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 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. 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 supportive evidence for the interest-spread channel.

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

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1 Introduction

In this paper, we explore the effects of patent protection in a distance-to-frontier R&D-based growth model. A novelty of our growth-theoretic analysis of patent policy is that we introduce financial frictions in the form of potentially binding credit constraints on R&D entrepreneurs. When 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 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. The intuition of this negative *financial distortionary* effect of patent protection can be explained as follows. Strengthening patent protection causes more severe monopolistic distortion, which in turn reduces aggregate income and tightens credit constraints faced by R&D entrepreneurs. As a result, the rates of innovation and economic growth decrease. This finding is consistent with recent studies that often find 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] 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: decreasing the interest-rate spread and increasing the default cost. 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 activity. We complement the analysis in Ang (2010, 2011) by considering the interactive effect of patent protection and financial development on economic growth. In summary, we find supportive evidence for 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

[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).

growth, it is important 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 static 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). 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).[3] 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 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 is the novel contribution 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 develop a distance-to-frontier R&D-based growth model with financial frictions based on Aghion *et al.* (2005) and Acemoglu *et al.* (2006). We consider a discrete-time model and use the model to explore the interactive effects of patent protection and credit constraints on the technology convergence of countries.

[3]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.

2.1 Households and workers/entrepreneurs

There is a continuum of countries, indexed by a superscript i, that are behind the world technology frontier.[4] 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 goods (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 $A_{t+1}^i = (1+r_t^i)A_t^i - C_t^i$. 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 an overlapping generation 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 $\kappa^i \in (0,1)$.[5] 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 goods

The final goods 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 goods 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 goods and factor inputs as given to maximize profit. The conditional labor demand function is given by

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

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

$W_t^i = (1-\alpha)Y_t^i/L_t^i$, 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

The intermediate goods sector is characterized by monopolistic competition. In each industry v, a monopolistic firm produces $x_t^i(v)$ units of intermediate goods using $x_t^i(v)$ units of final goods as inputs. Therefore, the profit function of the monopolistic 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 variable.[6] 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 and that the level of Y_t^i is decreasing in patent breadth β^i, which captures the effect of monopolistic distortion on the level of output. In the presence of credit constraints, patent protection would then generate a negative effect on R&D as a result of this monopolistic distortion as we will show later.

[6] The idea is that the unit cost for imitative firms to produce an identical product is β^i, which is increasing in the level of patent protection. Therefore, stronger patent protection allows the monopolistic producer to charge a higher markup; see also Li (2001) and Iwaisako and Futagami (2013) for a similar formulation. This formulation captures Gilbert and Shapiro's (1990) seminal insight on "breadth as the ability of the patentee to raise price".

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 goods 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^i over N_t^i R&D projects.[7] Therefore, the amount of final goods 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 $P_t^i = \min\{Z_t^i/(N_t^i\eta_t^i), 1\}$,[8] where $1/\eta_t^i$ captures the productivity of R&D in country i.

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 capturing financial frictions in country i. Under this assumption, $V_t^i(v)$ 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 capturing 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 $\mu_t^i \in (0,1)$.

[7] 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 $\varsigma = 1$.

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

Assumption 1 $(\overline{g}^{\theta}\underline{\eta})^{1/(1-\theta)} < \pi\left(\beta^i\right)/(\rho+\epsilon^i) < \min\{\underline{\eta}^{1/(1-\theta)}, [\overline{g}^{\theta}(\gamma+\underline{\eta})]^{1/(1-\theta)}\}$.[9]

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

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

which is also increasing in patent breadth β^i, for a given μ_t^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.

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.[10] 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

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

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

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

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. The balanced-growth level of R&D is 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, 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 $P_t^i(1+R_{t+1}^i)D_t^i = D_t^i$.

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. 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 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 on income Y_t^i and the financial distortion of the credit constraint. 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.

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

$$Z_t^i = \min\left\{\pi\left(\beta^i\right)\frac{\overline{g}}{\rho+\epsilon^i}, f^i\left(\frac{\alpha}{\beta^i}\right)^{\alpha/(1-\alpha)}\right\}N_t^i. \tag{17}$$

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. This threshold value of β^i is given by[11]

$$\beta_1(\underset{+}{f^i}, \underset{+}{\epsilon^i}) \equiv \frac{\alpha \overline{g}}{\alpha \overline{g} - (\rho + \epsilon^i) f^i}, \tag{18}$$

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.

Finally, whenever the credit constraint is binding, the growth rate of technology in country i is given by

$$g_t^i = \frac{\Delta N_t^i}{N_t^i} = \frac{1}{\gamma(\mu_t^i)^\phi + \underline{\eta}} \left[f^i \left(\frac{\alpha}{\beta^i} \right)^{\alpha/(1-\alpha)} \right]^{1-\theta}, \tag{19}$$

which is decreasing in the level of patent breadth β^i, for a given μ_t^i, capturing the *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. 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. ■

2.8 Transition dynamics

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

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

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

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

[11] 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 $h^i < 1 - (\rho + \epsilon^i)/(\alpha\overline{g})$.

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 (19) 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 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 premium 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 (18), we also define a second threshold value β_2 of patent breadth below (above) which $\frac{\partial H_2^i}{\partial \mu_t^i}|_{\mu_t^i=0} > 1$ ($\frac{\partial H_2^i}{\partial \mu_t^i}|_{\mu_t^i=0} < 1$).

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

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, although the credit constraint may be binding in the short run depending on the initial value of μ_0^i, the credit constraint does not bind in the long run. Therefore, 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.

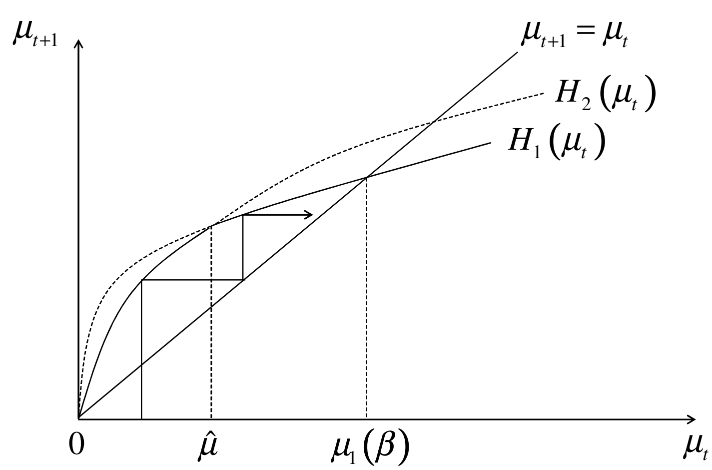

Figure 1: Transition dynamics under $\beta^i \leq \beta_1$

Case 2 *When* $\beta_1(f^i, \epsilon^i) < \beta^i < \beta_2(f^i)$,[12] *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 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.

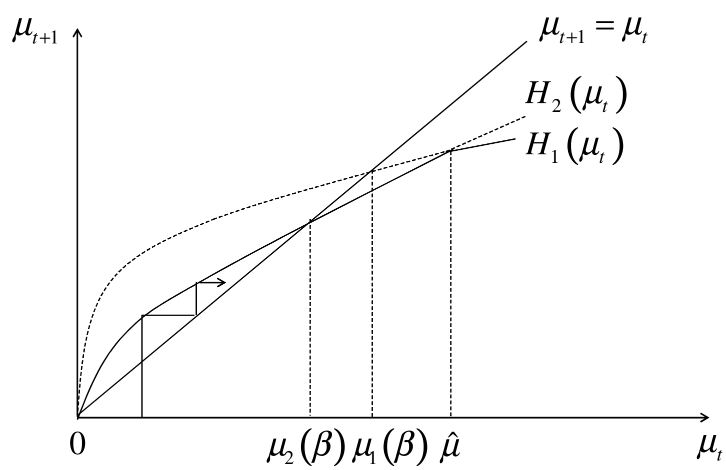

Figure 2: Transition dynamics under $\beta_1 < \beta^i < \beta_2$

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, μ_t^i converges to 0 as shown in Figure 3, and

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

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.

[12] To ensure $\beta_1 < \beta_2$, we assume $\underline{\eta} < f^i[\alpha\overline{g} - (\rho + \epsilon^i) f^i]^{\alpha(1-\theta)/(1-\alpha)} / \overline{g}^{(1-\alpha\theta)/(1-\alpha)}$.

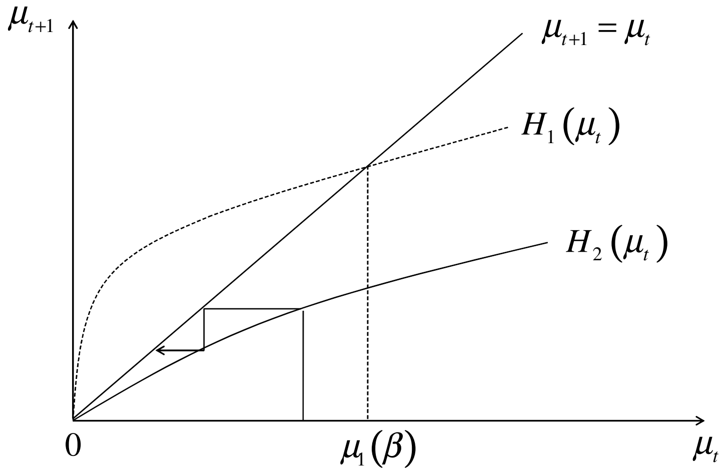

Figure 3: Transition dynamics under $\beta^i \geq \beta_2$

3 Patent breadth and credit constraints

Based on the results in the previous section, we can divide countries into three groups. Without loss of generality, we rearrange the order of the countries and denote the three groups as group 1, 2 and 3. For countries in group 1, their R&D activities are not restricted by the credit constraint, 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 $\beta^i \leq \beta_1(f^i, \epsilon^i)$, which is increasing in the default cost f^i and the interest-rate spread ϵ^i. For countries in group 2, their R&D activities are 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 $\beta_2(f^i)$ is increasing in the default cost f^i but independent of the interest-rate spread ϵ^i. For countries in group 3, their R&D activities are strongly restricted by the credit constraint. In this case, the technology growth rate in these countries is slower than that of the world technology frontier in the long run. 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. ■

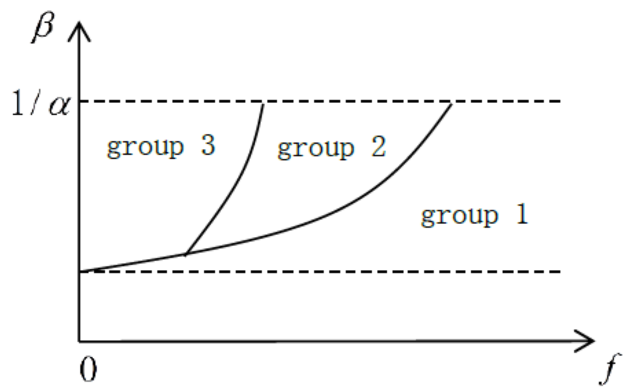

Figure 4

Figure 4 illustrates the three groups of countries. Countries in group 1 are not financially constrained 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. Countries in group 2 are 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. 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 that 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. Furthermore, the technology-maximizing level of patent protection β_1 is increasing in the interest-rate spread ϵ^i. Intuitively, a higher interest rate decreases the value of inventions and reduces entrepreneurs' incentives to invest in R&D. As a result, the credit constraint becomes less likely to bind, rendering patent protection to be more likely to have a positive 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 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 these results in Proposition 4.

Proposition 4 *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. In this case, the steady-state growth rate is given by $(1+\overline{g})\,\xi^i - 1 \leq \overline{g}$, where ξ^i 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. If financial development decreases the interest-rate spread (increases the default cost), then patent protection would be more likely to have a negative (positive) effect on the steady-state level of relative per-capita GDP under a higher level of financial development.

4.1 Data

The dataset consists of 105 countries from 1980 to 2009 featuring variables of economic growth, patent protection, financial development and other controls.[13] We transform the dataset into a cross section by taking annual average of each variable for each country. 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).[14] 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 share of GDP, denoted as *private credit*. The second indicator is deposit money banks' assets as a share of GDP, denoted as *bank assets*. The third indicator is liquid liabilities as a share of 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 share of 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 (17) 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 first 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

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

[14] 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.

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 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.

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 can approximate the steady-state level of relative per-capita GDP by $\bar{y}_i - \bar{y}_1$, and hence, this regression model can be 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 potential endogeneity of patent protection, we estimate the regression models using instrumental variables. We consider two cases. First, we assume that only financial development is endogenous. In this case, we instrument for F_i, $\beta_i \cdot F_i$ and $F_i \cdot (y_i - y_1)$ using legal origins, legal origins interacted with patent protection, and legal origins interacted with initial relative output, respectively. Second, we assume that both financial development and patent protection are endogenous. In this case, we use legal origins as the instrument for F_i, and lagged patent protection (averaged over 1960-1979) and initial relative output $(y_i - y_1)$ as the instruments for β_i.[15] The interacted terms between instruments are also used as instruments for the interacted terms of the endogenous variables. Tables I and III are for the first case, and Tables II and IV are for the second case.

[Insert Tables I and II here]

From Tables I and II, we find that the following results are robust and significant: (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

[15] Our results for *private credit* and *bank assets* are largely the same if we use only lagged patent protection as the instrument for β_i.

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. The tests of endogeneity of instrumented variables show that the measure of patent protection is likely to be exogenous, according to Table I (See the p-values for C-test). Hence, we use the coefficients in Table I here, but the coefficients in Table II are reasonably similar. From regression 2 of Table I, we have $\gamma_F + \gamma_{\beta F}\beta_i = 0.0435 - 0.0127 \cdot \beta_i$. Given a mean of 2.60 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 on 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 Table I, we have $\gamma_\beta + \gamma_{\beta F}F_i = 0.0137 - 0.0127 \cdot F_i$. Given a mean of 0.456 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 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. Finally, we also estimate the likelihood of convergence for each country. We use the coefficients in regression 2 of Table I 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 69 countries (out of 105) that are classified as most likely to converge.

[Insert Table V here]

5 Conclusion

In this study, we have explored the effects of patent protection and financial development on economic growth. The novelty of our analysis is that we consider the presence of credit constraints on R&D entrepreneurs. 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. Our regression analysis finds supportive evidence for the interest-spread channel under which strengthening patent protection is more likely to have a negative effect on innovation under a higher level of financial development. 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

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

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

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 $\pi(\beta^i)/(\rho + \epsilon^i) > (\overline{g}^\theta \underline{\eta})^{1/(1-\theta)}$ that ensures $\mu_1(\beta^i) > 0$. Evaluating $H_1^i(\mu_t^i)$ at $\mu_t^i = 1$ yields

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

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

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

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

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

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 105 countries over 1980-2009. Variables used for regression are listed below with definitions and data sources. The variables of annual change rate (i.e., economic growth rate and inflation rate) 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^{old}: the average degree of patent protection over 1960-1979, measured by the average index of patent rights. 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. Source: Penn World Table 7.1.
- gov_i: the average government expenditure as a share of GDP over 1980-2009. Source: Penn World Table 7.1.
- $open_i$: the average openness to trade over 1980-2009, defined as sum of real exports and imports as a share of GDP. Source: Penn World Table 7.1.
- $legal_i$: Dummy variables for British, French, German, Scandinavian and Socialist legal origins. Source: La Porta *et al.* (1999).

Summary statistics

Variable	# of obs	Mean	Std. dev.	Min	Max
β_i	105	2.600	0.900	0.5	4.721
F_i (private credit)	105	0.456	0.396	0.013	1.776
F_i (bank assets)	105	0.511	0.406	0.016	1.981
F_i (liquid liabilities)	105	0.526	0.423	0.063	2.721
g_i	105	0.014	0.017	-0.037	0.084
y_i	105	8.320	1.250	6.006	10.371
$\bar{y}_i$	105	8.471	1.343	5.816	10.804
β_i^{old}	100	1.627	0.745	0	3.825
sec_i	105	1.422	1.076	0.06	5.19
inf_i	105	0.030	0.003	0.017	0.038
gov_i	105	0.099	0.052	0.035	0.325
$open_i$	105	0.706	0.464	0.186	2.926

Legal origin classifications

- **British**: Australia, Bangladesh, Botswana, Canada, Cyprus, Fiji, United Kingdom, Ghana, Guyana, Hong Kong, 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, Rwanda, Senegal, El Salvador, Syria, Togo, Tunisia, Turkey, Uruguay, Venezuela, Zaire.
- **German**: Austria, Switzerland, Germany, Japan, Korea.
- **Scandinavian**: Denmark, Finland, Iceland, Norway, Sweden.
- **Socialist**: Bulgaria, China, Hungary, Poland, Romania, Vietnam.

Appendix C: Regression results

Table I: Convergence regression

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

Endogenous variables: F_i, $\beta_i \cdot F_i$, $F_i \cdot (y_i - y_1)$.

Instrument variables: $legal_i$, $legal_i \cdot \beta_i$, $legal_i \cdot (y_i - y_1)$.

	1	2	3	4	5	6
	Private credit		Bank assets		Liquid liabilities	
Control regressors	Empty	Full	Empty	Full	Empty	Full
Coefficient estimates						
γ_β	0.0148***	0.0137***	0.0186***	0.0146***	0.0176***	0.00732
	(3.68)	(3.74)	(4.86)	(3.39)	(5.64)	(0.61)
γ_F	0.0569***	0.0435***	0.0728***	0.0511***	0.0827***	-0.00383
	(2.87)	(2.69)	(3.74)	(2.67)	(3.17)	(-0.04)
$\gamma_{\beta F}$	-0.0149***	-0.0127***	-0.0194***	-0.0139***	-0.0221***	-0.000773
	(-2.87)	(-3.06)	(-4.09)	(-2.88)	(-3.43)	(-0.03)
γ_y	-0.00968**	-0.00834*	-0.0106**	-0.00675	-0.00478	0.000531
	(-2.16)	(-1.95)	(-2.56)	(-1.45)	(-1.55)	(0.08)
$\gamma_{\beta y}$	0.00459***	0.00444***	0.00489***	0.00386**	0.00352**	0.00291
	(3.04)	(2.74)	(3.93)	(2.37)	(2.57)	(1.65)
γ_{Fy}	-0.0235***	-0.0255***	-0.0213***	-0.0229***	-0.0183***	-0.0274**
	(-7.47)	(-8.49)	(-6.71)	(-7.75)	(-5.47)	(-2.62)
p-values						
Hansen's J-test	0.4137	0.3707	0.5810	0.3919	0.6953	0.3578
C-test	0.0148	0.0567	0.0549	0.4123	0.0703	0.1429
Sample size	105	105	105	105	105	105

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. In parentheses are t-statistics based on robust standard errors with small sample. In column (2), (4) and (6) we add control regressors sec, gov, inf, open. Hansen's J-test stands for the test of overidentification of instruments, C-test stands for testing the endogeneity of instrumented variables (orthogonality conditions). All regressions are estimated by GMM method. We use the command ivregress in Stata to perform the regressions.

Table II: Convergence regression

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

Endogenous variables: β_i, F_i, $\beta_i \cdot F_i$, $\beta_i \cdot (y_i - y_1)$, $F_i \cdot (y_i - y_1)$.

Instrument variables: β_i^{old}, $legal_i$, $legal_i \cdot \beta_i^{old}$, $\beta_i^{old} \cdot (y_i - y_1)$, $legal_i \cdot (y_i - y_1)$, $(y_i - y_1)$, $(y_i - y_1)^2$.

	1	2	3	4	5	6
	Private credit		Bank assets		Liquid liabilities	
Control regressors	Empty	Full	Empty	Full	Empty	Full
Coefficient estimates						
γ_β	0.0174***	0.0142***	0.0200***	0.0142**	0.0243***	0.0255**
	(3.78)	(2.83)	(4.39)	(2.63)	(3.60)	(2.08)
γ_F	0.0761***	0.0566*	0.0820***	0.0497*	0.121***	0.148
	(3.02)	(1.91)	(3.61)	(1.90)	(2.76)	(1.50)
$\gamma_{\beta F}$	-0.0202***	-0.0163**	-0.0214***	-0.0132**	-0.0317***	-0.0373
	(-3.12)	(-2.15)	(-3.82)	(-2.03)	(-2.90)	(-1.52)
γ_y	-0.0140***	-0.0121**	-0.0137***	-0.00945*	-0.0130**	-0.00921
	(-2.70)	(-2.48)	(-2.73)	(-1.86)	(-2.03)	(-1.25)
$\gamma_{\beta y}$	0.00689***	0.00676***	0.00636***	0.00574**	0.00673**	0.00607**
	(3.01)	(3.00)	(2.80)	(2.48)	(2.60)	(2.34)
γ_{Fy}	-0.0272***	-0.0296***	-0.0242***	-0.0261***	-0.0218***	-0.0207
	(-5.27)	(-5.80)	(-5.29)	(-4.97)	(-2.92)	(-1.64)
p-values						
Hansen's J-test	0.3845	0.2520	0.5016	0.3368	0.8266	0.7596
C-test for endog	0.2959	0.5524	0.4520	0.7029	0.0864	0.2320
Sample size	100	100	100	100	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. In column (2), (4) and (6) we add control regressors sec, gov, inf, open. Hansen's J-test stands for the test of overidentification of instruments, C-test stands for testing the endogeneity of instrumented variables (orthogonality conditions). All regressions are estimated by GMM method. We use the command ivregress in Stata to perform the regressions.

Table III: Relative-technology-level regression

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

Endogenous variables: F_i, $\beta_i \cdot F_i$.

Instrument variables: $legal_i$, $legal_i \cdot \beta_i$.

	1	2	3	4	5	6
	Private credit		Bank assets		Liquid liabilities	
Control regressors	Empty	Full	Empty	Full	Empty	Full
Coefficient estimates						
ζ_β	0.322***	0.334***	0.385***	0.368***	0.398***	0.403***
	(7.39)	(6.12)	(7.81)	(5.59)	(5.91)	(3.99)
ζ_F	3.085***	3.224***	2.990***	2.912***	2.772***	2.942***
	(11.21)	(7.15)	(11.16)	(5.66)	(6.59)	(3.74)
$\zeta_{\beta F}$	-0.711***	-0.778***	-0.703***	-0.696***	-0.660***	-0.727***
	(-9.34)	(-6.89)	(-9.86)	(-5.57)	(-6.06)	(-3.77)
ζ_y	0.870***	0.894***	0.858***	0.896***	0.897***	0.952***
	(38.84)	(27.14)	(36.99)	(27.71)	(27.82)	(33.80)
p-values						
Hansen's J-test	0.2612	0.3340	0.1195	0.0982	0.1034	0.1188
C-test for endog	0.5278	0.7230	0.4462	0.4513	0.8821	0.8558
Sample size	105	105	105	105	105	105

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. In parentheses are t-statistics based on robust standard errors with small sample. In column (2), (4) and (6) we add control regressors sec, gov, inf, open. Hansen's J-test stands for the test of overidentification of instruments, C-test stands for testing the endogeneity of instrumented variables (orthogonality conditions). All regressions are estimated by GMM method. We use the command ivregress in Stata to perform the regressions.

Table IV: Relative-technology-level regression

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

Endogenous variables: β_i, F_i, $\beta_i \cdot F_i$.

Instrument variables: β_i^{old}, $legal_i$, $legal_i \cdot \beta_i^{old}$, $(y_i - y_1)$, $legal_i \cdot (y_i - y_1)$.

	1	2	3	4	5	6
	Private credit		Bank assets		Liquid liabilities	
Control regressors	Empty	Full	Empty	Full	Empty	Full
Coefficient estimates						
ζ_β	0.421***	0.443***	0.398***	0.455***	0.370***	0.386***
	(4.83)	(3.71)	(4.02)	(3.66)	(3.12)	(3.70)
ζ_F	3.038***	3.683***	2.543***	3.089***	2.191***	2.532***
	(5.48)	(3.20)	(4.10)	(3.31)	(2.86)	(2.88)
$\zeta_{\beta F}$	-0.749***	-0.924**	-0.621***	-0.755***	-0.556***	-0.641***
	(-5.23)	(-3.32)	(-4.05)	(-3.31)	(-2.86)	(-2.96)
ζ_y	0.872***	0.891***	0.882***	0.903***	0.937***	0.969***
	(24.87)	(23.36)	(19.13)	(21.21)	(19.82)	(43.69)
p-values						
Hansen's J-test	0.4978	0.6504	0.3730	0.5270	0.4206	0.6043
C-test for endog	0.2158	0.3679	0.2987	0.4275	0.4979	0.6192
Sample size	100	100	100	100	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. In column (2), (4) and (6) we add control regressors sec, gov, inf, open. Hansen's J-test stands for the test of overidentification of instruments, C-test stands for testing the endogeneity of instrumented variables (orthogonality conditions). All regressions are estimated by GMM method. We use the command ivregress in Stata to perform the regressions.

Table V: Convergence club membership

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

Note: The estimated convergence parameters are based on the coefficients in regression 2 of Table I. 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 Iraq and positive (indicating divergence) in countries after (and including) Iraq.