0045	0.25	0.0426	0.321
18	0.0001	0.1911	0.0024	0.1997	0.0261	0.2566
19	0	0.1529	0.0008	0.1554	0.013	0.1982
20	0	0.1163	0.0007	0.1163	0.0047	0.1461

Panel B Utility models						
	Before patent reform		Benchmark		After patent reform	
Term	litigation rate	renew rate	litigation rate	renew rate	litigation rate	renew rate
1	0.0218	1	0.0001	1	0.4526	1
2	0.029	0.9089	0.0062	0.8762	0.5271	0.996
3	0.0282	0.8144	0.0068	0.7741	0.6038	0.9859
4	0.0221	0.702	0.0072	0.6782	0.5176	0.9612
5	0.0147	0.5893	0.0053	0.587	0.4373	0.9129
6	0.0112	0.487	0.0035	0.4907	0.3407	0.8472
7	0.0074	0.3998	0.0024	0.3956	0.2578	0.7549
8	0.0048	0.31	0.0011	0.3151	0.1733	0.6441
9	0.0036	0.2204	0.0006	0.2215	0.1002	0.4963
10	0.0012	0.1465	0.0003	0.1508	0.0374	0.3032

Table A4: Grant-rate adjusted ratio of valuation of individual patent (inventions/utility models)

	before 2009	after 2009
Min	46.60	4.22
1%	88.29	10.37
5%	112.22	13.52
10%	109.62	15.43
25%	105.46	14.92
50%	61.89	15.60
75%	23.69	8.49
90%	12.05	4.57
95%	8.72	3.40
99%	4.29	1.69
Max	2.40	1.64
Mean	18.72	6.65

Table A5: Ratio of total value of all granted patents (inventions/utility models)

	Number of granted patents	Total value of all granted patents	Value of inventions/value of utility models
2005-2008			
invention	520304	3.3e+11	19.34
utility models	578819	1.7e+10	
2009-2012			
invention	945462	6.3e+11	4.50
utility models	1725174	1.4e+11	
2013-2016			
invention	1677827	1.1e+12	4.04
utility models	3410354	2.8e+11	

Table A6: First-period patent value of differentiated ranges of damage awards

Range of damage awards (RMB)	10k-1100k	10k-1300k	110k-100k	310k-1000k
Min	82448.56	91864.59	242780.5	638737.19
1%	184703	187459.4	347329	723297.3
5%	274294	272452.7	435207.5	811258.5
10%	343832	344569.8	503328.4	872691.2
25%	479941.6	493859.5	635475.9	975086.2
50%	654182.3	672412.9	741270.6	1036768.0
75%	801600.3	800725.9	805810.4	1118315.5
90%	1032284	1103021	1017396	1252668.9
95%	1213326	1390110	1220050	1398300.2
99%	1574522	1779857	1592686	1712180.3
Max	3395633	4506284	4109116	4312429
Mean	676182.3	703084.1	761743.6	1062424.9
SD	302114.8	345459.6	249592.8	194762.15
#obs	10000	10000	10000	10000

Table A7: Aggregate litigation and renewal rates of simulated inventions with different range of damage awards

Damage awards range (RMB)	10k-1100k		10k-1300k		110k-100k		310k-1000k	
term	litigate rate	renew rate	litigate rate	renew rate	litigate rate	renew rate	litigate rate	renew rate
1	0	1	0	1	0	1	0	1
2	0.0659	0.9999	0.0942	0.9999	0.0949	1	0.1558	1
3	0.1531	0.9995	0.1925	0.9994	0.1925	1	0.3006	1
4	0.2546	0.9987	0.313	0.9979	0.2887	1	0.459	1
5	0.3899	0.9969	0.4207	0.9961	0.4238	0.9999	0.6194	1
6	0.373	0.9934	0.4094	0.9931	0.4068	0.9992	0.5747	1
7	0.3623	0.9823	0.3878	0.9829	0.3847	0.9969	0.5393	1
8	0.3395	0.963	0.3567	0.9646	0.3839	0.9896	0.4915	1
9	0.3017	0.931	0.3252	0.9375	0.3414	0.9718	0.4545	1
10	0.2725	0.8767	0.2944	0.8933	0.3069	0.9478	0.4129	0.9997
11	0.2306	0.813	0.2635	0.8391	0.2779	0.9145	0.3891	0.9989
12	0.1969	0.7395	0.2254	0.7776	0.2468	0.8673	0.3452	0.9958
13	0.1637	0.6554	0.1818	0.6982	0.216	0.8073	0.3026	0.9877
14	0.1297	0.5767	0.1508	0.623	0.1783	0.7377	0.2677	0.9706
15	0.0991	0.4987	0.1184	0.5406	0.1443	0.6659	0.2252	0.936
16	0.0725	0.4186	0.0794	0.4558	0.1112	0.5768	0.1785	0.8749
17	0.0486	0.3452	0.055	0.3795	0.0727	0.4865	0.1349	0.7837
18	0.0315	0.2824	0.0354	0.3078	0.0522	0.3962	0.0909	0.6608
19	0.017	0.2131	0.0184	0.238	0.0247	0.3069	0.053	0.5194
20	0.0069	0.1566	0.0072	0.1741	0.0099	0.2161	0.0187	0.3346

Table A8: Parameter estimates from alternative modeling and empirical strategy

	inventions		utility models	
	point estimate	95% CI	point estimate	95% CI
γ	0.70	[0.1,0.9]	0.57	[0.19,0.9]
σ	20172.70	[1000.41,20916.1]	5005.29	[1000.1,7819.55]
α	2.41	[1.39,23.03]	0.60	[0.44,21.7]
θ	0.63	[0.1,0.9]	0.48	[0.1,0.9]
l_0	0.59	[0.1,0.9]	0.57	[0.1,0.9]
c	200070.00	[183649,220715]	170002.30	[125689,193118]
β	49934.00	[33141.3,70900.4]	50007.01	[39038.7,95965.6]

Table A9: The first-period patent values from alternative modeling and empirical strategy (in local currency, RMB)

	Inventions			Utility models		
	Before the patent reform	benchmark	After patent reform	Before the patent reform	Benchmark	After patent reform
Min	30278.09	29038.09	30027.49	2113.346	2016.181	4369.46
1%	59380.39	57812.41	74004.63	4510.692	4458.094	5127.859
5%	85318.14	85973.02	134780.3	5406.095	5166.669	8214.481
10%	107876.1	107460.6	185593.3	6470.582	5996.896	18601.89
25%	163773.7	162232.9	341124.9	11866.3	9925.139	113925.8
50%	255723.3	254594.4	730867.1	32364.35	24941.09	546423.7
75%	380777.6	382135.6	1253914	76953.1	61182.55	1034851
90%	535409.9	539792	1625684	131457.1	115991	1394020
95%	636760.4	645344.5	1797278	186547.8	180590.8	1586218
99%	867307.2	891747.5	2022839	530520.4	524222.1	1731568
Max	2404957	2048585	2786481	1492770	1743376	2382141
Mean	295246.2	295652.7	824584.7	61676.93	54892.3	622779.4
SD	181261.9	181660.4	541844.6	95851.72	98686.19	519386.2
N	10000	10000	10000	10000	10000	10000

Table A10: Robustness checks on MLE's parameter capture

	inventions			**utility models**		
	true value	estimates	95% CI	true value	estimates	95% CI
γ	0.71	0.709	[0.103,0.899]	0.5	0.508	[0.201,0.898]
σ	20089	20088.997	[1000.18,21384.719]	4990	4990.000	[1335.962,71852.953]
α	4	4.000	[2.189,9.987]	0.35	0.350	[0.003,2]
θ	0.32	0.320	[0.101,0.9]	0.57	0.574	[0.1,0.9]
l_0	0.76	0.760	[0.1,0.9]	0.51	0.510	[0.209,0.9]

Table A11: Summary statistics on data used for reduced-form analyses

	Min	25%	50%	75%	Max	Mean	SD	N
Invention applications	0	0	1	2	5248	2.005476	25.85055	77976
Utility model applications	0	1	2	5	10557	4.329704	42.39732	77976
Utility model ratio	0	0.5	0.90625	1	1	0.705089	0.371459	77976
Family patents	0	0	0	0	978	0.087719	4.061531	77976
Patent portfolio	0	2	4	9	17932	7.94774	78.96435	77976
HHI	0.000729	0.00126	0.002118	0.007676	1	0.005906	0.011539	77976
High litigation exposure	0	0	0	0	1	0.024649	0.155053	77976
Litigation exposure	0	0	0	0	0.479248	0.002746	0.023715	77976
Top 1% patents	0	0	0	0	74	0.036386	0.488818	54582
Top 5% patents	0	0	0	0	356	0.18136	2.078954	54582
Top 10% patents	0	0	0	0	737	0.372797	4.066648	54582
Top 25% patents	0	0	0	1	1714	0.936243	9.155761	54582
Below median patents	0	0	0	0	1346	0.300746	6.11588	77976
SOE	0	0	0	0	1	0.040089	0.19617	77976
Publicly traded firms	0	0	0	0	1	0.086911	0.281707	77976

Table A12: Robustness checks for the difference-in-differences analysis on utility model ratio

dependent variable: utility model ratio					
	(1) IPC classes	(2) Yearly changing exposure	(3) exposure (2001-2004)	(4) winsorized	(5) positive inventions and utility models
High_litigation_exposure*Post		0.0697***	0.134***	0.0733***	0.112***
		(0.0186)	(0.0236)	(0.0187)	(0.0239)
Litigation_exposure*Post	0.00767*				
	(0.00417)				
Post	-0.0319**	-0.0186*	-0.0305***	-0.0264***	0.0608***
	(0.0134)	(0.00983)	(0.00868)	(0.00937)	(0.0124)
High_litigation_exposure		-0.0926***			
		(0.0183)			
Log(family patents)	-0.217***	-0.216***	-0.217***	-0.265***	-0.0717***
	(0.0109)	(0.0110)	(0.0109)	(0.0111)	(0.00889)
Log(patent portfolio)	0.274***	0.275***	0.275***	0.296***	0.177***
	(0.00303)	(0.00307)	(0.00303)	(0.00310)	(0.00487)
HHI	0.455	-0.793***	-0.794***	-0.756***	-0.375*
	(0.376)	(0.220)	(0.222)	(0.221)	(0.225)
Constant	0.293***	0.304***	0.293***	0.272***	0.175***
	(0.0147)	(0.0110)	(0.0103)	(0.0110)	(0.0160)
Firm FEs	Y	Y	Y	Y	Y
Indutry FEs	N	Y	Y	Y	Y
Province FEs	Y	Y	Y	Y	Y
Observations	77,976	77,976	77,976	75,859	14,745
R-squared	0.641	0.642	0.642	0.643	0.735
#Firms	77976	77976	77976	76303	28242

Note: All specifications use OLS models and utility model ratios as dependent variables. Column 1 uses litigation exposure measured by IPC classes. Column 2 uses yearly changing measures for litigation exposure (computed by industries). Column 3 measures the exposure from 2001 to 2004 (computed by IPC classes). Column 4 excludes observations with many invention applications or utility models (top 1%). Column 5 uses a sample containing observations with a positive number of invention patents and utility models. HHI is computed at the IPC class level for column 1 and the industry level for the rest of the columns. Robust standard errors are clustered at the firm level, shown in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Figure A.1: The PDF of Gamma distributions

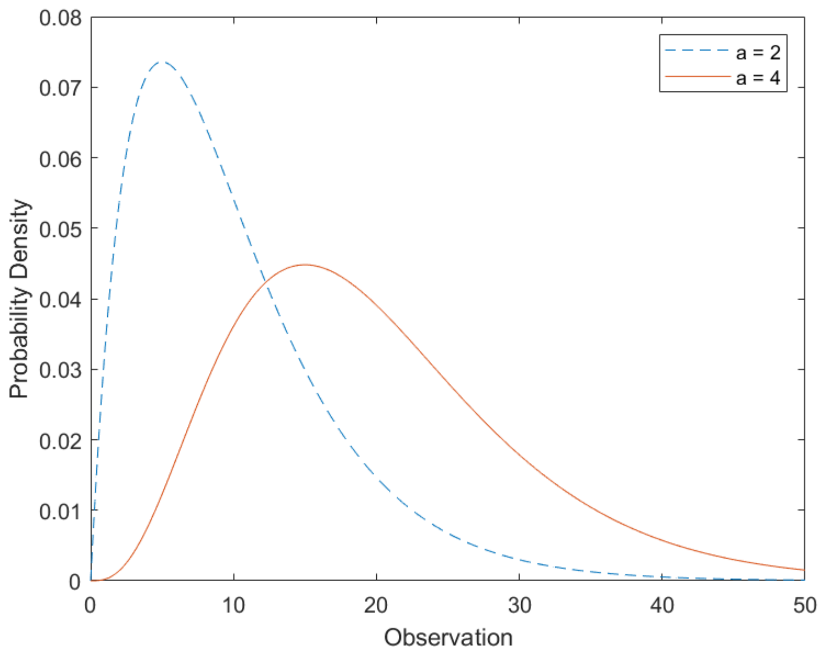


Figure A.2: Distribution of years from patent filing to patent litigation

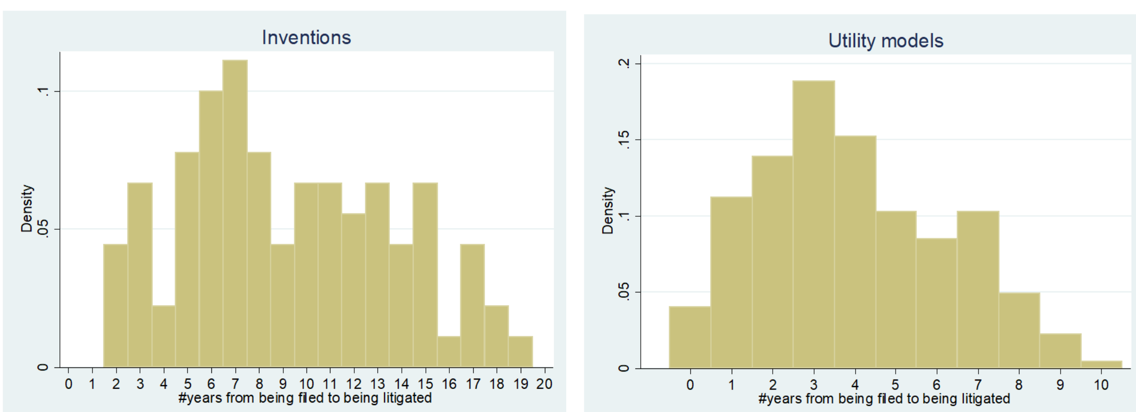


Figure A.3: Distribution of patent renewal terms (kernel density)

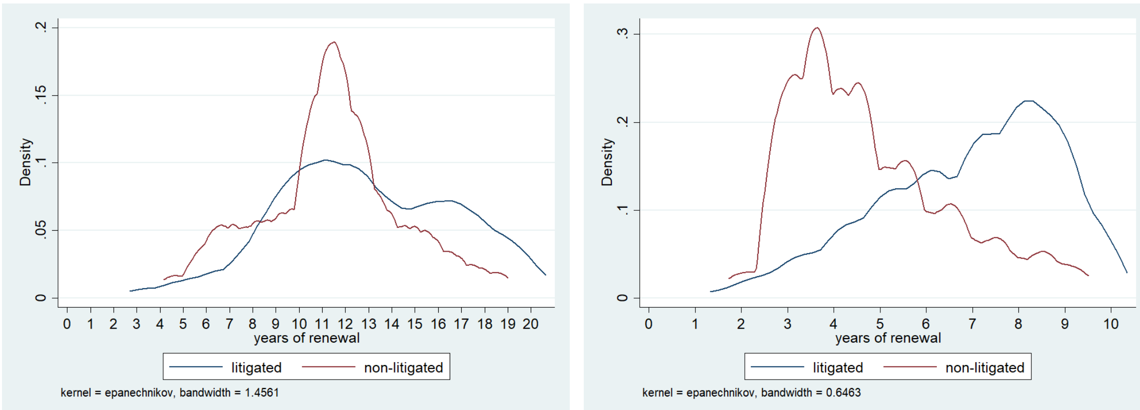


Figure A.4: Patent values at 10p, median and 90p

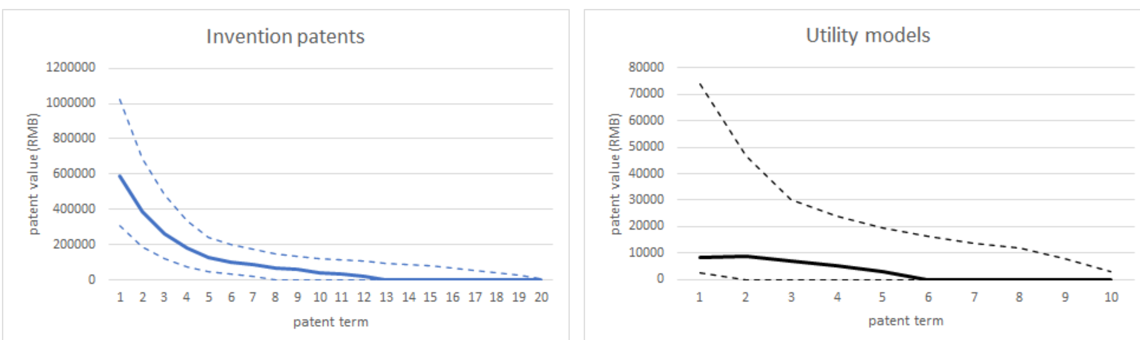


Figure A.5: Patent values at 10p, median and 90p in the benchmark scenario

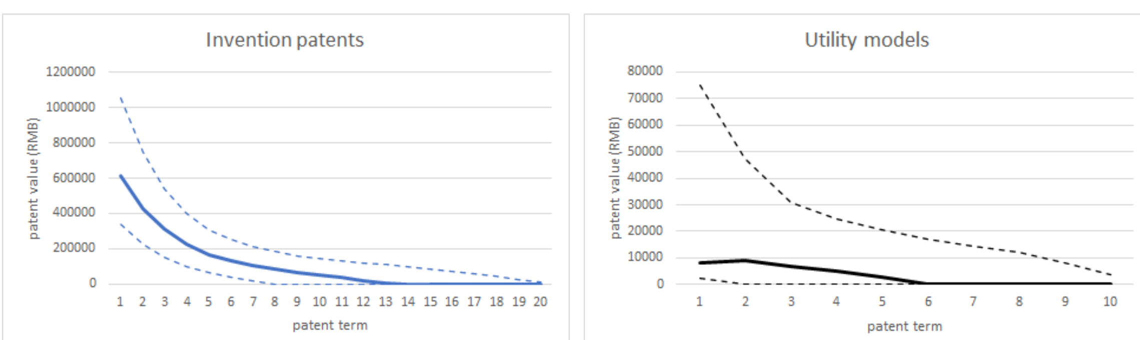


Figure A.6: Patent values at 10p, median and 90p after the patent reform

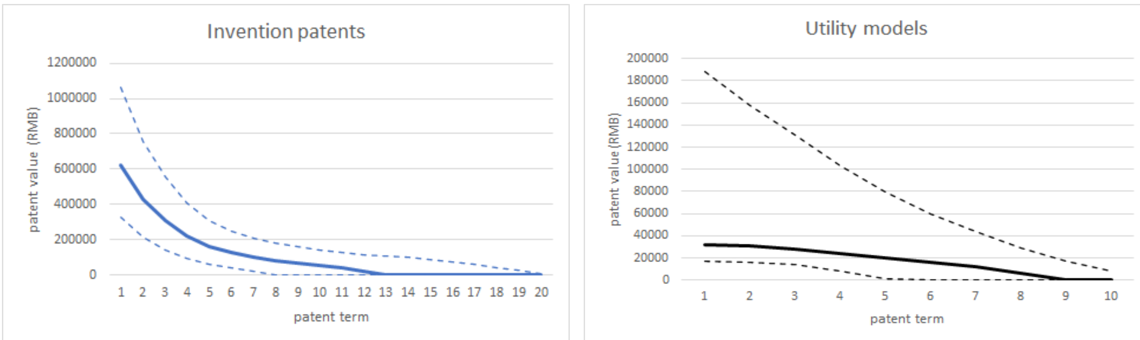
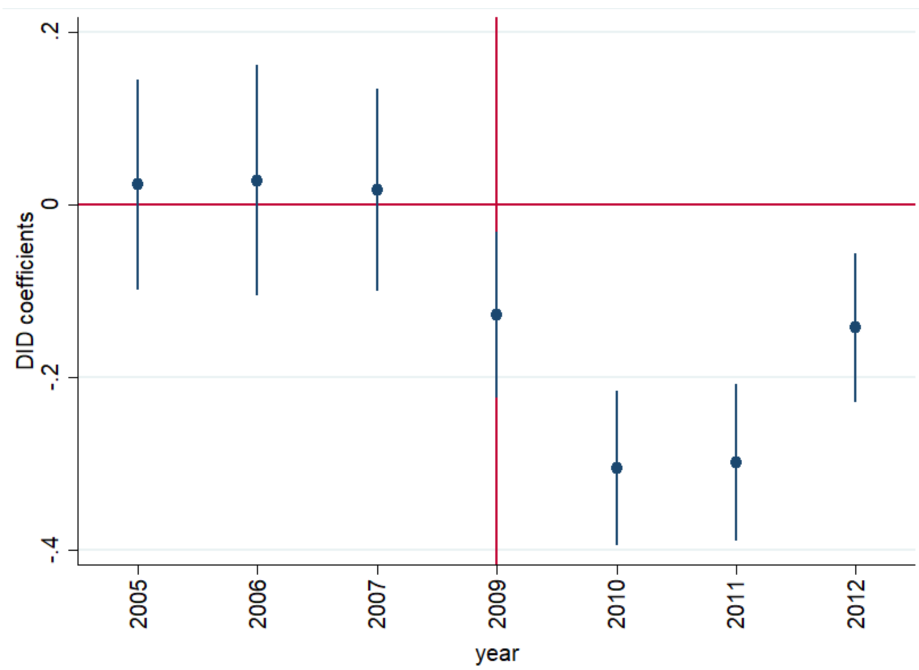


Figure A.7: The effect on the quality of invention patents (below-median)



Note: The x-axis shows the year; Y-axis shows the coefficients of the dynamic difference-in-differences estimation. The treated group is the industries with a higher-than median ratio of litigation occurrence before 2009. The dependent variable is the ratio of the number of invention patents whose quality is above median by filing year and IPC classes over the number of invention patent applications filed by the focal firm at year t. 2008 is set as the baseline year, thus omitted. Vertical lines show the 95% confidence intervals for point estimates.

B Robustness checks on the MLE method

To ensure the maximum likelihood estimation could produce robust results, I ran a simulation exercise to test how accurate the estimated parameters could be using this method. Specifically, I generate two sets of key parameters- γ,σ,α,θ, l_0- for invention patents and utility models, respectively (Table A10). Then I simulate 1000 utility models and 1000 invention patents with these parameters. The rest parameters of the model are calibrated following the same procedure introduced in section 4. After getting the two simulated data sets, I employ the same MLE method described in section 4 to estimate the key parameters. Given the stochastic components of the model, I run the estimation for 50 rounds for each data set [23].

Results are shown in Table A10. First, for the two types of patents, the medians of all parameters are almost the same as the true parameters I use to generate the data sets. This suggests that medians could be the statistics for parameter estimation. Furthermore, the 95% confidential intervals of estimated parameters seem not too far away from the median. This suggests that the parameter estimates by the maximum likelihood method yield numbers sitting at the center of the distribution of the estimated parameters, even for a small sample. In sum, this robustness exercise helps to confirm the reliability of the maximum likelihood method, at least for the sample and formal model I develop in section 3.

C Patent grant ratio adjustment

I introduce the method of calculating the grant rate, which estimates the expected patent value in Table A4. Typically, innovators make this comparison when they need to decide which type of patents to patent [24]. That said, the comparison on patent valuation needs to consider the possible failure of being rejected by the patent examiner [25]. Specifically, since utility models do not undergo rigorous examination, I assume their grant rate is 1. By contrast, filing an invention patent bears a specific risk of rejection. I calculate the invention grant rates using the IncoPat dataset from 2001 to 2008 (before patent reform)

[23] More rounds of simulation will certainly produce more accurate results. Therefore, the results from the 50-round estimation provide a "lower-bound" for our judgment on the accuracy of the estimates.

[24] In China, utility models are usually considered as "small inventions"- a substitute for invention patents with fewer inventive features. Therefore, innovators who decide to patent their inventions typically face the choice of filing an invention patent (slow, uncertain but broad) or a utility model (quick but narrow).

[25] I assume that the invention has already been done when innovators decide which type of patent to choose. Therefore, the innovation cost is sunk and not included in this back-of-envelope calculation.

and the period 2009 to 2012 (after patent reform). To mitigate the potential truncation problem [26]; I calculate the patent grant rate among patents already granted. While the composition of renewed patents might differ among patents filed in early and later years, I could still observe all rejection decisions made on these patents. Thus, I calculate the rejection rate as $\frac{\%rejected}{(\%rejected+\%renewed+\%expired)}$, where $\%rejected$ is the percentage points of rejected patents among all patents and $\%renewed$ and $\%expired$ are defined similarly. The grant rates of invention patents are one minus the rejection rate, which is 0.87 and 0.81 for patents filed from 2001 to 2008 and patents filed from 2009 to 2012, respectively. The slightly higher patent rejection rate after 2009 reflects the tightening in patent examination criteria imposed by the 2009 patent reform.

D Alternative model and parameter calibration

To test the sensibility of the major results to the modeling and parameter estimation strategy, I explore an alternative empirical approach in this section. For the modeling part, it mostly resembles the model introduced in section 3. Most changes are in the parameter estimation part. Instead of estimating five parameters, I estimate seven in this alternative setting, apart from the parameters estimated in the model from the main text- γ, the tech depreciation rate, σ, the variance of an exogenous shock to patent value, α, the position parameter of the distribution of initial patent value, θ, the share of profits extracted by the patent owner if the infringement is tolerated and l_0, the peak infringement hazards- I incorporate c, the litigation cost, and β, the shape parameter of the distribution of initial patent value, into the vector of parameters for estimation. Moving the litigation cost from the parameter for calibration to the parameter for estimation reduces the stochastic component of the model. Still, it tends to average off heterogeneity of litigation costs among patents. The rest of the empirical strategy is the same as the one in the main text, including the robustness test to confirm the feasibility of the MLE method, using a global search algorithm to find the initials, and the way to construct confidential intervals. I run 300 rounds of MLE estimation to pin down the final values of the parameters.

Table A8 reports the point estimates and the 95% confidential intervals. For γ, σ and l_0, both the magnitude and pattern of the estimates from this alternative model resemble those estimated from the five-parameter model of the main text (Table 2), which confirms the robustness of the main results for these three parameters. As for α, the parameter governing the distribution of initial patent value, the estimate of invention patents from

[26] Patents in a later batch of cohorts are less likely to exhibit the entire patent life cycle in the data I collect. For example, patents filed in 2012 tend to have fewer patents not renewed than those filed in 2001

the seven-parameter model is lower than that estimated from the five-parameter model. Still, the parameter estimate of utility models is larger than the five-parameter model. Put differently, the gap in the initial patent value between invention patents and utility models seems to be narrower in the seven-parameter model, which could be driven by the fact that this model fixates the litigation cost to a parameter and thus reduces the potential variation within the patent valuation. The other difference in the parameter estimates resides in θ, the share of profits extracted by the patent owner when the infringement is tolerated. The seven-parameter model estimates are around twice as large as those of the five-parameter model for invention patents and utility models. Though the magnitudes of these parameters are bigger, the general pattern- the relative ratio of θ among invention patents to θ among utility models- remains.

There are two parameters not estimated by the five-parameter model- litigation cost c and the gamma distribution shape parameter β. For litigation cost, the invention patents bear a higher cost than utility models, as expected; however, the magnitude of the litigation cost is around two-thirds of the upper bound of the range for damage awards. This implies that the litigation costs could be too high relative to the expected awards from patent remedies, consistent with the extremely low litigation rate observed in China. Moreover, the estimates of β for invention patents and utility models are close. They resemble the level I set up in the five-parameter model, further corroborating the robustness of this parameter in the main-text model.

Table A9 shows the simulated first-period patent value of the *de facto* statutory damage awards doctrine, the "benchmark“ scenario of UE or LP doctrines, and the scenario after the 2009 patent reform. Compared with the results in Table 3, the main findings of the five-parameter model still hold. First, the valuation of patents under the statutory damage awards and benchmark scenario is similar to the seven-parameter model, confirming the main finding that the statutory damage awards doctrine before 2009 seems to generate the appropriate patent value. With a closer look, though, the valuation of utility models appears to be slightly higher than that of the benchmark scenario, suggesting that the utility models have already been over-compensated, though minor, before 2009. This is consistent with the main finding from the five-parameter model that the litigation rates of utility models before 2009 are higher than those estimated from the benchmark scenario but the litigation rates of invention patents before 2009 are lower than the benchmark level. Second, when comparing the valuation under the scenario before 2009 and after 2009, the general pattern from the five-parameter model still holds- the valuation of utility models is enhanced to a more considerable extent than that of invention patents. However, the valuation of invention patents is also boosted according to this seven-parameter model. Specifically, the average value of utility models after the 2009 patent reform is almost ten times as significant as before 2009. In contrast, the average value of invention patents after the 2009 patent reform is merely 2.8 times as big as that before 2009. Taken together, both the parameter estimates and simulation exercises on patent valuation using the seven-parameter model generate results broadly consistent with the findings of the five-parameter model reported in the main text. Therefore, I confirm that the main findings are not sensitive to the modeling and estimation strategy.

E Descriptive Statistics of data used for structural estimation

Table A2 shows the summary statistics of sampled patents. Prior studies usually consider the number of claims, technological areas (usually identified by IPCs), foreign destinations of family patents, and inventors as measures for patent value (Allison et al., 2003; Lanjouw et al., 1998; Lanjouw and Schankerman, 1997). From this perspective, invention patents seem to be more valuable than utility models: both litigated, and non-litigated invention patents have a significantly larger number of claims, foreign destinations of family patents, inventors, and IPCs than utility models, litigated or non-litigated. This pattern is featured, in the model, of the positions of distributions of the initial value of the two types of patents: the gamma distribution of invention patents is to the right of that of utility models (Figure A.1).

If we compare litigated and non-litigated patents within each type of patents, however, the summary statistics provide a nuanced picture. Prior studies (Allison et al., 2003; Harhoff and Reitzig, 2004; Lanjouw and Schankerman, 2001) mostly focus on mature patent systems in Europe and the U.S., illustrate that litigated patents tend to be more valuable compared with non-litigated patents. For instance, litigated patents are featured of wider legal breadth (larger number of claims), more considerable international influence (more foreign destinations of family patents), and more intellectual inputs (more inventors). My sample of invention patents, however, exhibits a different pattern: litigated invention patents tend to have *narrower* legal breadth and international coverage (fewer claims and foreign destinations of family patents), and they are produced by *fewer* inventors. Plus, the likelihood for litigated invention patents to be traded (33%) is lower than that of non-litigated invention patents (45%) on average. Usually, patents of external value will be more likely to be traded. Therefore, these patterns indicate that invention patents that have been defended against infringement in court might *not* be the most valuable. This seems consistent with proposition 1: when the damage awards are limited within a range, patents with values beyond a specific range are less likely to be litigated.

The model also implies that this "adverse selection" pattern might be ameliorated as the patent value decreases. This intuition seems to be supported by the summary statistics of utility models. Being less valuable than invention patents, utility models will, as the model predicts, be more likely to exhibit the pattern consistent with the literature that valuable patents will be more likely to be litigated. This is because the entire distribution of the valuation of utility models likely falls below the threshold imposed by the upper bound of the damage awards so that the truncation does not distort the pattern. Panel C and D of table A2 confirms this prediction. Both the number of claims and the number of foreign destinations of family patents for litigated utility models are slightly larger rather than smaller than non-litigated utility models. The likelihood of patents being traded for litigated utility models (16%) is significantly higher than that of non-litigated utility models (4%). Though litigated utility models still have fewer IPCs and inventors than their non-litigated counterparts, the gap is much smaller than between litigated and non-litigated invention patents.

It is unsurprising that the invalidation likelihoods of litigated patents of both types are significantly higher than those of non-litigated patents. Invalidation is a legal procedure that allows any individual or organization to challenge the validity of a patent granted. Thus, invalidating the disputed patents is a common strategy employed by the defendant in patent infringement lawsuits, which, in return, leads to a high invalidation likelihood of litigated patents.

Figure A.2 shows distributions of the number of years from litigated patents being filed to the time the first infringement lawsuit was issued. The graph on the left shows the distribution of litigated invention patents: most litigated inventions were litigated within 15 years since the patent filing year, and seven years is the mode. On the other hand, litigated utility models have a much shorter cycle (graph on the right): most cases were filed within six years since the patent filing year, and the mode is three years.

Figure A.3 shows the distributions of patent renewal terms for sampled patents. Red lines are litigated patents, and blue lines are non-litigated patents. The literature suggests that the longer a patent is renewed, the more valuable the patent tends to be (Lanjouw and Schankerman, 1997; Pakes, 1984; Schankerman and Pakes, 1985). Thus, Figure A.3 also indicates the distribution of patent value. The graph on the left illustrates the pattern of invention patents. Litigated invention patents have a slightly "thicker" tail than non-litigated inventions, indicating that more litigated patents were renewed for longer than non-litigated patents. However, it is also evident that more non-litigated patents are seen around the hump of the distribution than litigated patents. This seems to suggest that the litigated and non-litigated invention patents differ in renewal terms, but the difference is insignificant. Nevertheless, the pattern of utility model renewal is different. The graph on the right shows that the distribution of litigated utility models is to the right of that of non-litigated utility models. This indicates that most litigated utility models are more valuable than most non-litigated utility models. Therefore, Figure A.3 further corroborates the pattern we have observed in the summary statistics: for the type of patents that tend to be more valuable (e.g., inventions), valuable patents are less likely to be litigated.