Financing Innovation with Innovation[*]

Zhiyuan Chen[†]
Renmin University

Minjie Deng[‡]
Simon Fraser University

Min Fang[§]
University of Toronto

This version: September 6, 2022
click here for the latest version

Abstract

This paper documents that firms increasingly finance innovation with their stock of innovation, measured as patents. We refer to this behavior as *financing innovation with innovation*. Drawing on patent collateral data from the US and China, we first show that (1) in both countries the number and the share of pledged patents as collateral have been rising steadily over the past decades, (2) Chinese firms, however, employ patents as collateral on a smaller scale and with a lower intensity than US firms, (3) firms increase their borrowing and innovation activities once they start to engage in patent collateral. We then construct a heterogeneous firm general equilibrium model featuring idiosyncratic productivity risk, innovation capital investment, and borrowing constrained by patent collateral. The model emphasizes two frictions that hinder the use of patent collateral: fixed inspection costs and low liquidation value of patent assets. We parameterize the model to firm-level data in the US and China respectively and find that both frictions are significantly more severe in China than in the US. Finally, counterfactual analyses show that the gains in innovation, output, and welfare from enhancing the liquidation value of patent assets in China to the US level are more substantial than reducing the inspection costs.

Keywords: Patent collateral; innovation investment; financial frictions; firm dynamics;
JEL Classification: E22, G32, O31, O33

[*]First version: September 2022. We thank seminar participants at COB (SHUFE) for useful comments. We thank financial support from China National Science Foundation project ID 72103192 (Zhiyuan Chen), SFU Presidential Research Start-Up Grant N000771 (Minjie Deng), and Swiss National Science Foundation project ID "New methods for asset pricing with frictions" (Min Fang). All errors are ours.

[†]Contact: chenzhiyuan@rmbs.ruc.edu.cn; School of Business, Renmin University of China, China

[‡]Contact: minjie.deng16@gmail.com; 8888 University Dr, Burnaby, BC V5A 1S6, Canada

[§]Contact: min.fang.ur@gmail.com; 150 St. George St., Toronto, Ontario M5S 3G7, Canada

1 Introduction

In the traditional view, financing investment in innovation using patents is difficult. The main reason is that the value of patents cannot be easily assessed and verified, which restricts the potential of using them as collateral to borrow from financial institutions (Hall and Lerner, 2010). However, as the world is evolving to a knowledge economy (Haskel and Westlake, 2017), firms increasingly pledge patents as collateral to obtain debt financing. We refer to the phenomenon of obtaining external debt financing using patent collateral as "*financing innovation with innovation*". In this paper, we document novel stylized facts of such a phenomenon and provide a quantitative assessment of the underlying frictions, mechanism, and welfare implications.

Although there is a growing tendency of using patents as collateral around the world, its penetration differs across countries. Drawing on patent collateral data from the world's two largest economies, the US and China, we document three stylized facts. First, both the number and the share of pledged patents as collateral have been rising steadily in both countries over the past decades. Second, Chinese firms, however, employ patents as collateral on a smaller scale and with a lower intensity than US firms.[1] The ratio of pledged patents increased from less than 5% to more than 15% from 1990 to 2015 in the US and from 0% to about 2% from 2005 to 2015 in China. It is worth noting that the growth in the number of pledged patents is enormous given the enlarging stock of patents over time. Finally, firm-level regressions show that firms increase their borrowing and innovation activities once they start to pledge patents as collateral.

To rationalize these stylized facts and shed light on the underlying frictions, mechanism, and welfare implications, we develop a heterogeneous firm model incorporating idiosyncratic productivity shocks, innovation capital, and collateral constraints. The key novel feature of our model is that firms could borrow against innovation capital up to a certain ratio that equals the liquidation value of patents after paying a fixed cost of inspection. There are essentially two important variables which reflect (1) the inspection technology used to evaluate patents, (2) the quality of financial institutions, (3) the frictions in the technological market : the fixed inspection cost and the liquidation value of patents. These two determinants govern the prevalence of using patents as collateral in the model.

The acceptance of using patents as collateral reflects the quality of financial institutions. For institutions to support patent-backed loans, market participants need to be able to examine the market value of patents and identify pledgeable patents (Kamiyama, Sheehan, and Martinez,

[1] In the US, patents have been increasingly used as collateral to support external financing since 1980. According to our data analysis, in 2014, the patent pledge ratio exceeded 15% in the US. In contrast, the practice of using patents as collateral is a relatively new concept. The first record of patent pledges in China was in 2005, which is 25 years later than in the US. Moreover, the patent pledging ratio is only around 2% in China.

2006). When issuing loans based on patent collateral, the lender would consider the fixed inspection cost and the liquidation value of the patent on the resale market.[2] Such an institutional status determines the equilibrium patent collateral participation ratio and the share of patents used as collateral of the economy. By comparing the model to the data on listed firms from the US and China, we find that both frictions are much more severe in China than in the US, with magnitudes of about ten times.

With such severe frictions in laggards, there is ample room for lagged countries, in this paper China, to stimulate innovation and further economic development through reducing such frictions. Considering the possibly strong policy implication of promoting the use of patent collateral, we conduct several counterfactual studies to show what will happen if China reduces the frictions to the US level. First, both reducing the inspection costs and increasing patent liquidation value could generate more innovation, more output, and welfare gains. Second, increasing the liquidation value of patents generates the most significant improvements. Third, there could be 27% more innovation capital and about 4% welfare gains in China if both frictions are reduced to the US level.

Literature Review To the best of our knowledge, this paper provides the first cross-country quantitative study on the welfare implications of debt financing with patent collateral. Although the practice of using patent collateral to obtain debt financing in US is well documented (see Amable, Chatelain, and Ralf (2010); Loumioti (2012); Hochberg, Serrano, and Ziedonis (2018); Mann (2018), among others), little is known about the advancement of using patent collateral in other countries. This limits the scope for understanding the policy implications for laggards. The comparative stylized facts we document for the world's two largest economies, i.e., the US and China, provide a more complete picture of the increasing tendency and future potential of promoting patent collateral from a global perspective. More importantly, by taking China as an example, our quantitative study implies that there is a great potential for lagged countries to improve the pledgeability of patents to stimulate innovation and improve welfare.

This study also contributes to a vast literature of quantitative studies on the impact of financial development on innovation investment and welfare. Most of these frameworks do not specify the role of patent collateral in debt financing (see Aghion et al. (2012); Midrigan and Xu (2014); Vereshchagina (2018); Caggese (2019); Altomonte et al. (2021); Chen (2022), among others). On the other hand, the stylized theoretical model which features patent collateral entering the

[2] The easiness of reselling patents after defaulting depends on the transaction frictions in the technological market Akcigit, Celik, and Greenwood (2016). The scale of patent transactions also differs greatly between the US and China. Zhang (2021) documents that, between 1998 and 2013, the percentage of patent assignment in the total number of granted patents is around 15% in the US and only around 4.4% in China. This reflects that the technological market in China entails higher frictions than the US.

borrowing constraints does not match real-life data on patent collateral (see Amable, Chatelain, and Ralf (2010) for example), thus lacking realistic welfare and policy implications of improving the pledgeability of patents. We fill the literature gap by constructing and calibrating a heterogeneous firm model in which patents can be pledged as collateral to obtain debt financing. By doing so, we quantify the innovation effect and welfare implication of promoting the practice of employing and accepting patent collateral, which has strong policy implications for a knowledge economy in years ahead.

Lastly, we contribute to a broader literature exploring the relationship between financial markets and innovation investment. Financial constraints have been found to have negative impacts on innovation activities (see Rajan and Zingales (1998); Cornaggia et al. (2015); Varela (2018); Duval, Hong, and Timmer (2020), among others)[3]. We add to this literature by emphasizing the role of patent collateral in facilitating innovative firms to obtain external financing in an environment of financial frictions. Specifically, we first document the growing trend of using patent collateral in both the US and China, and then quantify the welfare implication of improving the patent pledgeability in China to the US level.

Roadmap The remainder of this paper is organized as follows. In Section 2, we present stylized facts on the practice of using patent collateral in the US and China. In Section 3, we present the model. Section 4 provides the quantitative analysis, which includes model calibration and counterfactual analysis. We conclude the paper in Section 5.

2 Stylized Facts on Patent Pledges in the US and China

2.1 Institutions for Pledging Patents as Collateral

Institutions for pledging patents as collateral are similar in the US and China, though they differ in their efficiency of operations. Figure 1 plot (a) shows a flow chart of the process of obtaining external funds by employing patents as collateral. There are three main participants: patent owners, patent valuation companies, and lenders (including banks, equity investors, angel investors, etc.). Financially constrained patent owners who wish to pledge their patents as the collateral first need to obtain a patent valuation report from some patent valuation companies.[4] The patent

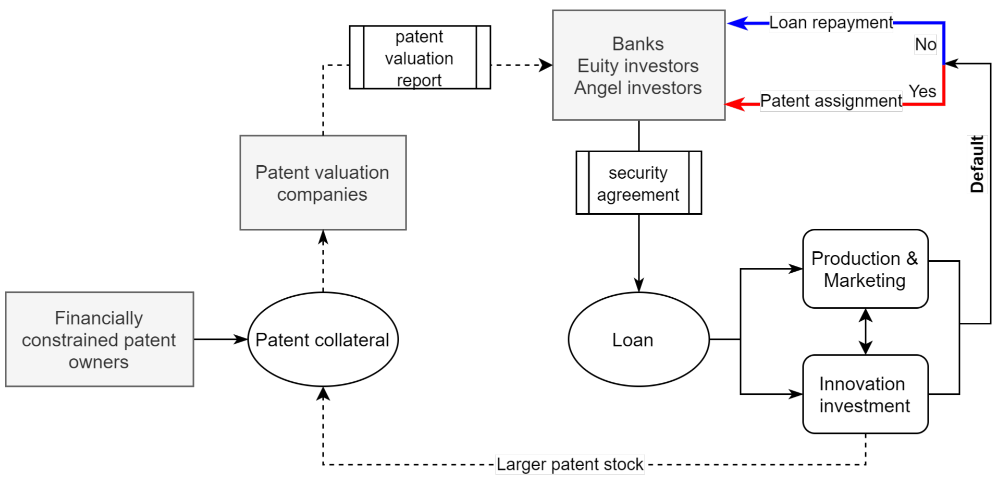
[3]See Kerr and Nanda (2015) for an earlier review of relevant empirical evidence.

[4]The patent valuation services range from basic valuation (current market value plus low & high estimates) to comprehensive valuation tailored to the product's market valuation. An example of a patent evaluation service provided by the US company *Transactions IP* could be found at `https://transactionsip.com/patent-valuation-services/`; An example of a Chinese patent evaluation company named *Ji Hui* can be found at: `http://zcpg.bjjihui.com/a/pxkc/lm1/1.html`.

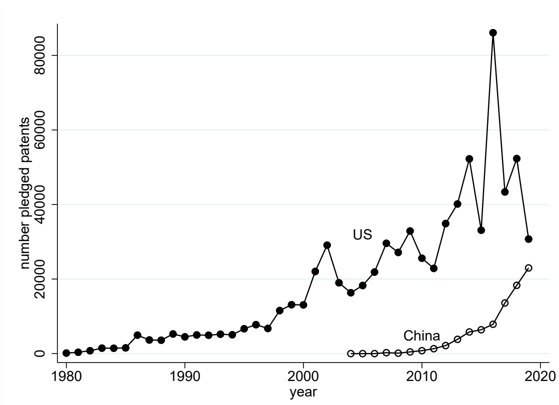
valuation report evaluates the financial value of the patent as an asset, usually based on the novelty of the patent and its market potential. Lenders, who usually lack professional knowledge to evaluate the patent, rely on the patent valuation report to decide whether to accept the patent as collateral and lend money to the patent owner.

After patent valuation, if the lender decides to take the patent as collateral to issue loans, a security agreement needs to be drafted and signed. The security agreement provides the lender with a security interest in the pledged patent collateral, with the terms and conditions specified. In the context of patent collateral, the security interest is an enforceable legal claim or lien on

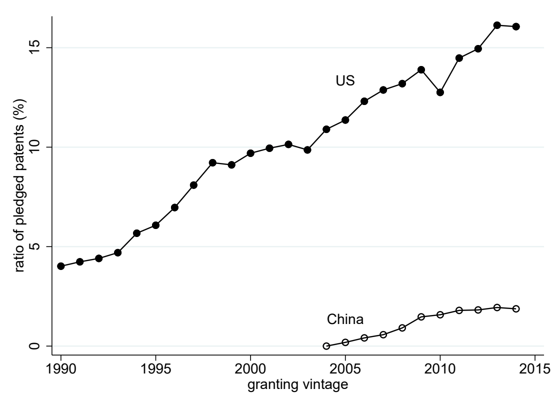
Figure 1: **Aggregate Stylized Facts on Patent Pledges in the US and China**



(a) Flow chart of obtaining patent-backed loans



(b) Total Number of Pledged Patents



(c) The Ratio of Pledged Patents

Notes: In plot (a), we illustrate the flow chart of the process of firms obtaining patent-backed loans. In plot (b), the total number of pledged patents in China is zero before 2005. In plot (c), we take a weighted average of utility models and inventions to calculate the ratio of pledged patents in China. The ratio of pledged patents in China was zero before 2005.

the patent collateral pledged to obtain a loan, which gives the lender the right to repossess all or part of the patent rights if the borrower defaults.[5] After receiving the loan, the borrower could use it for purposes of production, marketing, innovation, etc. All of these activities would affect the firm's profitability. In particular, if the loan is used to finance innovation, the borrower can accumulate more patents, which can put them in a better position in obtaining external financing in the future. This is exactly the channel that we call *financing innovation with innovation*. Lastly, if the borrower completes the loan repayment, the security agreement expires and the borrower resumes the patent rights. However, if the borrower defaults, the borrower loses his patent rights and the patent right is reassigned to the lender.

2.2 Aggregate-level Stylized Facts

First, we show the aggregate-level stylized facts of the growing tendency of using patent collateral both in the US and China.

Data Sources We obtain data on patent collateral in the United States from the Patent Assignment Dataset. The Patent Assignment Dataset contains information on transactions of patents recorded at the United States Patent and Trademark Office (USPTO), including security interest agreements which reflect patents being pledged as collateral for debt from 1970 to 2019. The data for all applied or granted patents are from the Historical Patent Data Files. It contains annual counts of patent applications, patent grants and patents-in-force from 1840 to 2014. The term "Patents" is referred to regular utility patents, which excludes applications and patents for designs, statutory invention registrations, plants, reissues and defensive publications. For other firm-level information, we obtain variables from Compustat and merge the patent information using The WRDS US Patents Compustat Link.

The data on China's patent collateral are from the China National Intellectual Property Administration (CNIPA), previously known as the China's State Intellectual Property Office (SIPO). For each patent used as loan collateral, CNIPA records the patent identification number, the pledgor and pledgee, and the length of the pledge. To make it comparable to the US patent collateral data, we focus on invention patents, which are perceived as the most innovative patents in China.[6] The use of patent as collateral was prohibited in China before 2003. To facilitate the comparison between China and US, we draw on these records covering between 2003 and 2014. To track the intensity of using patent collateral for each vintage of patents, we supplement the data on patent

[5]Recently, Ma, Tong, and Wang (2021) document that secured creditors exercise their control rights on collateralized patents when the borrowing innovative firm goes bankrupt.

[6]In the Appendix A.1.2, we show the patent pledge ratios for different types of patents (invention, utility, and design) in China, verifying that invention patent is the most frequently used in patent collateral.

pledges with the application date and authorization date for each patent. For detailed firm-level information, we obtain variables from the CSMAR and merge them with patent data. To the best of our knowledge, we construct the first Chinese data linking firm-level characteristics and patent collateral.

The Number of Patents Used as Collateral We first show the number of patent collateral in the US and China between 1990 and 2015. Figure 1 plot (b) shows the total number of pledged patents between 1980 and 2019. Using patents as collateral when borrowing has been a practice in the US since 1980 and has been growing steadily over the past three decades. However, it is relatively new for Chinese firms to pledge against patents when obtaining external funds. The earliest record of patent pledges in China was found in 2005. Despite that, in China, the number of pledged patents has been growing exponentially since 2010. By 2019, the scale of patent collateral in China is close to that of the US. This strong growing trend in China implies great potential for developing patent collateral to support investment in innovation.

Frequency-adjusted Patent Pledge Ratios Only comparing the total number of pledged patents can be misleading, as the total number of patents differs between China and the US. Therefore, we normalize the number of pledged patents using the total number of patents. Patents differ in their frequency of being used as collateral. The frequency of patent collateral usage reflects the patent holder's financial condition as well as the market prospect of patent. To reflect the intensity of using patent pledges more accurately, we adjust the number of patents using the frequency of patent collateral usage and calculate the ratios between pledged patents and total patents.[7] A patent can be used as collateral multiple times during its lifetime. We take advantage of this information and use it as a proxy for the liquidation value of the patent.[8]. That is, the patent being pledged more times is regarded as of higher liquidation value and can be resold more easily. Let $M_j(s)$ be the frequency that patent j is pledged as collateral within s years after its granting. We treat $M_j(s)$ as the proxy for the quality of this patent. $M_j(S)$ is used as a weight multiplied to patent j, reflecting its contribution in accounting for the usage of patent collateral. We then calculate the ratio of pledged patents in s years within granting vintage t as follows:

$$\gamma_t^q(s) = \frac{\sum_{j \in \mathcal{J}_t} M_j(s)}{\sum_{j \in \mathcal{J}_t}(1 + M_j(s))}, \tag{1}$$

where $\mathcal{J}_t$ is the index set of patents granted in year t. We calculate the ratio of pledged patents by choosing $s = 1, 3, 5, 7$, and set $s = 5$ in the benchmark case reported in the main text. Figure 1

[7] We report the non-adjusted pledged ratios in the Appendix A.1.1, and find no qualitative differences.

[8] In Appendix A.1.3, we document that around 56% (*resp.* 22%) of patents used more than once in patent collateral in the US (*resp.* China)

plot (c) shows the ratios of pledged patents in US and China from 1990 to 2014.[9] We find that US inventors pledge patents as collateral much more intensively than Chinese inventors. In the US, the patent pledge ratio rises from below 5% to over 15% from 1990 to 2014, implying an increased propensity of using patent pledges to obtain external funding. In sharp contrast, in China, the pledge ratio climbs from close to zero before 2005 to only around 2% in 2014. This shows that, as for the prevalence of patent pledges, China is far behind the US. This implies great potential ahead in encouraging firms to relieve their financing constraints by pledging against patents. This also motivates us to consider the economic impacts of stimulating Chinese financial institutions to accept patent collateral, which is the main purpose of the current paper.

2.3 Firm-level Evidence

Is the use of patent collateral effective? To answer this question, we employ firm-level data to investigate whether patent collateral could increase firms' borrowing and innovation investment.

Data Sources We merge the firm-level information from different data resources. For the US firm-level data, we link firms with individual patents using the firm-patent linkages provided by The WRDS US Patents Compustat Link. Details of variable construction and sample selection are in the Appendix A.2.1. For Chinese firm-level data, we obtain rich firm-level financial and innovation variables on Chinese listed firms from CSMAR, which can be viewed as the Compustat in China. We then link the patent data with the CSMAR data to construct the sample for empirical analysis. The corresponding details of variable construction and sample selection are in the Appendix A.2.2.

Empirical Strategy Our combined micro datasets provide detailed information on the link between firm characteristics and their usage of patent pledges. To employ a patent as collateral, firms have to accumulate some patent stock. Therefore, in our analysis we focus on innovative firms which have at least one active patent during the sample period. Using the merged firm-level samples, we show that relatively more US firms pledge patents as collateral than Chinese firms. In the US, 1,542 out of 2,848 innovative firms are patent pledgors, but only 214 out of 3,971 are patent pledgors in China (see Table 4 in the Appendix A.2.2).

We examine how borrowing and R&D investment respond to the activation of patent collateral. For firm i in year t, let Y_{it} be the outcome variable of interest, and PC_{it} be the indicator of using the patent as collaterals. We set PC_{it} to be one at the time the firm first uses pledge patents as collateral and afterwards. Otherwise, PC_{it} is equal to zero. We run the following two-way fixed

[9] Figures presenting results for all different time lengths can be found in Appendix A.

effects specification:

$$Y_{it} = \alpha + \beta PC_{it} + \boldsymbol{\gamma}\mathbf{Z}'_{it} + \lambda_i + \lambda_t + \xi_{it}, \tag{2}$$

where Y_{it} is the outcome variable. We use the firm's leverage ratio (total debt/total assets) to measure the firm's borrowing responses to patent collateral. To examine the innovation response, we use firm's R&D expenditures. $\mathbf{Z}_{it}$ is a vector of control variables. Our control variables include firms' ROE, ROA, Tobin's q, and total assets. These variables are standard in the macro finance and corporate finance literature. To account for unobserved firm-level factors that may lead to endogeneity issues, we control the firm-level fixed effects λ_i. The variable λ_t is a group of complete time dummies that account for the influence of macro factors such as monetary and fiscal policy adjustments. The error term is ξ_{it}. The parameter of interest is β. The estimates of β captures the impact of employing patent collateral on the outcomes. We run the regression using the US data and Chinese data, separately.

Firm-level Empirical Results Table 1 panel (a) reports the estimation results for the regressions based on equation (2) using US firm-level data. US firms pledging patents as collateral increase their leverage by 0.3%-0.8% and their R&D expenditures by 2.5%-6.8%, depending on empirical specifications. Panel (b) reports the estimation results for regressions based on equation (2) using Chinese firm-level data. Firms who employed patent as collateral increase their leverage by 2%-3.1%. We also find growth in R&D expenditures (9.8%-16.8%), suggesting that firms probably use patent collateral to finance their innovation.

2.4 Remarks on the Stylized Facts

In this section, we have documented several stylized facts. First, firms increasingly engage in patent collateral to borrow against their stock of innovation, measured as patents. Second, US patent holders employ patents as collateral on a greater scale and higher intensity than Chinese patent owners. And finally, firms increase their borrowing and innovation activities once they begin to engage in patent collateral. Based on these motivating facts, we construct a quantitative model incorporating financial frictions and patent collateral. The purpose is twofold. First, we employ the model to shed light on the underlying frictions that may hinder lagged countries in using patent collateral. Second, we rely on the model to evaluate the welfare gains of promoting patent collateral in China to the US level.

Table 1: **Responses of Leverage and R&D to Patent Collateral**

Panel (a) US Data								
	leverage				*log(R&D)*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
PC	0.008***	0.006***	0.003**	0.003**	0.068***	0.028***	0.025***	0.025***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.008)	(0.007)	(0.008)	(0.008)
L.log(asset)		0.033***	0.046***	0.046***		0.575***	0.589***	0.602***
		(0.001)	(0.001)	(0.001)		(0.005)	(0.007)	(0.008)
L.Tobin's Q			0.526***	0.521***			0.028	-0.013
			(0.003)	(0.003)			(0.021)	(0.021)
L.ROE			-0.052***				-0.211***	
			(0.003)				(0.025)	
L.ROA				-0.105***				-0.843***
				(0.010)				(0.070)
N	102093	92128	48821	48822	46953	41648	20678	20679
adj. R^2	0.754	0.778	0.890	0.889	0.944	0.960	0.970	0.970
Panel (b) Chinese Data								
	leverage				*log(R&D)*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
PC	0.031***	0.022**	0.021**	0.020**	0.168***	0.105**	0.100*	0.098*
	(0.010)	(0.009)	(0.009)	(0.009)	(0.056)	(0.053)	(0.053)	(0.053)
L.log(asset)		0.052***	0.072***	0.072***		0.610***	0.633***	0.634***
		(0.003)	(0.003)	(0.003)		(0.022)	(0.023)	(0.023)
L.Tobin's Q			0.016***	0.018***			0.044***	0.042***
			(0.001)	(0.001)			(0.009)	(0.009)
L.ROE			-0.237***				1.017***	
			(0.017)				(0.129)	
L.ROA				-0.777***				2.605***
				(0.030)				(0.222)
N	24000	20971	20325	20327	21901	19204	18651	18653
adj. R^2	0.725	0.752	0.763	0.774	0.808	0.840	0.844	0.845

Note: All regressions include firm and year fixed effects. Standard errors are in parentheses. * $p < 10\%$, ** $p < 5\%$, *** $p < 1\%$.

3 The Model

We consider an economy with financial frictions and innovation. Time t is discrete and infinite, $t = 1, ...,$. Each innovation firm $i = 1, ..., N$ is subject to idiosyncratic productivity shocks. Firms decide on investment in innovation to accumulate innovation capital, as well as how much labor and capital to hire, how much debt to borrow, and how much dividends to pay.

3.1 Technology and Innovation Firms

Each innovation firm i produces with productivity that consists of an idiosyncratic stochastic component z_{it} and an accumulative stock of innovation capital a_{it}, measured as patents, capital k_{it}, and labor l_{it} using the following production function:

$$y_{it} = (z_{it}a_{it}^{\gamma})k_{it}^{\alpha}l_{it}^{\nu}, \quad \gamma + \alpha + \nu < 1$$

where z_{it} is the stochastic idiosyncratic component of productivity of the firm i, which follows an exogenous Markov process $\log(z_{it}) = \rho_z \log(z_{it-1}) + \sigma_z \varepsilon_{it}$, where ε_{it} follows a standard normal random process. a_{it} is the endogenous component of productivity. γ, α and ν are the income shares of innovation capital, physical capital and labor, respectively. We require that $\gamma+\alpha+\nu < 1$ so that the production technology features decreasing return to scale.

Innovation firms do not own physical capital and labor, they rent physical capital and labor from the market with market prices r_t^k and w_t, respectively. The only intertemporal investment they make is innovation investment. Since firms can always repay the wage and rent bills within-period ($w_t l_{it} + r_t^k k_{it} < y_{it}$), firms' optimal labor supply and capital choices are determined by within-period wage, capital price, productivity, and innovation capital stock: $(z_{it}, a_{it}, r_t^k, w_t)$. Therefore, we could directly calculate firms' profits after paying the wage and capital rent $\{y_{it} - w_t l_{it} - (r_t^k)k_{it}\}$. The optimal choices are given by:

$$l_{it}^* = \left[\left(\frac{\nu}{w_t}\right)^{1-\alpha}\left(\frac{\alpha}{r_t^k}\right)^{\alpha} z_{it}a_{it}^{\gamma}\right]^{\frac{1}{1-\alpha-\nu}}, \quad \text{and} \quad k_{it}^* = \left[\left(\frac{\nu}{w_{it}}\right)^{\nu}\left(\frac{\alpha}{r_t^k}\right)^{1-\nu} z_{it}a_{it}^{\gamma}\right]^{\frac{1}{1-\alpha-\nu}}$$

Thus, the firm's production revenue after paying the wage and the capital rent is

$$f(z_{it}, a_{it}) = \max_{k,l}\left\{y_{it} - w_t l_{it} - r_t^k k_{it}\right\} = \left(\frac{\nu}{w_t}\right)^{\frac{\nu}{1-\alpha-\nu}}\left(\frac{\alpha}{r_t^k}\right)^{\frac{\alpha}{1-\alpha-\nu}}\left(z_{it}a_{it}^{\gamma}\right)^{\frac{1}{1-\alpha-\nu}} \tag{3}$$

3.2 Financing Innovation

The firm i can issue bond b_{it} to finance its innovation investment $(a_{it} - (1-\delta_a)a_{it-1})$. Since firms rent capital and labor which they could always repay within-period, the only purpose of debt borrowing is to finance its innovation investment in the model. Financial frictions occur due to information frictions and uncertainty in returns. Lenders require some collateral to back up their debt holdings in case of bad return shocks. Consistent with the previously documented stylized facts, we allow the innovation capital, measured as patents, to be used as collateral with two additional conditions. First, to debt holders, innovation collateral is less reliable than tangible assets due to a higher degree in uncertainty in innovation returns, so the liquidation value of patents is substantially lower than 100% ($\chi << 1$). Second, according to our study on the institutional arrangements for employing patent as collateral (See subsection 2.1), firms need to hire a professional appraisal agency to evaluate the collateral value of their innovation capital stock, which incurs a fixed inspection cost. Without loss of generality, we assume the inspection cost is an uniform distributed random variable $\xi \in [0, \bar{\xi}]$ paid in units of labor.[10]

For the sake of simplicity, we do not allow firms to finance its innovation with equity issuance, so dividend $d_{it} \geq 0$. Let $F_{it} = \{A, N\}$ indicate whether the firm decides to pay the fixed inspection costs. When $F_{it} = A$, the firm is active in paying the inspection cost, and when $F_{it} = N$, the firm does not pay the inspection costs and can only fund innovation investment using internal funds. Specifically, firms face a collateral constraint as follows:

$$b_{it}(1 + r_t) \leq \begin{cases} \chi(1 - \delta_a)a_{it} & if\, F_{it} = A \\ 0 & if\, F_{it} = N \end{cases}$$

where the debt needs to be repaid in $t + 1$ is always less than the innovation capital stock in $t + 1$. Since the firm always has the choice to cut back innovation capital and repay the debt, the non-negative dividend condition could always be satisfied and default never happens in equilibrium.

3.3 Recursive Problem for Innovation Firm

We write the firm's optimization recursively as in Benhima et al. (2022). The individual state variables of a firm are its idiosyncratic productivity z_{it} and its starting net worth n_{it-1} of the firm entering period t. Firms' decisions are divided into two sub-periods. In the first sub-period, firms maximize their total net revenue given their productivity and starting net worth. The firm decides how much innovation capital $q_t^a a_{it}$ to invest, whether to actively engage in patent collateral F_{it}, and how much debt b_{it} to hold if borrowing. Given the presence of the collateral constraint, the firm maximizes its end-of-period total net revenue

$$\pi^*(z_{it}, n_{it-1}, F_{it}) = \max_{a_{it}, b_{it}} \left\{ f(z_{it}, a_{it}) + (1 - \delta^a)q_t^a a_{it} - (1 + r_t)b_{it} \right\}, \tag{4}$$

subject to both constraints

$$q_t^a a_{it} = n_{it-1} + b_{it}, \tag{5}$$

[10] This random fixed cost setup is widely used in the lumpy investment literature (see Khan and Thomas (2008), Fang (2020), and Fang (2022)). This assumption helps to match the fact that firms' decisions of getting into patent collateral are not perfectly sorted by their states of productivity and net worth, which helps match the data better.

$$b_{it}(1+r_t) \le F_{it} \cdot \chi(1-\delta_a)a_{it}. \tag{6}$$

where $F_{it} = A$ (with the bool value 1) denotes that the firm participates in patent collateral and $F_{it} = N$ (with the bool value 0) denotes that the firm is not participating in patent collateral. The share of collateral χ stands for the liquidation value of patents which reflects the quality of institutions of the patent market.

In the second sub-period, entrepreneurs maximize their value function $v(z_{it}, n_{it-1}, F_{it})$ given their end of period total net revenue $\pi^*(z_{it}, n_{it-1}, F_{it})$ from the firm. We write the entrepreneur's optimization recursively. The expected (in terms of ξ) equity value of a firm owned by the entrepreneur is given by $v(z_{it}, n_{it-1}) = \frac{\xi^*}{\bar{\xi}} v(z_{it}, n_{it-1}, A) + (1 - \frac{\xi^*}{\bar{\xi}}) v(z_{it}, n_{it-1}, N)$. We denote the value function $v(z_{it}, n_{it-1}, F_{it})$ as the maximum of the present value of current and future dividends:

$$v(z_{it}, n_{it-1}, F_{it}) = \max_{d_{it}} \left\{ d_{it}(z_{it}, n_{it-1}, F_{it}) + \beta E_z[v(z_{i,t+1}, n_{it})] \right\} \tag{7}$$

where the firm's dividend d_{it} is subject to the time t non-negative dividend constraint: $d_{it} \ge 0$. The net worth follows the accumulation rule:

$$n_{it}(z_{it}, n_{it-1}, F_{it}) = \pi^*(z_{it}, n_{it-1}, F_{it}) - d_{it}(z_{it}, n_{it-1}, F_{it}) - \xi_{it}$$

We then have a threshold value for the inspection costs, which determines the use of patent collateral:

$$\xi^*(z_{it}, n_{it-1}) = \frac{\pi^*(z_{it}, n_{it-1}, A) - \pi^*(z_{it}, n_{it-1}, N)}{w_t}. \tag{8}$$

Firms with state (z_{it}, n_{it-1}) who draw the fixed cost higher than $\xi^*(z_{it}, n_{it-1})$ will not pledge patent as collateral, otherwise, they pay the drawn fixed cost and borrow using patent collateral.

3.4 Other Firms and Households

Physical Capital Producer There is a representative physical capital producer who owns and produces new aggregate physical capital using the technology $\Phi(I_t^k/K_t)K_t$, where I_t^k are units of the final good used to produce physical capital, $K_t = \int k_{it} di$ is the aggregate physical capital stock at the beginning of the period, $\Phi(I_t^k/K_t) = I_t^k + \frac{1}{2}\phi_k(I_t^k/K_t - \delta_k)^2 K_t$, and δ_k is the depreciation rate of physical capital. Profit maximization pins down the rent of the physical capital as $r_{t+1}^k = \phi_K(\frac{I_t^k}{K_t} - \delta_k) + \delta_k$, which will be constantly equal to δ_k in the steady state.

Innovation Capital Producer There is a representative innovation capital producer who produces new aggregate innovation capital using the technology $\Phi(I_t^a/A_t)A_t$, where I_t^a are units of the final good used to produce physical capital, $A_t = \int a_{it} di$ is the aggregate innovation capital stock at the beginning of the period, $\Phi(I_t^a/A_t) = \frac{\delta_a^{1/\phi_a}}{1-1/\phi_a} = \left(\frac{I_t^a/A_t}{\delta_a}\right)^{1-1/\phi_a} - \frac{\delta_a}{\phi_a - 1}$, and δ_a is the steady-state innovation investment rate. Profit maximization pins down the relative price of innovation capital as $q_t^a = \frac{1}{\Phi'(I_t^a/A_t)} = \left(\frac{I_t^a/A_t}{\delta_a}\right)^{1/\phi_a}$, which will be equal to 1 in the steady state.

Households There is a unit measure of continuous identical households with preferences over consumption C_t and labor supply L_t:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\eta}}{1-\eta} - \psi L_t \right)$$

subject to the budget constraint:

$$C_t + \frac{1}{1+r_t} B_t \leq B_{t-1} + W_t L_t$$

where E_0 is the expectation taken at the initial period 0, β is the discount factor of households, ψ is the disutility of working, r_t is the interest rate, B_t is one-period bonds and W_t is the nominal wage. Households choose consumption, labor, and bonds, which yields two Euler equations that determine both the real wage and the real interest rate: $W_t = -\frac{U_l(C_t,L_t)}{U_c(C_t,L_t)} = \psi C_t^{\eta}$ and $\frac{1}{1+r_t} = \beta \frac{U_c(C_{t+1},L_{t+1})}{U_c(C_t,L_t)} = \beta \left(\frac{C_t}{C_{t+1}}\right)^{\eta}$.

3.5 Equilibrium Definition

We now define the equilibrium of the model. We define $\mu(z, n, \xi)$ as the distribution of firms over their state vector (z, n, ξ).

Definition 1 *The **Recursive Competitive Equilibrium** for this economy is defined by a set of value functions and policy functions* $\{v(z,n), v^A(z,n), v^N(z,n), \xi^*(z,n), a'^{A*}(z,n), a'^{N*}(z,n)\}$, *a set of quantities* $\{C, L, K, Y(\Omega), A\}$, *a set of prices* $\{w, \Lambda, r, r^k, q\}$, *and a distribution* $\mu(z,n,\xi)$ *that solves the innovation firm's problem, other firms' problem, household's problem, and market clearing such that:*

*(i) **[Innovation Firm Optimization]** Taking the aggregate prices* $\{w, r, r^k, q, \Lambda\}$ *as given,* $v(z,n)$, $v^A(z,n)$, $v^N(z,n)$, *and* $\xi^*(z,n)$ *solve the firms' optimization (4) — (8) with associated decision rules* $a'^{A*}(z,n)$, $a'^{N*}(z,n)$.

*(ii) **[Household Optimization]** Taking the aggregate prices* $\{w, r\}$ *as given, {C, L, B} and* Λ *solve the household's utility maximization.*

*(iii) **[Other Firm Optimization]** Both capital producers maximize profit and determines the physical capital rent r^k and innovation capital price q^a.*

*(iv) **[Market Clearing]** The labor market clears, the bond market clears, and the final good market clears: $Y = C + I^k + I^a$.*

4 Quantitative Analysis

We now assess quantitatively how the easiness of patent collateral shapes firms' financing conditions and innovation. We first parameterize the model to both US and Chinese data. The key parameters that capture frictions in using patent collateral are parameterized to match the financing patterns observed in our firm-level data. We then show that the lack of patent collateral can quantitatively account for the observed patterns of financing innovation in the data. We finally conduct counterfactual exercises to consider the innovation and welfare gains from expanding patent collateral in China to the US level.

4.1 Parameterization

There are two groups of parameters. The first group of parameters is common to the US and China, and those in the second group are chosen to match data moments from the US and China, respectively. We provide the parameter values and the moments in the data and model in Appendix B.1.

Fixed Parameters The model is calibrated at an annual frequency. We set the discount factor $\beta = 0.96$, a conventional value in an annual model. We choose logarithmic utility and hours of working equal to 1/3 so that $\eta = 1$ and $\psi = 2$. We choose the decreasing return to scale of 85% as in Ottonello and Winberry (2020). We then set the physical capital share to 25% and innovation capital share to 15%, following estimates by Corrado, Hulten, and Sichel (2009) and as in Perez-Orive (2016) and Lopez and Olivella (2018), so $\{\alpha, \gamma, \nu\} = \{0.20, 0.15, 0.50\}$. To match the corresponding 12% tangible investment to output ratio and 5% intangible investment to output ratio as in NIPA, we choose the physical capital depreciation rate $\delta_k = 10\%$ and the innovation capital depreciation rate $\delta_a = 20\%$.

Fitted Parameters The second group of parameters is chosen to match moments on the average ratio of patent collateral of our firm-level sample, the participation ratio, and the standard deviation of the patent asset (adjusted by mean) in the US and China, respectively. For the AR(1) process of idiosyncratic productivity, we choose the persistent $\rho_z = 0.90$ and match the standard deviations $\sigma_z^{US} = 0.03$ and $\sigma_z^{CN} = 0.10$ to the patent asset standard deviation to mean ratio of the US (56.6%) and China (121.7%) respectively. The standard deviations indicate that Chinese innovation firms are facing more idiosyncratic volatility than US firms. We use two moments to identify the fixed inspection costs parameters ($\bar{\xi}^{US}$ and $\bar{\xi}^{CN}$) and the liquidation value parameters (χ^{US} and χ^{CN}). The patent collateral rate is defined as the ratio between number of patents used as collateral and the total active number of patents, whereas the collateral participation rate is the fraction of firms who have at least used their patents as collateral once among the firms who have patents. Because the fixed costs of inspection affects more on the firms' use of patent collateral at the extensive margin, the collateral participation rate will help us identify the fixed costs parameters. On the other hand, conditional on the inspection costs, the liquidation value of patents will generally affect the intensity of using patent collateral. Therefore the collateral participation rate will pin down the liquidation value parameters.

We match the fixed inspection costs $\bar{\xi}^{US} = 0.0075$, $\bar{\xi}^{CN} = 0.05$, and the liquidation values $\chi^{US} = 0.85$, $\chi^{CN} = 0.028$ using the average patent collateral rates of both economies (US=39%, CN=0.46%) and the collateral participation rates of both economies (US=54.1%, CN=5.4%), respectively. The result shows that Chinese firms facing much higher inspection costs of innovation collateral and a much lower innovation capital liquidation value. We illustrate the identifications of both frictions are in the section below. Both frictions jointly lead to a much lower patent collateral rate and a much lower collateral participation rate.

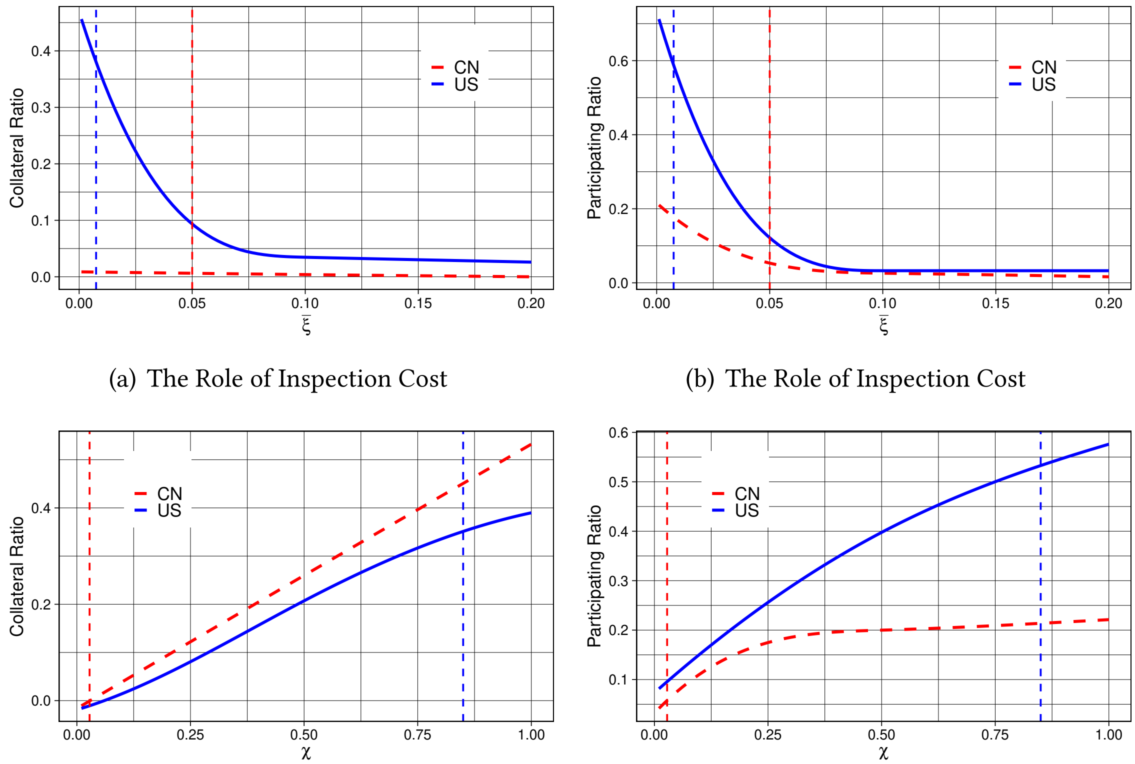
4.2 The Role of Patent Collateral Frictions

Now we show how the average patent collateral rate and collateral participation rate change with respect to the variations of the parameters governing the frictions.

Figure 2 plot (a) and (b) show how the average collateral ratio and participation ratio vary with inspection costs. The blue solid line stands for the US and red dashed line stands for China. The first observation is that reducing the inspection cost significantly increases the participation ratio in both the US and China, though the increase is less pronounced in China. Second, reducing the inspection cost also significantly increases the collateral ratio in the US, but not in China. Even reducing the inspection cost to almost zero (0.0001) cannot increase the collateral ratio to more than 1.2% since the liquidation value is too low (0.028) so that a significantly large of firms are still unwilling to overcome such costs to use patent collateral.

Figure 2 plot (c) and (d) show how the average collateral ratio and the participation ratio vary with the liquidation value. The blue solid line stands for the US and red dashed line stands for China. The first observation is that an increase in the liquidation value significantly increases

Figure 2: The Roles of Inspection Cost and Liquidation Value



(a) The Role of Inspection Cost

(b) The Role of Inspection Cost

(c) The Roles of Liquidation Value

(d) The Roles of Liquidation Value

Notes: This figure plots the variations of collateral ratio and participation ratio over the changes on the inspection cost and liquidation value for both the US and China. The blue solid line stands for the moments with respect to choices of the inspection costs in the US and the red dashed line stands for the moments with respect to choices of the inspection costs in China. The dashed vertical reference lines indicate the parameter choices of the inspection cost in both the US and China respectively.

the collateral ratio in both the US and China. Second, increasing the liquidation value will also significantly increase the participation ratio in the US, but not China after the liquidation value greater than 50%. Even increasing the liquidation value to 100% cannot increase the participation ratio to an additional gain of 3% since the inspection cost is too high (0.050).

Taken together, four plots jointly show that both types of patent collateral frictions matter for financing innovation with innovation in the model. Reducing the severity of either friction would significantly increase the degree of patent collateral in the model. To achieve a high level of patent collateral, reducing both frictions jointly would likely be the most effective.

Table 2: **Responses of Leverage and R&D to Patent Collateral in Model**

Panel (a) US Model								
	leverage				*log(R&D)*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
PC	0.2101***	0.2052***	0.1976***	0.1988***	0.1529***	0.3653***	0.2665***	0.2701***
	(0.0002)	(0.0003)	(0.0004)	(0.0004)	(0.0006)	(0.0010)	(0.0013)	(0.0015)
L.log(asset)		0.0055***	0.0058***	-0.0388***		-0.2990***	-0.2778***	0.4109***
		(0.0003)	(0.0003)	(0.0009)		(0.0017)	(0.0015)	(0.0041)
L.tobin's Q			0.1085***	0.1524***			1.2669***	0.4579***
			(0.0017)	(0.0020)			(0.0103)	(0.0124)
L.ROE			-0.0312				-8.9265***	
			(0.0544)				(0.4344)	
L.ROA				0.4430***				-6.9832***
				(0.0088)				(0.0366)
N	1000000	950000	900000	900000	945796	945796	895993	895993
adj. R^2	0.559	0.555	0.552	0.553	0.022	0.086	0.114	0.131
Panel (b) Chinese Model								
	leverage				*log(R&D)*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
PC	0.0171***	0.0171***	0.0162***	0.0162***	0.5562***	0.4216***	0.0597***	0.0867***
	(0.0000)	(0.0000)	(0.0001)	(0.0000)	(0.0028)	(0.0024)	(0.0020)	(0.0020)
L.log(asset)		-0.0000***	-0.0001***	-0.0002***		0.1675***	0.2071***	0.2009***
		(0.0000)	(0.0000)	(0.0000)		(0.0007)	(0.0006)	(0.0008)
L.tobin's Q			0.0000	0.0004***			1.3751***	1.3986***
			(0.0000)	(0.0000)			(0.0028)	(0.0034)
L.ROE			0.0221***				2.0375***	
			(0.0004)				(0.0456)	
L.ROA				0.0029***				0.1606***
				(0.0000)				(0.0058)
N	1000000	950000	900000	900000	901378	901378	854032	854032
adj. R^2	0.792	0.791	0.794	0.795	0.088	0.212	0.544	0.542

Note: Regression results using model-simulated data for US and China, respectively. * $p < 10\%$, ** $p < 5\%$, *** $p < 1\%$.

4.3 Financing Innovation with Innovation in the Model

We then replicate our empirical findings to show how patent collateral could boost innovation. We run the same regression equation (2) with almost the same specifications using model-simulated data. The only two differences are that, first, in the model, there are no aggregate shocks, so we do not control the variable λ_t which is a group of complete time dummies that account for the influence of macro factors such as monetary and fiscal policy adjustments, etc; second, in the model, there is resale of innovation capital while in the data we do not have negative R&D, so we replaced *log(R&D)* with *log(1+R&D)* to include most zero and negative values of changes in the stock of innovation capital. The results are robust if we exclude all zero and negative values of changes in the stock of innovation capital.

The results are in Table 2. Panel (a) reports the estimation results for regressions based on equation (2) using the US Model simulated firm-level data. US firms pledging patents as collateral increase their leverage by around 20% and their R&D expenditures by around 27% (column (8)). These coefficients are significantly positive but much larger than our empirical findings. This is because in the model, the only borrowing channel is *financing innovation with innovation*, which is particularly strong since other channels are not considered. Panel (b) reports the estimation results for regressions based on equation (2) using Chinese Model simulated firm-level data. Firms pledging patents as collateral increase their leverage by around 1.7%. We also find a large growth in R&D expenditures (around 8.7%, see column (8)), implying that firms probably use patents to finance their innovation. These coefficients are significant and quite close to our empirical findings. Overall, these results indicate that our model does a good job in fitting the non-targeted moments in the data.

4.4 What if China has US-level Frictions?

Finally, we demonstrate how the reductions in the frictions could improve welfare by showing the counterfactuals of China with US-level frictions. The results are shown in Table 3. Compared to the benchmark, in all counterfactuals, Chinese firms would increase financing innovation and improve aggregate economic outcomes. However, the reduction in inspection cost alone has only small improvements in aggregate economic outcomes, resulting in an increase of 0.18% in total output and 0.06% in total welfare. On the other hand, increasing the liquidation value to the US level significantly stimulates innovation investment and improves aggregate economic outcomes, resulting in about 14% increase in total output and about 4% increase in total welfare.

Our counterfactual analyses have strong real-world policy implications for lagged countries in terms of using patent collateral to promote economic growth. Given the stage of development of patent collateral in China, reducing fixed inspection cost (or, equivalently, adopting better evaluation technology) is much less effective than improving the liquidation value of patents in stimulating innovation and promoting welfare. Policies that include reducing frictions in the technological transaction markets and improving the legal protection of intellectual property

Table 3: **What if China has US-level Frictions?**

Model Outcomes	Benchmark	$\hat{\bar{\xi}}^{CN} = \bar{\xi}^{US}$	$\hat{\chi}^{CN} = \chi^{US}$	Both as US
Financing Innovation				
Patent collateral rate	0.47%	1.08%	43.5%	44.97%
Collateral participation rate	5.21%	15.37%	21.4%	30.46%
Economic Outcomes				
Changes in Total Output	-	0.18%	14.09%	14.06%
Changes in Total Capital	-	0.18%	14.08%	14.05%
Changes in Total Patent	-	0.36%	27.31%	27.18%
Changes in Total Consumption	-	0.04%	3.99%	4.03%
Changes in Total Welfare	-	0.06%	3.96%	3.89%

Note: This table reports the counterfactual results of reducing patent collateral frictions. In the three counterfactuals, we assume China has the US-level frictions on inspection cost, liquidation value, and both, respectively. We report on the status of financing innovation and aggregate economic outcomes.

rights would be a first-order consideration in unleashing the potential of patent collateral.

5 Conclusion

We study the emerging firm behavior of *financing innovation with innovation*. Using firm-level data and patent collateral data from both the US and China, we first show empirical evidence that (1) both the number of pledged patents and the share of patents being used as collateral have been rising steadily in the US and China; (2) however, US patent holders employ patents as collateral on a greater scale and intensity than Chinese patent owners. (3) firms that initiated patent collateral increases borrowing and innovation activities. We then rationalize these facts in a heterogeneous firm general equilibrium model with two barriers that hinder patent collateral: high fixed inspection costs and low liquidation value of patent asset. We show that both frictions matter for the difference between the US and China, but the gains in innovation and welfare from enhancing the liquidation value of patents in China to the US level are more substantial.

References

Aghion, Philippe, Philippe Askenazy, Nicolas Berman, Gilbert Cette, and Laurent Eymard. 2012. "Credit constraints and the cyclicality of R&D investment: Evidence from France." *Journal of the European Economic Association* 10 (5):1001–1024.

Akcigit, Ufuk, Murat Alp Celik, and Jeremy Greenwood. 2016. "Buy, Keep, or Sell: Economic Growth and the Market for Ideas." *Econometrica* 84 (3):943–984.

Altomonte, Carlo, Domenico Favoino, Monica Morlacco, and Tommaso Sonno. 2021. "Markups, intangible capital and heterogeneous financial frictions." *unpublished manuscript* .

Amable, Bruno, Jean-Bernard Chatelain, and Kirsten Ralf. 2010. "Patents as collateral." *Journal of Economic Dynamics and Control* 34 (6):1092–1104.

Benhima, Kenza, Omar Chafik, Min Fang, and Wenxia Tang. 2022. "Short-term Finance, Long-term Effects: Theory and Evidence from Morocco." *Working Paper Available at SSRN 4105607* .

Caggese, Andrea. 2019. "Financing constraints, radical versus incremental innovation, and aggregate productivity." *American Economic Journal: Macroeconomics* 11 (2):275–309.

Chen, Zhiyuan. 2022. "Finance and TFP Dynamics: The Role of R&D Investment." *Available at SSRN 4002874* .

Chen, Zhiyuan and Jie Zhang. 2019. "Types of patents and driving forces behind the patent growth in China." *Economic Modelling* 80:294–302.

Cornaggia, Jess, Yifei Mao, Xuan Tian, and Brian Wolfe. 2015. "Does banking competition affect innovation?" *Journal of Financial Economics* 115 (1):189–209.

Corrado, Carol, Charles Hulten, and Daniel Sichel. 2009. "Intangible capital and US economic growth." *Review of income and wealth* 55 (3):661–685.

Duval, Romain, Gee Hee Hong, and Yannick Timmer. 2020. "Financial frictions and the great productivity slowdown." *The Review of Financial Studies* 33 (2):475–503.

Fang, Min. 2020. "Lumpy Investment, Fluctuations in Volatility and Monetary Policy." *Working Paper Available at SSRN 3543513* .

———. 2022. "A Note on nonconvex adjustment costs in lumpy investment models: Mean versus variance." *Macroeconomic Dynamics* :1–12.

Hall, Bronwyn H. and Josh Lerner. 2010. "Chapter 14 - The financing of R&D and innovation." In *Handbook of The Economics of Innovation*, vol. 1, edited by Bronwyn H. Hall and Nathan Rosenberg. North-Holland, 609 – 639.

Haskel, Jonathan and Stian Westlake. 2017. "Capitalism without capital." In *Capitalism without Capital*. Princeton University Press.

Hochberg, Yael V, Carlos J Serrano, and Rosemarie H Ziedonis. 2018. "Patent collateral, investor commitment, and the market for venture lending." *Journal of Financial Economics* 130 (1):74–94.

Kamiyama, Shigeki, Jerry Sheehan, and Catalina Martinez. 2006. "Valuation and exploitation of intellectual property." *OECD working paper* .

Kerr, William R. and Ramana Nanda. 2015. “Financing innovation.” *Annual Review of Financial Economics* 7 (1):445–462.

Khan, Aubhik and Julia K Thomas. 2008. “Idiosyncratic shocks and the role of nonconvexities in plant and aggregate investment dynamics.” *Econometrica* 76 (2):395–436.

Lopez, Jose Ignacio and Virginia Olivella. 2018. “The importance of intangible capital for the transmission of financial shocks.” *Review of Economic Dynamics* 30:223–238.

Loumioti, Maria. 2012. “The use of intangible assets as loan collateral.” *Available at SSRN 1748675* .

Ma, Song, Joy Tianjiao Tong, and Wei Wang. 2021. “Bankrupt innovative firms.” *Management Science* .

Mann, William. 2018. “Creditor rights and innovation: Evidence from patent collateral.” *Journal of Financial Economics* 130 (1):25–47.

Midrigan, Virgiliu and Daniel Yi Xu. 2014. “Finance and misallocation: Evidence from plant-level data.” *American Economic Review* 104 (2):422–58.

Ottonello, Pablo and Thomas Winberry. 2020. “Financial heterogeneity and the investment channel of monetary policy.” *Econometrica* 88 (6):2473–2502.

Perez-Orive, Ander. 2016. “Credit constraints, firms precautionary investment, and the business cycle.” *Journal of Monetary Economics* 78:112–131.

Rajan, Raghuram G. and Luigi Zingales. 1998. “Financial dependence and growth.” *The American Economic Review* 88 (3):559–586.

Varela, Liliana. 2018. “Reallocation, competition, and productivity: Evidence from a financial liberalization episode.” *The Review of Economic Studies* 85 (2):1279–1313.

Vereshchagina, Galina. 2018. “Financial constraints and economic development: the role of innovative investment.” 2018 Meeting Papers 1107, Society for Economic Dynamics.

Zhang, Yiran. 2021. “Quantitative Assessment on Frictions in Technology Market.” MPRA Paper 109470, University Library of Munich, Germany.

Online Appendix for "Financing Innovation with Innovation" by Zhiyuan Chen, Minjie Deng, and Min Fang (Not for Publication)

A Empirical Appendix

A.1 Patent Pledges

In this subsection, we provide a more detailed description of patent pledges for US and China datasets.

A.1.1 Non Frequency-Adjusted Pledge Ratios

The non-quality weighted patent pledged ratio is calculated as:

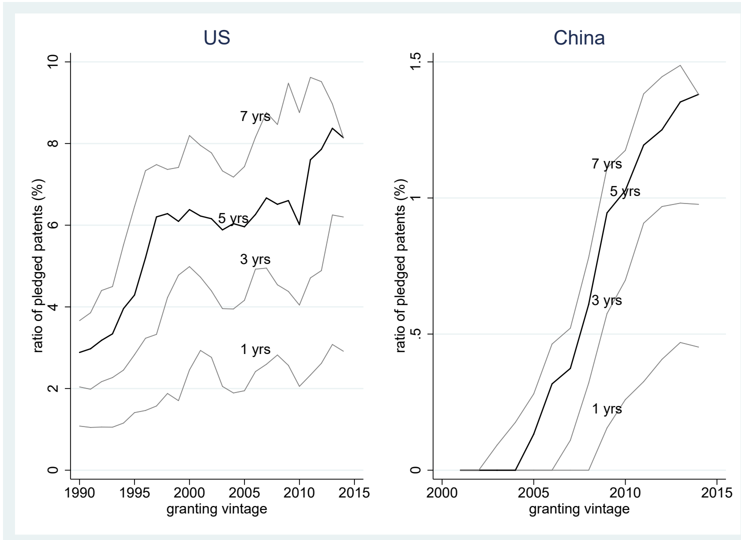
$$\gamma_t^{nq}(s) = \frac{\sum_{j \in \mathcal{J}_t} \mathbb{I}_j(s)}{\|\mathcal{J}_t\|} \tag{9}$$

where $\mathbb{I}_j(s)$ is an indicator function equal to one if patent j is used as patent collateral during s periods within granting vintage t, and $\|\mathcal{J}_t\|$ is the total number of patents granted in year t.

Figure 3 Panel A shows the non-quality weighted patent pledge ratios with $s = 1, 3, 5, 7$. In Figure 3 Panel B, we display the corresponding quality-weighted patent pledge ratios. The dark solid line indicates the time horizon we choose as the benchmark ($s = 5$). As we increase s, the resulting pledge ratios increase because patents are more likely to be employed as patent collateral as they age. The gap in patent pledge ratios between the US and China is quite stable to the choice of different values for s, though the magnitude varies with different choices for s.

The quality-weighted patent pledge ratios are higher than the non-quality-weighted patent pledge ratios, as patents are usually pledged more than once. However, we only see a nuanced difference for Chinese data. This is because the frequencies of being pledged for each patent are lower than those in the US. Lastly, we see a steady growing trend in patent pledge ratios in China, indicating advancements in the patent market and improvements in the functioning of financial intermediaries.

Panel A: Non-Quality Weighted Patent Pledge Ratios



Panel B: Quality Weighted Patent Pledge Ratios

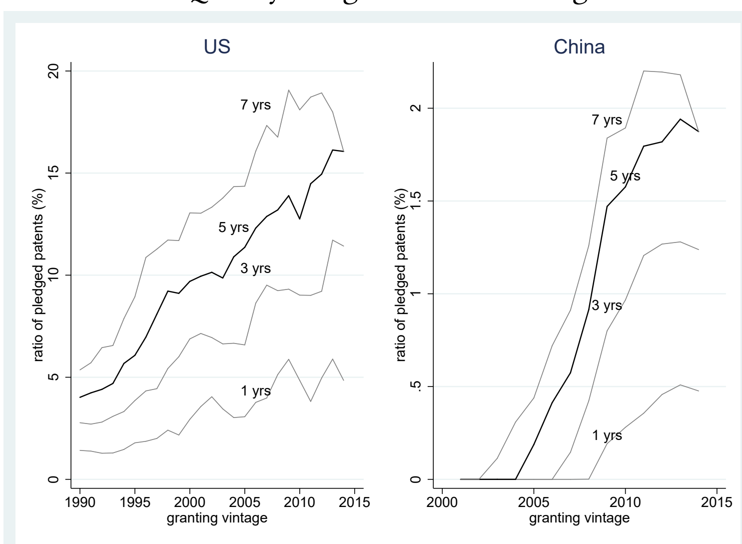


Figure 3: US-China Comparison of Patent Pledges for Different Windows

A.1.2 Patent Pledges by Types

Figure 4 plots the fraction of patent pledges by the type of patent granted and the age of granting, as well as their average numbers. Invention patents have the highest pledging ratio, utility model patents have a lower pledging ratio, and design patents have the lowest pledging fraction. This ranking is consistent with the usual conjecture on the ranking of the liquidation value for different patents (Chen and Zhang, 2019).[11] For invention patents, their pledging ratios have reached around 4 percent in recent years, and utility models below 2 percent. Design patents, which has the least novelty, have pledging ratios close to zero.

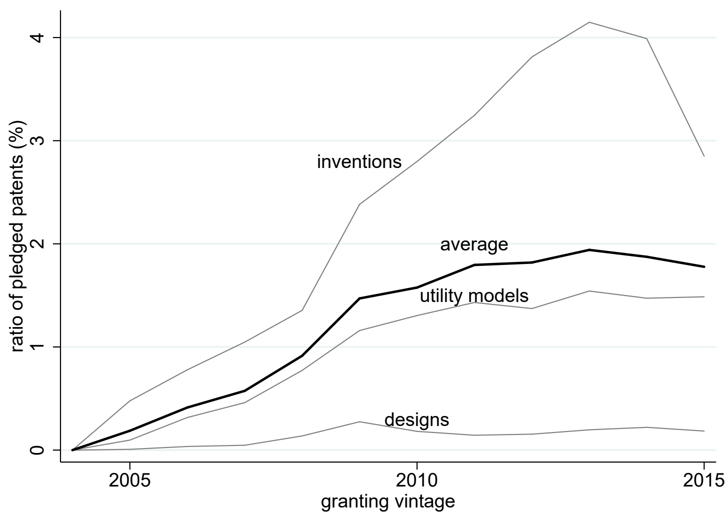


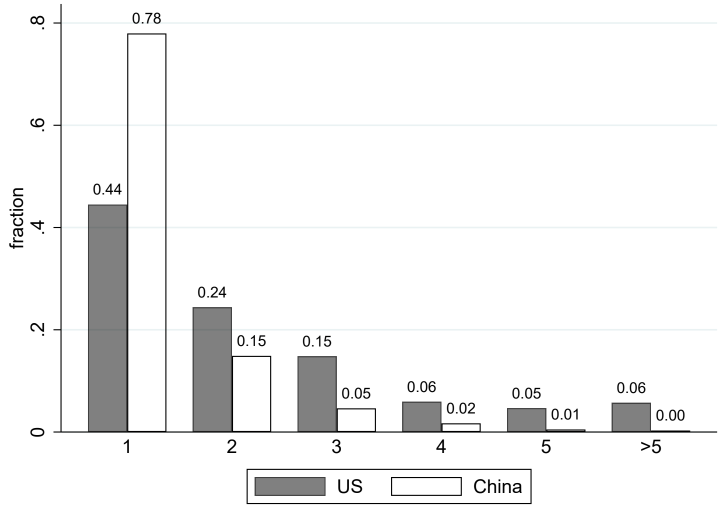
Figure 4: Patent Pledges for Three Different Types of Patents in China

A.1.3 Frequencies of Patent Pledges

Figure 5 shows the distribution of average repeated pledging times for all pledged patents in the US and China. A large fraction of patents are pledged only once. Around 44% (resp. 78%) of pledged patents in the US (resp. China) are only employed once. Pledged patents are more likely to be repeatedly used in US than in China. Percentage drop as more repetitive uses of patent collateral occur. Around 24% of pledged patents are repeatedly used twice in the US, but this number is only 15% in China. In the US, 15% of the patents are pledged three times. Moreover, 6% of the pledged patents are repeatedly employed more than five times in the US. While in China, this fraction is zero.

[11] In China's patent law, invention is referred to the new technical solution proposed for the product, method or related improvement; the utility model refers to a new technical solution suitable for practical use proposed for shape, construction or their combination. According to Article 22 of the Patent Law of the P.R.C.: any invention or utility model for which patent right may be granted must possess novelty, inventiveness and practical applicability. In comparison, the requirement for the approving of design patents is in Article 24 of the Patent Law of the P.R.C as ". . . . . . must not be identical with or similar to any design which, before the date of filing, has been publicly disclosed in publications in the country or abroad or has been publicly used in the country, and must not collide with any prior legal rights obtained by any other person."

Figure 5: Frequencies of Patent Pledges for US and China



A.2 Firm-level Data

A.2.1 Compustat and Patent Data

US Data We link firms with individual patents using the gvkey-patnum (gvkey identifies firm ID and patnum indicates patent number) linkages provided by The WRDS US Patents Compustat Link. The Compustat contains rich firm-level information on publicly listed US firms, which allows us to explore the features of the firms.[12] The WRDS US Patents Compustat Link covers patents granted between the years 2011 and 2019 and the matching is done with company names using fuzzy name matching algorithms. Also, the geographical information and corporate hierarchy information from WRDS Subsidiary database has been used for fine-tuning the matching results. After matching individual patent information to its corresponding firms, we can compare the characteristics of firms who hold patents and who do not hold patents.

In addition to existing firm-level variables, such as assets and sales, we also construct firm-level investment and leverage. Investment for firm j at time t is defined as the ratio (×100%) of quarterly capital expenditures (*capxy*) to the lag of quarterly property, plant and equipment (*ppentq*). Leverage is defined as the debt-to-asset ratio which is the sum of debt maturing within one year and debt maturing in more than one year (*dlcq+dlttq*) over total assets (*atq*).

Sample Selection First, we keep observations with Current ISO Country Code - Headquarters (*loc*) as USA. Second, we disregard observations from financial sector firms (SICs 6000-6999), non-

[12] Although Compustat only includes public firms, it covers a big fraction of U.S. output.

profit organizations and governmental enterprises (SICs 8000s & 9000s), as well as utilities (SICs 4900-4999). Third, we drop firm-quarter observations with missing or negative sales and with missing, or non-positive total assets. Lastly, we winsorize investment and leverage at the top and bottom 5% of the distribution.

Firm Distribution After merging Compustat data with patent data using The WRDS US Patents Compustat Link, we have panel data containing 102,797 observations for 5,210 firms. In our sample, about 55% (2,848 out of 5,210) of the firms have at least one patent (see Table 4 Panel A). The firms with patents are generally bigger and invest more. Figure 6 compares the histograms of assets, sales, investment, and leverage for firms with at least one patent to the firm with no patents. The firms with patents are generally bigger and invest more. In terms of leverage, a large fraction of both firms with patents and without patents have nearly zero leverage. We plot for the firms with at least 1% of leverage. Firms with patents have slightly lower average leverage (0.225 versus 0.240), but the median leverage is similar (0.207 versus 0.200). The observations with patents have a smaller standard deviation than those without patents (0.195 versus 0.224).

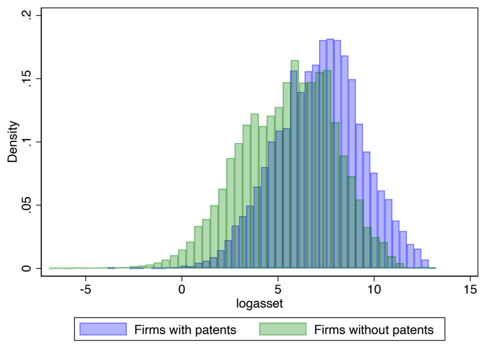
We then match the above data with patent collateral information to compare the characteristics of firms that use their patents as collateral to firms whose patents are never used as collateral. Figure 7 compares the histograms of assets, sales, investment, and leverage for firms that have pledged their patents once and those firms who have never pledged their patents. Firms that pledged their patents are, in general, smaller but invest more. Also, firms who pledged their patents have higher leverage. The comparison indicates that patent collateral provides a way for firms that are smaller but are active in investment to obtain funding.

A.2.2 CSMAR Data

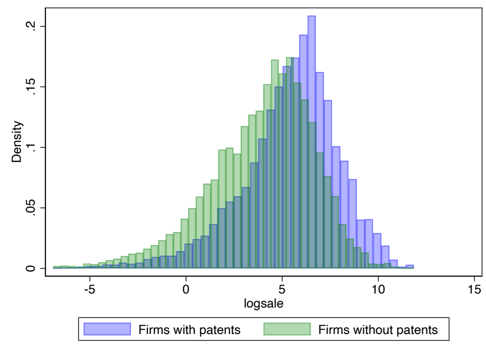
Chinese Data We obtain rich firm-level financial and innovation variables on Chinese listed firms from CSMAR.[13] To explore the differences in firm characteristics between patent pledgors and non patent pledgors, we link the CSMAR data with the data on China's patent collateral using firm names. To ensure the quality of the matching, we also perform fuzzy matching using the stem words in firm names and have manually checked its efficiency. In our sample during 2009 and 2019, 214 unique firms (347 firm-year observations) are matched to the patent collateral database. On average, each firm pledge around 5.86 times when using patents as collateral, resulting in 2,035 patent-year counts and 1,629 unique patents.[14]

[13] CSMAR is usually viewed as the Compustat in China.

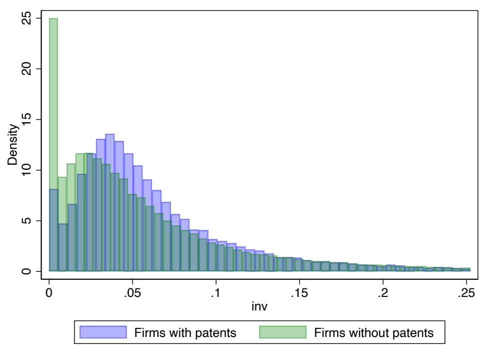
[14] Top three industries using patent collateral are computers & communication equipment, special equipment, and pharmaceutical manufacturing.



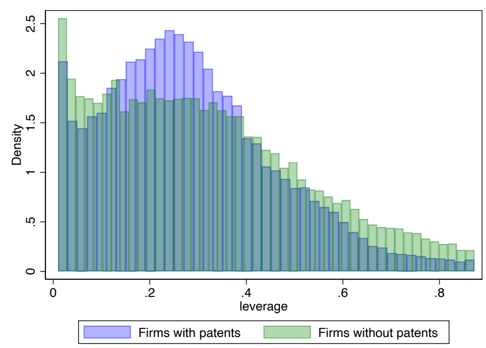
(a) Assets



(b) Sales



(c) Investment



(d) Leverage

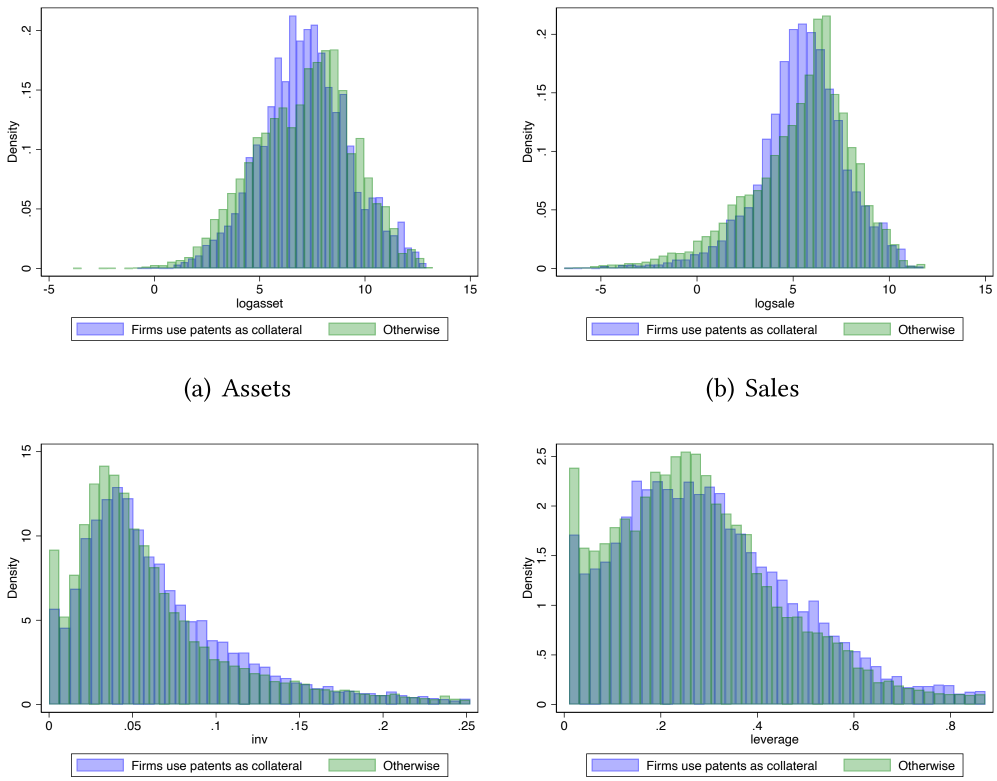
Figure 6: Firm characteristics with patents and without patents

Note: For leverage, we plot the diagrams for firms whose leverage is at least 0.01.

Because owning a patent is a prerequisite for using patents as collateral, we focus on innovative firms which have at least one granted invention or utility patent in our sample. Table 4 Panel B reports number of different types of firms. Out of 4,635 firms, 3,971 firms (around 85.7%) have at least one granted patent, of which only 214 firms (around 5.4%) have used patent as collateral.

Variables Construction We obtain detailed firm-level information from China Stock Market Accounting Research (CSMAR). We perform our empirical analysis using the yearly data. The variables of *logassets*, *logsales* and *leverage* and are defined as we did for the Compustat data. We construct investment using two ways:

1. Total investment in a year is calculated as the total cash payments for purchasing long-run assets (including fixed assets, intangible assets and other long-run assets) subtracted by cash earned from disposal of long-run assets. Investment rate is the ratio of the total investment to the sum of lagged fixed assets and intangible assets.



(a) Assets

(b) Sales

(c) Investment

(d) Leverage

Figure 7: Firm characteristics with patents collateral and without patents collateral

Note: The diagrams are for the firms who hold at least one patent. For leverage, we plot the diagrams for firms whose leverage is at least 0.01.

Table 4: Number of Innovators and Patent Pledgors

	non patent pledgors	patent pledgors	Total
Panel A: US			
	non patent pledgors	patent pledgors	Total
Non Innovator	2362	0	2362
Innovator	1306	1542	2848
Total	3668	1542	5210
Panel B: China			
	non patent pledgors	patent pledgors	Total
Non Innovator	664	0	664
Innovator	3,757	214	3,971
Total	4,421	214	4,635

2. Alternatively, the yearly total investment is defined as the net increase in fixed assets, which is defined as the current total fixed asset minus the lagged total asset, and plus the depreciation of fixed assets, oil and gas assets, and biological assets. Then the investment rate is

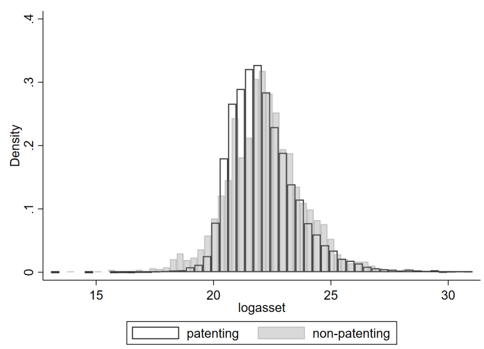
the ratio of the total investment to the lagged total fixed assets.

Sample Selection We merge the patent collateral database with the CSMAR data. We find that these listed firms have started to pledge patents as collateral since 2010. On the other hand, the most recent year of patent collateral data is 2019. Thus, we include Chinese listed firms between 2010 to 2019 that are contained in the CSMAR dataset. Our dataset includes mostly manufacturing firms, but also covers firms operating in service sectors. The final sample contains 29,537 observations and 4,305 firms. To avoid the influence of outliers, we also winsorize investment rate and leverage at the top and bottom 5% of the distribution.

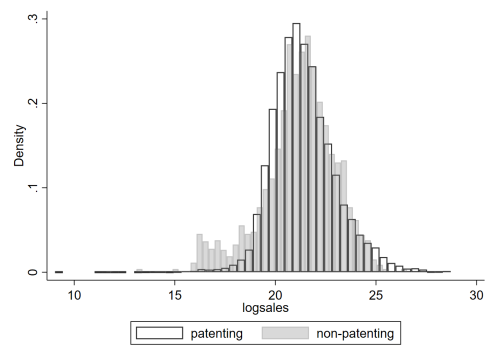
Firm Distribution In the Chinese data, the difference between patenting firms and non-patenting firms is relatively more nuanced than we documented using the US data. Figure 8 compares the histograms of assets, sales, investment, and leverage for Chinese firms with at least one patent with those of firms without patents. We do not see much difference in the firm size measured by the log of assets and sales. But in terms of investment, patenting firms invest more than non-patenting firms. Regarding leverage, patenting firms tend to have lower leverage ratio than non-patenting firms (mean value: 0.429 versus 0.481; median value: 0.420 versus 0.494), which is broadly consistent with the US data. However, note that Chinese firms on average have higher leverage ratios than US firms, indicating that debt financing is more prominent in China, perhaps due to the underdeveloped capital market.

Figure 9 compares the histograms of assets, sales, investment, and leverage for firms that have pledged their patents as collateral once and those firms who have never pledged their patents. The firms who pledged their patents are generally slightly smaller but invest more. But firms who pledged their patents have lower leverage, indicating that they have limited access to debt financing prior to using patent collateral.

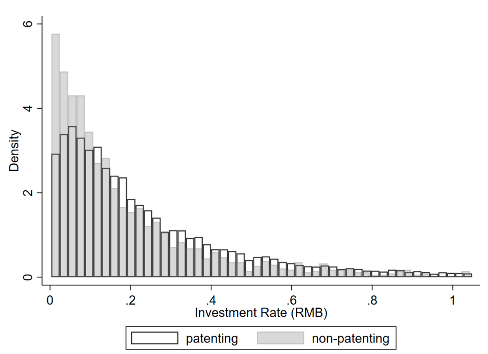
Figure 8: Firm characteristics with patents and without patents



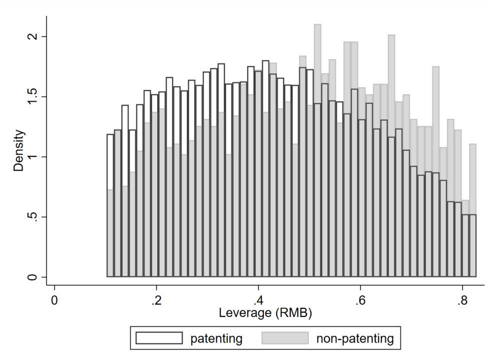
(a) Assets



(b) Sales



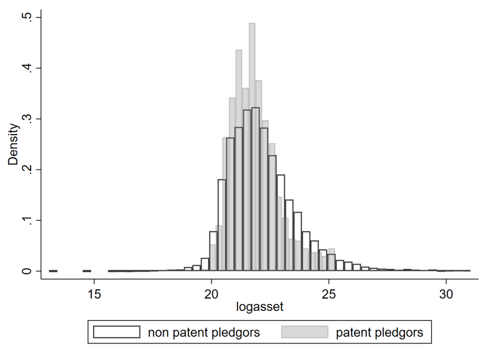
(c) Investment



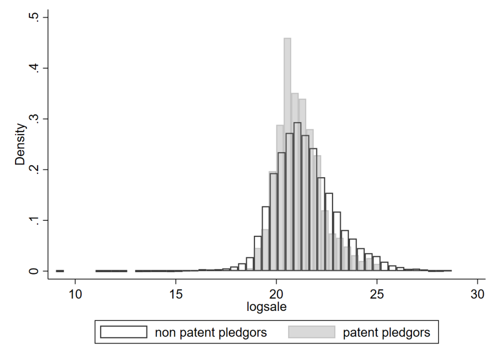
(d) Leverage

Note: For leverage, we plot the diagrams for firms whose leverage is at least 0.01.

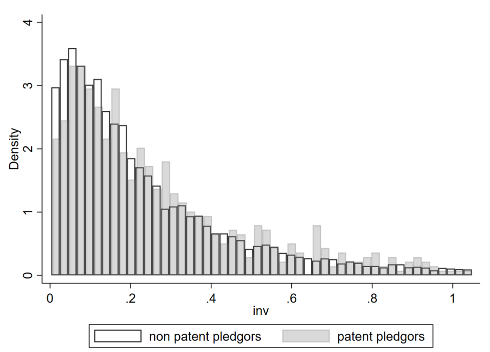
Figure 9: Firm characteristics with patents collateral and without patents collateral



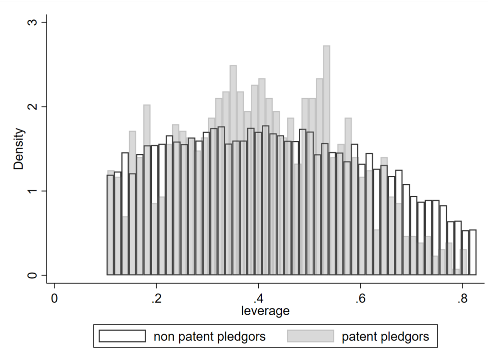
(a) Assets



(b) Sales



(c) Investment



(d) Leverage

Note: The diagrams are for the firms who hold at least one patent. For leverage, we plot the diagrams for firms whose leverage is at least 0.01.

B Theoretical Appendix

B.1 Supplements to Parameterization

Table 5: Fixed Parameters

Parameter	Description	Value
β	Discount factor	0.96
η	Log utility	1
ψ	Leisure preference	2
α	Physical capital share	0.20
γ	Innovation capital share	0.15
ν	Labor share	0.50
δ_k	Physical capital depreciation rate	0.10
δ_a	Innovation capital depreciation rate	0.20

Notes: This table reports the values for the assigned parameters in the model.

Table 6: Fitted Parameters

Parameter	Description	U.S.	China
$\bar{\xi}$	Inspection cost of innovation collateral	0.0075	0.05
χ	Innovation capital liquidation value	0.85	0.028
ρ_z	Productivity persistence (fixed)	0.90	0.90
σ_z	Productivity volatility	0.03	0.10

Notes: This table reports the values for the estimated parameters in the model to match the moments in Table 7.

Table 7: Targeted Moments

	US		China	
	Data	Model	Data	Model
Patent collateral rate (%)	39.0	37.6	0.46	0.47
Collateral participation rate (%)	54.1	54.4	5.4	5.2
Patent assets std/mean (%)	56.6	56.6	121.7	121.1

Notes: This table reports the moments that we target to estimate the parameters listed in Table 6. The moments are average annualized moments. The patent collateral rate is calculated as the ratio between number of patents used as collaterals and the total active number of patents. The collateral participation rate is the fraction of firms who have at least used their patents as collateral once among the firms who have patents. "Patent assets standard deviation and mean" calculates the standard deviation and mean for log(intangible assets), for which the units are millions of dollars (RMBs for China).