Do Stronger Patents Stimulate or Stifle Innovation? The Crucial Role of Financial Development

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Abstract

This study explores the effects of patent protection in an R&D-based growth model with financial frictions. We find that whether stronger patent protection stimulates or stifles innovation depends on credit constraints faced by R&D entrepreneurs. When credit constraints are non-binding (binding), strengthening patent protection stimulates (stifles) R&D. The overall effect of patent protection on innovation follows an inverted-U pattern. By relaxing the credit constraints, financial development stimulates innovation. Furthermore, patent protection is more likely to have a positive effect on innovation under a higher level of financial development. We consider cross-country panel regressions and find supportive evidence for this result.

JEL classification: O31, O34, E44

Keywords: Patent protection, credit constraints, economic growth, convergence

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1 INTRODUCTION

In this study, we explore the effects of patent protection in an R&D-based growth model. Our growth-theoretic analysis of patent policy features financial frictions in the form of potentially binding credit constraints on R&D entrepreneurs. As in Aghion, Howitt and Mayer-Foulkes (2005), due to moral hazard, R&D entrepreneurs may not be able to borrow as much as they want for their R&D investment. When these credit constraints are non-binding, we find that strengthening patent protection by increasing patent breadth leads to a larger amount of monopolistic profit, which stimulates R&D and technological progress. This positive *monopolistic-profit* effect captures the traditional view of patent protection. However, when the credit constraints are binding, we find that the monopolistic distortion arising from patent protection leads to more severe financial frictions, which stifle R&D and slow down technological progress. We refer to this effect as a negative *financial distortionary* effect of patent protection.

The intuition of this financial distortionary effect can be explained as follows. As in the seminal study by Nordhaus (1969), patent protection causes monopolistic distortion, which in turn reduces aggregate income in general equilibrium and tightens credit constraints faced by R&D entrepreneurs in the presence of financial frictions. Our mechanics relies on credit constraints to make R&D a constant fraction of aggregate income. Then, the monopolistic distortion of patent protection on aggregate income reduces R&D and economic growth when credit constraints are binding. Hence we find that credit constraints jeopardize the classical Schumpeterian trade-off between static and dynamic efficiency: less static efficiency (i.e., lower output) by causing less R&D entails less dynamic efficiency (i.e., lower growth). In this case, stronger patent protection reduces the rates of innovation and economic growth, in addition to reducing the level of output.

This finding is consistent with recent studies that often find the presence of negative effects of patent protection on innovation.[1] Furthermore, we find that the positive monopolistic-profit effect of patent protection prevails when the level of patent protection is below a threshold value, whereas the negative financial distortionary effect of patent protection prevails when the level of patent protection is above the threshold. Therefore, the overall effect of patent protection on R&D and innovation follows an inverted-U pattern that is commonly found in empirical studies.[2]

We consider the case in which a higher level of financial development relaxes credit constraints by making it more difficult for borrowers to defraud. As in Aghion, Howitt and Mayer-Foulkes (2005), we find that a higher level of financial development stimulates innovation. Intuitively, when R&D entrepreneurs are less likely to defraud, banks are more willing to lend to them for R&D investment. Furthermore, we have a novel finding that patent protection is more likely to have a positive effect on innovation under a higher level of financial development. The intuition of this result can be explained as follows. When banks become more willing to lend to R&D entrepreneurs, the credit constraints are less likely to be binding, in which case patent protection has a positive effect on innovation.

We test this theoretical implication using cross-country panel regression. We find that patent protection and financial development have a positive interaction effect on innovation. Ang (2010, 2011) also empirically explores the effects of patent protection and financial development on R&D activities. We complement the analysis in Ang by considering the interaction effect of patent protection and financial development on economic growth. Their positive interaction effect on innovation is consistent with our theoretical finding that patent protection is more likely to have a positive effect on innovation under a higher level of financial development. Therefore, to capture the complete effects of patent policy on economic growth, it is useful to explore how the effect of patent protection changes under different levels of financial development.

This study relates to the literature on patent policy. In this literature, Nordhaus (1969) provides the seminal study in which he shows that increasing patent length causes a positive effect on innovation and a negative static distortionary effect on welfare. While Nordhaus focuses on a partial-equilibrium framework, we consider a dynamic general-equilibrium (DGE) model in which the monopolistic distortion caused by patent protection interacts with financial frictions to affect credit constraints and stifle innovation. Subsequent studies in this literature, such as Gilbert and Shapiro (1990) and Klemperer (1990), explore patent breadth in addition to patent length. Scotchmer (2004) provides a comprehensive review of this patent-design literature. Our study instead explores the effects of patent policy in a DGE model in which the financial distortionary effect of patent policy arises through a general-equilibrium channel. Therefore, this study relates more closely to the macroeconomic literature on patent policy and economic growth based on DGE models.

The seminal DGE analysis of patent policy is Judd (1985), who finds that an infinite patent length maximizes innovation and eliminates the relative-price distortion because all industries charge the same markup. Our model features an infinite patent length under which the relative-price distortion is absent as in Judd.[3] However, we show that patent breadth interacts with a financial distortion that affects credit constraints and R&D. Subsequent studies in this literature explore patent breadth as an alternative patent-policy instrument; see for example, Li (2001), Goh and Olivier (2002) and Iwaisako and Futagami (2013).[4] Some of these studies also find that strengthening patent protection has an inverted-U effect on innovation and growth. Our study differs from these previous studies by exploring the effects of patent protection in the presence of financial frictions. In other words, we analyze the interaction between patent protection and credit constraints, which is the novel contribution of this study.

The rest of this paper is organized as follows. Section 2 documents stylized facts. Section 3 describes the R&D-based growth model. Section 4 presents theoretical results. The final section concludes.

2 STYLIZED FACTS

In this section, we document the empirical relationship between patent protection, financial development and economic growth. Specifically, we use cross-country panel data, which consist of 48 countries from 1998 to 2014. We consider the following empirical specification:

$$Growth_{i,t+1} = \delta_0 + \delta_1 IPR_{i,t} + \delta_2 IPR_{i,t} * FD_{i,t} + \Gamma\chi_{i,t} + \delta_i + \delta_t + \varepsilon_{i,t}, \tag{1}$$

where $Growth_{i,t+1}$ is the growth rate of GDP or per capita GDP in country i, $IPR_{i,t}$ is an index of patent protection, and $FD_{i,t}$ is the level of financial development. $\chi_{i,t}$ denotes a vector of the following control variables: $FD_{i,t}$, the degree of openness, the unemployment rate and the quality of institutions.[5] Specifically, the degree of openness is defined as the sum of exports and imports as a share of GDP, whereas the quality of institutions is measured by investment risks from the International Country Risk Guide.[6] δ_i is the country fixed effects. δ_t is the year fixed effects.

We use the index of patent strength constructed by Papageorgiadis, Cross and Alexiou (2014) to measure the level of patent protection.[7] This patent index has the following advantages. First, observations are available at annual frequency.[8] Second, the index captures patent enforcement in addition to the strength of statutory protection.[9]

For the measurement of financial development, we follow King and Levine (1993), Beck, Demirgüç-Kunt and Levine (2010) and Manova (2013) to use the ratio of private credit by deposit money banks and other financial institutions to GDP, denoted by *private credit*, as a proxy for the overall development of a country's financial system.[10] As stated in Levine, Loayza and Beck (2000), *private credit* excludes credit granted to the public sector and credit granted by the central bank and development banks, and hence, it better captures the overall level of financial development. In addition, we also use the ratio of deposit money banks' assets to GDP, denoted by *bank assets*, as a robustness check. Data for these two variables can be obtained from the Global Financial Development Database.[11]

Differentiating the rate of economic growth with respect to IPR yields

$$\frac{\partial Growth_{i,t+1}}{\partial IPR_{i,t}} = \delta_1 + \delta_2 FD_{i,t}. \tag{2}$$

Our theoretical model in the subsequent sections predicts that $\delta_1 < 0$ and $\delta_2 > 0$. In other words, for a country that has a low level of financial development (i.e., a small $FD_{i,t}$), the effect of IPR on economic growth is negative. For a country that has a high level of financial development (i.e., a large $FD_{i,t}$), the effect of IPR on economic growth becomes positive.

Table 1 reports our benchmark results. In the first two columns, financial development is measured by *private credit*, whereas in the last two columns, it is measured by *bank assets*. In some columns, $Growth_{i,t+1}$ is measured by the growth rate of GDP. In other columns, $Growth_{i,t+1}$ is measured by the growth rate of GDP per capita. As shown in the Table 1, all the coefficients of the interaction term between patent protection and financial development are positive and significant, whereas the coefficients of patent protection are all negative and significant.[12] We also run a t-test on patent protection and its interaction with financial development, which shows that the effect of patent protection on economic growth is negative and significant for countries with the lowest level of financial development (positive and significant for countries with the highest level of financial development). To verify the validity of our results, we also drop the highest and lowest one-percent outliers of IPR from our sample. As shown in Table 2, the results are similar.

[Insert Table 1 and Table 2 here]

3 AN R&D-BASED GROWTH MODEL WITH CREDIT FRICTIONS

The R&D-based growth model originates from the seminal work by Romer (1990). In this section, we consider a discrete-time version and follow Aghion, Howitt and Mayer-Foulkes (2005) to incorporate financial frictions into the Romer model.

3.1 Households and Workers/Entrepreneurs

There is a unit continuum of infinitely-lived households. These households own intangible capital (in the form of patents that generate monopolistic profits) and consume final good (numeraire). The lifetime utility function of a household is given by

$$U = \sum_{t=0}^{\infty} \frac{C_t}{(1+\rho)^t}, \tag{3}$$

where the parameter $\rho > 0$ is the subjective discount rate and C_t is consumption of the household at time t. The asset-accumulation equation is $A_{t+1} = (1+r_t)A_t - C_t$. From standard dynamic optimization, the linear utility function implies that in equilibrium the real interest rate is equal to the discount rate, such that $r_t = \rho$ for all t.

In addition to the infinitely-lived households in the economy, we follow previous studies to assume the presence of overlapping generations of workers/entrepreneurs in each period to create a need for the entrepreneurs to borrow funding for R&D. At the beginning of each period t, L workers enter the economy, and they work to earn wage W_t. At the end of the period, each worker becomes an entrepreneur and devotes part of her wage income κW_t to R&D, where $\kappa \in (0, 1]$.[13] At the beginning of the next period, those entrepreneurs who have succeeded in their R&D projects sell their inventions to households and use the proceeds for consumption. Without loss of generality, we normalize L to unity. A worker who enters the economy in period t has the utility function $u_t = y_t + E_t[o_{t+1}]/(1+\rho)$, where

y_t denotes consumption when young and $E_t[o_{t+1}]$ denotes expected consumption when old. If the amount of her R&D spending Z_t is less than κW_t, then a worker/entrepreneur simply consumes $W_t - Z_t$ in period t or saves part of it subject to the market interest rate r_t. However, if $Z_t > \kappa W_t$, then the worker/entrepreneur would need to apply for a loan subject to credit constraints, which will be described in details in Section 3.7.

3.2 Final Good

The final-good sector is perfectly competitive. Firms in this sector employ workers and use a mass of differentiated intermediate goods $v \in [0, N_t]$ to produce final good using the following production function:

$$Y_t = (L_t)^{1-\alpha} \int_0^{N_t} [x_t(v)]^{\alpha} dv, \tag{4}$$

where the parameter $\alpha \in (0, 1)$ determines labor intensity $1 - \alpha$ in production. L_t is labor input. $x_t(v)$ is the amount of intermediate good $v \in [0, N_t]$, and N_t is the number of available intermediate goods at time t. Competitive firms take the prices of final good and factor inputs as given to maximize profit. The conditional labor demand function is given by $W_t = (1 - \alpha)Y_t/L_t$, where $L_t = L = 1$ from the market-clearing condition. The conditional demand function for intermediate good v is given by

$$x_t(v) = \left[\frac{\alpha}{p_t(v)}\right]^{1/(1-\alpha)}, \tag{5}$$

where $p_t(v)$ is the price of intermediate good v.

3.3 Intermediate Goods

Each differentiated intermediate good v is produced by a firm that owns the patent of the product and has market power, which is determined by the level of patent protection to be explained below. In industry v, the firm produces $x_t(v)$ units of intermediate goods using

$x_t(v)$ units of final good as inputs. Therefore, the profit function of the firm in industry v is

$$\Pi_t(v) = p_t(v)\, x_t(v) - x_t(v) = [p_t(v) - 1]\left[\frac{\alpha}{p_t(v)}\right]^{1/(1-\alpha)}, \tag{6}$$

where the second equality follows from (5).

Using (6), one can derive the profit-maximizing price $p_t(v)$ given by $1/\alpha$. To capture the effects of patent protection, we follow Goh and Olivier (2002) to model patent breadth $\beta \in (1, 1/\alpha)$ as a policy parameter. The idea is that the unit cost for imitative firms to produce $x_t(v)$ is β, which is assumed to be increasing in the level of patent protection. Therefore, a larger patent breadth β allows the monopolistic producer of $x_t(v)$, who owns the patent, to charge a higher markup without losing her market share.[14] In this case,

$$p_t(v) = \beta. \tag{7}$$

Combining (6) and (7), we obtain the amount of profit as a function of patent breadth given by

$$\Pi_t(v) = (\beta - 1)\left(\frac{\alpha}{\beta}\right)^{1/(1-\alpha)} \equiv \pi(\beta), \tag{8}$$

which is increasing in patent breadth β for $\beta < 1/\alpha$.

3.4 Aggregate Production Function

Substituting (5) and (7) into (4) yields

$$Y_t = \left(\frac{\alpha}{\beta}\right)^{\alpha/(1-\alpha)} N_t. \tag{9}$$

Equation (9) shows that the growth rate of Y_t is determined by the growth rate of N_t. Furthermore, for a given N_t, the level of Y_t is decreasing in patent breadth β, which captures the effect of markup distortion on the level of output.[15] In other words, by increasing the price of intermediate goods, a larger markup leads to less intermediate goods being produced and also less final good being produced.[16] In the presence of credit constraints, patent protection would then generate a negative effect on R&D as a result of this markup distortion as we will show later.

3.5 R&D and the Value of Patents

There is an R&D sector. In each period t, workers/entrepreneurs devote final good to R&D at the end of the period to invent new intermediate goods that will be produced in the next period. To ensure balanced growth, we assume that each entrepreneur spreads her R&D spending Z_t over N_t R&D projects.[17] Therefore, the amount of final good that an entrepreneur devotes to each of her R&D projects is Z_t/N_t, and the probability of her R&D projects being successful is $P_t = \min\{Z_t/(N_t\eta_t), 1\}$,[18] where $1/\eta_t$ captures the productivity in R&D. We adopt the following specification for η_t:

$$\eta_t = \gamma \left(\frac{Z_t}{N_t} \right)^{\theta}, \tag{10}$$

where $\gamma > 0$ and $\theta \in (0, 1)$. The term $(Z_t/N_t)^{\theta}$ captures an intratemporal duplication externality of R&D as in Jones and Williams (2000). Given the unit continuum of R&D entrepreneurs and the independence of R&D projects (across entrepreneurs), the law of large numbers applies, so that the accumulation of inventions at the aggregate level follows a deterministic process given by

$$\Delta N_t \equiv N_{t+1} - N_t = \frac{Z_t}{\eta_t} = \frac{N_t}{\gamma} \left(\frac{Z_t}{N_t} \right)^{1-\theta}, \tag{11}$$

where $Z_t/\eta_t = N_t Z_t/(N_t\eta_t)$ is the number of successful R&D projects in period t.

Each R&D project has a probability P_t to give rise to a new variety of intermediate goods. When a new variety is successfully invented at the end of period t, production of the intermediate goods begins in period $t+1$. We denote the value of an invention created in period t as $V_t(v)$. The discount rate for future profits is given by $r_t = \rho$ for all t. $V_t(v)$ can be expressed as

$$V_t(v) = \sum_{s=t}^{\infty} \frac{\Pi_{s+1}(v)}{(1+r)^{s+1-t}} = \frac{\pi(\beta)}{\rho}, \tag{12}$$

which is increasing in patent breadth β. The positive effect of β captures the positive effect of patent protection on the value of inventions.

3.6 Equilibrium Without Credit Constraints

In this section, we explore the equilibrium level of R&D in the absence of credit constraints. The zero-expected-profit condition of R&D is given by $P_t V_t = Z_t/N_t$, which can be expressed as

$$V_t = \eta_t \Leftrightarrow \frac{\pi(\beta)}{\rho} = \gamma \left(\frac{Z_t}{N_t}\right)^{\theta}. \tag{13}$$

Therefore, the level of R&D at time t is given by

$$Z_t = \left[\frac{\pi(\beta)}{\gamma\rho}\right]^{1/\theta} N_t, \tag{14}$$

which is increasing in β. The growth rate of technology in the absence of credit constraints is given by

$$\frac{\Delta N_t}{N_t} = \frac{1}{\gamma}\left(\frac{Z_t}{N_t}\right)^{1-\theta} = \frac{1}{\gamma^{1/\theta}}\left[\frac{\pi(\beta)}{\rho}\right]^{(1-\theta)/\theta} \equiv g_1. \tag{15}$$

The growth rate g_1 in (15) is increasing in patent breadth β capturing the positive *monopolistic profit* effect of patent protection on innovation. Proposition 1 summarizes this result, which is often found in the literature; see for example Judd (1985), Li (2001), O'Donoghue and Zweimüller (2004) and Horii and Iwaisako (2007).

PROPOSITION 1 *In the absence of credit constraints, stronger patent protection leads to a higher growth rate of technology.*

Proof. Use (8) and (15) to show that g_1 is increasing in β. ■

3.7 Equilibrium With Credit Constraints

Before the end of a period, each entrepreneur devotes her wage income κW_t to N_t R&D projects without borrowing. If the R&D spending Z_t exceeds her wage income κW_t, then she would have to borrow $D_t = Z_t - \kappa W_t$ from a bank to finance her R&D projects. If her R&D projects succeed, she repays the loan plus an interest payment equal to $(1+R_{t+1})D_t$ at the end of the period. If her R&D projects fail, she becomes bankrupt and repays nothing to the bank. Therefore, if the entrepreneur truthfully reveals the outcome of her R&D projects, the expected payment received by the bank is $P_t(1+R_{t+1})D_t + (1-P_t)0$. When banks make zero expected profit, we have $P_t(1+R_{t+1})D_t = D_t$, which implies $P_t(1+R_{t+1}) = 1$. In other words, a higher probability P_t of R&D success reduces the interest rate R_{t+1} charged by competitive banks.

What makes it difficult to borrow is that an entrepreneur may want to default even when her projects are successful. As in Aghion, Howitt and Mayer-Foulkes (2005), banks do not observe the outcome of R&D projects, and hence, the problem of moral hazard arises.[19] Specifically, by paying a hiding cost hZ_t where $h \in (0,1)$, an entrepreneur can hide the outcome of her projects and avoid repaying the loan. The cost parameter h is an indicator of banks' effectiveness in securing repayment and measures the level of financial development. We follow Aghion, Howitt and Mayer-Foulkes to assume that in case an entrepreneur decides to defraud, the entrepreneur must incur the hiding cost before observing the outcome of her R&D projects. Therefore, entrepreneurs would not defraud if and only if the following incentive-compatibility (IC) constraint holds:

$$hZ_t \geq P_t(1+R_{t+1})D_t = D_t, \tag{16}$$

where $D_t = Z_t - \kappa W_t = Z_t - \kappa(1-\alpha)Y_t$. Substituting this condition into (16) yields

$$Z_t \leq \frac{\kappa(1-\alpha)Y_t}{1-h} = \frac{\kappa(1-\alpha)}{1-h}\left(\frac{\alpha}{\beta}\right)^{\alpha/(1-\alpha)} N_t, \tag{17}$$

where the last equality uses (9). We refer to this IC constraint as a credit constraint, which becomes tighter as patent breadth β increases capturing an interaction between the monopolistic distortion of patent protection and the financial distortion of the credit constraint. The intuition can be explained as follows. When patent breadth β increases, aggregate income Y decreases due to the markup distortion. As a result, a larger β reduces the income of entrepreneurs and their ability to borrow for R&D. This interaction effect exists so long as entrepreneurs' ability to borrow is affected by their income and in turn entrepreneurs' income is related to aggregate income.

For convenience, we define $f \equiv \kappa(1-\alpha)/(1-h) \in (0,\infty)$ as a composite parameter that is increasing in the hiding cost h. Then, substituting (17) into (11) yields the growth rate of technology, in the presence of a binding credit constraint, as follows:

$$\frac{\Delta N_t}{N_t} = \frac{1}{\gamma}\left[\left(\frac{\alpha}{\beta}\right)^{\alpha/(1-\alpha)} f\right]^{1-\theta} \equiv g_2. \tag{18}$$

The equilibrium growth rate g_2 in (18) is decreasing in the level of patent breadth β capturing the abovementioned *financial distortionary* effect of patent protection on innovation. Furthermore, a higher level of financial development f reflected by a larger hiding cost increases the growth rate of technology as in Aghion, Howitt and Mayer-Foulkes (2005).[20] We summarize these results in Proposition 2.

PROPOSITION 2 *In the presence of binding credit constraints, stronger patent protection leads to a lower growth rate of technology. A higher level of financial development leads to a higher growth rate of technology.*

Proof. Use (18) to show that g_2 is decreasing in β and increasing in f. ■

In the previous section, we find that when the credit constraint is not binding, our model features the classic trade-off of patent protection that yields a static loss in output and a dynamic gain in growth. In this section, we show that when the credit constraint becomes binding, this trade-off disappears. Specifically, the dynamic gain becomes a dynamic loss in growth whereas the static loss in output is still present.

Equations (14) and (17) show that the equilibrium level of R&D spending Z_t satisfies

$$Z_t = \min\left\{\left[\frac{\pi(\beta)}{\gamma\rho}\right]^{1/\theta}, \left(\frac{\alpha}{\beta}\right)^{\alpha/(1-\alpha)} f\right\} N_t. \tag{19}$$

There exists a unique value of patent breadth β below (above) which the credit constraint does not bind (is binding) in the long run. Equating $[\pi(\beta)/(\gamma\rho)]^{1/\theta}$ and $(\alpha/\beta)^{\alpha/(1-\alpha)} f$ yields this threshold value β^*, which is determined by

$$(\beta^* - 1)\left(\frac{\alpha}{\beta^*}\right)^{(1-\theta\alpha)/(1-\alpha)} = \gamma\rho f^{\theta}, \tag{20}$$

where the left-hand side of (20) is increasing in β^*. Therefore, the threshold value β^* is increasing in f. The intuition of this result can be explained as follows. A larger hiding cost reduces entrepreneurs' incentives to defraud and enables them to borrow more funding for R&D. In this case, the credit constraint is less likely to be binding, which in turn increases the threshold value of patent breadth.

4 PATENT BREADTH AND CREDIT CONSTRAINTS

Based on the results in the previous section, we can consider two scenarios. First, the level of patent breadth satisfies $\beta < \beta^*$, where the threshold β^* is derived in (20). Second, the level of patent breadth satisfies $\beta > \beta^*$. According to this classification, the equilibrium growth rate is given by

$$g = \begin{cases} \underset{+}{g_1(\beta)}, & \text{if } \beta < \underset{+}{\beta^*(f)} \\ g_2(\underset{-}{\beta}, \underset{+}{f}), & \text{if } \beta > \underset{+}{\beta^*(f)} \end{cases}. \tag{21}$$

We summarize these results in Proposition 3.

PROPOSITION 3 *When the level of patent protection is below β^*, the equilibrium growth rate is increasing in patent breadth. When the level of patent protection is above β^*, the equilibrium growth rate is decreasing in patent breadth and increasing in the hiding cost. The overall effect of patent breadth on the equilibrium growth rate follows an inverted-U pattern, and the growth-maximizing level of patent breath is increasing in the level of financial development.*

Proof. Use (21) to show that (a) g_2 is increasing in f and (b) g is initially increasing in β and then becomes decreasing in β after passing the threshold β^*. Then, use (20) to show that β^* is increasing in f. ■

When the level of patent protection is below β^*, entrepreneurs are not financially constrained. In this case, stronger patent protection increases the amount of monopolistic profit, which in turn stimulates R&D and increases the equilibrium growth rate. When the level of patent protection is above β^*, entrepreneurs become financially constrained. In this case, stronger patent protection amplifies monopolistic distortion and reduces the level of output, which in turn tightens the credit constraint on R&D and decreases the equilibrium growth rate. A higher level of financial development increases the hiding cost, which in turn enables the entrepreneurs to borrow more funding for R&D and increases the equilibrium growth rate.

For a given hiding cost, an increase in the level of patent protection may cause the financial constraint to change from non-binding to binding; therefore, there exists a growth-maximizing level of patent protection β^*. This growth-maximizing level of patent protection

β^* is determined by the level of financial development f. Specifically, β^* is increasing in f. Therefore, as a country becomes more financially developed, it should implement a stronger patent system to stimulate innovation. Intuitively, as mentioned before, a larger hiding cost reduces entrepreneurs' incentives to defraud, which enables them to borrow more funding for R&D. In this case, the credit constraint is less likely to be binding, which in turn increases the threshold value β^* of patent breadth and renders patent protection more likely to have a positive effect on R&D. We summarize this result in Proposition 4, which is consistent with the stylized facts in Section 2.

PROPOSITION 4 *Patent protection is more likely to have a positive effect on innovation under a higher level of financial development.*

Proof. Because β^* is increasing in f as shown in (20), a larger f expands the range of β in which g is increasing in β. ■

4.1 Extensions

In this section, we consider an alternative assumption under which R&D entrepreneurs' ability to borrow depends on profit income in addition to wage income. For simplicity, we assume $\kappa = 1$; in other words, the entrepreneurs can devote to R&D projects the entire amount of wage income W_t and profit income $\pi(\beta)N_t$.[21] In this case, the amount of borrowing becomes

$$D_t = Z_t - [W_t + \pi(\beta)N_t] = Z_t - [(1-\alpha)Y_t + \pi(\beta)N_t]\,. \tag{22}$$

As a result, the IC constraint $hZ_t \geq D_t$ can be expressed as

$$Z_t \leq \frac{1}{1-h}\left[(1-\alpha)Y_t + \pi(\beta)N_t\right] = \frac{1}{1-h}\left[(1-\alpha)\left(\frac{\alpha}{\beta}\right)^{\alpha/(1-\alpha)} + \pi(\beta)\right]N_t. \tag{23}$$

Substituting (23) into (11) yields the growth rate of technology under a binding credit constraint as follows:

$$\frac{\Delta N_t}{N_t} = \frac{1}{\gamma}\left[\frac{1}{1-h}\Omega(\beta)\right]^{1-\theta}, \tag{24}$$

where $\Omega(\beta) \equiv (1-\alpha)(\alpha/\beta)^{\alpha/(1-\alpha)} + \pi(\beta) = (\beta/\alpha - 1)(\alpha/\beta)^{1/(1-\alpha)} > 0$. Differentiating $\Omega(\beta)$ with respect to β yields

$$\frac{\partial\Omega(\beta)}{\partial\beta} = \Omega(\beta)\left(\frac{1}{\beta-\alpha} - \frac{1}{\beta-\alpha\beta}\right) < 0. \tag{25}$$

Therefore, under a binding credit constraint, the equilibrium growth rate is decreasing in patent breadth even when the entrepreneurs can also devote profit income into R&D. Intuitively, the negative effect of patent protection on wage income dominates its positive effect on profit income in our model.

However, if entrepreneurs can use the value of existing patents, instead of just current profit income, as means of internal finance, then the positive effect of patent protection on the value of patents may relax the credit constraint. To explore this scenario, we consider another assumption under which R&D entrepreneurs' ability to borrow depends on the value of patents in addition to wage income. In this case, the amount of borrowing becomes

$$D_t = Z_t - [W_t + V_t N_t] = Z_t - \left[(1-\alpha)Y_t + \frac{\pi(\beta)N_t}{\rho}\right]. \tag{26}$$

As a result, the IC constraint $hZ_t \geq D_t$ can be expressed as

$$Z_t \leq \frac{1}{1-h}\left[(1-\alpha)Y_t + \frac{\pi(\beta)N_t}{\rho}\right] = \frac{1}{1-h}\left[(1-\alpha)\left(\frac{\alpha}{\beta}\right)^{\alpha/(1-\alpha)} + \frac{\pi(\beta)}{\rho}\right]N_t. \tag{27}$$

Substituting (27) into (11) yields the growth rate of technology under a binding credit constraint as follows:

$$\frac{\Delta N_t}{N_t} = \frac{1}{\gamma}\left[\frac{1}{1-h}\Psi(\beta)\right]^{1-\theta}, \tag{28}$$

where

$$\Psi(\beta) \equiv \left(\frac{1-\alpha}{\alpha}\beta + \frac{\beta-1}{\rho}\right)\left(\frac{\alpha}{\beta}\right)^{1/(1-\alpha)} > 0. \tag{29}$$

Differentiating $\Psi(\beta)$ with respect to β yields

$$\frac{\partial\Psi(\beta)}{\partial\beta} = \Psi(\beta)\left[\frac{(1-\alpha)/\alpha + 1/\rho}{\beta(1-\alpha)/\alpha + (\beta-1)/\rho} - \frac{1}{\beta - \alpha\beta}\right], \tag{30}$$

which is negative if and only if

$$\rho > \frac{1-\alpha\beta}{\beta-\alpha\beta} \in (0,1). \tag{31}$$

Even if we consider a conservatively low annual discount rate of 3.5% and 20 years for one generation, then the discount rate ρ would be equal to $(1+0.035)^{20} - 1 = 0.99$, which in turn implies that the above inequality is likely to hold. Therefore, this section confirms the robustness of our theoretical results.

5 CONCLUSION

In this study, we have explored the effects of patent protection and financial development on economic growth. We find that whether strengthening patent protection has a positive or negative effect on technological progress depends on credit constraints. When credit constraints are not binding, strengthening patent protection has a positive effect on economic growth. When credit constraints are binding, strengthening patent protection has a negative effect on growth. An increase in the level of patent protection may cause the credit constraints to become binding. As a result, the overall effect of patent protection on economic growth follows an inverted-U pattern. A higher level of financial development relaxes credit constraints by increasing the hiding cost. As a result, a higher level of financial development stimulates innovation. Furthermore, patent protection is more likely to have a positive effect on innovation under a higher level of financial development. Our regression results show that strengthening patent protection is indeed more likely to have a positive effect on innovation under a higher level of financial development. Therefore, this study shows the importance of an often neglected interaction between the monopolistic distortion caused by patent protection and the financial distortion caused by credit constraints.

APPENDIX: DESCRIPTION OF THE DATA SET

The empirical analysis is based on a panel dataset for 48 countries from 1998 to 2014. Variables used in the regressions are listed below with definitions and data sources. Table A1 reports the summary statistics of these variables.

- $Growth_{i,t+1}$: the rate of economic growth. There are two measures: 1) annual growth rate of GDP per capita; and 2) annual growth rate of GDP. Source: World Bank Database.

- $IPR_{i,t}$: an index of patent protection. Source: Papageorgiadis, Cross and Alexiou (2014).

- $FD_{i,t}$: the level of financial development. There are two measures: 1) private credit by deposit money banks and other financial institutions as a share of GDP (*private credit*); and 2) deposit money banks' assets as a share of GDP (*bank assets*). Source: Čihák *et al.* (2012).

- $Unemp_{i,t}$: the unemployment rate. Source: World Bank Database.

- $Open_{i,t}$: the degree of openness, defined as the sum of exports and imports of goods and services as a share of GDP. Source: World Bank Database.

- $Insq_{i,t}$: the quality of institutions. Source: International Country Risk Guide.

[Insert Table A1 here]

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Footnotes

[1]See for example Jaffe and Lerner (2004), Bessen and Meurer (2008) and Boldrin and Levine (2008).

[2]See for example Qian (2007) and Lerner (2009).

[3]Gilbert and Shapiro (1990) also show that the optimal patent length is infinite and argue that "the policy margin of patent length is not a useful one on which to operate."

[4]For other patent-policy instruments, see O'Donoghue and Zweimüller (2004) and Kiedaisch (2015) on patentability requirement, Furukawa (2007), Horii and Iwaisako (2007) and Chu, Cozzi and Galli (2014) on protection against imitation, Dinopoulos and Syropoulos (2007) and Davis and Şener (2012) on rent protection activities, and Chu (2009), Chu, Cozzi and Galli (2012), Chu and Pan (2013) and Cozzi and Galli (2014) on blocking patents. None of these studies consider financial frictions.

[5]See Appendix for a detailed description and sources of the data.

[6]See Fan and Gao (2017) who also use this index to measure the quality of institutions.

[7]Data available at: https://www.liverpool.ac.uk/management/research/projects/patent-systems/

[8]Another influential patent index in the literature is the Ginarte-Park index in Ginarte and Park (1997) and Park (2008). However, this index is only available quinquennially.

[9]See Papageorgiadis, Cross and Alexiou for a detailed discussion.

[10]If we use the ratio of private credit by deposit money banks to GDP instead, the results are similar.

[11]Data available at: http://www.worldbank.org/en/publication/gfdr/data/financial-structure-database

[12]To mitigate the problem of endogeneity, we have also used the lagged values of IPR and FD as their instrumental variables and find that our results (available upon request) still hold.

[13]Here we assume that the entrepreneur may not be able to devote her entire wage income to R&D. Our results also hold when $\kappa = 1$.

[14]See also Li (2001) and Iwaisako and Futagami (2013) for a similar formulation. This formulation captures Gilbert and Shapiro's (1990) insight on "breadth as the ability of the patentee to raise price" and originates from the patent-design literature; see for example Gallini (1992) who considers the case in which a larger patent breadth increases the imitation cost of imitators.

[15]Here we assume that a change in patent policy applies to all patents. If the policy change applies to only new patents, then its distortionary effects would gradually arise, rather than occurring immediately. Furthermore, there will be an additional relative-price distortion because old and new patented goods have different markups.

[16]This distortionary effect would be absent if $x_t(v)$ were produced from a fixed factor input instead of the

final good. However, if we follow Romer (1990) to assume that intermediate goods are produced from capital, then the markup distortion would still exist because the presence of markup and profits lowers capital income and reduces capital accumulation. For example, Chu (2010) uses US data to calibrate a generalized version of the Romer model to quantify the distortionary effect of the patent system and finds that increasing the patent length could lead to a non-negligible decrease in capital investment.

[17] To ensure the innovation probability $P_t \leq 1$ in the presence of growth in Z_t, we only need to assume that entrepreneurs spread their R&D spending Z_t over ςN_t R&D projects, where $\varsigma > 0$. Without loss of generality, we set $\varsigma = 1$.

[18] For simplicity, we assume that an entrepreneur's R&D projects either all succeed or all fail.

[19] As in Aghion, Howitt and Mayer-Foulkes, we do not consider the case in which patents can be used as collateral. To be more precise, we assume that *future* patents cannot be used as collateral because R&D projects have not been completed as the stage of borrowing. See Amable, Chatelain and Ralf (2010) for an interesting analysis on patents as collateral.

[20] If financial friction is modeled as screening of R&D projects as in Aghion and Howitt (2009, Ch. 6) instead of credit constraints, then financial development would still stimulate innovation. However, patent breadth would no longer have a negative effect on innovation due to the absence of credit constraints. In reality, financial development should affect the screening of R&D projects and the tightness of credit constraints. So long as credit constraints are present, the negative effect of patent breadth on innovation would exist whenever they are binding.

[21] This is also equal to the interest income $r_t A_t = \rho V_t N_t = \pi(\beta) N_t$.

Table 1: Effects of patent protection on economic growth				
	private credit		bank assets	
	GDP	GDP per capita	GDP	GDP per capita
$IPR * FD$	0.931***	0.886***	0.708***	0.676***
	(0.268)	(0.254)	(0.272)	(0.261)
IPR	-0.878**	-0.863**	-0.937**	-0.927**
	(0.362)	(0.363)	(0.399)	(0.399)
other controls	yes	yes	yes	yes
country fixed effects	yes	yes	yes	yes
year fixed effects	yes	yes	yes	yes
observations	776	776	776	776
R-squared	0.569	0.540	0.559	0.529

Note: * p<0.10, ** p<0.05, *** p<0.01. IPR denotes the index of patent protection. FD denotes the level of financial development. Other control variables include FD, the degree of openness, the unemployment rate and the quality of institutions. In the first two columns, financial development is measured by private credit, whereas in the last two columns it is measured by bank assets. The dependent variable is economic growth measured by either the growth rate of GDP or the growth rate of GDP per capita. Robust standard errors are in parentheses.

Table 2: Effects of patent protection (removing outliers)				
	private credit		bank assets	
	GDP	GDP per capita	GDP	GDP per capita
$IPR * FD$	0.930***	0.878***	0.708**	0.673**
	(0.311)	(0.290)	(0.311)	(0.295)
IPR	-0.950**	-0.920**	-1.004**	-0.983**
	(0.381)	(0.381)	(0.423)	(0.422)
other controls	yes	yes	yes	yes
country fixed effects	yes	yes	yes	yes
year fixed effects	yes	yes	yes	yes
observations	762	762	762	762
R-squared	0.572	0.541	0.561	0.530

Note: In this table, we drop the highest and lowest one-percent outliers of IPR. * $p<0.10$, ** $p<0.05$, *** $p<0.01$. IPR denotes the index of patent protection. FD denotes the level of financial development. Other control variables include FD, the degree of openness, the unemployment rate and the quality of institutions. In the first two columns, financial development is measured by private credit, whereas in the last two columns it is measured by bank assets. The dependent variable is economic growth measured by either the growth rate of GDP or the growth rate of GDP per capita. Robust standard errors are in parentheses.

Table A1: Summary statistics					
Variable	Obs	Mean	S.D.	Min	Max
$Growth_{i,t+1}$ (GDP)	776	3.030	3.610	-14.80	25.56
$Growth_{i,t+1}$ (GDP per capita)	776	2.170	3.510	-14.42	24.38
$IPR_{i,t}$	776	6.300	2.090	2.270	9.900
$FD_{i,t}$ (private credit)	776	0.870	0.500	0.080	2.620
$FD_{i,t}$ (bank assets)	776	0.930	0.480	0.110	2.630
$Open_{i,t}$	776	0.900	0.710	0.160	4.430
$Unemp_{i,t}$	776	7.920	4.710	0.580	27.47
$Insq_{i,t}$	776	5.800	2.150	1.670	10.00