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Chu, Angus C. and Cozzi, Guido and Pan, Shiyuan and Zhang, Mengbo

Fudan University, University of St. Gallen, Zhejiang University, University of California, Los Angeles

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

Angus C. Chu Guido Cozzi Shiyuan Pan Mengbo Zhang

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Abstract

This study explores the effects of patent protection in a distance-to-frontier 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. An excessively high level of patent protection prevents a country from converging to the world technology frontier. A higher level of financial development influences credit constraints through two channels: decreasing the interest-rate spread and increasing the default cost. Through either channel, a higher level of financial development stimulates innovation, but the two channels of financial development interact with the effects of patent protection differently. Via the interest-spread (default-cost) channel, patent protection is more likely to have a negative (positive) effect on innovation under a higher level of financial development. We test these results using cross-country regressions and find that patent protection and financial development have a negative interaction effect on innovation.

JEL classification: O31, O34, E44
Keywords: Patent protection, credit constraints, economic growth, convergence

Chu: anguscccc@gmail.com. China Center for Economic Studies, School of Economics, Fudan University, Shanghai, China. Cozzi: guido.cozzi@unisg.ch. Department of Economics, University of St. Gallen, St. Gallen, Switzerland. Pan: shiyuanpan@zju.edu.cn. School of Economics, Zhejiang University, Hangzhou, China. Zhang: mbzhangucla@g.ucla.edu. Department of Economics, University of California, Los Angeles, United States. The authors would like to thank Margaret Davenport for her excellent research assistance. The usual disclaimer applies.

1 Introduction

In this study, we explore the effects of patent protection in a distance-to-frontier R&D-based growth model, in which a country invests in R&D to adopt technologies from abroad and may gradually converge to the world technology frontier. 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 *et al.* (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 will entail 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]

In terms of transition dynamics, we find that at an early stage of development, credit constraints tend to be binding because there are many novel technologies for the entrepreneurs to transfer from the frontier. As the economy converges to the world technology frontier, credit constraints may become non-binding if the level of patent protection is low or may remain binding if the level of patent protection is high. An excessively high level of patent protection even prevents a country from converging to the world technology frontier. In this case, the country's technology level relative to the world technology frontier converges to zero in the long run.

We consider the case in which a higher level of financial development influences credit constraints through two channels: increasing the default cost as in Aghion *et al.* (2005) and decreasing the interest-rate spread. Empirical studies, such as Lerner and Schoar (2005), Qian and Strahan (2007) and Liberti and Mian (2010), often find that financial development reduces interest rates and the collateral spread of capital. We find that by decreasing the interest-rate spread or increas-

[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).

ing the default cost, a higher level of financial development stimulates innovation. Intuitively, by decreasing the interest-rate spread, the interest rate becomes lower, which in turn increases the present value of future monopolistic profits and the value of inventions. By increasing the default cost, R&D entrepreneurs are less likely to default, and hence, banks are more willing to lend to entrepreneurs for their R&D investment.

Interestingly, the two channels of financial development interact with the effects of patent protection in different ways. We find that via the interest-spread (default-cost) channel, patent protection is more likely to have a negative (positive) effect on innovation under a higher level of financial development. The intuition of these results can be explained as follows. When the interest-rate spread decreases, the present value of future profits and the value of inventions increase. Consequently, entrepreneurs are incentivized to borrow more funding for R&D, rendering the credit constraints more likely to be binding in which case patent protection has a negative effect on innovation. When the default cost increases, banks become more willing to lend to R&D entrepreneurs, rendering the credit constraints less likely to be binding in which case patent protection has a positive effect on innovation.

We test the above theoretical implications using cross-country regressions. We find that patent protection and financial development have direct positive effects on economic growth. This finding is consistent with Ang (2010, 2011) who also empirically explore the effects of both patent protection and financial development on R&D activities. We complement the analysis in Ang (2010, 2011) by considering the interaction effect of patent protection and financial development on economic growth. In summary, we find that patent protection and financial development have a negative interaction effect on innovation, which is consistent with the interest-spread channel through which patent protection is more likely to have a negative 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 take into consideration the interaction between patent protection and 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 (1969) 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 (1985).[3] However, we show that patent breadth interacts

[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."

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 and in a distance-to-frontier R&D-based growth model that enables us to explore the technology convergence of countries. Chu, Cozzi and Galli (2014) also analyze the effects of patent protection in a distance-to-frontier model and show that the innovation-maximizing level of patent protection depends on the income level of a country. However, the abovementioned studies neither feature financial frictions nor consider the interaction between patent protection and credit constraints, which are the novel contributions of this study.

The rest of this paper is organized as follows. Section 2 describes the model. Section 3 presents the theoretical results. Section 4 discusses the regression results. The final section concludes.

2 An R&D-based growth model with credit frictions

In this section, we consider a distance-to-frontier R&D-based growth model with financial frictions based on the seminal work of Aghion *et al.* (2005) and Acemoglu *et al.* (2006). We modify their Schumpeterian model into a variety-expanding model and allow the value of inventions to depend on multiple periods of profits and an interest-rate spread that affects the present value of future profits. We consider a discrete-time model and use the model to explore the interaction effects of patent protection and credit constraints on the technology convergence of countries.

2.1 Households and workers/entrepreneurs

There is a continuum of countries, indexed by a superscript i, that are behind the world technology frontier.[5] For simplicity, we follow previous studies to assume that countries do not exchange goods or factors but are subject to international technology spillovers from the frontier. There is a unit continuum of infinitely-lived households in each country. These households own intangible capital (in the form of patents that generate monopolistic profits) and consume final good (numeraire). The lifetime utility function of the representative household in country i is given by

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

where the parameter $\rho > 0$ is the subjective discount rate and C_t^i is consumption of the representative household in country i at time t. The asset-accumulation equation is $A_{t+1}^i = (1+r_t^i)A_t^i - C_t^i$.

[4]For other patent-policy instruments, see O'Donoghue and Zweimuller (2004) and Kiedaisch (2015) on patentability requirement, Furukawa (2007) and Horii and Iwaisako (2007) on protection against imitation, Dinopoulos and Syropoulos (2007) and Davis and Sener (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. These studies neither consider financial frictions nor the distance-to-frontier approach.

[5]In this study, we do not model the behavior of the technology frontier and simply take it as given.

From standard dynamic optimization, the linear utility function implies that in equilibrium the real interest rate is equal to the discount rate, such that $r_t^i = \rho$.

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^i. At the end of the period, each worker becomes an entrepreneur and devotes part of her wage income $\kappa^i W_t^i$ to R&D, where $\kappa^i \in (0,1]$.[6] 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 $u_t^i = y_t^i + E_t[o_{t+1}^i]/(1+\rho)$, where y_t^i denotes consumption when young and $E_t[o_{t+1}^i]$ denotes expected consumption when old. If the amount of her R&D spending Z_t^i is less than $\kappa^i W_t^i$, then a worker/entrepreneur simply consumes $W_t^i - Z_t^i$ in period t or saves part of it subject to the market interest rate r_t^i. However, if $Z_t^i > \kappa^i W_t^i$, then the worker/entrepreneur would need to apply for a loan subject to credit constraints, which will be described in details in Section 2.7.

2.2 Final good

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

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

where the parameter $\alpha \in (0,1)$ determines labor intensity $1-\alpha$ in production. L_t^i is labor input. $x_t^i(v)$ is the amount of intermediate goods $v \in [0, N_t^i]$, and N_t^i is the number of available intermediate goods in country i 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 $W_t^i = (1-\alpha)Y_t^i/L_t^i$, where $L_t^i = L = 1$ from the market-clearing condition. The conditional demand function for intermediate goods is given by

$$x_t^i(v) = \left[\frac{\alpha}{p_t^i(v)}\right]^{1/(1-\alpha)}, \tag{2}$$

where $p_t^i(v)$ is the price of intermediate goods v in country i.

2.3 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.

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

In industry v, the firm produces $x_t^i(v)$ units of intermediate goods using $x_t^i(v)$ units of final good as inputs. Therefore, the profit function of the firm in industry v is

$$\Pi_t^i(v) = p_t^i(v)\, x_t^i(v) - x_t^i(v) = \left[p_t^i(v) - 1\right]\left[\frac{\alpha}{p_t^i(v)}\right]^{1/(1-\alpha)}, \tag{3}$$

where the second equality follows from (2).

Using (3), one can derive the profit-maximizing price $p_t^i(v)$ given by $1/\alpha$. To capture the effects of patent protection, we follow Goh and Olivier (2002) to model patent breadth $\beta^i \in (1, 1/\alpha)$ as a policy parameter. The idea is that the unit cost for imitative firms to produce $x_t^i(v)$ is β^i, which is assumed to be increasing in the level of patent protection; therefore, a larger patent breadth β^i allows the monopolistic producer of $x_t^i(v)$, who owns the patent, to charge a higher markup without losing her market share.[7] In this case,

$$p_t^i(v) = \beta^i. \tag{4}$$

Combining (3) and (4), we obtain the amount of profit as a function of patent breadth given by

$$\Pi_t^i(v) = \left(\beta^i - 1\right)\left(\frac{\alpha}{\beta^i}\right)^{1/(1-\alpha)} \equiv \pi(\beta^i), \tag{5}$$

which is increasing in β^i for $\beta^i \leq 1/\alpha$.

2.4 Aggregate production function

Substituting (2) and (4) into (1) yields

$$Y_t^i = \left(\frac{\alpha}{\beta^i}\right)^{\alpha/(1-\alpha)} N_t^i. \tag{6}$$

Equation (6) shows that the growth rate of Y_t^i is determined by the growth rate of N_t^i. Furthermore, for a given N_t^i, the level of Y_t^i is decreasing in patent breadth β^i, which captures the effect of markup distortion on the level of output. 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.[8] 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.

[7] See also Li (2001) and Iwaisako and Futagami (2013) for a similar formulation in R&D-based growth models. 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.

[8] This distortionary effect would be absent if $x_t^i(v)$ 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. However, allowing for capital accumulation would complicate the transition dynamics substantially.

2.5 R&D and the value of patents

In each country, 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. Here "new" intermediate goods refer to novelty only for the domestic economy as these intermediate goods have already been developed at the frontier. In other words, R&D is for the purpose of technology transfer from the frontier to the domestic economy. Furthermore, patentability requirement being based on local novelty is a common assumption in this type of models.

To ensure balanced growth, we assume that each entrepreneur spreads her R&D spending Z_t^i over N_t^i R&D projects.[9] Therefore, the amount of final good that an entrepreneur devotes to each of her R&D projects is Z_t^i/N_t^i, and the probability of her R&D projects being successful is $P_t^i = \min\{Z_t^i/(N_t^i\eta_t^i), 1\}$,[10] where $1/\eta_t^i$ captures country i's productivity in R&D.

We follow Acemoglu (2009, chapter 18) to assume that η_t^i is an increasing function in N_t^i/N_t, where N_t is the level of technology at the world technology frontier. N_t grows at a constant rate $\overline{g} > 0$, which is taken as given by other countries. Let's define country i's relative technology level to the frontier as $\mu_t^i \equiv N_t^i/N_t \in (0, 1)$, which is an inverse measure of the country's distance to the world technology frontier. We adopt the following specification for η_t^i:

$$\eta_t^i = [\gamma(\mu_t^i)^\phi + \underline{\eta}] \left(\frac{Z_t^i}{N_t^i}\right)^\theta, \tag{7}$$

where the parameters $\{\gamma, \underline{\eta}\} > 0$ and $\{\theta, \phi\} \in (0, 1)$ are common across countries. This specification features the catching-up effect under which a less developed country that has a smaller μ_t^i is able to grow faster by absorbing more world technologies. The term $(Z_t^i/N_t^i)^\theta$ 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

$$\Delta N_t^i \equiv N_{t+1}^i - N_t^i = \frac{Z_t^i}{\eta_t^i} = \frac{N_t^i}{\gamma(\mu_t^i)^\phi + \underline{\eta}} \left(\frac{Z_t^i}{N_t^i}\right)^{1-\theta}, \tag{8}$$

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

Each R&D project has a probability P_t^i 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 $V_t^i(v)$. Here we assume that the discount rate for future profits is given by $r^i + \epsilon^i = \rho + \epsilon^i$, where $\epsilon^i \geq 0$ denotes an exogenous interest-rate spread in country i.[11] For example, Lerner and Schoar (2005),

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

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

[11] Our exogenous interest rate spread is analogous to the exogenous interest premium in Smets and Wouters (2007). A potential microfoundation for this friction can be a financial transaction cost (in terms of final good), which reduces the value of intangible capital in the form of patents.

Qian and Strahan (2007) and Liberti and Mian (2010) find that financial development reduces interest rates, the contracting cost of financing and the collateral spread of capital. Here we use the parameter ϵ^i to capture these financial frictions in a simple way.[12]

Under the assumption above, $V_t^i(v)$ can be expressed as

$$V_t^i(v) = \sum_{s=t}^{\infty} \frac{\Pi_{s+1}^i(v)}{(1+r^i+\epsilon^i)^{s+1-t}} = \frac{\pi(\beta^i)}{\rho+\epsilon^i}, \tag{9}$$

which is increasing in patent breadth β^i and decreasing in ϵ^i. The positive effect of β^i captures the positive effect of patent protection on the value of inventions. In a country that is more financially developed, there are less financial frictions, which in turn reduce the interest-rate spread ϵ^i and increase the value of inventions. Finally, we make the following parameter restriction, which guarantees that $P_t^i \in (0,1)$ and $\mu_t^i \in (0,1)$.

Assumption 1 $(\overline{g}^\theta \underline{\eta})^{1/(1-\theta)} < \pi(\beta^i)/(\rho+\epsilon^i) < \min\{\underline{\eta}^{1/(1-\theta)}, [\overline{g}^\theta(\gamma+\underline{\eta})]^{1/(1-\theta)}\}$.[13]

2.6 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 $P_t^i V_t^i = Z_t^i / N_t^i$, which can be expressed as

$$V_t^i = \eta_t^i \Leftrightarrow \frac{\pi(\beta^i)}{\rho+\epsilon^i} = [\gamma(\mu_t^i)^\phi + \underline{\eta}] \left(\frac{Z_t^i}{N_t^i}\right)^\theta. \tag{10}$$

Therefore, the level of R&D in any period t is given by

$$Z_t^i = \left[\frac{\pi(\beta^i)/(\rho+\epsilon^i)}{\gamma(\mu_t^i)^\phi + \underline{\eta}}\right]^{1/\theta} N_t^i, \tag{11}$$

which is increasing in β^i for a given level of relative technology μ_t^i. The growth rate of technology is given by

$$g_t^i \equiv \frac{\Delta N_t^i}{N_t^i} = \frac{1}{\gamma(\mu_t^i)^\phi + \underline{\eta}} \left(\frac{Z_t^i}{N_t^i}\right)^{1-\theta} = \frac{1}{[\gamma(\mu_t^i)^\phi + \underline{\eta}]^{1/\theta}} \left[\frac{\pi(\beta^i)}{\rho+\epsilon^i}\right]^{(1-\theta)/\theta}. \tag{12}$$

For a given μ_t^i, the growth rate g_t^i in (12) is increasing in patent breadth β^i capturing the positive *monopolistic profit* effect of patent protection on innovation. Furthermore, a higher level of financial development in the form of a decrease in the interest-rate spread ϵ^i increases the growth rate of technology. We summarize these results in Proposition 1.

[12] See Sunaga (2017) for an interesting model of innovation cycles with an endogenous interest rate spread.

[13] The assumption $\pi(\beta^i)/(\rho+\epsilon^i) < \underline{\eta}^{1/(1-\theta)}$ ensures $P_t^i < 1$ for $\mu_t^i \in (0,1)$. Derivations available upon request.

Proposition 1 *In the absence of credit constraints, stronger patent protection leads to a higher growth rate of technology. A higher level of financial development in the form of a decrease in the interest-rate spread also leads to a higher growth rate of technology.*

Proof. Proven in text. ■

In the long run, μ_t^i converges to a steady state, in which N_t^i grows at the same rate as N_t.[14] Setting g_t^i to the world technology growth rate $\overline{g}$ in (12) yields the steady-state level of relative technology μ_t^i given by

$$\mu^i = \frac{1}{\gamma^{1/\phi}} \left\{ \frac{1}{\overline{g}^{\theta}} \left[\frac{\pi(\beta^i)}{\rho + \epsilon^i} \right]^{(1-\theta)} - \underline{\eta} \right\}^{1/\phi} \equiv \mu_1(\underset{+}{\beta^i}, \underset{-}{\epsilon^i}), \tag{13}$$

which is increasing in the level of patent breadth β^i and decreasing in the interest-rate spread ϵ^i. Note that Assumption 1 ensures $\mu_1 \in (0, 1)$ in the steady-state equilibrium. Substituting (13) into (11) yields the balanced-growth level of R&D given by

$$Z_t^i = \pi(\beta^i) \frac{\overline{g}}{\rho + \epsilon^i} N_t^i, \tag{14}$$

which is increasing in patent breadth β^i and decreasing in the interest-rate spread ϵ^i. In other words, an increase in patent breadth β^i or a decrease in the interest-rate spread ϵ^i causes the entrepreneurs to want to do more R&D.

2.7 Equilibrium with credit constraints

Before the end of a period, each entrepreneur devotes her wage income $\kappa^i W_t^i$ to N_t^i R&D projects without borrowing. If the R&D spending Z_t^i exceeds her wage income $\kappa^i W_t^i$, then she would have to borrow $D_t^i = Z_t^i - \kappa^i W_t^i$ 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 $(1 + R_{t+1}^i) D_t^i$ 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 $P_t^i(1 + R_{t+1}^i) D_t^i + (1 - P_t^i)0$. When banks make zero expected profit, we have $P_t^i(1 + R_{t+1}^i) D_t^i = D_t^i$, which implies $P_t^i(1 + R_{t+1}^i) = 1$.

What makes it difficult to borrow is that an entrepreneur may want to default even when her projects are successful. We follow Aghion *et al.* (2005) to assume that banks do not observe the outcome of R&D projects, and hence, the problem of moral hazard arises.[15] Specifically, by paying a default cost $h^i Z_t^i$ where $h^i \in (0, 1)$, an entrepreneur can hide the outcome of her projects and avoid repaying the loan. The cost parameter h^i is an indicator of banks' effectiveness in securing repayment and partly measures the level of financial development in the country. In case

[14] We show the stability of this steady state in Section 2.8.

[15] As in Aghion *et al.* (2005), 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 *et al.* (2010) for an interesting analysis on patents as collateral.

an entrepreneur decides to default, the entrepreneur must incur the default cost before observing the outcome of her R&D projects. Therefore, entrepreneurs would not default if and only if the following incentive-compatibility (IC) constraint holds:

$$h^i Z_t^i \geq P_t^i (1 + R_{t+1}^i) D_t^i = D_t^i, \tag{15}$$

where $D_t^i = Z_t^i - \kappa^i W_t^i = Z_t^i - \kappa^i (1-\alpha) Y_t^i$. Substituting this condition into (15) yields

$$Z_t^i \leq \frac{\kappa^i (1-\alpha) Y_t^i}{1-h^i} = \frac{\kappa^i (1-\alpha)}{1-h^i} \left(\frac{\alpha}{\beta^i}\right)^{\alpha/(1-\alpha)} N_t^i, \tag{16}$$

where the last equality uses (6). We refer to this IC constraint as a credit constraint, which becomes tighter as patent breadth β^i 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^i increases, aggregate income Y_t^i decreases due to the markup distortion. As a result, a larger β^i 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 $f^i \equiv \kappa^i (1-\alpha)/(1-h^i) \in (0, \infty)$ as a composite parameter that is increasing in the default cost h^i. Then, substituting (16) into (8) yields the growth rate of technology in the presence of a binding credit constraint:

$$g_t^i = \frac{\Delta N_t^i}{N_t^i} = \frac{1}{\gamma(\mu_t^i)^\phi + \underline{\eta}} \left[f^i \left(\frac{\alpha}{\beta^i}\right)^{\alpha/(1-\alpha)} \right]^{1-\theta}. \tag{17}$$

For a given μ_t^i, the growth rate g_t^i in (17) is decreasing in the level of patent breadth β^i capturing the abovementioned *financial distortionary* effect of patent protection on innovation. Furthermore, a higher level of financial development in the form of an increase in the default cost f^i increases the growth rate of technology.[16] 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 in the form of an increase in the default cost leads to a higher growth rate of technology.*

Proof. Proven in text. ■

Equations (14) and (16) show that the balanced-growth level of R&D spending Z_t^i satisfies

$$Z_t^i = \min \left\{ \pi\left(\beta^i\right) \frac{\overline{g}}{\rho + \epsilon^i}, f^i \left(\frac{\alpha}{\beta^i}\right)^{\alpha/(1-\alpha)} \right\} N_t^i. \tag{18}$$

[16] If financial friction is modeled as screening of R&D projects as in Aghion and Howitt (2009, chapter 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.

There exists a unique value of patent breadth β^i below (above) which the credit constraint does not bind (is binding) in the long run. Equating $\pi\left(\beta^i\right)\overline{g}/(\rho+\epsilon^i)$ and $f^i(\alpha/\beta^i)^{\alpha/(1-\alpha)}$ yields this threshold value of β^i given by[17]

$$\beta_1(\underset{+}{f^i},\underset{+}{\epsilon^i}) \equiv \frac{\alpha\overline{g}}{\alpha\overline{g}-(\rho+\epsilon^i)f^i}, \tag{19}$$

which is increasing in the country's default cost f^i and the interest-rate spread ϵ^i. The intuition of these two results can be explained as follows. First, a larger default cost f^i reduces entrepreneurs' incentives to default 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. Second, a *lower* interest-rate spread ϵ^i increases entrepreneurs' incentives to invest in R&D. As a result, the credit constraint becomes more likely to be binding, which in turn decreases the threshold value of patent breadth. In this case, a higher level of financial development has different implications on the threshold value of patent breadth depending on whether financial development is reflected by an increase in the default cost or a decrease in the interest-rate spread.

2.8 Transitional dynamics and convergence

Using the definition of relative technology level μ_t^i, we can derive its law of motion given by

$$\frac{\mu_{t+1}^i}{\mu_t^i}=\frac{N_{t+1}^i}{N_t^i}\Big/\frac{N_{t+1}}{N_t} \Leftrightarrow \mu_{t+1}^i=\left(\frac{1+g_t^i}{1+\overline{g}}\right)\mu_t^i. \tag{20}$$

In the absence of credit constraints, we use (12) to express the law of motion for μ_t^i as

$$\mu_{t+1}^i=\frac{\mu_t^i}{1+\overline{g}}\left\{1+\frac{1}{[\gamma(\mu_t^i)^\phi+\underline{\eta}]^{1/\theta}}\left[\frac{\pi(\beta^i)}{\rho+\epsilon^i}\right]^{(1-\theta)/\theta}\right\}\equiv H_1^i(\mu_t^i). \tag{21}$$

Even if the credit constraint does not bind in the long run, it may be binding in the short run when μ_t^i is small. When the credit constraint is binding, we can use (17) to express the law of motion for μ_t^i as

$$\mu_{t+1}^i=\frac{\mu_t^i}{1+\overline{g}}\left\{1+\frac{1}{\gamma(\mu_t^i)^\phi+\underline{\eta}}\left[f^i\left(\frac{\alpha}{\beta^i}\right)^{\alpha/(1-\alpha)}\right]^{1-\theta}\right\}\equiv H_2^i(\mu_t^i). \tag{22}$$

Combining (21) and (22) implies that country i's technology level relative to the frontier evolves according to the following law of motion:

$$\mu_{t+1}^i=\min\{H_1^i(\mu_t^i),H_2^i(\mu_t^i)\},$$

from which we derive a threshold value $\hat{\mu}^i$ of relative technology level below (above) which $H_2^i<H_1^i$ ($H_1^i<H_2^i$). In other words, when relative technology level μ_t^i is below this threshold $\hat{\mu}^i$, μ_{t+1}^i evolves

[17] To ensure that the threshold value $\beta_1<1/\alpha$, we assume $f^i<(1-\alpha)\alpha\overline{g}/(\rho+\epsilon^i)$, which is equivalent to $h^i<1-(\rho+\epsilon^i)/(\alpha\overline{g})$.

according to $H_2^i(\mu_t^i)$ that is subject to the credit constraint. In contrast, when relative technology level μ_t^i is above the threshold $\hat{\mu}^i$, μ_{t+1}^i evolves according to $H_1^i(\mu_t^i)$ that is free from the credit constraint. The threshold value $\hat{\mu}^i$ is given by

$$\hat{\mu}^i(\underset{+}{\beta^i}, \underset{-}{f^i}, \underset{-}{\epsilon^i}) \equiv \left\{ \frac{1}{\gamma} \left[\frac{\pi(\beta^i)}{(f^i)^\theta (\rho + \epsilon^i)} \left(\frac{\beta^i}{\alpha} \right)^{\alpha\theta/(1-\alpha)} - \underline{\eta} \right] \right\}^{1/\phi}, \tag{23}$$

which is increasing in patent breadth β^i but decreasing in the default cost f^i and in the interest-rate spread ϵ^i. Intuitively, at a higher level of patent protection, the credit constraint is more likely to be binding, which in turn expands the range of μ_t^i within which μ_{t+1}^i evolves according to $H_2^i(\mu_t^i)$ that is subject to the credit constraint. In contrast, when either the default cost or the interest-rate spread increases, the credit constraint becomes less likely to be binding, which in turn shrinks the range of μ_t^i within which μ_{t+1}^i evolves according to $H_2^i(\mu_t^i)$.

In the following lemmata, we derive some properties of the functions $\{H_1^i(\mu_t^i), H_2^i(\mu_t^i)\}$, which will be useful in determining the value of μ_t^i at the steady state.

Lemma 1 *$H_1^i(\mu_t^i)$ is increasing and concave w.r.t. μ_t^i, and satisfies the following properties:*

$$H_1^i(0) = 0,\ H_1^i(1) < 1,\ \frac{\partial H_1^i}{\partial \mu_t^i}|_{\mu_t^i=0} > 1.$$

Proof. See Appendix A. ■

Lemma 2 *$H_2^i(\mu_t^i)$ is increasing and concave w.r.t. μ_t^i, and satisfies the following properties:*

$$H_2^i(0) = 0,$$

$$\frac{\partial H_2^i}{\partial \mu_t^i}|_{\mu_t^i=0} = \frac{1}{1+\overline{g}} \left\{ 1 + \frac{1}{\underline{\eta}} \left[f^i \left(\frac{\alpha}{\beta^i} \right)^{\alpha/(1-\alpha)} \right]^{1-\theta} \right\}.$$

Proof. See Appendix A. ■

In addition to the first threshold value β_1 of patent breadth defined in (19), we also define a second threshold value β_2 of patent breadth below (above) which $\frac{\partial H_2^i}{\partial \mu_t^i}|_{\mu_t^i=0} > 1$ ($\frac{\partial H_2^i}{\partial \mu_t^i}|_{\mu_t^i=0} < 1$).

$$\beta_2(\underset{+}{f^i}) \equiv \alpha \left[\frac{f^i}{(\underline{\eta}\overline{g})^{1/(1-\theta)}} \right]^{(1-\alpha)/\alpha}, \tag{24}$$

which is increasing in the default cost f^i. We now consider three possibilities.

Case 1 *When $\beta^i \leq \beta_1(f^i, \epsilon^i)$, we have $\hat{\mu}^i \leq \mu_1(\beta^i, \epsilon^i)$. In this case, the credit constraint is initially binding and then becomes non-binding before reaching the steady state.*

In this case, the credit constraint is initially binding given a sufficiently low initial value of μ_0^i. Intuitively, when the initial level of μ_0^i is low, the developing economy can transfer many new technologies from the frontier. Therefore, given the large incentives for R&D, the credit constraint is binding at the early stage of development. Overtime, μ_t^i rises above $\hat{\mu}^i$, which is below the steady-state level. At this point $\hat{\mu}^i$, the credit constraint becomes non-binding, and then μ_t^i converges to the steady state in the long run. The steady-state value of relative technology μ_t^i is given by $\mu^i = \mu_1(\beta^i, \epsilon^i)$, which is increasing in patent breadth β^i as shown in (13). The long-run growth rate of technology in this country is $\overline{g}$. Figure 1 shows that the steady state is stable.

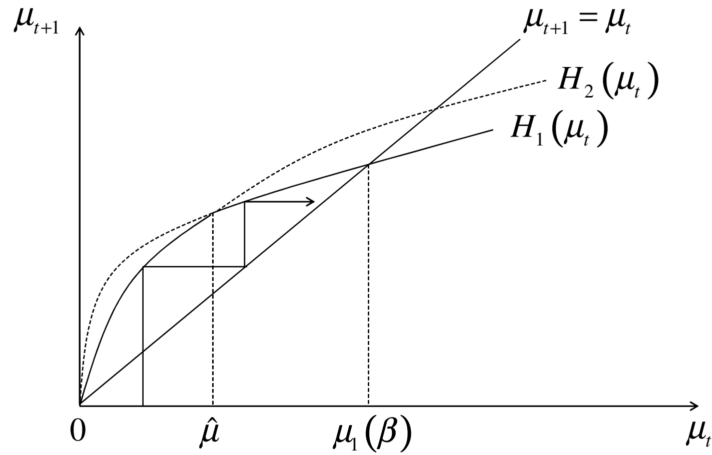

Figure 1: Convergence under $\beta^i \leq \beta_1$

Case 2 *When* $\beta_1(f^i, \epsilon^i) < \beta^i < \beta_2(f^i)$,[18] *we have* $\hat{\mu}^i > \mu_1(\beta^i)$ *and* $\frac{\partial H_2^i}{\partial \mu_t^i}|_{\mu_t^i=0} > 1$*. In this case, the credit constraint is initially binding and remains binding after reaching the steady state.*

In this case, the credit constraint is initially binding for the same reason as before. Overtime, the developing economy converges to the steady state without reaching the point $\hat{\mu}^i$ at which the credit constraint would have become non-binding. In other words, the credit constraint is binding even in the long run. The steady-state value of relative technology level μ_t^i is determined by the fixed point $\mu^i = H_2^i(\mu^i)$, which yields

$$\mu^i = \left\{ \frac{1}{\gamma} \left[\frac{1}{\overline{g}} \left[f^i \left(\frac{\alpha}{\beta^i} \right)^{\alpha/(1-\alpha)} \right]^{1-\theta} - \underline{\eta} \right] \right\}^{1/\phi} \equiv \mu_2(\underset{-}{\beta^i}, \underset{+}{f^i}), \tag{25}$$

which is decreasing in patent breadth β^i and increasing in the default cost f^i. The long-run growth rate of technology in this country is $\overline{g}$. Figure 2 shows that the steady state is stable.

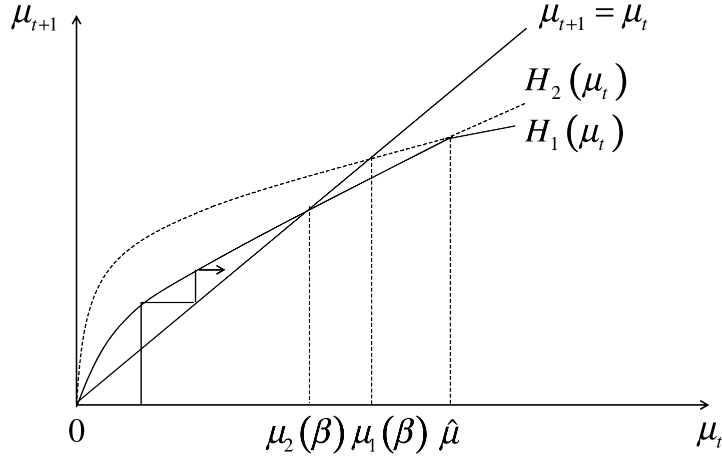

Figure 2: Convergence under $\beta_1 < \beta^i < \beta_2$

[18] Together with $\bar{g} < 1$, Assumption 1 ensures that $\beta_1 < \beta_2$. Derivations are available upon request.

Case 3 *When $\beta^i \geq \beta_2(f^i)$, we have $\hat{\mu}^i > \mu_1(\beta^i)$ and $\frac{\partial H_2^i}{\partial \mu_t^i}|_{\mu_t^i=0} \leq 1$. In this case, the credit constraint is always binding. Furthermore, the economy diverges from the frontier.*

In this case, the credit constraint is always binding. Furthermore, the level of R&D in the economy is so low that μ_t^i grows at a lower rate than the frontier. Figure 3 shows that μ_t^i converges to 0, at which point we have

$$\lim_{t\to\infty} \frac{\mu_{t+1}^i}{\mu_t^i} = \lim_{\mu_t^i \to 0} \frac{H_2^i(\mu_t^i)}{\mu_t^i} = \frac{1}{1+\overline{g}} \left\{ 1 + \frac{1}{\underline{\eta}} \left[f^i \left(\frac{\alpha}{\beta^i} \right)^{\alpha/(1-\alpha)} \right]^{1-\theta} \right\} \equiv \xi^i(\underset{-}{\beta^i}, \underset{+}{f^i}) \leq 1. \tag{26}$$

Therefore, the balanced growth rate in country i in this case is

$$g^i = \lim_{t\to\infty} \left[(1+\overline{g}) \frac{\mu_{t+1}^i}{\mu_t^i} - 1 \right] = (1+\overline{g})\,\xi^i - 1 \leq \overline{g}, \tag{27}$$

where ξ^i is decreasing in patent breadth β^i and increasing in the default cost f^i.

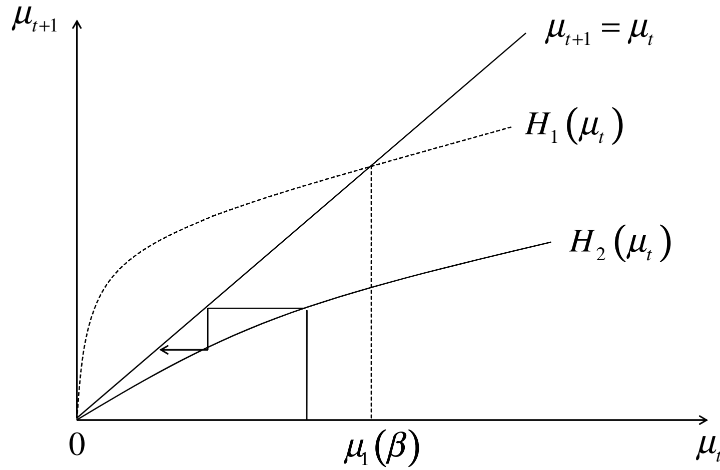

Figure 3: Divergence under $\beta^i \geq \beta_2$

3 Patent breadth and credit constraints

Based on the results in the previous section, we can divide countries into three groups. We denote the three groups as group 1, 2 and 3.

Group 1: For countries in group 1, their R&D activities are not restricted by the credit constraint at the steady state, and their technologies grow at the same rate as the world technology frontier in the long run. The levels of patent protection in these countries satisfy $\beta^i \leq \beta_1(f^i, \epsilon^i)$, where the threshold $\beta_1(f^i, \epsilon^i)$ derived in (19) is increasing in the default cost f^i and the interest-rate spread ϵ^i.

Group 2: For countries in group 2, their R&D activities are always restricted by the credit constraint, but these countries can still keep pace with the growth rate of the world technology frontier in the long run. The levels of patent protection in these countries satisfy $\beta_1(f^i, \epsilon^i) < \beta^i < \beta_2(f^i)$, where the threshold $\beta_2(f^i)$ derived in (24) is increasing in the default cost f^i but independent of the interest-rate spread ϵ^i.

Group 3: For countries in group 3, their R&D activities are always strongly restricted by the credit constraint. In this case, the long-run technology growth rate g^i derived in (26) and (27) is slower than that of the world technology frontier. The levels of patent protection in these countries satisfy $\beta^i \geq \beta_2(f^i)$.

According to this classification, the relative technology level μ^i of a country in the steady state is given by

$$\mu^i = \begin{cases} \mu_1(\underset{+}{\beta^i}, \underset{-}{\epsilon^i}), & \text{if } \beta^i \leq \beta_1(\underset{+}{f^i}, \underset{+}{\epsilon^i}) \\ \mu_2(\underset{-}{\beta^i}, \underset{+}{f^i}), & \text{if } \beta_1(\underset{+}{f^i}, \underset{+}{\epsilon^i}) < \beta^i < \beta_2(\underset{+}{f^i}) \\ 0, & \text{if } \beta^i \geq \beta_2(\underset{+}{f^i}) \end{cases}, \tag{28}$$

and the balanced growth rate of technology is given by

$$g^i = \begin{cases} \overline{g}, & \text{if } \beta^i \leq \beta_1(\underset{+}{f^i}, \underset{+}{\epsilon^i}) \\ \overline{g}, & \text{if } \beta_1(\underset{+}{f^i}, \underset{+}{\epsilon^i}) < \beta^i < \beta_2(\underset{+}{f^i}) \\ (1+\overline{g})\,\xi^i(\underset{-}{\beta^i}, \underset{+}{f^i}) - 1 \leq \overline{g}, & \text{if } \beta^i \geq \beta_2(\underset{+}{f^i}) \end{cases}. \tag{29}$$

We summarize these results in Proposition 3.

Proposition 3 *There are three types of balanced growth paths in the world. First, when $\beta^i \leq \beta_1(f^i, \epsilon^i)$, relative technology level μ^i converges to μ_1, and the growth rate of technology converges to $\overline{g}$. In this case, μ_1 is increasing in patent breadth β^i and decreasing in the interest-rate spread ϵ^i. Second, when $\beta_1(f^i, \epsilon^i) < \beta^i < \beta_2(f^i)$, relative technology level μ^i converges to μ_2, and the growth rate of technology converges to $\overline{g}$. In this case, μ_2 is decreasing in patent breadth β^i and increasing in the default cost f^i. Third, when $\beta^i \geq \beta_2(f^i)$, relative technology level μ^i converges to zero, and the growth rate of technology converges to $(1+\overline{g})\,\xi^i - 1$, which is decreasing in patent breadth β^i and increasing in the default cost f^i.*

Proof. Proven in text. ■

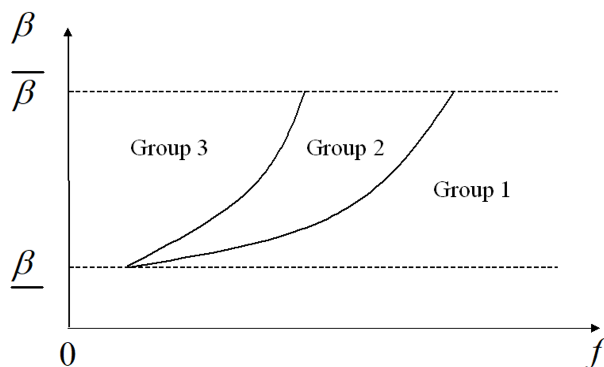

Figure 4

Figure 4 illustrates the three groups of countries.[19] Countries in group 1 are not financially constrained at the steady state due to a high default cost f^i. In this case, stronger patent protection increases the amount of monopolistic profit, which in turn stimulates R&D and increases the relative technology level μ_1 in the long run. A higher level of financial development in the form of a lower interest-rate spread ϵ^i increases the value of inventions and the relative technology level μ_1 in the long run.

Countries in group 2 are always financially constrained due to a moderate default cost f^i. 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 relative technology level μ_2 in the long run. A higher level of financial development in the form of a higher default cost f^i enables the entrepreneurs to borrow more funding for R&D, which in turn increases the relative technology level μ_2 in the long run.

For a given value of the default cost f^i, an increase in the level of patent protection may cause a country in group 1 to fall into group 2; therefore, there exists a technology-maximizing level of patent protection β_1. This technology-maximizing level of patent protection β_1 is affected by the level of financial development. First, it is increasing in the default cost f^i. As mentioned before, a larger default cost f^i reduces entrepreneurs' incentives to default, 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_1 of patent breadth and renders patent protection more likely to have a positive effect on R&D.

Second, the technology-maximizing level of patent protection β_1 is increasing in the interest-rate spread ϵ^i; in other words, a decrease in the interest-rate spread leads to a lower technology-maximizing level of patent protection. Intuitively, a lower interest rate increases the value of inventions and raises entrepreneurs' incentives to invest in R&D. As a result, the credit constraint becomes more likely to bind, which in turn decreases the threshold value β_1 of patent breadth and renders patent protection more likely to have a negative effect on R&D.

A higher level of financial development *increases* the cost of default but *decreases* the interest-rate spread in a country. Therefore, under a higher level of financial development, it is not clear

[19] The relative position of the curves in Figure 4 can be derived analytically. Together with $\bar{g} < 1$, Assumption 1 ensures that countries in group 1 never fall directly into group 3. Derivations are available upon request.

whether patent protection would become more likely to have a positive or negative effect on innovation. This depends on whether financial development increases the default cost or decreases the interest-rate spread. We summarize all the above results in Proposition 4.

Proposition 4 *Financial development has a positive effect on innovation (measured by the relative technology level in the long run) whereas patent protection has an inverted-U effect on innovation. If financial development increases the default cost, then patent protection would be more likely to have a positive effect on innovation under a higher level of financial development. If financial development decreases the interest-rate spread, then patent protection would be more likely to have a negative effect on innovation under a higher level of financial development.*

Proof. Proven in text. ■

Finally, countries in group 3 have a very low default cost f^i. Given that R&D entrepreneurs have strong incentives to default in this case, they are not able to borrow much funding for R&D. As already shown in Proposition 3, the steady-state growth rate of these countries is given by $(1+\overline{g})\,\xi^i - 1 \leq \overline{g}$, where $\xi^i(\beta^i, f^i)$ derived in (26) is decreasing in the level of patent breadth. An increase in the default cost helps to mitigate this problem and raises the steady-state growth rate.

4 Empirical analysis

In this section, we examine the empirical evidence of our theoretical predictions. The implications of our theory that will be tested are the followings:

1. The likelihood that a country converges to the frontier growth rate increases with its level of financial development but decreases with its level of patent protection.
2. In a country that converges to the frontier growth rate, financial development has a positive effect on the steady-state level of per-capita GDP relative to the frontier.
3. In a country that converges to the frontier growth rate, patent protection has an ambiguous effect on the steady-state level of per-capita GDP relative to the frontier.
4. Under a higher level of financial development, patent protection can be more likely to have a negative or positive effect on the steady-state level of relative per-capita GDP.

4.1 Data

The dataset consists of 103 countries from 1980 to 2009 featuring variables of economic growth, patent protection, financial development and other controls.[20] The data of the variables are available either annually or every 5 years on the years ending with 0 or 5. We transform the

[20] See Appendix B for description and sources of data.

dataset into a cross section by taking annual average of the annually available variables for each country and taking average of all available observations over the sample period for the variables available every 5 years. The growth rate of a country is taken to be the average annual growth rate of GDP per capita between 1980 and 2009. For the measure of patent protection within a country, we consider the commonly used index of patent rights developed by Ginarte and Park (1997) and Park (2008).[21] The data for financial development is based on the Financial Development and Structure Dataset from Cihak *et al.* (2012).

Following King and Levine (1993) and Beck *et al.* (2010), we take advantage of three indicators of financial intermediation that can proxy the overall development of a country's financial system. The first measure is the private credit by deposit money banks and other financial institutions as a ratio to GDP, denoted as *private credit*. The second indicator is deposit money banks' assets as a ratio to GDP, denoted as *bank assets*. The third indicator is liquid liabilities as a ratio to GDP, denoted as *liquid liabilities*. We use *private credit* as our preferred measure of financial development as in Ang (2010, 2011) and consider the other two measures as robustness checks because as stated in Levine *et al.* (2000), *private credit* excludes credit granted to the public sector and credit granted by the central bank and development banks.

In our theoretical model, the amount of borrowing as a ratio to output is given by

$$\frac{D_t^i}{Y_t^i} = \frac{Z_t^i - \kappa^i W_t^i}{Y_t^i} = \min\left\{\pi\left(\beta^i\right)\frac{\overline{g}}{\rho+\epsilon^i}\left(\frac{\beta^i}{\alpha}\right)^{\alpha/(1-\alpha)}, f^i\right\} - \kappa^i(1-\alpha),$$

where the second equality follows from (18) and (6). Therefore, D_t^i/Y_t^i is increasing in the default cost f^i and decreasing in the interest-rate spread ϵ^i. In other words, an increase in D_t^i/Y_t^i in the data may reflect the effect of a larger f^i or the effect of a smaller ϵ^i.

4.2 Convergence regression

We use the convergence regression model based on Aghion *et al.* (2005) to test our theoretical implications. The starting point of this model is that each country is assumed to be on a transition path towards its steady state. From (20)-(22), patent protection and financial development affect the relative growth rate of a country that is converging to the frontier given by $(1+g_t^i)/(1+\overline{g}) = \mu_{t+1}^i/\mu_t^i$. In particular, (21) and (22) show that the initial relative technology level has a negative effect on the transitional relative growth rate and that financial development always has a positive effect regardless of whether it increases the default cost f^i or decreases the interest-rate spread ϵ^i. In countries without binding credit constraints, patent protection positively affects the transitional relative growth rate, whereas in countries with binding credit constraints, patent protection negatively affects the transitional relative growth rate.

This empirical analysis is an extension of Aghion *et al.* (2005) with the addition of patent protection, so we follow them to approximate our theoretical model by the following cross-sectional

[21] The index covers five dimensions: 1) extent of coverage; 2) membership in international patent agreements; 3) provisions for loss of protection; 4) enforcement mechanisms; and 5) duration of protection. Each dimension is assigned a value between zero and one. The overall index is the unweighted sum of these five values, with a larger value reflecting a higher level of patent protection.

regression, which can be used to investigate the effects of patent protection and financial development on the steady-state level of per-capita GDP growth relative to the frontier:

$$\begin{aligned} g_i - g_1 &= \gamma_0 + \gamma_\beta \beta_i + \gamma_F F_i + \gamma_{\beta F} \beta_i \cdot F_i + \gamma_y \cdot (y_i - y_1) \\ &\quad + \gamma_{\beta y} \cdot \beta_i \cdot (y_i - y_1) + \gamma_{Fy} \cdot F_i \cdot (y_i - y_1) + \gamma_x x_i + \varepsilon_i, \end{aligned} \tag{30}$$

where g_i denotes the average annual growth rate of per-capita GDP, β_i denotes the average level of patent protection, F_i denotes the average level of financial development, y_i is the log of initial per-capita GDP, x_i is a set of other control variables and ε_i is the disturbance term with mean zero. The subscript i denotes country, and country 1 is the technology leader, which we take to be the United States; hence we exclude the United States in all regressions.

Define country i's initial relative per-capita GDP as $\hat{y}_i \equiv y_i - y_1$. Then we can rewrite (30) as

$$g_i - g_1 = \lambda_i \cdot (\hat{y}_i - \hat{y}_i^*),$$

where the steady-state value $\hat{y}_i^*$ is given by setting the right-hand side of (30) to zero (i.e., when the growth rate difference is zero):

$$\hat{y}_i^* = \frac{\gamma_0 + \gamma_\beta \beta_i + \gamma_F F_i + \gamma_{\beta F} \beta_i \cdot F_i + \gamma_x x_i + \varepsilon_i}{-(\gamma_y + \gamma_{\beta y} \cdot \beta_i + \gamma_{Fy} \cdot F_i)}. \tag{31}$$

In (30), λ_i is a country-specific convergence parameter given by

$$\lambda_i = \gamma_y + \gamma_{\beta y} \cdot \beta_i + \gamma_{Fy} \cdot F_i. \tag{32}$$

It is useful to note that a country converges to the technology frontier if and only if the growth rate of its relative per-capita GDP depends negatively on the initial $\hat{y}_i$; that is, if and only if $\lambda_i < 0$. Thus, from implication 1 we know that the likelihood of convergence would increase with financial development and decrease with patent protection if and only if

$$\gamma_{Fy} < 0 \text{ and } \gamma_{\beta y} > 0. \tag{33}$$

From (31), the long-run effects of financial development and patent protection on the relative output of a country that converges are as follows:

$$\frac{\partial \hat{y}_i^*}{\partial F_i} = \underbrace{-\frac{1}{\lambda_i}}_{+} \underbrace{(\gamma_F + \gamma_{\beta F} \beta_i + \gamma_{Fy} \hat{y}_i^*)}_{?}, \tag{34}$$

and

$$\frac{\partial \hat{y}_i^*}{\partial \beta_i} = \underbrace{-\frac{1}{\lambda_i}}_{+} \underbrace{(\gamma_\beta + \gamma_{\beta F} F_i + \gamma_{\beta y} \hat{y}_i^*)}_{?}. \tag{35}$$

4.3 Relative-technology-level regression

In addition to the convergence regression, we also consider the following relative-technology-level regression:

$$\bar{y}_i - \bar{y}_1 = \zeta_0 + \zeta_\beta \beta_i + \zeta_F F_i + \zeta_{\beta F} \beta_i \cdot F_i + \zeta_y \cdot (y_i - y_1) + \zeta_x x_i + \nu_i, \tag{36}$$

where $\bar{y}_i$ is the average log of per-capita GDP, ν_i is another disturbance term with mean zero, and the other variables are defined in the same way as in the convergence regression. This regression model also captures the implications from (21) and (22) that patent protection and financial development affect a country's relative technology level with respect to the technology frontier. It is useful to note that our data sample covers 30 years, so we try to approximate the steady-state level of relative per-capita GDP by $\bar{y}_i - \bar{y}_1$, and hence, this regression model is used as an additional test of implications 2-4.

4.4 Regression results

Considering the endogeneity of financial development as discussed in Aghion *et al.* (2005) and also the endogeneity of patent protection, we estimate the regression models using instrumental variables. We follow Aghion *et al.* (2005) to use legal origins as the instrument for financial development F_i. Given that patent protection β_i may be also endogenous, we use the following two instruments. The first instrument is the initial relative income $y_i - y_1$.[22] The second instrument is a simulated instrumental variable (SIV). For country i, we use the average degree of patent protection of all the other countries (except country i) in 1980 as an instrument for country i's average patent protection over 1980-2009. We refer to this instrument as simulated patent protection and denote it as β_i^{siv}. This variable is to control for the endogenous response of patent protection to changes in innovation activities within a country, and we assume that the changes are not correlated across countries.[23] The interacted terms between instruments are also used as instruments for the interacted terms of the endogenous variables.[24] We consider both GMM and 2SLS for robustness of estimation. Tables I and III report the estimation results from the 2-step generalized method of moments (GMM), and Tables II and IV report the results from two-stage least squares (2SLS).

Regarding the assumption of variable endogeneity and the choice of instrumental variables, we use a joint test on the endogeneity of all endogenous regressors (including patent protection, financial development, their interacted terms, and their interaction with initial relative income), and a joint test on the exogeneity/orthogonality of suspect instruments. In our regressions we focus on the exogeneity of simulated instrumental variables, so the suspect instruments are simulated

[22] To be more precise, we do not use $y_i - y_1$ as an instrument but only use its interaction with legal origins as an instrument for $\beta_i * F_i$ and its squared term as an instrument for $\beta_i * (y_i - y_1)$.

[23] For a discussion of SIV, see for example Currie and Jonathan (1996) and Mahoney (2015). We use SIV to deal with the issue of weak instruments. We find that if we use initial relative GDP and/or initial openness as instruments for patent protection, the two variables suffer from the problem of weak instruments. Moreover, we tried using lagged patent protection, which is the degree of patent protection within each country (from 1960 to 1979) before our sample period. All these regressions results are available upon request.

[24] Hence, the excluded instruments include the simulated patent protection, dummies of legal origins, the interacted terms between simulated patent protection and legal origins, the interacted terms between legal origins and initial relative income, and the squared term of initial relative income.

patent protection and its interacted terms with legal origins and initial relative income. The p-values of these tests are reported in all tables. As reported in Table I and II, the p-values of endogeneity tests of endogenous regressors are overall below 10%, which implies these regressors are indeed endogenous statistically. Moreover, the exogeneity tests of suspect instruments do not reject the null hypothesis that these instruments are exogenous. Hence the simulated patent protection is exogenous statistically. These results support our assumption of variable endogeneity and the choice of instrumental variables, which ensures the robustness of our regression results to some extent.

[Insert Tables I and II here]

From Tables I and II, we find that the following results are robust and significant for most of the regressions: (1) $\gamma_{\beta y} > 0$, $\gamma_{Fy} < 0$, $\gamma_y < 0$; and (2) $\gamma_\beta > 0$, $\gamma_F > 0$, $\gamma_{\beta F} < 0$. The first set of results $\{\gamma_{\beta y} > 0,\ \gamma_{Fy} < 0,\ \gamma_y < 0\}$ supports implication 1. It is useful to recall that a country converges to the technology frontier if and only if $\lambda_i = \gamma_y + \gamma_{\beta y} \cdot \beta_i + \gamma_{Fy} \cdot F_i < 0$. Therefore, $\gamma_{Fy} < 0$ and $\gamma_{\beta y} > 0$ imply that the likelihood of convergence increases with financial development but decreases with patent protection.

To understand the implications of the second set of results $\{\gamma_\beta > 0,\ \gamma_F > 0,\ \gamma_{\beta F} < 0\}$, let's being by assuming that all countries lag behind the United States in the steady state; i.e., $\hat{y}_i^* < 0$. Financial development would have a positive long-run effect on the relative income of each country that converges if and only if $\gamma_F + \gamma_{\beta F}\beta_i + \gamma_{Fy}\hat{y}_i^* > 0$. In this term, $\gamma_{\beta F}\beta_i$ is negative because the estimated $\gamma_{\beta F}$ is negative, whereas $\gamma_{Fy}\hat{y}_i^*$ is positive because the estimated γ_{Fy} is negative. The result $\gamma_F > 0$ implies that financial development is likely to have a positive long-run effect, and this positive effect is unlikely to vanish or become negative because $\gamma_F + \gamma_{Fy}\hat{y}_i^* > 0$. This finding is consistent with implication 2. We also consider the magnitude of the coefficients. From regression 1 of Table II, we have $\gamma_F + \gamma_{\beta F}\beta_i = 0.0833 - 0.0234 \cdot \beta_i$. Given a mean of 2.568 for β_i, $\gamma_F + \gamma_{\beta F}\beta_i$ is positive for the average country. Together with $\gamma_{Fy}\hat{y}_i^* > 0$, financial development has a positive long-run effect on the relative income of the average country. Moreover, we use equation (34) to compute the long-run effect of financial development and find that financial development has a positive long-run effect in the vast majority of countries.

As for patent protection, it would have a positive long-run effect in each country that converges if and only if $\gamma_\beta + \gamma_{\beta F}F_i + \gamma_{\beta y}\hat{y}_i^* > 0$. In this term, $\gamma_{\beta F}F_i$ is negative because the estimated $\gamma_{\beta F}$ is negative, and $\gamma_{\beta y}\hat{y}_i^*$ is also negative because the estimated $\gamma_{\beta y}$ is positive. The result $\gamma_\beta > 0$ implies that patent protection may have a positive long-run effect, but this positive effect may turn negative because $\gamma_{\beta F}F_i + \gamma_{\beta y}\hat{y}_i^* < 0$. From regression 1 of Table II, we have $\gamma_\beta + \gamma_{\beta F}F_i = 0.0211 - 0.0234 \cdot F_i$. Given a mean of 0.448 for F_i, the average country has $\gamma_\beta + \gamma_{\beta F}F_i > 0$. However, given that $\gamma_{\beta y}\hat{y}_i^* < 0$ and that F_i can be as large as 1.776, patent protection would have a negative long-run effect in countries with sufficiently large F_i. In other words, patent protection has a negative (positive) long-run effect when the level of financial development F_i is high (low). Using equation (35) to compute the long-run effect of patent protection, we find that patent protection has a positive (negative) long-run effect in about one-third (two-thirds) of the countries, and these countries have a low (high) level of financial development. This finding is consistent with implications 3 and 4 as well as the scenario in which the interest-spread channel dominates in

influencing credit constraints. In other words, when the level of financial development is low (i.e., a high interest-rate spread in the model), patent protection has a positive long-run effect. When the level of financial development is high (i.e., a low interest-rate spread in the model), the effect of patent protection becomes negative.

[Insert Tables III and IV here]

From Tables III and IV, we find that $\zeta_\beta > 0$, $\zeta_F > 0$, $\zeta_{\beta F} < 0$ and $\zeta_y > 0$. The implications of this set of results are similar to the above, so we do not repeat the discussion and simply report the results as a robustness check.

[Insert Table V here]

Finally, we also estimate the likelihood of convergence for each country. We use the coefficients in regression 1 of Table II to compute the estimated value of convergence parameter λ_i, and its standard deviation. We follow Aghion *et al.* (2005) to classify a country as most likely to converge in growth if its estimated λ_i is at least two standard deviations below zero, as most likely to diverge in growth if its estimated λ_i is at least two standard deviations above zero, and as uncertain to converge otherwise. As reported in Table V, we find that none of the countries in our sample is classified as most likely to diverge, and there are 48 countries (out of 102, since the United States is excluded) that are classified as most likely to converge.

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 influences credit constraints via two channels: decreasing the interest-rate spread and increasing the default cost. These two channels have different implications on the effects of patent protection. Our regression analysis finds evidence that strengthening patent protection is more likely to have a negative effect on innovation under a higher level of financial development, which is consistent with the interest-spread channel. These results show the importance of an often neglected interaction between the monopolistic distortion caused by patent protection and the financial distortion caused by credit constraints.

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Appendix A: Proofs

Proof of Lemma 1. From (21), we see that $H_1^i(0) = 0$. Simple differentiations yield

$$\frac{\partial H_1^i}{\partial \mu_t^i} = \frac{1}{1+\overline{g}} \left\{ 1 + \frac{(1-\phi)\,\gamma(\mu_t^i)^\phi + \underline{\eta}}{[\gamma(\mu_t^i)^\phi + \underline{\eta}]^{(1+\theta)/\theta}} \left[\frac{\pi(\beta^i)}{\rho + \epsilon^i} \right]^{(1-\theta)/\theta} \right\} > 0, \tag{A1}$$

$$\frac{\partial^2 H_1^i}{\partial\left(\mu_t^i\right)^2} = -\frac{\gamma\phi(\mu_t^i)^{\phi-1}}{1+\overline{g}} \frac{(1-\phi)\,\gamma(\mu_t^i)^\phi/\theta + (\phi + 1/\theta)\,\underline{\eta}}{[\gamma(\mu_t^i)^\phi + \underline{\eta}]^{(1+2\theta)/\theta}} \left[\frac{\pi(\beta^i)}{\rho + \epsilon^i} \right]^{(1-\theta)/\theta} < 0. \tag{A2}$$

Evaluating (A1) at $\mu_t^i = 0$ yields

$$\frac{\partial H_1^i}{\partial \mu_t^i}|_{\mu_t^i=0} = \frac{1}{1+\overline{g}} \left\{ 1 + \frac{1}{\underline{\eta}^{1/\theta}} \left[\frac{\pi(\beta^i)}{\rho + \epsilon^i} \right]^{(1-\theta)/\theta} \right\} > 1, \tag{A3}$$

which is satisfied due to the assumption $\pi(\beta^i)/\left(\rho + \epsilon^i\right) > (\overline{g}^\theta \underline{\eta})^{1/(1-\theta)}$ that ensures $\mu_1(\beta^i) > 0$. Evaluating $H_1^i\left(\mu_t^i\right)$ at $\mu_t^i = 1$ yields

$$H_1^i(1) = \frac{1}{1+\overline{g}} \left\{ 1 + \frac{1}{\left(\gamma + \underline{\eta}\right)^{1/\theta}} \left[\frac{\pi(\beta^i)}{\rho + \epsilon^i} \right]^{(1-\theta)/\theta} \right\} < 1, \tag{A4}$$

which is satisfied due to the assumption $\pi\left(\beta^i\right)/\left(\rho + \epsilon^i\right) < [\overline{g}^\theta(\gamma + \underline{\eta})]^{1/(1-\theta)}$. ■

Proof of Lemma 2. From (22), we see that $H_2^i(0) = 0$. Simple differentiations yield

$$\frac{\partial H_2^i}{\partial \mu_t^i} = \frac{1}{1+\overline{g}} \left\{ 1 + \frac{(1-\phi)\,\gamma(\mu_t^i)^\phi + \underline{\eta}}{\left[\gamma(\mu_t^i)^\phi + \underline{\eta}\right]^2} \left[f^i \left(\frac{\alpha}{\beta^i} \right)^{\alpha/(1-\alpha)} \right]^{1-\theta} \right\} > 0, \tag{A5}$$

$$\frac{\partial^2 H_2^i}{\partial\left(\mu_t^i\right)^2} = -\frac{\gamma\phi(\mu_t^i)^{\phi-1}}{1+\overline{g}} \frac{(1-\phi)\,\gamma(\mu_t^i)^\phi + (1+\phi)\,\underline{\eta}}{\left[\gamma(\mu_t^i)^\phi + \underline{\eta}\right]^3} \left[f^i \left(\frac{\alpha}{\beta^i} \right)^{\alpha/(1-\alpha)} \right]^{1-\theta} < 0. \tag{A6}$$

Evaluating (A5) at $\mu_t^i = 0$ yields

$$\frac{\partial H_2^i}{\partial \mu_t^i}|_{\mu_t^i=0} = \frac{1}{1+\overline{g}} \left\{ 1 + \frac{1}{\underline{\eta}} \left[f^i \left(\frac{\alpha}{\beta^i} \right)^{\alpha/(1-\alpha)} \right]^{1-\theta} \right\}. \tag{A7}$$

■

Appendix B: Description of the dataset

The empirical analysis is based on a panel dataset for 103 countries over 1980-2009. Variables used for regression are listed below with definitions and data sources. The annual growth rate of per capita real GDP are calculated through log differences. In the cross-section regressions, the annual variables are all averaged over the sample period.

- g_i: the averaged annual growth rate of real per capita GDP. Source: Penn World Table 7.1.
- y_i: the log of real per capita GDP at the initial period (1980). Source: Penn World Table 7.1.
- $\bar{y}_i$: the average log of real per capita GDP. Source: Penn World Table 7.1.
- β_i: the average degree of patent protection over 1980-2009, measured by the average index of patent rights. Source: Park (2008).
- β_i^{siv}: the average degree of simulated patent protection in 1980, measured by the average index of patent rights excluding the country in question. Source: Park (2008).
- F_i: the average level of financial development. There are three measures: 1) the average value of private credit by deposit money banks and other financial institutions as a share of GDP (*private credit*); 2) the average value of deposit money banks' assets as a share of GDP (*bank assets*); 3) the average value of liquid liabilities as a share of GDP (*liquid liabilities*). Source: Cihak *et al.* (2012).
- sec_i: the average years of secondary schooling in the population over 15 in the initial period (1980). Source: Barro and Lee (2013).
- inf_i: the average inflation rate over 1980-2009, defined as log difference of GDP deflator. The data of Zaire is not available in the dataset. Source: World Development Indicator.
- gov_i: the average government expenditure as a share of GDP over 1980-2009. The data of Zambia is not available in the dataset. Source: World Development Indicator.
- $open_i$: the average openness to trade over 1980-2009, defined as sum of real exports and imports as a share of GDP. Source: World Development Indicator.
- $legal_i$: Dummy variables for British, French, German, Scandinavian and Socialist legal origins. Source: La Porta *et al.* (2008).

Summary statistics

Variable	# of obs	Mean	Std. dev.	Min	Max
β_i	103	2.568	0.907	0.500	4.721
F_i (private credit)	103	0.448	0.388	0.013	1.776
F_i (bank assets)	103	0.502	0.396	0.016	1.981
F_i (liquid liabilities)	103	0.511	0.395	0.063	2.721
g_i	103	0.014	0.017	-0.037	0.084
y_i	103	8.309	1.256	6.006	10.371
β_i^{siv}	103	1.897	0.009	1.872	1.917
sec_i	103	1.409	1.073	0.060	5.190
inf_i	102	0.473	1.492	0.012	9.718
gov_i	102	0.153	0.046	0.048	0.290
$open_i$	103	0.729	0.467	0.206	3.549

Legal origin classifications

- **British**: Australia, Bangladesh, Botswana, Canada, Cyprus, United Kingdom, Ghana, Guyana, India, Ireland, Israel, Jamaica, Kenya, Liberia, Sir Lanka, Malawi, Malaysia, Nepal, New Zealand, Pakistan, Papua New Guinea, Sudan, Singapore, Sierra Leone, Swaziland, Thailand, Trinidad and Tobago, Tanzania, Uganda, United States, South Africa, Zambia, Zimbabwe.

- **French**: Argentina, Burundi, Belgium, Benin, Bolivia, Brazil, Central African Republic, Cote d'Ivoire, Cameroon, Congo Republic, Colombia, Costa Rica, Dominican Republic, Algeria, Ecuador, Egypt, Spain, France, Gabon, Greece, Guatemala, Honduras, Haiti, Indonesia, Iran, Iraq, Italy, Jordan, Luxembourg, Morocco, Mexico, Mali, Malta, Mozambique, Mauritania, Mauritius, Niger, Nicaragua, Netherlands, Panama, Peru, Philippines, Portugal, Paraguay, Romania, Rwanda, Senegal, El Salvador, Syria, Togo, Tunisia, Turkey, Uruguay, Venezuela, Vietnam, Zaire.

- **German**: Austria, Bulgaria, Switzerland, China, Germany, Hungary, Japan, Korea Republic, Poland.

- **Scandinavian**: Denmark, Finland, Iceland, Norway, Sweden.

Appendix C: Regression results

Table I: Convergence regression: 2-step GMM

Regression equation: $g_i - g_1 = \gamma_0 + \gamma_\beta \beta_i + \gamma_F F_i + \gamma_{\beta F} \beta_i \cdot F_i + \gamma_y \cdot (y_i - y_1)$
$+\gamma_{\beta y} \cdot \beta_i \cdot (y_i - y_1) + \gamma_{Fy} \cdot F_i \cdot (y_i - y_1) + \gamma_x x_i + \varepsilon_i$.

	1	2	3	4	5	6	7	8	9
	Private credit			Bank assets			Liquid liabilities		
Control regressors	Empty	Policy	Full	Empty	Policy	Full	Empty	Policy	Full
Coefficient estimates									
γ_β	0.0166***	0.0375***	0.0378***	0.0190***	0.0418***	0.0456***	0.0195**	0.0242*	0.0215*
	(3.16)	(3.90)	(3.43)	(3.09)	(3.67)	(3.30)	(2.54)	(1.71)	(1.70)
γ_F	0.0626*	0.126***	0.126**	0.0745**	0.146**	0.160**	0.0972*	0.0569	0.0495
	(1.85)	(2.85)	(2.54)	(2.04)	(2.62)	(2.49)	(1.72)	(0.61)	(0.59)
$\gamma_{\beta F}$	-0.0174**	-0.0382***	-0.0383***	-0.0195**	-0.0412***	-0.0448***	-0.0255*	-0.0191	-0.0169
	(-2.07)	(-3.19)	(-2.85)	(-2.18)	(-2.87)	(-2.71)	(-1.76)	(-0.80)	(-0.80)
γ_y	-0.0125**	-0.0265***	-0.0272***	-0.0119*	-0.0263***	-0.0302***	-0.00866	-0.0104	-0.00766
	(-2.37)	(-3.72)	(-3.17)	(-1.96)	(-3.32)	(-2.98)	(-1.24)	(-1.28)	(-0.98)
$\gamma_{\beta y}$	0.00640***	0.0128***	0.0129***	0.00565***	0.0119***	0.0130***	0.00500**	0.00769***	0.00693***
	(3.17)	(4.27)	(3.90)	(2.80)	(4.32)	(3.99)	(2.37)	(3.18)	(2.94)
γ_{Fy}	-0.0242***	-0.0223***	-0.0221***	-0.0223***	-0.0185***	-0.0172**	-0.0177**	-0.0243**	-0.0249**
	(-4.70)	(-4.09)	(-3.93)	(-4.39)	(-2.96)	(-2.58)	(-2.09)	(-2.23)	(-2.47)
First-stage F-test									
β	189.6	81.16	83.67	189.6	81.16	83.67	189.6	81.16	83.67
F	13.36	9.836	9.022	11.79	11.59	10.94	12.70	4.531	4.547
$\beta \times F$	29.08	11.69	11.46	25.64	17.83	17.29	32.85	10.23	10.86
$\beta \times y$	102.8	13.70	13.38	102.8	13.70	13.38	102.8	13.70	13.38
$F \times y$	45.70	9.034	8.719	43.82	8.129	7.902	8.995	5.054	4.961
OID (p-value)	0.2681	0.5038	0.4816	0.3594	0.8061	0.7889	0.4217	0.2686	0.3076
ENDOG (p-value)	0.0985	0.0246	0.0450	0.1055	0.0277	0.0523	0.0441	0.0429	0.0634
EXOG (p-value)	0.2043	0.3695	0.3404	0.2614	0.6721	0.6321	0.3587	0.2852	0.2976
R^2	0.293	0.202	0.202	0.271	0.070	0.023	0.123	0.310	0.329
F-test	14.04	9.493	10.01	15.64	9.422	8.285	9.184	8.439	11.61
Sample size	102	100	100	102	100	100	102	100	100

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. In parentheses are t-statistics based on robust standard errors with small sample. We use legal origins as the instrument for F_i. We use simulated patent protection β_i^{siv} and initial relative income $y_i - y_1$ as instruments for β_i. In all regressions we exclude the US, which is assumed to be the frontier. In columns (2), (3), (5), (6), (8) and (9), we drop Zaire and Zambia due to missing data. In columns (2), (5) and (8), we add policy regressors sec, gov, inf, open. In columns (3), (6) and (9), we add policy regressors plus dummy for OPEC countries. The term "First-stage F-test" represents the F stats in first-stage regressions of endogenous variables. "OID" stands for Hansen J overidentification test of all instruments. "ENDOG" represents the endogeneity test of endogenous regressors. "EXOG" stands for C test of exogeneity/orthogonality of suspect instruments, where the suspect instruments are simulated patent protection and its interacted terms with legal origins and initial relative income. All regressions are estimated by 2-step GMM estimator. We use the command "ivreg2" in Stata to perform the regressions.

Table II: Convergence regression: 2SLS

Regression equation: $g_i - g_1 = \gamma_0 + \gamma_\beta \beta_i + \gamma_F F_i + \gamma_{\beta F} \beta_i \cdot F_i + \gamma_y \cdot (y_i - y_1)$
$+\gamma_{\beta y} \cdot \beta_i \cdot (y_i - y_1) + \gamma_{Fy} \cdot F_i \cdot (y_i - y_1) + \gamma_x x_i + \varepsilon_i.$

	1	2	3	4	5	6	7	8	9
	Private credit			Bank assets			Liquid liabilities		
Control regressors	Empty	Policy	Full	Empty	Policy	Full	Empty	Policy	Full
Coefficient estimates									
γ_β	0.0211***	0.0335***	0.0337***	0.0228***	0.0392***	0.0414***	0.0209*	0.0329**	0.0307**
	(2.95)	(3.06)	(2.72)	(2.85)	(3.05)	(2.69)	(1.90)	(2.01)	(1.99)
γ_F	0.0833*	0.127**	0.127**	0.0915*	0.151**	0.159**	0.0905	0.106	0.0965
	(1.86)	(2.54)	(2.22)	(1.69)	(2.42)	(2.21)	(1.16)	(0.99)	(0.99)
$\gamma_{\beta F}$	-0.0234**	-0.0369***	-0.0369**	-0.0242*	-0.0414**	-0.0436**	-0.0238	-0.0318	-0.0291
	(-2.05)	(-2.72)	(-2.39)	(-1.81)	(-2.58)	(-2.34)	(-1.21)	(-1.17)	(-1.18)
γ_y	-0.0161**	-0.0237***	-0.0241**	-0.0155**	-0.0246***	-0.0269**	-0.0106	-0.0158*	-0.0142
	(-2.25)	(-2.81)	(-2.44)	(-2.02)	(-2.65)	(-2.33)	(-1.20)	(-1.68)	(-1.47)
$\gamma_{\beta y}$	0.00748**	0.0109***	0.0110***	0.00679**	0.0109***	0.0115***	0.00593**	0.00959***	0.00914***
	(2.58)	(2.97)	(2.79)	(2.55)	(3.02)	(2.81)	(2.38)	(2.95)	(2.75)
γ_{Fy}	-0.0235***	-0.0214***	-0.0214***	-0.0209***	-0.0175**	-0.0169**	-0.0208*	-0.0217*	-0.0223*
	(-3.25)	(-3.16)	(-2.99)	(-2.87)	(-2.35)	(-2.08)	(-1.91)	(-1.70)	(-1.88)
First-stage F-test									
β	189.6	81.16	83.67	189.6	81.16	83.67	189.6	81.16	83.67
F	13.36	9.836	9.022	11.79	11.59	10.94	12.70	4.531	4.547
$\beta \times F$	29.08	11.69	11.46	25.64	17.83	17.29	32.85	10.23	10.86
$\beta \times y$	102.8	13.70	13.38	102.8	13.70	13.38	102.8	13.70	13.38
$F \times y$	45.70	9.034	8.719	43.82	8.129	7.902	8.995	5.054	4.961
OID (p-value)	0.2681	0.5038	0.4816	0.3594	0.8061	0.7889	0.4217	0.2686	0.3076
ENDOG (p-value)	0.0985	0.0246	0.0450	0.1055	0.0277	0.0523	0.0441	0.0429	0.0634
EXOG (p-value)	0.2043	0.3695	0.3404	0.2614	0.6721	0.6321	0.3587	0.2852	0.2976
R^2	0.249	0.210	0.209	0.223	0.055	0.022	0.090	0.148	0.184
F-test	9.605	8.007	8.629	8.930	6.336	5.877	6.337	6.623	8.322
Sample size	102	100	100	102	100	100	102	100	100

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. In parentheses are t-statistics based on robust standard errors with small sample. We use legal origins as the instrument for F_i. We use simulated patent protection β_i^{siv} and initial relative income $y_i - y_1$ as instruments for β_i. In all regressions we exclude the US, which is assumed to be the frontier. In columns (2), (3), (5), (6), (8) and (9), we drop Zaire and Zambia due to missing data. In columns (2), (5) and (8), we add policy regressors sec, gov, inf, open. In columns (3), (6) and (9), we add policy regressors plus dummy for OPEC countries. The term "First-stage F-test" represents the F stats in first-stage regressions of endogenous variables. "OID" stands for Hansen J overidentification test of all instruments. "ENDOG" represents the endogeneity test of endogenous regressors. "EXOG" stands for C test of exogeneity/orthogonality of suspect instruments, where the suspect instruments are simulated patent protection and its interacted terms with legal origins and initial relative income. All regressions are estimated by 2SLS estimator. We use the command "ivreg2" in Stata to perform the regressions.

Table III: Relative-technology-level regression: 2-step GMM

Regression equation: $\bar{y}_i - \bar{y}_1 = \zeta_0 + \zeta_\beta \beta_i + \zeta_F F_i + \zeta_{\beta F} \beta_i \cdot F_i + \zeta_y \cdot (y_i - y_1) + \zeta_x x_i + \nu_i$.

	1	2	3	4	5	6	7	8	9
	Private credit			Bank assets			Liquid liabilities		
Control regressors	Empty	Policy	Full	Empty	Policy	Full	Empty	Policy	Full
Coefficient estimates									
ζ_β	0.336***	0.357***	0.352***	0.415***	0.433***	0.429***	0.407***	0.401***	0.387***
	(5.50)	(4.81)	(4.67)	(6.26)	(5.26)	(5.13)	(5.63)	(4.58)	(4.70)
ζ_F	3.197***	3.310***	3.319***	3.334***	3.413***	3.381***	3.215***	3.060***	3.078***
	(8.16)	(8.26)	(8.43)	(9.82)	(9.04)	(9.18)	(9.15)	(8.05)	(8.19)
$\zeta_{\beta F}$	-0.740***	-0.789***	-0.791***	-0.776***	-0.813***	-0.805***	-0.753***	-0.762***	-0.768***
	(-7.40)	(-7.36)	(-7.50)	(-9.10)	(-8.39)	(-8.47)	(-8.15)	(-7.20)	(-7.38)
ζ_y	0.864***	0.901***	0.908***	0.838***	0.892***	0.889***	0.899***	0.943***	0.960***
	(26.49)	(30.17)	(27.47)	(24.76)	(28.44)	(25.57)	(24.27)	(32.65)	(33.34)
First-stage F-test									
β	194.5	79.72	83.33	194.5	79.72	83.33	194.5	79.72	83.33
F	9.576	9.914	9.184	7.946	8.351	8.363	11.12	3.532	3.713
$\beta \times F$	11.70	5.562	5.558	11.54	5.608	6.022	34.65	7.674	8.308
OID (p-value)	0.3158	0.4284	0.4361	0.2812	0.4381	0.4252	0.3226	0.2301	0.2973
ENDOG (p-value)	0.4931	0.3440	0.3946	0.4401	0.1724	0.1910	0.4052	0.1383	0.0980
EXOG (p-value)	0.0938	0.1425	0.1452	0.0841	0.1467	0.1397	0.1937	0.2991	0.3816
R^2	0.954	0.956	0.956	0.951	0.953	0.960	0.934	0.951	0.951
F-test	1105.0	770.5	671.7	1376.3	774.0	685.2	1213.0	893.7	763.9
Sample size	102	100	100	102	100	100	102	100	100

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. In parentheses are t-statistics based on robust standard errors with small sample. We use legal origins as the instrument for F_i. We use simulated patent protection β_i^{siv} and initial relative income $y_i - y_1$ as instruments for β_i. In all regressions we exclude the US, which is assumed to be the frontier. In columns (2), (3), (5), (6), (8) and (9), we drop Zaire and Zambia due to missing data. In columns (2), (5) and (8), we add policy regressors sec, gov, inf, open. In columns (3), (6) and (9), we add policy regressors plus dummy for OPEC countries. The term "First-stage F-test" represents the F stats in first-stage regressions of endogenous variables. "OID" stands for Hansen J overidentification test of all instruments. "ENDOG" represents the endogeneity test of endogenous regressors. "EXOG" stands for C test of exogeneity/orthogonality of suspect instruments, where the suspect instruments are simulated patent protection and its interacted terms with legal origins and initial relative income. All regressions are estimated by 2-step GMM estimator. We use the command "ivreg2" in Stata to perform the regressions.

Table IV: Relative-technology-level regression: 2SLS

Regression equation: $\bar{y}_i - \bar{y}_1 = \zeta_0 + \zeta_\beta \beta_i + \zeta_F F_i + \zeta_{\beta F} \beta_i \cdot F_i + \zeta_y \cdot (y_i - y_1) + \zeta_x x_i + \nu_i$.

	1	2	3	4	5	6	7	8	9
	Private credit			Bank assets			Liquid liabilities		
Control regressors	Empty	Policy	Full	Empty	Policy	Full	Empty	Policy	Full
Coefficient estimates									
ζ_β	0.292***	0.305***	0.304***	0.369***	0.400***	0.400***	0.391***	0.422***	0.414***
	(4.34)	(3.64)	(3.61)	(5.16)	(4.40)	(4.39)	(4.76)	(4.29)	(4.23)
ζ_F	2.784***	2.833***	2.840***	2.918***	3.051***	3.045***	2.941***	2.995***	2.996***
	(5.43)	(4.79)	(4.85)	(5.92)	(5.78)	(6.04)	(5.74)	(6.13)	(6.03)
$\zeta_{\beta F}$	-0.643***	-0.674***	-0.676***	-0.684***	-0.734***	-0.733***	-0.698***	-0.761***	-0.762***
	(-5.06)	(-4.45)	(-4.48)	(-5.83)	(-5.63)	(-5.84)	(-5.62)	(-6.14)	(-6.12)
ζ_y	0.882***	0.896***	0.901***	0.864***	0.889***	0.888***	0.898***	0.942***	0.956***
	(25.42)	(29.39)	(26.68)	(23.01)	(27.69)	(24.88)	(21.56)	(30.42)	(28.65)
First-stage F-test									
β	194.5	79.72	83.33	194.5	79.72	83.33	194.5	79.72	83.33
F	9.576	9.914	9.184	7.946	8.351	8.363	11.12	3.532	3.713
$\beta \times F$	11.70	5.562	5.558	11.54	5.608	6.022	34.65	7.674	8.308
OID (p-value)	0.3158	0.4284	0.4361	0.2812	0.4381	0.4252	0.3226	0.2301	0.2973
ENDOG (p-value)	0.4931	0.3440	0.3946	0.4401	0.1724	0.1910	0.4052	0.1383	0.0980
EXOG (p-value)	0.0938	0.1425	0.1452	0.0841	0.1467	0.1397	0.1937	0.2991	0.3816
R^2	0.960	0.963	0.963	0.959	0.960	0.960	0.944	0.954	0.955
F-test	1023.6	690.9	604.0	1127.0	642.5	578.7	698.1	731.3	623.6
Sample size	102	100	100	102	100	100	102	100	100

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. In parentheses are t-statistics based on robust standard errors with small sample. We use legal origins as the instrument for F_i. We use simulated patent protection β_i^{siv} and initial relative income $y_i - y_1$ as instruments for β_i. In all regressions we exclude the US, which is assumed to be the frontier. In columns (2), (3), (5), (6), (8) and (9), we drop Zaire and Zambia due to missing data. In columns (2), (5) and (8), we add policy regressors sec, gov, inf, open. In columns (3), (6) and (9), we add policy regressors plus dummy for OPEC countries. The term "First-stage F-test" represents the F stats in first-stage regressions of endogenous variables. "OID" stands for Hansen J overidentification test of all instruments. "ENDOG" represents the endogeneity test of endogenous regressors. "EXOG" stands for C test of exogeneity/orthogonality of suspect instruments, where the suspect instruments are simulated patent protection and its interacted terms with legal origins and initial relative income. All regressions are estimated by 2SLS estimator. We use the command "ivreg2" in Stata to perform the regressions.

Table V: Convergence club membership

1 Countries most likely to converge		2 Countries uncertain to converge		
Cyprus	Ireland	United Kingdom	Greece	Poland
Japan	Pakistan	Canada	Gabon	Bulgaria
Thailand	India	Germany	Finland	Hungary
Malaysia	Bangladesh	Austria	Denmark	Romania
Switzerland	Honduras	Netherlands	Turkey	
Jordan	New Zealand	Sweden	Rwanda	
China	Iran	Mali	Mexico	
Guyana	Morocco	Israel	Philippines	
Malta	Paraguay	France	Central African Republic	
Luxembourg	Brazil	Peru	Botswana	
Iceland	Costa Rica	Australia	Congo Republic	
Singapore	Bolivia	Togo	Sudan	
Papua New Guinea	Nepal	Korea Republic	Algeria	
Portugal	Cote d'Ivoire	Ecuador	Iraq	
Tunisia	Uruguay	Zambia	Tanzania	
Panama	Swaziland	Norway	Italy	
Mozambique	Trinidad and Tobago	Malawi	Argentina	
Indonesia	Dominican Republic	Zimbabwe	Ghana	
South Africa	Venezuela	Burundi	Jamaica*	
Egypt	Senegal	Benin	Sri Lanka	
Mauritius	Colombia	Niger	Uganda	
Vietnam	Mauritania	Syria	Haiti	
Nicaragua	Kenya	Zaire	El Salvador	
Spain		Cameroon	Sierra Leone	
Guatemala		Liberia	Belgium	

Note: The estimated convergence parameters are based on the coefficients in regression 1 of Table II. The estimated convergence parameter increases within each group, as you move down each list and then to the right. There are three groups of classification: countries most likely to converge, countries uncertain to converge, and countries most likely to diverge in growth rate. A country is classified to the first group if its estimated convergence parameter is at least two standard deviation below zero, to the third group if its estimated convergence parameter is at least two standard deviation above zero, and to the second group otherwise. However, there is no country that belongs to the third group according to our estimates.

* The estimated convergence parameter is negative (indicating convergence) in countries before Jamaica and positive (indicating divergence) in countries after (and including) Jamaica.