Financial Innovation and Endogenous Growth

Luc Laeven, Ross Levine, and Stelios Michalopoulos*

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Abstract

Is financial innovation necessary for sustaining economic growth? To address this question, we build a Schumpeterian model in which entrepreneurs earn profits by inventing better goods and profit-maximizing financiers arise to screen entrepreneurs. The model has two novel features. First, financiers engage in the costly but potentially profitable process of innovation: they can invent better methods for screening entrepreneurs. Second, every screening process becomes less effective as technology advances. The model predicts that technological innovation and economic growth eventually stop unless financiers innovate. Empirical evidence is consistent with this dynamic, synergistic model of financial and technological innovation.

Keywords: Screening; Financial Intermediation; Invention; Economic Growth; Corporate Finance; Technological Change; Entrepreneurship.

JEL classification Numbers: G0; O31; O4

1 Introduction

Two observations motivate this paper. First, a considerable body of research documents that technology and finance have evolved together, often in a synergistic manner, over several centuries (Allen and Gale, 1994; Frame and White, 2004; Goetzmann, 2009; Tufano, 2003). For example, to finance the construction of vast railroads in the 19th and 20th centuries, financial entrepreneurs developed specialized investment banks and accounting systems to facilitate screening and monitoring by distant investors (Chandler, 1965, 1977; Baskin and Miranti, 1997; and Neal, 1990). More recently, financial entrepreneurs developed modern venture capital firms to screen information technology start-ups. And, still more recently, financiers designed new financial institutions for identifying biotechnology endeavors with the highest probability of commercial success (Gompers and Lerner, 2001; Schweitzer, 2006). Econometric evidence from the United States (Amore, et al 2013; Chava et al 2013) and around the world (Beck et al 2013) suggests a strong connection between finance and technological innovation.

Second, economists have not yet developed models of the coevolution of technology and finance in which both technological and financial improvements reflect the actions of profit-maximizing agents. Existing Schumpeterian models of technological innovation examine "technological entrepreneurs," who choose how much to invest in the risky, but potentially lucrative, process of improving technology (Aghion and Howitt, 2009). These models either ignore the financial system, or presume that economies are endowed with fixed, unchanging financial systems, or assume that finance changes in a mechanical manner with economic activity. Thus, these models do not include "financial entrepreneurs", who choose how much to invest in, for example, the risky, but potentially lucrative, process of improving their abilities to identify the most promising technological entrepreneurs. As such, existing models cannot provide insights into how the policies, laws, and regulations that shape the incentives of technological and financial entrepreneurs interact to determine the rate of economic growth.

In this paper, we add two novel features to the canonical model of Schumpeterian growth, so that we can explore the interaction of finance and technology. First, we model *both* technological and financial innovation as reflecting the explicit, profit-maximizing choices of individuals. In textbook Schumpeterian models, technology evolves based on the choices of entrepreneurs. Our model also includes financial entrepreneurs, who choose how much to invest in the risky activity of improving the screening of technological entrepreneurs. Investors will pay for improved screening information because it increases the probability of investing in profitable technologies. Just as successful technological innovation generates temporary rents for the technological

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entreprencur in textbook Schumpeterian models, successful financial "innovation" generates temporary rents for financiers who are better at screening technological entrepreneurs than their competitors in our model. Thus, financial entrepreneurs choose how much to invest in improving the screening of technological entrepreneurs based on the expected profits from this activity.

A second novel feature is that every screening modality becomes less effective at identifying promising entrepreneurs as technology advances. Moving up the Schumpeterian technological quality ladder, any particular screening procedure becomes less effective at identifying the entrepreneur with the best chance of successfully making the next technological innovation. That is, informational asymmetries widen endogenously as technologies advance. For example, the processes for screening the potential builders of new, cross-Atlantic ships in the 16th century were less effective at screening innovations in railroad technologies in the 19th century. Technological innovation makes existing screening technologies obsolete.

The core implications of the theory are that (1) technological and financial innovation will be positively correlated and (2) economic growth will eventually stagnate unless financiers innovate. In terms of positive synergies between technological and financial innovation, first note that technological change increases the returns to financial innovation. As technology advances, any given screening technology becomes less and less effective at identifying capable technological innovators as informational asymmetries grow. Thus, the benefits–and hence profits–from improving the screening of entrepreneurs grow with technological advances. The synergies work in the other direction too. Better screening boosts the expected profits from technological innovation, because the expected returns from investing in technological innovation grow when financiers are better at identifying the most promising projects (innovators). In terms of stagnation, the model stresses that existing screening methods become increasingly inadequate at identifying promising technological innovations as the world's technological frontier advances. Consequently, unless financiers innovate and improve screening technologies in tandem, the probability of finding successful entrepreneurs declines, slowing growth. With appropriate policies, laws, and regulations, however, the drive for profits by financial and technological entrepreneurs alike can produce a continuing stream of financial and technological innovations that sustain growth.

It is worth emphasizing and clarifying the model's boundaries. First, we examine the role of the financial system in screening entrepreneurs before they are funded. We do not model the role of the financial system in diversifying risk, easing transactions, monitoring loans, or

enhancing the governance of firms once they are funded. Second, we use the term "financial innovation" to refer broadly to any change in the financial system that improves the screening of technological entrepreneurs. Thus, financial innovation is neither limited to the invention of new financial instruments, nor is it limited to innovation by financial institutions. Financial innovation includes more mundane financial improvements, such as the new financial reporting procedures that facilitated the screening and monitoring of railroads in the 19th century, improvements in data processing and credit scoring that enhanced the ability of banks to evaluate borrowers since the 1970s, and the establishment and upgrading of private credit bureaus around the world during the last few decades. Third, we are not the first to model the relationship between finance and growth. For example, Greenwood and Jovanovic (1990), Bencivenga and Smith (1991), Levine (1991), King and Levine (1993a), Greenwood, Sanchez, and Wang (2010), and many other papers discussed in Levine (2005a) examine how finance influences the allocation of capital and hence long-run growth. But, to the best of our knowledge, we are the first to develop a growth model in which improvements in finance are determined by agents *choosing* to invest in the risky, but potentially profitable, process of financial innovation. In this way, we examine the coevolution of technology and finance.

Although this paper's main contribution is the development of a theoretical framework in which technological and financial entrepreneurs drive economic growth, we also examine the model's predictions empirically. Our theory yields an estimation equation that differs in one key dimension from the textbook model of finance and growth (Aghion and Howitt, 2009): our theory predicts that financial innovation, i.e., the *rate of financial system improvement*, affects the speed at which economies converge to the world technology frontier, while the textbook model implies that *only* the level of financial development influences growth.

We evaluate the relationship between financial innovation and economic growth using different measures of financial innovation and different estimation methods. To measure financial development, we use the ratio of private credit to Gross Domestic Product (GDP), which has been used by many authors. To proxy for financial innovation, we primarily use the growth rate of the ratio of private credit to GDP. As an additional measure of financial innovation, we construct an indicator of how quickly each country adopted one particular modality for improving the screening of entrepreneurs: the year in which a country's banking system developed, if ever, a private credit bureau to share information about potential borrowers (Djankov et al., 2007). We first extend the cross-country specification used by Aghion, Howitt, and Mayer-Foulkes (2005) to assess whether the rate of financial innovation shapes the speed of

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convergence to the growth path of the leading economy. We then employ a panel GMM estimator to address concerns about omitted country traits and simultaneity bias, and to exploit the time-series dimension of the data.

The empirical findings are more consistent with our dynamic, synergistic model of financial and technological innovation than with existing theories of financial development and growth. In the pure cross-sectional analyses, we find that financial innovation boosts the speed with which economies converge to the growth path of the economic leader. And, in the panel GMM estimation, we find that financial innovation, but not the level of financial development, boosts the rate of economic growth, especially for countries much poorer than the economic leader.

This paper's theoretical model and empirical results contribute to policy debates. The analyses indicate that regulations or policies that restrict or raise the costs of financial innovation can slow technological innovation and long-run economic growth. For example, several studies indicate that the relaxation of regulatory restrictions on competition among U.S. banks in the 1970s and 1980s facilitated financial innovations that improved the functioning of the financial system (Silber, 1983; Kane, 1983, 1988; Petersen and Rajan, 2002).

Of course, not all financial innovations promote economic growth. For example, many have sought to understand the role of financial innovation in triggering the recent financial crisis. Researchers suggest that financial innovation in conjunction with investors who neglect small risks (Gennaioli, Shleifer, and Vishny, 2012), investors with biased expectations or institutionalized constraints (Shleifer and Vishny, 2010), or excessively competitive banking markets (Thakor, 2012) can induce instability. And, Allen and Carletti (2006) presciently warned that financial innovations such as securitization that transfer credit risk can hinder the effective screening of borrowers, boosting financial fragility. Additionally, many have argued that agency problems arising from short-term oriented compensation contracts and conflicted rating agencies led to excessive risk taking by financial intermediaries (Acharya and Naqvi, 2012; Bolton, Freixas, and Shapiro, 2012). Consistent with these views, Dell'Ariccia, Igan, and Laeven (2012), Keys, Mukherjee, Seru, and Vig (2010), and Mian and Sufi (2009) find that securitization reduced lending standards and increased loan delinquency rates, while simultaneously boosting the supply of loans and financier profits (Loutskina and Strahan, 2009). And, Henderson and Pearson (2010) show that financial institutions engineered financial products that exploited investors' misunderstanding of the payoffs to these products. Within the context of our framework, it is straightforward to extend the model to allow for rent-seeking financial

innovations that slow growth (as we do in the longer, working paper version of this paper). However, our purpose in this paper is not to argue that all financial innovations accelerate growth. Rather, we present a model and evidence consistent with the view that financial innovation is necessary for sustaining economic growth. Thus, financial regulations that impede financial innovation with the goal of enhancing financial stability might have material growth effects.

The paper is organized as follows. Section 2 outlines the model's basic structure , and Section 3 solves the model and derives testable implications. Section 4 provides suggestive empirical evidence, and Section 5 concludes.

2 The Basic Structure of the Model

We begin with the discrete-time Schumpeterian growth model developed by Aghion, Howitt, and Mayer-Foulkes (2005). Economic activity occurs in k countries, which do not exchange goods or factors of production, but do use each others' technological ideas. There is a continuum of individuals in each country. Each country has a fixed population, N, which is normalized to one, so that aggregate and per capita quantities coincide. Each individual lives two periods and is endowed with three units of labor in the first period and none in the second. The utility function is linear in consumption, so that $U = c_1 + \beta c_2$, where c_1 is consumption in the first period of life, c_2 is consumption in the second period of life, and $\beta \in (0, 1)$ is the rate at which individuals discount the utility of consumption in period 2 relative to that in period 1.

2.1 Final Output

In every period the economy produces a final good combining labor and a continuum of specialized intermediate goods according to the following production function:

$$Z_t = N^{1-\alpha} \int_0^1 A_{i,t}^{1-\alpha} x_{i,t}^\alpha di; \qquad \alpha \in (0, 1), \tag{1}$$

where $x_{i,t}$ is the amount of intermediate good i in period t with technology level of $A_{i,t}$. N is the labor supply. The final good Z is used for consumption, as an input into entrepreneurial and financial innovation, and an input into the production of intermediate goods.

The production of the final good, which we define as the numeraire, occurs under perfectly competitive conditions. Thus the price of each intermediate good equals its marginal product:

$$p_{i,t} = \alpha \left(\frac{A_{i,t}}{x_{i,t}} \right)^{1-\alpha}. \tag{2}$$

2.2 Intermediate Goods

In each intermediate goods sector i, a continuum of individuals with an entrepreneurial idea is born in period $t-1$. Only one entrepreneur in a sector has a capable idea, i.e., an idea with a positive probability of producing a successful innovation in period t.

The quality of each entrepreneurial idea is unknown *both* to the entrepreneur and to households looking to invest in entrepreneurial ideas, which generates a demand for "screening." As we detail below, screening in a particular goods sector i is done either by households using a standard screening technology or by a financier who may improve upon the standard screening technology by successfully engaging in the costly, risky, and potentially profitable process of financial innovation. Based on the screening assessment, households fund the entrepreneur designated as capable.[1]

Let $\mu_{i,t}^e$ equal the probability that the capable entrepreneur successfully innovates, so that the level of technology of intermediate goods sector i in period t, $A_{i,t}$, is defined as:

$$A_{i,t} = \left\{ \begin{array}{ll} \bar{A}_t & \text{with probability } \mu_{i,t}^e \\ A_{i,t-1} & \text{with probability } 1 - \mu_{i,t}^e \end{array} \right\}, \tag{3}$$

where $\bar{A}_t$ is the world technology frontier. Following the endogenous growth literature, technological innovation—or, more accurately, technological transfer—involves the costly, uncertain process of adapting ideas from the world technology frontier to the domestic economy. Innovation is necessary to transfer a technology because technology and technological expertise have tacit, country-specific qualities. Thus, when the capable entrepreneur successfully innovates, the level of technology jumps to $\bar{A}_t$. This world technology frontier grows at a constant rate g, which is taken as given for now (we derive it formally below).

A successful technological innovator enjoys a production cost advantage over entrepreneurs who do not innovate. Namely, she can produce intermediate goods at the rate of one unit of intermediate good per one unit of final good as input. Entrepreneurs who do not innovate can produce at the rate of one unit of intermediate good per χ units of final good as input, where $\chi > 1$. In every intermediate sector, there exists an unlimited number of people—the

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[1] The assumption that entrepreneurs do not know whether their entrepreneurial idea is going to be profitable is important and well-documented. In the model, if entrepreneurs know that they have zero probability of successfully innovating, then they will not ask for funding because they only receive profits from a successful innovation. Hence, there would be no demand for financial screening. The historical examples presented above, along with work by Chernow (1990), Goetzmann and Rouwenhorst (2005), Gompers and Lerner (2001), Schweitzer (2006), and Tufano (2003), indicate that financiers provide information both to investors and entrepreneurs about the profitability of entrepreneurial ideas. For example, venture capitalists provide guidance to high-tech innovators about the marketability and value of their ideas.

competitive fringe—capable of producing at the rate of one unit of intermediate good per χ units of the final good as input.

Thus, successful innovators become the sole producers in their respective intermediate sectors. They charge a price equal to the unit cost of the competitive fringe (χ) and earn monopoly profits for one period. In intermediate goods sectors where entrepreneurial innovation is unsuccessful, production occurs under perfectly competitive conditions, so that the price equals the unit cost of the competitive fringe (χ) and unsuccessful innovators earn zero profits. Thus, in all intermediate goods sectors, the price, p_{it}, equals χ.

Successful innovators earn monopoly profits for one period. After that period, the incumbent monopolist dies and her technology can be imitated costlessly within the country. As stated above—and as emphasized throughout the endogenous growth literature, we assume that it is costly to transfer technologies from the world technology frontier to a particular country. Using the demand function for intermediate goods from equation (2), the quantity demanded for intermediate good i equals:

$$x_{i,t} = \left(\frac{\alpha}{\chi} \right)^{\frac{1}{1-\alpha}} A_{i,t} . \tag{4}$$

Since profits per intermediate good equal $\chi - 1$, a successful innovator earns profits of:

$$\pi_{i,t} = \pi \bar{A}_{i,t}, \text{where } \pi = (\chi - 1) \left(\frac{\alpha}{\chi} \right)^{\frac{1}{1-\alpha}} . \tag{5}$$

2.3 Financiers

There is a single financier in each sector that screens entrepreneurs to identify the capable one. In return to their screening services, financiers are paid a share of entrepreneurial profits which we describe formally below. Financiers provide their assessments to households and entrepreneurs, who use this information to make investment decisions. In the model, financiers are not organized in any particular institutional or legal form, such as a commercial bank, rating agency, or private equity firm; financiers are simply agents that screen entrepreneurial ideas. This fits both the real world, in which financiers organize in a variety of forms, and our broad conception of financial innovation, in which financiers create and modify their institutional and legal forms to screen entrepreneurs more effectively.

For each intermediate good sector i, there is a financier born each period $t - 1$. This financier may engage in financial innovation in order to improve the screening technology next period. A successful financial innovation in sector i allows the financier to identify the capable

entrepreneur in sector i with probability one. In the absence of successful financial innovation, households use the existing, imperfect screening technology (the "standard" screening technology defined below) to select the capable entrepreneur.

Let $\mu_{i,t}^f$ equal the probability that a financier successfully innovates and improves the screening technology in sector i, so that the level of screening technology in intermediate goods sector i in period t, $m_{i,t}$, is defined as:

$$
m_{i,t} = \left\{ \begin{array}{ll} \bar{A}_t & \text{with probability } \mu_{i,t}^f \\ m_{t-1} & \text{with probability } 1 - \mu_{i,t}^f \end{array} \right\}. \tag{6}
$$

For symmetry and simplicity of notation, we index the world screening frontier by the world technology frontier, $\bar{A}_t$. As the technological frontier advances, the frontier screening technology also advances, though the actual screening technology, m_t, may lag behind the frontier screening technology, $\bar{A}_t$. As with entrepreneurial innovation, financial innovation involves the costly and risky process of transferring screening methodologies from the world frontier to a particular country. As with intermediate goods technology, screening and financial expertise have tacit, country-specific qualities that must be addressed in adapting frontier screening technology to any particular country.

The successfully innovating financier in sector i identifies the capable entrepreneur with probability one and is the monopolist provider of the frontier screening technology, $\bar{A}_t$. If unsuccessful, households can screen entrepreneurial ideas in sector i during period t using the common economy-wide screening technology of period $t-1$, m_{t-1}. As with technological entrepreneurs, we assume that it is costless within a country to imitate the screening technology from last period, so that a successful financial innovator maintains the monopoly position for only one period.

Households in a country in period t have free access to a common, economy-wide screening technology. We make the simplifying assumption that the latter equals the average of the screening technologies across all sectors in period $t-1$, m_{t-1}. Mechanically, this assumption means that we do not have to keep track of the distance of each sector's screening technology from the frontier; rather, we can simply trace the average distance from the frontier across all sectors in a country. The underlying intuition is that (a) last period's screening technologies can be costlessly used by all sectors within a country and (b) when entrepreneurs in each sector try to innovate to attain the world technology frontier, $\bar{A}_t$, such innovative activity involves using technological ideas from multiple sectors. For example, biotechnology innovation in period t will typically involve the use of recent innovations in information technology, chemistry, and

other sectors, so that screening biotech entrepreneurs in period t requires an ability to screen technologies from these other sectors as well. Thus, the common screening technology in period t is an amalgam of each sector's screening technology from period $t-1$, which is freely available within the country in period t.

This assumption, however, is not qualitatively important. Rather than defining the common, economy-wide screening technology as the average of last period's screening technologies, we could define the common, economy-wide screening technology as the maximum screening technology across all sectors in the last period. This yields the same qualitative predictions. Indeed, for the common, economy-wide screening technology, we could choose any point in the distribution of sector-specific screening technologies from last period without loss of generality. Furthermore, allowing each intermediate sector to maintain its own screening technology over time delivers cumbersome mathematics without altering the qualitative predictions.

The probability that the capable entrepreneur, $\lambda_{i,t}$, is identified in sector i is a function of the gap between the level of the good's frontier technology and the level of the screening technology. If the financier successfully innovates (which occurs with probability $\mu_{i,t}^f$), then there is no gap, and the financier identifies the capable entrepreneur with probability one. If the financier does not successfully innovate (which occurs with probability $1-\mu_{i,t}^f$), then the financial gap in period t reflects the difference between the technological frontier and last period's common, economy-wide screening technology. In this case the probability that households correctly identify the capable entrepreneur is less than one. Specifically,

$$\lambda_{i,t} = m_{i,t}/\bar{A}_t = \left\{ \begin{array}{ll} \bar{A}_t/\bar{A}_t = 1 & \text{with probability } \mu_{i,t}^f \\ m_{t-1}/\bar{A}_t = \frac{\lambda_{t-1}}{1+g} & \text{with probability } 1-\mu_{i,t}^f \end{array} \right\}, \tag{7}$$

where, as described above, g is the growth rate of the world technology leader. Note that within a sector, households have the same screening technology and therefore identify the same entrepreneur as the capable one. Consequently, households finance only one entrepreneur per sector. Across sectors in which financiers did not successfully innovate, the households correctly identify the capable entrepreneur in λ_t sectors, whereas in $1-\lambda_t$ sectors, the households finance an incapable entrepreneur. Formally, screening projects by the households is deterministic within a sector but stochastic across sectors.

In the presence of technological innovation in the world frontier but in the absence of domestic financial innovation, the screening technology becomes increasingly ineffective at identifying the capable entrepreneur. This growing financial gap reduces the probability that the society invests in the best entrepreneurial ideas with adverse ramifications on technological

change. More formally, as technology advances (as $\bar{A}_t$ increases) and without a concomitant advance in the screening technology, $m_{i,t}$, the probability that households successfully identify and fund the capable entrepreneur, $\lambda_{i,t} = m_{i,t}/\bar{A}_t$, falls.

Financiers are paid by entrepreneurs in the form of a share, $\delta_{i,t}$, of entrepreneurial profits. For simplicity but without loss of generality we assume that, though all entrepreneurs sign a perfectly enforceable contract before screening regarding this share, only one entrepreneur in a sector is designated as capable by the financier when the latter innovates successfully. This designated entrepreneur, therefore, is the only one in the sector that receives capital from households.
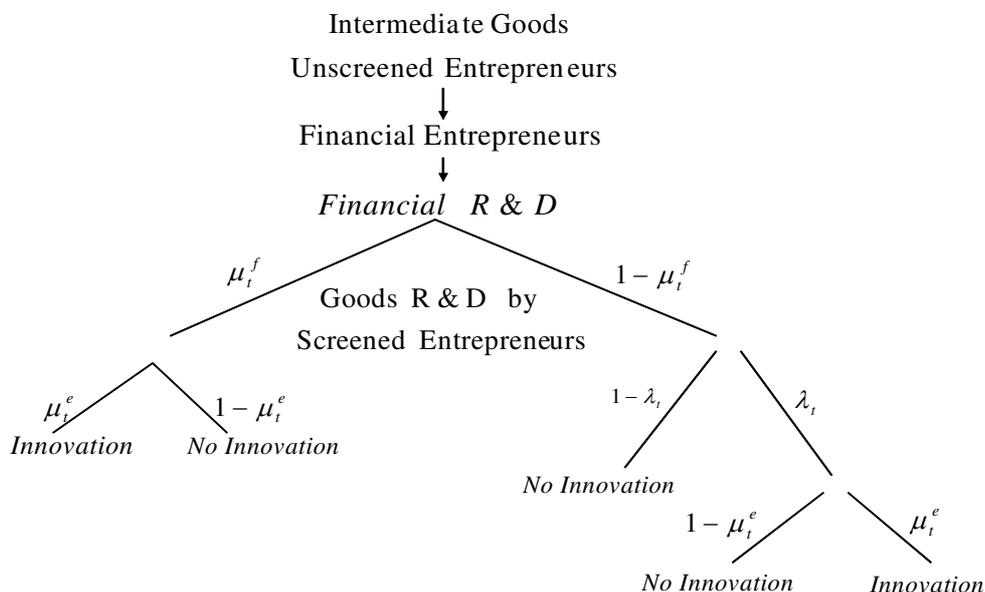
The financier's fraction of entrepreneurial profits, $\delta_{i,t}$, is determined endogenously in the model. In sectors with successful financial innovation, the successful financier is the sole provider of the frontier screening technology and charges a monopoly price in the form of a high share of entrepreneurial profits. That is, the successful, financier charges a price such that the entrepreneur is ex-ante indifferent between using the frontier screening technology and using the old screening technology available to the households. Without loss of generality, we assume that households can employ the old screening technology at zero cost, so that entrepreneurs screened by households keep 100% of the profits.

2.4 Timing of Events

At the beginning of period $t-1$ in each sector, the financier borrows money from households and invests in financial innovation. If the financier successfully innovates, then this new screening technology identifies the capable entrepreneur in the sector with probability one in period t. In this case entrepreneurs contract with her and she becomes the single seller of screening services in the sector. If the financier does not innovate, then the households screen the projects, using the old screening technology from period $t-1$, which is available at zero cost, and the entrepreneur designated as capable borrows from the households and invests in innovation.

In period t, uncertainty about entrepreneurial innovation is resolved. If the entrepreneur successfully innovates, she repays the households for their investment in innovation, pays the contracted fraction of profits to the financier, and keeps the remaining profits. If the financier and entrepreneur successfully innovate, then the financier pays back households who lent money for financial innovation.

Figure 1 below summarizes all possible scenarios.

Intermediate Goods

Unscreened Entrepreneurs

$\downarrow$

Financial Entrepreneurs

$\downarrow$

Financial R & D

μ_t^f $1 - \mu_t^f$

Goods R & D by
Screened Entrepreneurs

μ_t^e $1 - \mu_t^e$ $1 - \lambda_t$ λ_t

Innovation   *No Innovation*

No Innovation

$1 - \mu_t^e$ μ_t^e

No Innovation   *Innovation*

3 Innovation and Aggregate Growth

3.1 Entrepreneurial Innovation

The probability that a capable entrepreneur successfully innovates in period t, $\mu_{i,t}^e$, depends positively on the amount of resources invested in entrepreneurial innovation during period $t-1$, $N_{i,t-1}^e$, so that:

$$N_{i,t-1}^e = (\theta \mu_{i,t}^e)^\gamma \bar{A}_t, \quad \gamma > 1. \tag{8}$$

As in Aghion and Howitt (2009), the cost of entrepreneurial innovation in terms of final goods input increases proportionally with the world technology frontier, $\bar{A}_t$, so that it becomes more expensive to maintain an innovation rate of $\mu_{i,t}^e$ as the technology frontier advances. Moreover, θ is a an economy-wide constant reflecting institutional and other characteristics that affect the cost of innovation at every level of technological sophistication.

In equilibrium, each capable entrepreneur chooses $N_{i,t-1}^e$ to maximize expected profits. Given the contractual agreement between entrepreneurs and financiers, the entrepreneur

designated as capable keeps the fraction $(1 - \delta_{i,t})$ of expected entrepreneurial profits $\Pi_{i,t}^e$, so that:

$$\Pi_{i,t}^e = (1 - \delta_{i,t}) \left(\beta \mu_{i,t}^e \pi \bar{A}_t - N_{i,t-1}^e \right). \tag{9}$$

Risk-neutral individuals in the first period of life provide resources to entrepreneurs designated as capable by financiers.[2] They provide resources to entrepreneurs at a sector-specific interest rate that is an inverse function of the quality of the screening technology in the sector. Defining the risk free interest rate as $r = 1/\beta - 1$, the interest rate charged to an entrepreneur that is rated as capable by a successful financier is $R_{i,t}^e = \frac{1+r}{\mu_{i,t}^e}$. In turn, households charge the interest rate of $R_{i,t}^e = \frac{1+r}{\lambda_{i,t} \mu_{i,t}^e}$ to entrepreneurs selected by the economy-wide screening technology from the last period. Recall that $\lambda_{i,t} = 1$ for financiers that successfully innovate, so these two interest rates are consistent.

Consider first entrepreneurs that are screened by successful financiers, so that the selected entrepreneur knows with probability one that she is the capable one. The profit-maximizing probability of entrepreneurial innovation comes from maximizing (9) by choosing $\mu_{i,t}^e$ subject to (8):

$$\mu_{i,t}^{e*} = \left(\frac{\beta \pi}{\gamma \theta^{\gamma}} \right)^{1/(\gamma-1)}, \tag{10}$$

where we assume that $\beta \pi < \gamma \theta^{\gamma}$ to ensure that the equilibrium probability of successful entrepreneurial innovation is less than one ($\mu_{e,t}^* < 1$) under perfect financial screening. Since entrepreneurs repay financiers only when they successfully innovate, $\delta_{i,t}$ does not affect investment in entrepreneurial innovation.

From (10), the comparative statics of when a financier successfully innovates are intuitive. Entrepreneurs invest more in innovation and boost the probability of success when (1) the net profits per unit of the intermediate good, π, are higher and (2) the cost of entrepreneurial innovation, θ, is lower. If π and θ are common across sectors, then $\mu_{i,t}^{e*} = \mu^{e*} \ \forall \ i$.

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[2] We assume that all investment is domestically financed, but allowing for perfect international capital mobility would not change the analysis given the structure of the model. First, linear utility with a constant discount rate implies that individuals are indifferent between investing domestically or abroad, so that perfect capital mobility yields the same results. Second, we treat financial and technological innovation symmetrically: Entrepreneurs in a country must engage in the costly, risky process of adapting a technology from the frontier country to their domestic market. Similarly, financiers must engage in the costly, risky process of adapting a screening methodology from the frontier country to a particular domestic market. Whether the financier that undertakes these costly, risky "innovations" is domestic or foreign is irrelevant for our purposes.

Substituting (10) into (9) yields the net expected profits of an entrepreneur screened by a successful financier,

$$\Pi_{i,t}^{e*} = (1 - \delta_{i,t})\mu^{e*}\varphi\bar{A}_t, \tag{11}$$

where $\varphi = \beta\pi(1 - 1/\gamma)$.

Now, consider entrepreneurs screened by households using the old, imperfect screening technology, m_{t-1}. Under these conditions, the entrepreneur keeps all the profits, so that $\delta_{i,t} = 0$. Thus, the expected profits to an imperfectly screened entrepreneur, $\Pi_{i,t}^{e'}$, i.e., the expected profits of an entrepreneur screened using the old screening technology is:

$$\Pi_{i,t}^{e'} = \beta\lambda_{i,t}\mu_{i,t}^e\pi\bar{A}_t - N_{t-1}^e. \tag{12}$$

Consequently, the profit-maximizing probability of entrepreneurial innovation for imperfectly screened entrepreneurs, $\mu_{e,t}^{'}$, is:

$$\mu_{i,t}^{e'} = (\lambda_{i,t})^{\frac{1}{\gamma-1}}\mu^{e*}. \tag{13}$$

Substituting (13) in (12) one derives the maximal net expected revenue of an entrepreneur selected using the old screening technology as:

$$\Pi_{i,t}^{e'} = (\lambda_{i,t})^{\frac{\gamma}{\gamma-1}}\mu^{e*}\varphi\bar{A}_t. \tag{14}$$

The following Lemma establishes the properties of entrepreneurial innovation in sector i when using the old screening technology, $\lambda_{i,t}$,

Lemma 1 *The properties of entrepreneurial innovation in sectors using the old, imperfect screening technology:*

1. *Entrepreneurs invest more in innovation and boost the probability of successful innovation when (1) the net profits per unit of the intermediate good, π, are higher and (2) the cost of entrepreneurial innovation, θ, is lower, i.e.,*

$$\frac{\partial \mu_{i,t}^{e'}}{\partial \pi} > 0, \quad \frac{\partial \mu_{i,t}^{e'}}{\partial \theta} < 0.$$

2. *The rate of entrepreneurial innovation is an increasing function of the standard screening technology, $\lambda_{i,t}$, i.e.,*

$$\frac{\partial \mu_{i,t}^{e'}}{\partial \lambda_{i,t}} > 0.$$

Proof. These properties follow by directly differentiating equation (13). □

We can now derive the fraction of entrepreneurial profits accruing to the entrepreneur $(1 - \delta_{i,t})$ and the financier $(\delta_{i,t})$. For the unscreened entrepreneurs in the beginning of period $t-1$ to be indifferent between choosing a contract with a financier or using the economy-wide screening technology supplied by the households, these two alternatives must deliver the same expected profits. Formally, (11) must equal (14), so that:

$$\delta_{i,t} = 1 - (\lambda_{i,t})^{\frac{\gamma}{\gamma-1}} . \tag{15}$$

Equation (15) indicates that the better is the economy's financial screening capacity (higher $\lambda_{i,t}$) the lower is the fraction of entrepreneurial profits ($\delta_{i,t}$) that a successful financier can demand. This occurs because if the standard screening technology is close to the frontier screening technology, then households offer a close substitute. On the other hand, if the available screening technology is a poor substitute for newly developed screening capabilities, then the financier can obtain a larger fraction of expected entrepreneurial profits.

3.2 Financial Innovation

As with entrepreneurial innovation, the probability that the financier in sector i successfully innovates during period $t-1$ and identifies the entrepreneur capable of innovation in period t, $\mu_{i,t}^f$, depends positively on the amount of resources invested in financial innovation during period $t-1$, $N_{i,t-1}^f$:

$$N_{i,t-1}^f = (\theta_f \mu_{i,t}^f)^\gamma \bar{A}_t, \quad \gamma > 1, \tag{16}$$

where the cost of financial innovation in terms of the final goods input increases proportionally with the world technology frontier, $\bar{A}_t$. Thus, it becomes more expensive to maintain the same rate of financial innovation, $\mu_{i,t}^f$, as the technological frontier advances since the entrepreneurs that are screened by financiers are striving to reach the world technology frontier.

The financier chooses $N_{i,t-1}^f$ to maximize expected profits, $\Pi_{i,t}^f$. Since a successfully innovating financier keeps the fraction $\delta_{i,t}$ of expected entrepreneurial profits, $\Pi_{i,t}^{e*}$, the financier's expected profits equals:

$$\Pi_{i,t}^f = \mu_{i,t}^f \beta \delta_{i,t} \Pi_{i,t}^{e*} - N_{i,t-1}^f. \tag{17}$$

The financier maximizes profits by borrowing $N_{i,t-1}^f$ worth of final goods and investing these resources in financial innovation. Risk-neutral individuals lend to financiers seeking to

innovate at an interest rate of $R_t^f = \frac{1+r}{\mu_{t,i}^f \mu_{t,i}^e}$, which is a function of the risk free interest rate, r, the probability that the financier successfully innovates, and the probability that the entrepreneur designated by the financier as capable successfully innovates. After substituting (15) into (17), the financier chooses to borrow and invest in financial innovation such that the profit-maximizing probability of successful financial innovation in sector i during period t is:

$$\mu_{i,t}^{f*} = \left(\frac{\beta \mu_t^{e*} \varphi (1 - (\lambda_{i,t})^{\frac{\gamma}{\gamma-1}})}{\gamma \theta_f^\gamma} \right)^{\frac{1}{\gamma-1}}, \tag{18}$$

where we assume that $\theta_f > \theta$ to ensure that the rate of financial innovation is less than one.

3.3 Aggregating the Financial System

To examine the efficiency of a country's financial system, we aggregate across individual sectors to focus on the average, or representative, probability that the capable entrepreneur is identified,

$$\lambda_t = \int_0^1 \lambda_{i,t} di,$$

where $\lambda_{i,t}$ equals the probability that the entrepreneur capable of innovating in sector i during period t is chosen. From equation (7), the average level of financial efficiency evolves according to the following equation:

$$\lambda_t = \mu_t^f + (1 - \mu_t^f) \frac{\lambda_{t-1}}{1+g} . \tag{19}$$

Financiers identify the capable entrepreneur with probability one in fraction μ_t^f of the sectors in which the financial innovation is successful. Since we aggregate financial screening quality across a continuum of sectors, we ignore negligible relative size differences. In the remaining $1 - \mu_t^f$ of the sectors, households identify the capable entrepreneur with a probability of $\frac{\lambda_{t-1}}{1+g} < 1$.

To obtain the steady state level of average financial screening, let $\lambda_t = \lambda_{t-1} = \lambda^*$ and $\mu_t^f = \mu^{f*}$ in the steady state and then solve for λ^* in equation (19):

$$\lambda^* = \frac{\mu^{f*}}{g + \mu^{f*}} . \tag{20}$$

Directly differentiating equation (20) yields a key result:

$$\frac{\partial \lambda^*}{\partial \mu^{f*}} > 0. \tag{21}$$

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The higher is the steady state rate of financial innovation, μ^{f*}, the more efficient is the economy's financial system at identifying capable entrepreneurs in the steady state, λ^*.

The steady state profit-maximizing innovation probability of the financial system is determined by replacing $\lambda_{i,t} = \lambda^*$ into (18), so that:

$$\mu^{f*} = \left(\frac{\beta \mu^{e*} \varphi (1 - (\lambda^*)^{\frac{\gamma}{\gamma-1}})}{\gamma \theta_f^\gamma} \right)^{\frac{1}{\gamma-1}}. \tag{22}$$

Finally, combining (20) and (22), yields the implicit function:

$$F(\mu^{e*}, \mu^{f*}, \theta_f) \equiv 0, \tag{23}$$

which characterizes the equilibrium innovation rate of the financial system. The following Lemma summarizes the properties of an economy's financial innovation rate:

Lemma 2 *The properties of financial innovation in the steady state:*

1. *Financial innovation is an increasing function of the rate at which entrepreneurs innovate:*

$$\frac{\partial \mu^{f*}}{\partial \mu^{e*}} > 0.$$

2. *Financial innovation is a decreasing function of the costs of financial innovation, θ_f:*

$$\frac{\partial \mu_t^{f*}}{\partial \theta_f} < 0.$$

3. *Financial innovation is an increasing function of the rate at which the world technology frontier, g, advances:*

$$\frac{\partial \mu_t^{f*}}{\partial g} > 0.$$

Proof. Repeated differentiation of equation (22) according to the Implicit Function Theorem delivers the results. □

We present the comparative statics of μ_t^{f*} with respect to entrepreneurial innovation μ^{e*} to highlight the nexus between entrepreneurial and financial innovation. It is straightforward to show that since μ^{e*} itself is a function of exogenous features of the economy (θ, π), (part 1 of Lemma 1), changes in these structural parameters will affect the equilibrium financial innovation accordingly.

Stagnant entrepreneurial innovation reduces the expected profits from financial inno-
vation, which in turn (a) reduces investment in financial innovation, (b) slows the rate of
improvement in the screening technology, (c) lowers the probability that capable entrepreneurs
are selected, and hence (d) impedes technological innovation and growth. Put differently, there
is a multiplier effect associated with changes in entrepreneurial innovation that reverberates
through the rate of financial innovation back to the rate of technological change.

Policies, regulations, and institutions that impede financial innovation have large effects
on the rate of technological innovation. Thus, countries in which it is more expensive to
innovate financially (higher θ_f) will tend to experience slower rates of technological growth.
Cross-economy differences in the cost of financial innovation can arise for many reasons. For
example, a large literature suggests that some legal systems (for example, those that rely on
case law) are more conducive to financial innovation than other systems (such as those that
rely less heavily on case law to adapt to changing conditions), which has been documented by
Levine (2005b), Gennaioli and Shleifer (2007), and Levine (2005a, 2005b).

3.4 Aggregate Economic Activity

This section aggregates an economy's economic activity and examines its components. We
define the economy's average level of technological productivity, A_t, as:

$$A_t = \int_0^1 A_t(i)di,$$

where aggregation is performed across the continuum of intermediate sectors.

To derive the law of motion of the average level of technological productivity, note that
in equilibrium, the expected rate of entrepreneurial and financial innovation is the same across
sectors, i.e. $\mu_{i,t}^f = \mu_t^f$ and $\mu_{i,t}^e = \mu_t^e$. Then, one can simply use the branches of Figure 1 and
equation (13) to derive the law of motion of average productivity:

$$A_{t+1} = (\mu_{t+1}^f \mu_{t+1}^e + (1-\mu_{t+1}^f)\lambda_{t+1}^{1/(\gamma-1)}\mu_{t+1}^e)\bar{A}_{t+1} + (1-\lambda_{t+1}^{1/(\gamma-1)}\mu_{t+1}^e - \mu_{t+1}^f\mu_{t+1}^e + \mu_{t+1}^f\lambda_{t+1}^{1/(\gamma-1)}\mu_{t+1}^e)A_t.$$
(24)

Inspecting (24) reveals that a country's average technological productivity in period $t+1$ is a
weighted average of sectors that implement the frontier technology, $\bar{A}_{t+1}$, and of sectors using
the average technology of period t, A_t. The weights are functions of (a) the rate of financial
innovation, μ_{t+1}^f, (b) the quality of the financial screening technology, λ_{t+1}, and (c) the proba-
bility of successful entrepreneurial innovation, μ_{t+1}^e. In particular, the productivity parameter

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will equal $\bar{A}_{t+1}$ both in sectors where financiers and entrepreneurs successfully innovated and in sectors where financiers did not innovate, but where, nevertheless, the funded entrepreneurs successfully innovated.

To derive the per capita gross domestic product within a country, note that it is composed of wages in the final goods sector and profits in the intermediate goods and financial sectors. In terms of wages, note that final good production can be summarized by $Z_t = \zeta A_t$ where $\zeta = (\alpha/\chi)^{\alpha/(1-\alpha)}$, which may be derived by substituting (4) into (1). Since by assumption the final goods sector is competitive, the wage rate w_t is the marginal product of labor in the production of the final good, so that $w_t = (1 - \alpha)Z_t = (1 - \alpha)\zeta A_t$.[3] In terms of profits, successful entrepreneurs earn $\pi \overline{A}_t$, where $\pi = (\chi - 1)\left(\frac{\alpha}{\chi}\right)^{\frac{1}{1-\alpha}}$. Thus, per capita gross domestic product is the sum of added value across sectors:

$$Y_t = w_t + \mu_t \pi_t = (1 - \alpha)\zeta A_t + \mu_t \pi \overline{A}_t \ , \tag{25}$$

where μ_t is the fraction of goods' sectors with successful entrepreneurial innovation in period t.

3.5 Equilibrium Economic Performance Across Countries

We now characterize the growth rate of Y_t as a function of the underlying parameters of the model economy. Denote a country's inverse distance from the world technological frontier as $a_t = A_t/\bar{A}_t$. Each economy takes the evolution of the frontier as given (see below how this is derived). Thus, the technology gap evolves according to:

$$a_{t+1} = (\mu_{t+1}^f \mu_{t+1}^e + (1 - \mu_{t+1}^f)\lambda_{t+1}^{1/(\gamma-1)}\mu_{t+1}^e) + \frac{\left(1 - \lambda_{t+1}^{1/(\gamma-1)}\mu_{t+1}^e - \mu_{t+1}^f \mu_{t+1}^e + \mu_{t+1}^f \lambda_{t+1}^{1/(\gamma-1)}\mu_{t+1}^e\right)}{1 + g} a_t \equiv H(a_t) \ . \tag{26}$$

This converges in the long run to the steady state value:

$$a_{ss} = \frac{(1 + g)\mu^*}{g + \mu^*} \ ,$$

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[3]Unlike Aghion et al. (2005), where the proportionality of the wage rate to the domestic productivity determines the level of technology investment in a credit-constrained country, this ratio plays no role in determining entrepreneurial investment in our model. As shown in equations (10) and (13), the probability of entrepreneurial innovation depends only on entrepreneurial profits and the level of the financial screening technology. Domestic productivity determines the amount that a financier and an entrepreneur can borrow from households in period t. Since we assume that neither financiers nor entrepreneurs can hide their proceeds, households are willing to lend any amount at the prevailing interest rate.

where $\mu^* = \mu^{f*}\mu^{e*} + (1 - \mu^{f*})(\lambda^*)^{1/(\gamma-1)}\mu^{e*}$ is the fraction of innovating entrepreneur sectors.

As in other multi-country Schumpeterian models, the growth rate of the technological frontier is determined by the equilibrium rate of entrepreneurial innovations in the leading country labeled 1.[4] That is,

$$g = \mu_1^{f*}\mu_1^{e*} + (1 - \mu_1^{f*})(\lambda_1^*)^{1/(\gamma-1)}\mu_1^{e*}. \tag{27}$$

The following Proposition summarizes the properties of an economy attempting to implement the world technology frontier.

Proposition 1 *An economy's steady state technology gap displays the following properties:*

1. *The steady state technology gap is decreasing at the cost of financial innovation, θ_f, i.e.,*

$$\frac{\partial a_{ss}}{\partial \mu^{f*}}\frac{\partial \mu^{f*}}{\partial \theta_f} < 0.$$

2. *The steady state technology gap is increasing at the rate of entrepreneurial innovation, μ^{e*}, i.e.,*

$$\frac{\partial a_{ss}}{\partial \mu^{e*}}\frac{\partial \mu^{e*}}{\partial \theta} < 0, \; \frac{\partial a_{ss}}{\partial \mu^{e*}}\frac{\partial \mu^{e*}}{\partial \pi} > 0$$

Proof. The first property obtains by differentiating a_{ss} with respect to μ^{f*} and taking into account the second part of Lemma 2. The second property obtains by taking into account that both the net profits per unit of the intermediate good, π, and the cost of entrepreneurial innovation, θ, (see part 1 of Lemma 1) shape entrepreneurial innovation which in turn determines the steady state technological gap.

Corollary 1 *An economy blocking financial innovation will eventually stagnate irrespective of the initial level of screening technology, λ_t.*

$$a_{ss} = 0 \; if \; \theta_f \to \infty.$$

Proof. When the cost of financial innovation goes to infinity, $\theta_f \to \infty$, then part 2 of Lemma 2 implies that financial entrepreneurs allocate no resources towards R&D and thus financial and subsequently technological innovation stagnate.

The next section briefly discusses the derived properties.

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[4]There is no need to explicitly specify the size of innovation for the leader since it does not affect the equilibrium innovation probability. To see that, assume that the leader's technological jump from period $t-1$, is $h > 1$, i.e. $A_t = hA_{t-1}$. Looking at (9) it becomes clear that the size of the jump, h, multiplies both the expected revenues and the innovation costs leaving the equilibrium rate of entrepreneurial innovation unaffected.

3.6 Dynamic versus Static Financial Markets

The model economy predicts that regardless of the screening capability of the financial system in period t, λ_t, anything that prohibits financial innovation will eventually stop economic growth as illustrated in Figure 2a.
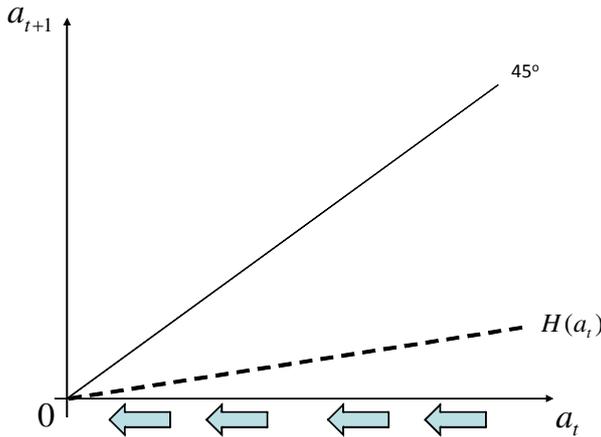

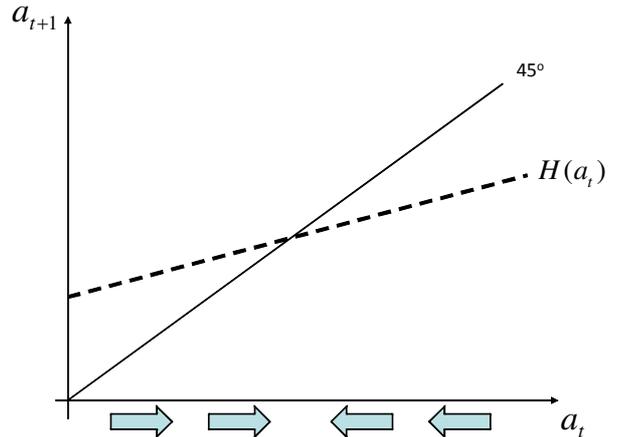Figure 2a: Static Financial Markets   Figure 2b: Dynamic Financial Markets

Initially, the consequences of impeding innovation may have negligible effects on the rate of entrepreneurial innovation if the initial efficiency of the screening technology is high. Inevitably, however, as the world technology frontier advances and renders the initial screening technology increasingly obsolete, the absence of financial innovation produces a large and growing gap between actual and potential growth.

Graphically, this scenario is equivalent to the $H(a_t)$ curve in Figure 2b shifting downwards over time in the absence of financial innovation–with $H(a_t)$ given by equation (26) Eventually, the $H(a_t)$ curve hits the origin as in Figure 2a. This financially induced poverty trap is not caused by standard credit constraints. Rather, it arises because financiers fail to innovate and improve the screening technology in tandem with the world-technology frontier. Introducing financial innovation in such a dormant financial system will boost growth, allowing for convergence to the world growth rate. It is straightforward to show this by verifying that the per capita gross domestic product in a financially innovating economy, i.e. $\mu^{f*} > 0$, derived in (25), grows at the rate of the world technology frontier.

Due to the synergies between financial and entrepreneurial innovation, interventions in either sector have an amplifying effect on the economy's innovation rate. For instance, among economies that invest in financial innovation, further decreasing the barriers to financial inno-

vation will shift the $H(a_t)$ curve upwards in Figure 2b, increasing a country's steady state level of technology relative to the frontier, a_{ss}. In a similar fashion, factors affecting entrepreneurial innovation also shape a country's steady state technology gap.

4 Some Empirical Evidence on Financial Innovation and Growth

4.1 Preliminaries

This section provides empirical evidence on the model's key prediction: Without financial innovation, economic growth will slow regardless of the initial level of financial development. This prediction differs from existing models that ignore the potential role of financial innovation in facilitating technological innovation and economic growth and that focus only on the impact of the level of financial development on long-run growth.

As emphasized in the Introduction, researchers have already documented close ties between financial innovation and economic growth. Indeed, it is this research that helped motivate our theoretical model. Tufano (2003), Goetzmann (2009), Neal (1990), Gompers and Lerner (2001), and others describe how financial innovations fostered technological advancements over the centuries. Amore, Schneider, and Zaldokas (2013) show that exogenous increases in bank credit across the states of the United States spurred innovation in nonfinancial firms, as measured by the production of patents. Interpreting bank credit as a proxy for financial innovation, these findings suggest that financial innovation boosts technological innovation. In a cross-country study, Beck, Chen, and Song (2013) show that economic growth is positively associated with how much a country's banking system spends on research and development. Interpreting research and development spending by banks as a proxy for innovation, this research advertises the positive association between financial innovation and economic growth.

We contribute to these empirical studies in several ways. First, while existing cross-economy studies of financial innovation and growth add financial innovation as an additional explanatory variable into a standard, reduced-form empirical growth regression, we assess the specific regression specification emerging from theory. Second, we test the predictions of our model against a well-specified alternative. While Aghion, Howitt, and Mayer-Foulkes (2005) (henceforth AHM) stress that the level of financial development accounts for the rate at which economies converge to the technological leader, we highlight the role of financial innovation. Third, besides using the growth rate of credit to the private firms (as a share of GDP) as a proxy for financial innovation, we also examine another proxy of financial innovation: the speed with which a country's banks create a private credit bureau as a new mechanism for improving the

screening of technological entrepreneurs. While both proxies are imperfect measures of financial innovation, they provide complementary information. Finally, since pure cross-economy analyses face endogeneity problems and do not exploit the time-series dimension of the data, we also employ a panel GMM estimator to assess the impact of both financial development and financial innovation on economic growth while controlling for other features of the economy.

4.2 Econometric model and data

To test the predictions of our model against a well-specified alternative, we build on AHM's analyses. The AHM cross-country regression framework is as follows:

$$g - g_1 = \beta_0 + \beta_1 F + \beta_2 (y - y_1) + \beta_3 F(y - y_1) + \beta_4 X + \varepsilon, \tag{28}$$

where $g - g_1$ is average growth rate of per capita income relative to U.S. growth over the period 1960-95, F is financial development, which is measured as credit to the private sector as a share of GDP, $y - y_1$ is log of per capita income relative to U.S. per capita income, X is set of control variables, and ε is an error term. The data are from Levine, Loayza, and Beck (2000). Consistent with their theoretical model, AHM find that β_1 is not significantly different from zero and β_3 is negative and significant, indicating that the level of financial development accelerates the rate at which economies converge to the technological frontier.

Our model encompasses the AHM framework but differs in one key aspect: it stresses the importance of financial innovation, not financial development. Indeed, in our model, the level of financial development in any period is an outcome of previous financial innovations. Therefore, our amended regression framework reads as follows:

$$g - g_1 = b_0 + b_1 F + b_2 (y - y_1) + b_3 F(y - y_1) + b_4 X + b_5 f + b_6 f(y - y_1) + u, \tag{29}$$

where f denotes financial innovation over the sample period 1960-95. Our model predicts that $b_6 < 0$: the speed of convergence depends positively on financial innovation. The model also predicts that b_5 will be insignificant, indicating a vanishing steady-state growth effect. This prediction derives from the assumption that the technological leader already possesses a financial system that innovates at the growth-maximizing rate, so that faster financial innovation would not increase the probability of picking capable entrepreneurs. Note that f is measured over the sample period, while F is measured at the beginning of the sample period, i.e., F does not include improvements to the financial system's screening technology during the period.

We use two measures of financial innovation. First, we use the growth rate of credit to the private sector as a share of GDP, so that f equals the annual growth rate of F over the period from 1960 to 1995. Since a large body of research uses the ratio of credit to the private sector to GDP as a proxy for the level of financial development, as discussed in Levine (2005), it is natural to use the growth rate of financial development as a proxy for improvements in the financial system. Furthermore, although surges in the ratio of credit to GDP over short horizons might reflect unsustainable credit booms, this is unlikely to be the case over a 35 year period, increasing the likelihood that the growth rate of credit to GDP from 1960 to 1995 provides information on the rate of improvement in the country's financial system. Similarly, since this proxy for financial innovation omits credit to the government or public enterprises, it is unlikely to reflect expansionary fiscal policies or increased expenditures by public entities and hence more likely to gauge improvements in financial services. Nevertheless, credit growth is not an ideal proxy of financial innovation because it does not explicitly measure any particular financial innovation.

Second, we calculate how quickly a country's banking system adopts and implements one particular financial innovation: the adoption of a private credit bureau. This second measure of financial innovation, f, equals the fraction of years between 1960 and 1995 that a private credit bureau was in place, which is obtained from Djankov et al. (2007). Since banking systems do not eliminate private credit bureaus once they are created, this measure of financial innovation is larger, the earlier a country's banking system created a private credit bureau. Private credit bureaus are organizations that provide credit information on individuals and firms. They are commonly established by private banks to share credit information about the creditworthiness of borrowers.[5] Such bureaus allow banks to obtain credit information on customers of other banks and serve as an important input into screening entrepreneurial endeavors. As of 2003, private credit bureaus operated in 55 out of the 133 countries covered by Djankov et al. (2007).

For comparison purposes, we test the empirical predictions of our model using the same dataset and the same set of control variables, X, as in AHM. These control variables include measures of educational attainment (*school*), government size (*gov*), inflation (*pi*), black market

[5] The world's oldest private credit bureau, Equifax, was founded in Atlanta, Georgia in 1899 as Retail Credit Company. It began with two brothers, Cator and Guy Woolford, keeping a list of customers and their creditworthiness for their local Retail Grocer's Association. They would sell their book to other merchants in the association and credit reporting was born. With the onset of credit scoring models, developed by engineer Bill Fair and mathematician Earl Isaac in the late 1950s who founded the Fair Isaac Corporation (producer of the well-known FICO credit scores) and the passage of the 1968 Fair Credit Reporting Act in the US, private credit bureaus became an increasingly important provider of credit information.

premium (bmp), openness to trade ($trade$), revolutions and coups ($revc$), political assassinations ($assass$), and ethnic diversity ($avelf$). The summary statistics of our main regression variables, including data definitions, are reported in Table 1.

4.3 Cross-country regressions

We start by running a cross-country OLS regression, limiting the sample to countries with data on the initial level of financial development in 1960. King and Levine (1993b) find that the level of financial development in 1960 predicts subsequent rates of long-run growth. Although AHM use average private credit over the period 1960-95, we use the initial level of private credit to GDP because the average includes financial innovation–improvements in financial development–during the period.

Table 2 presents the cross-country regression results. First, the results on financial innovation in regression (1) are consistent with the central prediction from our model. The estimated value of the coefficient on the interaction between financial innovation, f, and the deviation of GDP from U.S. GDP ($y - y_1$), i.e., b_6, enters negatively and significantly and with a point estimate of -0.09. And, consistent with theory, the estimated value of b_5 (the coefficient on f) is not statistically different from zero. The economic effect of this result is large. A one-standard-deviation increase in financial innovation (3.08), when evaluated at the mean of the income differential with the lead country, ($y - y_1$), (-1.37), implies an increase in growth relative to U.S. growth ($g - g_1$) of 0.383. This is about one-fifth of the standard deviation of the growth differential with the U.S. (1.7).

Second, regression (1) confirms the AHM findings. The estimated value of b_3 is negative and statistically significant, while the estimated value of b_1 is not significantly different from zero. From the perspective of regression (1), therefore, one might conclude that both the initial level of financial development and financial innovation account for convergence to the growth leader.[6] As we demonstrate below, however, the results on the level of financial development are not robust to using panel data techniques.

Third, the results hold when using the private credit bureau proxy of financial innovation. The interaction between the private credit bureau proxy of financial innovation and the deviation of GDP from U.S. GDP ($y - y_1$) enters negatively and significantly at the ten percent level. When incorporating the private credit bureau proxy, the level of financial development

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[6]This finding does not follow from our theoretical model, which only stresses the role of financial innovation. Nevertheless, a fairly natural generalization would get both the level of financial development and the innovation rates to be important determinants of economic performance.

and its interaction with the deviation from U.S. GDP per capita do not enter significantly.

Fourth, as a falsification test, we examine public credit registries. Credit information sharing arrangements can be organized by the government (typically the central bank) in the form of a public credit registry. Private credit bureaus, however, usually gather more information and offer a broader range of services to lenders than public credit registries, according to Jappelli and Pagano (2002). Consistent with this view, we find that the speed with which a country creates a public credit bureau is unrelated to economic growth or convergence.

Fifth, Table 2 presents two sets of instrumental variables (IV) regressions. We follow AHM, instrumenting for F and $F(y - y_1)$ using legal origin, L, and legal origin interacted with initial relative output $(L(y - y_1))$. Legal origin is a set of three dummy variables, first used by La Porta et al. (1997, 1998), indicating whether the country's legal system is based on French, English, German, or Scandinavian traditions. La Porta et al. (1997, 1998) argue that legal origin explains variation in the protection of the rights of shareholders and creditors. Levine et al. (2000) argue that legal origin constitutes a good set of instruments for financial development because they are predetermined variables, have a bearing on the enforceability of financial contracts, have a strong effect on financial development, and should affect growth primarily though their impact on financial development.

As an instrument for financial innovation, f, we use a measure of financial reforms that ease restrictions on the operation of the financial system, which in turn encourages financiers to invest more in innovation to enhance screening. We use the change over the period 1973-1995 in the Abiad and Mody (2005) financial reform index, R, as an instrument for f, and instrument $f(y - y_1)$ using $R(y - y_1)$. Abiad and Mody (2005) create an aggregate country-level index of financial reform for a sample of 35 countries over the period 1973-1996 by aggregating six subcomponents that each obtain a score between 0 and 3, with higher scores denoting more liberalization. The six subcomponents relate to credit controls, interest rate controls, entry barriers in the banking sector, operational restrictions, privatization in the financial sector, and restrictions on international financial transactions. Past research motivates the use of financial liberalization as an instrument for financial innovation. For example, Silber (1983) and Kane (1983 and 1988) find that the liberalization of the U.S. banking industry spurred innovations within the banking sector .

As reported in columns (4) and (5) of Table 2, we assess the strength and validity of the instrumental variables. To test the strength of our instruments, we use F-tests of joint significance of the excluded instruments in the first stage regressions of F, $F(y - y_1)$, f, and

$f(y - y_1)$. As shown, the results generally reject the null hypothesis that the instruments do not explain variation in the endogenous variables. In the two IV specifications—one using credit growth as a proxy for financial innovation and the second using the speed with which a country's banking system implemented a private credit bureau, the instruments reject the first-stage F-test at the 10% level for three of the endogenous variables and for the fourth instrumented regressor, the F-test has a p-value of 0.10. To further test the validity of the instruments, we use the Hansen-Sargan test, where the null hypothesis is that the instruments are uncorrelated with the second-stage residuals. As shown, the instruments do not reject the Hansen-Sargan test, meaning that we do not reject the null hypothesis that the instruments only explain growth through their influence on the specified endogenous variables.

The IV results are consistent with those from the OLS specifications. The interaction between financial innovation and the deviation of GDP from U.S. GDP enters negatively and significantly. The estimated IV coefficients for the interaction term between financial innovation and GDP deviation are larger in absolute value than the OLS estimates. This difference between the IV and OLS estimates is consistent with the presence of measurement error bias. If financial innovation is measured with error and the true impact of financial innovation on growth is positive, the OLS estimate will be biased toward zero. To the extent that the instruments are not correlated with this measurement error, then IV estimates will be free from this bias.

4.4 Panel GMM regressions

This section uses panel econometric techniques to examine the impact of financial innovation, the level of financial development, and other potential growth determinants on the convergence of countries to the growth path of the technological leader, while (a) controlling for simultaneity and omitted variable bias and (b) exploiting the time-series dimension of the data. We use the panel dataset from Levine et al (2000), which is a non-overlapping panel of seven five-year intervals from 1960 to 1995, and the first-difference Generalized-Method-of Moments (GMM) estimator developed by Arrellano and Bond (1991).

More specifically, the panel version of equation (29) is given by

$$g_{i,t} - g_{1i,t} = b_0 + b_1 F_{i,t} + b_2(y_{i,t} - y_{1_{i,t}}) + b_3 F_{i,t}(y_{i,t} - y_{1_{i,t}}) + b_4 X_{i,t} + b_5 f_{i,t} + b_6 f_{i,t}(y_{i,t} - y_{1_{i,t}}) + \delta_i + u_{i,t},$$

(30)

where the t subscripts indicate the particular five-year period, so that $t = 1, 2, \ldots 7$, for each country i, data permitting, δ_i is the coefficient on a country-specific effect, and where we also

control for a time-specific effect in each period in the panel.[7] We refer to this as the levels equation, and to the equation in first differences as the difference equation.

Arrellano and Bond (1991) develop a difference estimator under the assumptions that (a) $u_{i,t}$ is not serially correlated and (b) the explanatory variables are uncorrelated with future realizations of $u_{i,t}$.[8] As instrumental variables, they propose using lagged values of the explanatory variables in levels as instruments for the explanatory variables in the difference equation. The consistency of this GMM estimator depends on the validity of the assumption that the error terms do not exhibit serial correlation and on the validity of the instruments. To address these issues we use two specification tests. The first is the Hansen-Sargan test of over-identifying restrictions, which tests the overall validity of the instruments by analyzing the sample analog of the moment conditions used in the estimation process. The second test examines the hypothesis that the error term is not serially correlated. We test whether the differenced error term is second-order serially correlated (by construction, the differenced error term is first-order serially correlated even if the original error term is not). Failure to reject the null hypotheses of both tests gives support to our model.

With one modification, we use this GMM estimator to examine the impact of financial innovation, the level of financial development, and other potential growth determinants on economic growth. When moving to the panel data, we find that there is (1) little within-country variation in GDP per capita differences, $(y_{i,t} - y_{1_{i,t}})$, over the five year periods and (2) considerable within-country variation in the growth rate of private credit, f, over such periods (associated with business-cycles and banking system problems). These features undermine the usefulness of using the interaction between GDP per capita differences and financial innovation in this panel setting. Thus, we modify the setting by splitting the sample between economies that are above and below the median GDP per capita gap respectively. That is, we use a standard growth regression, split the sample between those above and below the median differences of GDP per capita from the lead country, and assess whether (1) financial innovation speeds economic growth and (2) financial innovation spurs the rate of growth more in countries

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[7]Some may raise concerns that financial innovation is a long-run phenomenon that cannot be usefully examined using panel data based on five-year intervals. Without ignoring the limitations, we offer the panel results as additional evidence concerning the linkages between financial innovation and economic growth.

[8]Using these moment conditions, Arellano and Bond (1991) propose a two-step GMM estimator. In the first step the error terms are assumed to be independent and homoskedastic across countries and over time. In the second step, the residuals obtained in the first step are used to construct a consistent estimate of the variance-covariance matrix, thus relaxing the assumptions of independence and homoskedasticity. The two-step estimator is thus asymptotically more efficient relative to the first-step estimator. We refer to the GMM estimator based on these conditions as the difference estimator.

that are below the median GDP per capita gap with the lead country.

Table 3 indicates that financial innovation is positively associated with economic growth and the impact of financial innovation is stronger for countries farther away from the growth path of the leading economy. Table 3 presents three regressions. The first includes the full sample and the next two limit the sample to those observations for which the log per capita income of the country minus the log per capita income of the United States at the beginning of each five-year period is below–or above–the sample median for that period. Thus, we differentiate between countries "far" or "close" to the leading country. This provides a test of the theory, which predicts that financial innovation will have a bigger effect on growth for economies farther away from the leading economy. As shown at the bottom of the Table 3, the specification tests do not reject the hypothesis that the instruments are valid. That is, in none of the equations, are null hypotheses of no second-order serial correlation and no correlation between the instruments and errors in the second stage regressions rejected.

While financial innovation, as measured by the growth rate of private credit to GDP of each five-year period, is positively related to economic growth in all of the equations, it is notably larger for the sample of economies far from the economic leader. The difference between the estimated coefficient in column (2) for observations far from the leader is statistically significantly larger than the estimated coefficient in column (3) for observations close to the leader at the 10 percent significance level. The results indicate that a one standard deviation increase in 5-year period financial innovation will boost economic growth over the same period by 0.76 percentage points for observations far from the leader (as compared to 0.47 percentage points for observations close to the leader). This is a large effect as the standard deviation of real per capita growth over the same period is 2.9 percentage points.

5   Concluding Remarks

Historically, financial innovation has been a ubiquitous feature of expanding economies. Whether it is the development of new financial instruments, the formation of new financial institutions, or the emergence of new financial reporting techniques, successful technological innovations have often required the invention of new financial arrangements.

In this paper, we model technological and financial innovation as reflecting the profit-maximizing decisions of individuals and explore the implications for economic growth. We build a Schumpeterian endogenous growth model in which technological entrepreneurs can earn monopoly profits by inventing better goods and financiers emerge to screen these techno-

logical entrepreneurs. The model has two novel features. First, financiers engage in the costly, risky, and potentially profitable process of financial innovation: they can invent better methods for screening entrepreneurs. Successful financial innovators are more effective at screening entrepreneurs than financiers with the standard screening methods, and their increased screening effectiveness generates monopoly rents and hence the economic motivation for financial innovation. The second novel feature of the model is that every particular screening method becomes obsolete as technology advances. The model predicts that financial innovation is necessary for sustaining economic growth; that is, technological innovation and economic growth will eventually stop unless financiers innovate.

The empirical evidence is more consistent with our model of the joint, endogenous evolution of financial and technological innovation than with earlier theories of financial development and growth. Textbook models predict that only the level of financial development influences the rate of technological innovation and growth. In contrast, our model predicts that financial innovation plays a dominant role in shaping the rate of technological innovation and growth. Though subject to ample qualifications, cross-country and panel evidence indicate that financial innovation accelerates the speed with which economic converge to the growth path of the economic leader.

From a policy perspective, this paper's analyses stress the value of institutions, laws, regulations, and policies that facilitate financial innovations. Without financial innovations that enhance the screening of technological entrepreneurs, the model indicates that economic growth will slow. Of course, our results do not imply that all financial innovations promote economic growth. For example, asset securitization, while fostering the transfer of credit risk by financial institutions, can hinder the screening and monitoring efforts by these financial institutions, hurting financial stability (Allen and Carletti (2006), Keys, Mukherjee, Seru, and Vig (2010), and Wang and Zia (2014)). Regulators might, therefore, have legitimate concerns about the impact of some financial innovations on financial stability in particular and the allocation of credit more generally. The analysis in this paper simply suggests that regulations that stymie financial innovation can have an enduring, adverse impact on economic growth.

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Table 1. Summary Statistics

This table presents summary statistics of our main regression variables. g–g1 is the growth rate of real per capita GDP of the country minus the U.S. growth rate in real per capita GDP, both are computed over the period 1960-95. Growth is the growth rate of real per capita GDP of the country. Fin development is measured as private credit to GDP in 1960. y–y1 is log of per capita income relative to U.S. per capita income. Fin innovation is the average growth rate of private credit to GDP over the period 1960-95. Private credit bureau is the fraction of years a private credit bureau existed within the period 1960–95 (from Djankov et al., 2007). Public credit register is the fraction of years a public credit register existed within the period 1960–95 (from Djankov et al., 2007). School is average years of schooling in the population over 25 in 1960. Gov is government size, measured as government expenditure as a share of GDP, averaged over 1960–95. Pi is inflation rate, measured as the log difference of consumer price index average from 1960–95. Bpm is the black market premium, computed as the ratio of the black market exchange rate and the official exchange rate minus one. Trade is openness to trade, measured as the sum of real exports and imports as a share of real GDP, averaged over 1960–95. Revc is number of revolutions and coups, averaged over 1960–90. A revolution is defined as any illegal or forced change in the top of the governmental elite, any attempt at such a change, or any successful or unsuccessful armed rebellion whose aim is independence from central government. Assass is number of political assassinations per 1000 inhabitants, averaged over 1960–90. Avelf is ethnic diversity, measured as the average value of five indices of ethno-linguistic fractionalization, with values ranging from 0 to 1, where higher values denote higher levels of fractionalization. Panel B reports the summary statistics of the variables used in the cross-sectional regressions, while Panel B reports the summary statistics for the growth, financial development, and financial innovation variables used in the GMM regressions with 5-year period non-overlapping panel data.

Variable	Obs	Mean	Std. Dev.	Minimum	Maximum
Panel A: Cross section 1960-95					
g–g1	56	0.284	1.698	-4.524	4.941
y–y1	56	-1.372	0.802	-3.007	0.000
Fin development	56	24.400	20.950	1.666	115.392
Fin development×(y–y1)	56	-23.250	16.792	-75.633	0.000
Fin innovation	56	2.568	3.075	-10.465	10.509
Fin innovation×(y–y1)	56	-3.313	6.634	-20.319	31.474
Private credit bureau	51	0.384	0.393	0.000	1.000
Private credit bureau×(y–y1)	51	-0.377	0.530	-2.005	0.000
Public credit register	51	0.164	0.300	0.000	1.000
Public credit register×(y–y1)	51	-0.164	0.284	-1.087	0.000
School	56	4.315	2.487	0.540	10.070
Gov	56	14.557	5.022	6.681	30.626
Pi	56	16.567	19.124	3.629	90.783
Bmp	56	26.513	52.816	0.000	277.420
Trade	56	59.603	38.465	14.050	231.686
Revc	56	0.159	0.233	0.000	0.970
Assass	56	0.311	0.521	0.000	2.467
Avelf	56	0.254	0.245	0.003	0.872
Panel B: Panel data 1960-95					
Growth	440	0.016	0.029	-0.100	0.110
Fin development	440	0.381	0.323	0.020	2.060
Fin innovation	440	0.022	0.095	-0.406	0.760

Table 2. Financial Development, Financial Innovation, and Growth – OLS and IV estimates

This table presents ordinary least squares (OLS) and instrumental variable (IV) estimates of a regression model with as dependent variable the growth rate of real per capita GDP of the country minus the US growth rate in real per capita GDP, g–g1, computed over the period 1960–95. Fin development is measured as private credit to GDP in 1960. Fin innovation is the average growth rate of private credit to GDP over the period 1960–95. Credit bureau is the fraction of years a private credit bureau existed over the period 1960–95. Public credit register is the fraction of years a public credit register existed over the period 1960–95. Control variables are defined in Table 1. The regressions in Columns (1) to (3) are estimated using OLS, and in Columns (4) to (5) using IV. The instrumental variables are legal origin and the change in the Abiad and Mody (2005) financial reform index over the period 1973–95. A constant term is included but not reported. ***, **, and * denote significance at the 1 percent, 5 percent, and 10 percent level, respectively.

Dependent variable: g-g1 VARIABLES	(1) OLS	(2) OLS	(3) OLS	(4) IV	(5) IV
$(y–y1)$	-0.305	0.100	-0.652	0.233	0.351
	(0.404)	(0.711)	(0.718)	(0.598)	(0.557)
Fin development	0.000	0.002	-0.002	0.003	-0.019
	(0.006)	(0.008)	(0.009)	(0.008)	(0.012)
Fin development×$(y–y1)$	-0.032**	-0.027*	-0.024	-0.017	-0.034
	(0.014)	(0.014)	(0.016)	(0.020)	(0.025)
Fin innovation	0.047			0.037	
	(0.083)			(0.167)	
Fin innovation×$(y–y1)$	-0.091**			-0.310***	
	(0.041)			(0.105)	
Credit bureau		-0.900			1.074
		(0.829)			(1.320)
Credit bureau×$(y–y1)$		-1.698*			-1.880***
		(0.945)			(0.670)
Public credit register			0.062		
			(0.969)		
Public credit register×$(y–y1)$			-0.146		
			(1.337)		
School	0.178*	0.096	0.208	-0.007	-0.090
	(0.097)	(0.142)	(0.126)	(0.114)	(0.141)
Gov	0.004	0.034	0.033	0.010	0.047
	(0.038)	(0.036)	(0.041)	(0.031)	(0.030)
Pi	0.011	-0.014	-0.002	-0.000	-0.034***
	(0.010)	(0.014)	(0.016)	(0.009)	(0.011)
Bmp	-0.012**	-0.011**	-0.013*	0.004	-0.010***
	(0.005)	(0.005)	(0.006)	(0.004)	(0.003)
Trade	0.009	0.005	0.012	-0.006	-0.007
	(0.006)	(0.009)	(0.010)	(0.007)	(0.008)
Revc	-2.553**	-0.525	-1.504	-3.487**	0.286
	(0.992)	(1.007)	(0.990)	(1.570)	(0.844)
Assass	0.036	-0.137	0.112	0.287	-0.650*
	(0.325)	(0.374)	(0.371)	(0.521)	(0.370)
Avelf	0.197	0.582	-0.473	-2.378**	1.530
	(0.936)	(1.050)	(1.229)	(0.951)	(1.000)
1st-stage F-test: Fin development (p-value)	--	--	--	0.10	0.10
1st-stage F-test: Fin development×$(y–y1)$ (p-value)	--	--	--	0.09	0.09
1st-stage F-test: Fin innovation	--	--	--	0.00	0.06
1st-stage F-test: Fin innovation×$(y–y1)$	--	--	--	0.00	0.00
Hansen-Sargan test (p-value)	--	--	--	0.26	0.95
Observations	56	51	51	47	47
R-squared	0.682	0.585	0.464	0.371	0.409

Table 3. Financial Development, Financial Innovation, and Growth – GMM estimates

This table presents first-difference GMM dynamic panel estimates of a regression model with the 5-year average growth rate of real per capita GDP of the country as dependent variable. The panel data set consists of non-overlapping periods of 5 years each for 77 countries for the period 1960-1995. Log per capita income of the country at the beginning of each 5-year period. Fin development is private credit to GDP averaged over each 5-year period. Fin innovation is the average growth rate of private credit to GDP over each 5-year period. School is average years of schooling in the population over 25 averaged over each 5-year period. Gov is government size, measured as government expenditure as a share of GDP, averaged over each 5-year period. Pi is inflation rate, measured as the log difference of consumer price index averaged over each 5-year period. Bmp is the black market premium averaged over each 5-year period. Trade is openness to trade, measured as the sum of real exports and imports as a share of real GDP, averaged over each 5-year period. The regression in column (2) limits the sample to those observations for which the log per capita income of the country minus the log per capita income of the U.S. per capita income at the beginning of each 5-year period is below the sample median. The regression in column (3) limits the sample to those observations for which the log per capita income of the country minus the log per capita income of the U.S. per capita income at the beginning of each 5-year period is equal to or above the sample median. The United States, the leader, is excluded from the sample. Year effects and a constant are included but not reported. For each time period, we use all available lags of the specified variables in levels dated t-2 as instruments in the differences equation. ***, **, and * denote significance at the 1 percent, 5 percent, and 10 percent level, respectively.

Dependent variable: Growth	(1)	(2)	(3)
	Full sample	Far from leader	Close to leader
Log per capita income	-0.116***	-0.100***	-0.114***
	(0.036)	(0.031)	(0.026)
Fin development	0.046	0.077	-0.036
	(0.054)	(0.0725)	(0.0407)
Fin innovation	0.063**	0.080**	0.049*
	(0.030)	(0.035)	(0.028)
School	-0.000	0.010	0.005
	(0.012)	(0.011)	(0.009)
Gov	0.106	0.173	-0.291*
	(0.100)	(0.113)	(0.162)
Pi	-0.002	-0.002	-0.007
	(0.020)	(0.026)	(0.023)
Bmp	0.000	0.000	-0.003
	(0.001)	(0.002)	(0.004)
Trade	0.051*	0.013	0.063*
	(0.030)	(0.032)	(0.033)
Second-order serial correlation (p-value)	0.635	0.996	0.204
Hansen-Sargan test (p-value)	0.365	0.501	0.623
Observations	362	171	191
Number of countries	77	45	40