WP/09/119

IMF Working Paper

A Multi-industry Model of Growth with Financing Constraints

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INTERNATIONAL MONETARY FUND

 WP/08/119

IMF Working Paper

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A Multi-industry Model of Growth with Financing Constraints

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Authorized for distribution by Martin Mühleisen[1]

May 2009

Abstract

This paper develops a multi-industry growth model in which firms require external funds to conduct productivity-enhancing R&D. The cost of research is industry-specific. The tightness of financing constraints depends on the level of financial development and on industry characteristics. Over time, a financially constrained economy may converge to the growth path of a frictionless economy, so long as an industry with the fastest expanding technological frontier does not permanently fall behind due to low R&D. The model's industry dynamics map into a differences-in-differences regression, in which industry growth depends on the interaction between financial development and industry level R&D intensity.

JEL Classification Numbers: G18, O14, O16, O33, O47.

Keywords: Financial development, industry growth, R&D intensity, external finance dependence, convergence dynamics, structural change.

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I Introduction

Empirical evidence suggests that the impact of financial development on growth varies across industries. In a well known paper, Rajan and Zingales (1998) show that industries with a greater tendency to draw on external funds grow disproportionately faster in financially developed environments.[1] This means that financing constraints may not only affect aggregate outcomes, but also the *structure* of less financially developed economies.

The finance-growth link has been modeled extensively, but mainly in a one-sector context.[2] A multisector model of the finance-growth nexus is desirable for several reasons.[3] First, an explicit theoretical foundation for observed cross-industry differences in the finance-growth interaction can only be provided in a model with multiple industries and a clearly-defined mechanism relating financing constraints to industry growth. Second, a multisector framework is required to understand the *aggregate implications* of differences in industry growth. For example, aggregate growth need not slow if resources are shifted away from industries that are most severely affected by financial underdevelopment towards others. Third, industry growth differences necessarily result in *structural change*, which can only be analyzed in a multisector framework.

In this model, the mechanism through which financing constraints affect growth combines productivity-enhancing R&D and productivity-driven structural change. In the model, agents raise external funds to pursue R&D, which allows them to move closer to the productivity frontier in each industry. Industries differ in terms of the cost of research, and in terms of the tightness of financing constraints. The cost of research depends on the industry-specific cost of producing and absorbing industrial knowledge. Financing constraints are modeled as a borrowing limit that depends on the entrepreneurs' wealth (potential collateral), as in Evans and Jovanovic (1989). The tightness of financing constraints may vary depending on the level of institutional development, as well as on industry characteristics.

The model features a "benchmark" economy, where institutional development is sufficiently advanced that financing constraints do not limit R&D spending. In the *benchmark* economy, optimal R&D spending is related to the growth rate of the industry productivity frontier. In *financially constrained* economies, R&D investment may be below the optimum

[1] See Levine (2005) for a survey of the empirical literature on finance and growth, including a discussion of the importance of industry studies in controlling for endogeneity and identifying specific channels through which finance impacts growth.

[2] See for instance Greenwood and Jovanovic (1990), Bencivenga and Smith (1991), De la Fuente and Marín (1996), Khan (2001) and Aghion, Howitt and Mayer-Foulkes (2005).

[3] An emerging literature uses multisector models to look at the impact of financing constraints on GDP *levels*, including Buera, Kaboski and Shin (2008), Raei (2008) and Uras (2009). However, these papers do not address the issues of industry growth and structural change.

in the benchmark economy, which slows productivity growth. Nonetheless, a financially constrained economy may potentially converge to the benchmark economy in the long-run. Along the convergence path, economies may experience structural change, driven by industry differences in productivity growth rates, as in Ngai and Pissarides (2007).

A model that combines productivity-enhancing R&D and productivity-driven structural change is appropriate for analyzing the finance-growth interaction for the following reasons. First, R&D intensity is positively related to productivity growth at the industry level – as found in Terleckyj (1980). Second, a key function of R&D is the adoption of technologies developed elsewhere – as argued by Cohen and Levinthal (1990) and Griffith, Redding and Van Reenen (2004). Third, R&D is highly sensitive to the financial environment – as shown by Carlin and Meyer (2003), Hall (2005) and others. The idea that financial underdevelopment may affect economic outcomes by hindering the adoption of new technologies through R&D is the basis of the one-sector growth model of Aghion, Howitt and Mayer-Foulkes (2005), which examines convergence patterns of countries with different levels of financial development.

In the model presented here, the productivity growth rate of an industry can be decomposed into the growth rate of the industry technological frontier, and the rate at which industry productivity converges to this frontier. This means that any cross-country variation in industry growth rates results from differences in rates of productivity convergence. Productivity convergence is affected by financing constraints, with convergence in R&D-intensive industries being particularly affected by such constraints.

The model features several *channels* through which R&D intensive industries may be especially sensitive to financing constraints.

- Greater *need:* R&D intensive industries tend to have greater need for external funding, i.e. they tend to have a larger share of borrowed funds in expenditures. This implies that any financing constraint is more likely to "bind" in more R&D intensive industries.

- Lower *ability:* R&D-intensive industries are considered to be intrinsically less able to raise funds, for example because R&D generates intangible assets (which are inherently difficult to collateralize) or because in such industries problems of asymmetric information are particularly acute. See Hall (2005).

- Faster *convergence:* R&D intensive industries tend to experience more rapid productivity growth. Any reduction of R&D activity may lead firms in such industries to fall disproportionately farther behind the frontier, so that financing constraints may especially hamper convergence in such industries.

The industry results have the following aggregate implications. In principle, if a given industry falls behind its technological frontier, this need not affect aggregate outcomes in the long-run so long as resources are shifted to *other* industries. Over time, productivity-driven structural change implies that the economy eventually becomes more and more specialized so that, in the simplest version of the model, one industry grows to dominate the economy in the limit.[4] We refer to this industry as the "limiting industry." As a result, aggregate income in a less financially developed economy fails to converge to that in the benchmark economy if financial development is so low that the limiting industry is financially constrained. For reasonable parameterizations, this industry turns out to be the one with the fastest rate of expansion of the technological frontier.

We provide empirical evidence to support the key assumptions and results of the model. The structure of the model is validated by the existence of a strong link between research intensity, industry growth and the tendency to draw on external funds. Furthermore, the patterns of structural change exhibited by the model economy provide an integrated framework that accounts for the empirical finding in Rajan and Zingales (1998) – that more financially dependent industries grow relatively faster in financially developed economies – as well as the finding of Ilyina and Samaniego (2008) that the same is true of R&D intensive industries, and the finding of Fisman and Love (2007) that the same is true of rapidly growing industries. Indeed, the differences-in-differences regression specifications in these papers can be interpreted in terms of a Taylor approximation to the equilibrium dynamics of the model economy developed in this paper. Testing the full regression specification implied by the model confirms that R&D intensive industries grow disproportionately faster in financially developed economies.

Section II introduces the model, and Section III characterizes the equilibrium dynamics of industry productivity change and aggregate growth. Section IV maps the model into the data. Section V suggests directions for future research.

II Economic Environment

Time is discrete and indexed by $t \in \mathbb{N}$. The model economy produces $J \in \mathbb{N}$ types of final good. The world productivity frontier Z^*_{jt} for the production of each good j expands over time by an industry-specific factor $g_j > 1$, so that $Z^*_{j,t+1} = Z^*_{jt} g_j$. Knowledge spillovers are unlimited in the sense that the technological frontier in industry j is available to all firms in

[4] Given the complexity of characterizing structural change in a multisector context, we focus on this version of the model for the sake of tractability. In the technical appendix we describe an extension of the model in which the limiting structure of the economy may contain more than one industry but the main predictions of the model continue to hold.

the industry: however, each firm can adopt the frontier technology only by means of R&D. Thus, R&D determines the firm's ability to absorb knowledge, as in Cohen and Levinthal (1990).

In our stylized framework, agents live for two periods. When they are young, they supply labor to a competitive market, and choose to become entrepreneurs, or researchers, or to remain workers when old. Entrepreneurs may establish a firm in any industry, hire workers and purchase research services.

Although the frontier technology is available to all firms in a given industry, to implement it at a particular firm requires customization. Entrepreneurs and researchers meet, and the researcher invests in R&D to uncover how to implement the frontier technology at the firm with which he is matched. To the extent that research succeeds, the firm moves closer to the technological frontier.

In the model, imperfect substitutability among final goods implies that industry shares are determined by relative prices and, as a result, *changes* in industry shares are driven by changes in relative prices. Assumptions on the relationship between entrepreneurs and researchers imply that changes in relative prices between goods reflect relative rates of productivity growth, which renders the model analytically tractable.

A Economic Agents and Firms

In each period, a cohort of economic agents of mass 1 is born. Agents live for two periods, enjoying consumption c_t and using labor $l_t \in [0,1]$, to earn utility $U(c_t, l_t)$ in each period t. The discount factor is $\beta < 1$.

There are $J > 1$ industries that produce final goods. If c_{jt} is consumption of each, then:

$$c_t = \left[\sum_{j=1}^{J} \xi_j c_{jt}^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{\varepsilon}{\varepsilon-1}}, \quad \sum_{j=1}^{J} \xi_j = 1, \tag{1}$$

where $\varepsilon > 0$ is the elasticity of substitution across goods.

An agent born in period t solves

$$\max_{b_t, c_t, l_t, c_{t+1}, l_{t+1}} \left\{U(c_t, l_t) + \beta U(c_{t+1}, l_{t+1})\right\} \tag{2}$$

subject to agent-specific budget constraints presented below. We assume that the utility function is as follows:

$$U(c_t, l_t) = c_t - \lambda l_t. \tag{3}$$

This functional form abstracts from risk aversion, focusing the analysis on the relative profitability of different activities. Labor is the numeraire, and in equilibrium the price of labor equals λ in any interior solution. Henceforth, λ is normalized to one, so all prices are expressed relative to the marginal disutility of labor.

Let q_{jt} be the price of good j. The budget constraint for a young agent is:

$$\sum_j q_{jt} c_{jt} + b_t \leq w_t l_t, \forall t \tag{4}$$

where l_t is time spent working, w_t is a competitive wage and b_t is savings. Agents save by purchasing bonds b_t. The interest rate is r_t.

The budget constraint for an old agent who is neither an entrepreneur nor a researcher is:

$$\sum_j q_{jt+1} c_{jt+1} \leq b_t (1 + r_t) + w_t l_t, \forall t \tag{5}$$

Entrepreneurs and researchers use up their labor in setting up firms and research labs, respectively. The budget constraint for an old entrepreneur is

$$\sum_j q_{jt+1} c_{jt+1} \leq b_t (1 + r_t) + \Theta_{t+1}, \forall t \tag{6}$$

where Θ_t is the entrepreneur's expected profit. The budget constraint for an old researcher is:

$$\sum_j q_{jt+1} c_{jt+1} \leq b_t (1 + r_t) + \Pi_{t+1}, \forall t \tag{7}$$

where Π_t is the researcher's expected profit. Both Θ_t and Π_t will be specified later.

B Production

B.1 Final goods

Production of any final good j requires labor l_{jt} and a continuum of intermediate goods $x_{jt}(i)$, where $i \in [0, 1]$. Output at a firm in any industry j is

$$y_{jt} = l_{jt}^{\alpha_l} \int_0^1 Z_{jt}(i)^{1-\alpha_x} x_{jt}(i)^{\alpha_x} \, di, \tag{8}$$

where $Z_{jt}(i)$ is the productivity with which the firm uses intermediate good i. We assume that the labor share of income α_l and the share that accrues to intermediate producers α_x are both positive, and that the share of income accruing to the entrepreneur $1-(\alpha_x+\alpha_l)$ is strictly positive as well. A firm's productivity is defined as:

$$Z_{jt} = \int_0^1 Z_{jt}(i)\,di. \tag{9}$$

When a new firm is established, it randomly imitates a firm in that industry that was active in the previous period, as in Luttmer (2007) or Gabler and Licandro (2008). However, it need not be that $Z_{jt}(i) = Z_{j,t-1}(i)$, because of the possibility of research.

B.2 Intermediate goods

Intermediate goods need to be customized to enable a given firm to use them at the frontier level of efficiency. Conditional on success in customizing a given variety i, a researcher who is matched with a firm can produce any quantity $x_{jt}(i)$ of the customized good using one unit of good j per unit of intermediate[5] i. The successfully customized intermediate good can then be used at the frontier efficiency Z^*_{jt} (the R&D process is described in more detail below). There are immediate (though imperfect) spillovers of new knowledge, so that any researcher other than the innovator may produce copies of a customized intermediate at cost $\chi > 1$ in units of good j (we can think of $\chi - 1$ as a cost of imitation). In the absence of innovation, variety i will be used at the previous period's productivity level $Z_{j,t-1}(i)$. The market for customized intermediates i is described below: the price of intermediate i is $p_{jt}(i)$.

The above assumptions imply that researchers will charge the limit price $p_{jt}(i) = \chi q_{jt}$. As for varieties i without successful innovation in the current period, production will take place under perfect competition, also at price $p_{jt}(i) = \chi q_{jt}$.

Profits from production are:

$$\Theta_{jt} = \max_{l_{jt},x_{jt}} \left\{ q_{jt}y_{jt} - w_t l_{jt} - \int x_{jt}(i)\,p_{jt}(i)\,di \right\} \tag{10}$$

The return to an innovator for successfully customizing intermediate i for a given firm is:

[5] The assumption that $x_{jt}(i)$ requires good j for its production has several interpretations: (1) literally in terms of intermediate use of good j, in which case the assumption is consistent with the fact that input-ouput tables are generally sparse away from the diagonal; (2) in terms of "prototype" goods that are not for sale but which must be produced to learn the optimal configuration of good features or that are simply "tests" or "failed attempts" at production; or (3) in terms of productivity, or "output foregone," so that R&D literally increases the "yield" of productive activity, defined as $y_{jt} - \int \left[\mu_{jt}(i) + \chi\left(1-\mu_{jt}(i)\right)\right] x_{jt}(i)\,di$ where $\mu_{jt}(i) = 1$ if research on i was successful and $\mu_{jt}(i) = 0$ otherwise.

$$\pi_{jt} = x_{jt}(i)(\chi - 1) q_{jt}. \tag{11}$$

where x_{jt} is the demand for the intermediate at price $p_{jt}(i)$.

Under these assumptions, **productivity dynamics** at the firm level can be described as follows. For each industry j, there is a world technology frontier Z_{jt}^* for the efficiency of customized intermediates. Each period the frontier expands by a factor g_j, which all firms take as given, and which is determined by research in the benchmark economy (as discussed later).

Suppose that research succeeds over a random subset of intermediates of measure μ_{jt} (which is endogenized later). Then,

$$Z_{jt}(i) = \begin{cases} Z_{jt}^* & \text{with probability } \mu_{jt} \\ Z_{j,t-1} & \text{with probability } 1 - \mu_{jt} \end{cases}$$

Assuming that the chance of a successful innovation is uncorrelated with i, firm productivity evolves according to:[6]

$$Z_{jt} = Z_{jt}^* \mu_{jt} + Z_{j,t-1}(1 - \mu_{jt}) \tag{12}$$

Define **relative productivity** of a firm in industry j as $z_{jt} = Z_{jt}/Z_{jt}^*$, so that a higher z_{jt} corresponds to a smaller gap between its current productivity and the frontier productivity. Then, (12) can be rewritten:

$$z_{jt} = \mu_{jt} + \frac{(1 - \mu_{jt})}{g_j} z_{j,t-1}. \tag{13}$$

C Research

Young agents decide whether in their old age they will become entrepreneurs, researchers, or neither. When old, entrepreneurs use their labor to establish a firm, and choose an industry to enter. Researchers use their labor to establish a research lab, which may be used in any industry. Then, agents are matched pair-wise according to the function

$$M_t = \min\{N_t^e, N_t^r\} \tag{14}$$

[6] In principle, the entrepreneur can keep her "old" productivity: however, as is typical of quality ladder models, she will be at least as well off adopting the new technology.

where M_t is the number of matches, N_t^e is the number of entrepreneurs and N_t^r is the number of researchers. In the remainder of the paper we assume that $N_t^e < N_t^r$.[7]

Researchers are able to customize intermediates for the firm they are matched with. Customized intermediates are used at the frontier productivity Z_{jt}^*, whereas other intermediates are used at the previous period's productivity $Z_{j,t-1}(i)$.

At a certain cost, the researcher uncovers how to customize for the firm a random subset of intermediates $[0,1]$ of measure μ_{jt}. For a given choice of μ_{jt}, the research cost equals $\tilde{n}_j\left(\mu_{jt}\right)/z_{j,t-1}$ units of labor.[8] As in Jovanovic and Nyarko (1996), the research cost is increasing in the gap between the current state of technology and the frontier.

Industries vary in terms of $\tilde{n}_j(\cdot)$, the R&D cost function.[9] Specifically, we assume that there is an industry-specific parameter $\kappa_j > 0$ that scales the cost of research, so $\tilde{n}_j\left(\mu_{jt}\right) = \kappa_j n\left(\mu_{jt}\right)$. The function $n(\cdot)$ satisfies $n(0) = 0$ and $\lim_{\mu\to 1} n(\mu) = \infty$. In addition, $n'(\mu) > 0$ and $n''(\mu) > 0$ for all $\mu \geq 0$. All these properties are inherited by $\tilde{n}_j(\cdot)$.

Parameter κ_j is central to industry variation in productivity dynamics. Industries with higher κ_j need to devote more resources to R&D to achieve the same rate of innovation success μ_{jt}. In equilibrium, the relationship between κ_j and optimal research intensity will depend on the optimal choice of μ_{jt} in each industry. Later we show that if research intensity and productivity growth are positively related (as indicated by empirical evidence), then κ_j is *negatively* related to R&D intensity.

A researcher chooses μ to maximize:

$$\begin{aligned} \Pi_{jt} &= \max_{\mu} \left\{\pi_{jt}\mu - \tilde{n}_j(\mu)/z_{j,t-1}\right\} \\ & \quad s.t. \\ & \quad \tilde{n}_j(\mu)/z_{j,t-1} \leq vW_t \end{aligned} \tag{15}$$

Variable W_t is the researcher's wealth, and $v \geq 1$ is a borrowing limit, as in Evans and Jovanovic (1989). The borrowing limit may vary across countries and industries.[10] Specifically, let $v = v(F, A_j)$, where F is the level of financial development, and A_j is an index of industry-

[7] This assumption rules out an effect we call "research pass-through." We discuss it in the Appendix along with the possibility that $N_t^e \geq N_t^r$.

[8] This labor must be hired, because the researcher's labor was already used to create the lab. If not, then our results would hold except that R&D costs below some level would be unaffected by financing constraints.

[9] In our model, R&D spending depends on industry-specific costs of producing and absorbing industrial knowledge. The evidence is broadly consistent with such "cost" or "opportunity" driven theories of industry differences in R&D intensity: see the survey of Cohen and Levin (1989).

[10] Since in their youth researchers earn at most w_t, their wealth when old is $W_t \leq w_t(1+r)$. Since $w_t = 1$, then $W_t \leq (1+r)$.

specific technological characteristics that enable firms to overcome financing constraints in less financially-developed environments.

Definition 1 *Parameter F is the level of* ***financial development****, representing the quality of institutions that enable transparency and disclosure, so that for any industry j, $\frac{\partial v(F,A_j)}{\partial F} > 0$ for any A_j (defined below).*

Definition 2 *Parameter A_j - which will be referred to as the* ***ability to access external funds*** *- is an index of industry-specific technological characteristics, such that for a given level of financial development F, higher A_j increases the borrowing limit $v(F, A_j)$, i.e., $\frac{\partial v(F,A_j)}{\partial A_j} \geq 0$, and a more developed financial system (higher F) disproportionately benefits industries with low A_j, i.e., $\frac{\partial^2 v(F,A_j)}{\partial F \partial A_j} \leq 0$.*

Parameter A_j may, for example, depend on the extent to which the industry uses durable assets in the production process. In Kiyotaki and Moore (1997), industries that use more fixed assets may have less difficulties raising external funds in a less financially developed country because durable assets can serve as collateral.[11] See Ilyina and Samaniego (2008) for a discussion of possible technological determinants of the ability to draw on external funds.

We do not make any assumptions, a priori, about the relationship between A_j and κ_j, although the literature has suggested that research-intensive industries may experience special difficulties raising external funds – for example, because R&D investments are intangible and inherently difficult to collateralize, or because asymmetric information problems may be more severe. See Hall (2005) for a survey of the financing difficulties experienced by research-intensive firms.

D Technological frontier

We assume the existence of a *"benchmark economy"*, where financial development is at some level F^* that is sufficiently high that financing constraints are not binding in any industry. As a result, R&D investment is always optimal. As we show later, if financing constraints do not bind, research activity and the industry's position relative to the technological frontier each converge to limiting values: there exist values z_j^* and μ_j^* such that $z_{jt} \to z_j^*$, $\mu_{jt} \to \mu_j^*$. We also assume that in the *benchmark economy* $\mu_{jt} = \mu_j^*$ and $z_{jt} = z_j^*$ $\forall j, t$. Productivity gaps z_{jt} and innovation rates μ_{jt} in economies where financing constraints do bind may or

[11] Aghion, Howitt and Mayer-Foulkes (2005) derive a credit constraint of the form of v as the equilibrium of a game in which researchers may hide the returns from R&D at a cost, so the model can be interpreted in terms of difficulties in monitoring and verifiability in research-intensive activities. In this case, higher v implies that it is more costly for borrowers to withhold the returns from research. See also Aghion, Banerjee and Piketty (1999).

may not converge to these limits, and the conditions under which productivity convergence occurs is one of the subjects of our study.

The expansion of the technological frontier in each industry j is driven by spillovers from research in the benchmark economy, so that:

$$g_j = \sigma \mu_j^* + 1, \ \sigma > 0. \tag{16}$$

Thus, R&D is carried out in order to produce output using the frontier level of knowledge, but in the benchmark economy research also has the effect of pushing the frontier forward. Productivity growth is more rapid in industries where κ_j is low, so that innovation is a "low hanging fruit."

We define the following "industry characteristics", based on optimal behavior in the benchmark economy.

Definition 3 *The optimal **R&D intensity** of industry j is the R&D share of expenditures in industry j in the benchmark economy:* $RND_j \equiv \frac{\kappa_j n\left(\mu_j^*\right)/z_j^*}{\kappa_j n\left(\mu_j^*\right)/z_j^* + l_{jt} + \int x_{jt}(i) p_{jt}(i) di}$.

Definition 4 *The **need for external funds** of industry j is the amount of external funds used in industry j as a share of expenditures of industry j in the benchmark economy:* $D_j \equiv \frac{\kappa_j n\left(\mu_j^*\right)/z_j^* + l_{jt} + \int x_{jt}(i) p_{jt}(i) di - W}{\kappa_j n\left(\mu_j^*\right)/z_j^* + l_{jt} + \int x_{jt}(i) p_{jt}(i) di}$, *where W is the amount of internal funds.*

Observe that R&D intensity and the need for external funds are positively related, i.e., higher RND_j entails higher D_j. Moreover, there is a range of values of parameter κ_j such that R&D intensity is positively linked to productivity growth in the benchmark economy:

Lemma 1 *There exists κ^* such that RND_j, μ_j^* and g_j^* are positively related across industries for $\kappa_j \in [\kappa^*, \infty)$. There exists $\kappa^{**} > \kappa^*$ such that RND_j is zero for $\kappa_j \in [\kappa^{**}, \infty)$.*

Henceforth we focus on the range $\kappa_j \in [\kappa^*, \infty)$, which is consistent with a positive empirical relationship between research spending and productivity growth across industries found by Terleckyj (1980) among others. We also provide empirical evidence in Section IV.

E Aggregate equilibrium conditions

Let M_{jt} be the mass of firms in each industry, so that $M_t \equiv \sum_j M_{jt}$. Entrepreneurs may enter any industry so, in any equilibrium in which there is production in all industries, it must be that the profits from entrepreneurship in any industry are equal: $\Theta_{jt} = \Theta_t \ \forall j$. If $N_t^r \geq N_t^e$, then some researchers are unmatched, so the expected return to becoming a researcher is $\frac{\sum_j M_{jt} \Pi_{jt}}{N_t^r}$. Since agents are indifferent between research and entrepreneurship in equilibrium, $\Theta_t = \frac{\sum_j M_{jt}\Pi_{jt}}{N_t^r}$. Finally, since old agents may also work, it must be that $\Theta_t = 1$, so that

$$N_t^r = \sum_j M_{jt}\Pi_{jt}$$

Since the population of old agents is 1, and since only old agents may become entrepreneurs or researchers, we require

$$N_t^r + M_t \leq 1$$

Let Y_t^R equal aggregate output including research activity. Then,

$$Y_t^R = \sum_j M_{jt} + \sum_j M_{jt} l_{jt} + \sum_j M_{jt}\pi_{jt}\mu_{jt} - \sum_j M_{jt}\kappa_j n\left(\mu_{jt}\right)/z_{jt}$$

The total value of final goods produced in any industry is $V_{jt} = q_{jt}c_{jt}$, and total income from research is $V_t^R = \sum_j M_{jt}\pi_{jt}\mu_{jt} - \sum_j M_{jt}\kappa_j n\left(\mu_{jt}\right)/z_{jt}$. It is straightforward to verify that $Y_t^R = \sum_j V_{jt} + V_t^R$.

Current national income accounting procedures do not consider R&D as part of GDP. In the remainder of the paper, we assume that aggregate output is measured by $Y_t = \sum_j M_{jt}q_{jt}c_{jt}$, which includes production of final goods and services but not R&D expenditures. This approach will simplify our discussion of the aggregate impact of financing constraints.[12]

III Model Equilibrium

This section derives the aggregate equilibrium behavior of the model economy, which reflects the impact of financing constraints on industry productivity dynamics. We consider an economy other than the benchmark economy, in which initial productivity gaps (initial conditions) are such that $z_{j0} \leq z_j^*$ in all industries j.

A Equilibrium productivity dynamics

We begin by characterizing the effect of financing constraints on equilibrium research activity in less financially developed economies. Recall that the return to entrepreneurship $\Theta_t = 1$. Since the production technology exhibits decreasing returns to scale, and since the share of entrepreneurial returns is constant over time, this condition determines the equilibrium link between goods prices and industry productivity.

[12] Feasibility and market clearing constraints are reported in the technical appendix.

Lemma 2 *If $N_t^r \geq N_t^e$, there are unique positive values ψ^* and l^* such that $q_{jt}Z_{jt} = \psi^*$ and $l_{jt} = l^*$ for all j, t.*

The entrepreneur cannot invest more than a finite multiple v of her wealth W_t, where for now we suppress the dependence of v upon F and A_j. Since $W_t \leq 1 + r$, the entrepreneur is constrained if and only if

$$\tilde{n}_j\left(\mu_j^*\right) > z_{j,t-1} v\left(1+r\right). \tag{17}$$

To characterize equilibrium industry productivity dynamics we consider two loci. First we study the dynamics of a firm that invests the optimal level of research input. Then we study the dynamics of a firm that devotes all available financial resources to research, regardless of whether or not this is unconstrained-optimal. "Available financial resources" refers to internally generated funds leveraged up to the maximum borrowing limit vW_t. The firm will be on the latter locus,unless available financial resources exceed optimal research spending.

Let $\tilde{\mu}_j(\cdot)$ be the inverse of $\tilde{n}_j(\cdot)$. Suppose that v is very large – large enough that financing constraints do not bind for any j. Optimal investment is given by the first order condition to problem (15). Relative productivity z_{jt} follows the law of motion $z_{jt} = H_j^1\left(z_{j,t-1}\right)$ where, using (13), the function H_j^1 is given implicitly by

$$z_{jt} = \tilde{\mu}\left(\frac{\pi z_{j,t-1}}{\kappa_j z_{jt}}\right) + \frac{\left[1 - \tilde{\mu}\left(\frac{\pi z_{j,t-1}}{\kappa_j z_{jt}}\right)\right]}{g_j} z_{j,t-1}. \tag{18}$$

where $\pi = \pi_{jt} z_{jt}$ is a function of parameters that does not change over time. Also, z_{jt} converges to the steady state value z_j^* where, using (13) and (16),

$$z_j^* \equiv \frac{\sigma \mu_j^* + 1}{\sigma + 1} < 1 \tag{19}$$

Next, suppose that researchers devote all their available financial resources towards research. Then, $\mu_{jk} = \tilde{\mu}_j\left(v\left(1+r\right) z_{j,t-1}\right)$. Productivity dynamics in this case are given by $z_{jt} = H_j^2\left(z_{j,t-1}\right)$ where again using (13),

$$H_j^2\left(z_{j,t-1}\right) = \tilde{\mu}\left(\frac{v\left(1+r\right) z_{j,t-1}}{\kappa_j}\right) + \frac{\left[1 - \tilde{\mu}\left(\frac{v(1+r) z_{j,t-1}}{\kappa_j}\right)\right]}{g_{jt}} z_{j,t-1}. \tag{20}$$

Finally, since equilibrium research spending will equal the optimal amount unless the latter exceeds the borrowing limit, in equilibrium z_{jt} is given by:

$$z_{jt} = H_j\left(z_{j,t-1}\right) \equiv \min\left\{H_j^1\left(z_{j,t-1}\right), H_j^2\left(z_{j,t-1}\right)\right\} \tag{21}$$

The function $H_j(z_{j,t-1})$ determines the link between financing constraints and industry productivity dynamics.

Lemma 3 *The functions $H_j^1(\cdot)$ and $H_j^2(\cdot)$ have the following properties:*

(i) $H_j^1(\cdot)$ does not depend on v; $H_j^2(\cdot)$ is strictly increasing in v for all $z_{j,t-1} > 0$

(ii) $H_j^1(\cdot)$ and $H_j^2(\cdot)$ are strictly increasing, and $H_j^2(\cdot)$ is strictly concave.

(iii) The function $H_j^1(\cdot)$ has two fixed points, at the values $z_{j,t-1} \in \{0, z^*\}$.

(iv) The function $H_j^2(\cdot)$ has two fixed points, at the values $z_{j,t-1} \in \{0, z^{**}\}$, where z^{**} is increasing in v.

(v) for sufficiently low v, $\lim_{z\to 0} \frac{dH_j^1(z)}{dz} > \lim_{z\to 0} \frac{dH_j^2(z)}{dz}$.

Based on Lemma 3, the space of parameter values can be divided into three regions, in which productivity dynamics behave differently.[13] Recalling that $v = v(F, A_j)$,

Region 1 For sufficiently high levels of F, $\mu_{jt} \to \mu_j^*$ and $z_{jt} \to z_j^*$. Higher financial development shifts H_j^2 upwards, and may affect industry growth rates along the convergence path, for the range where $H_j^1(z_{j,t-1}) > H_j^2(z_{j,t-1})$, but it does not affect the limit z_j^*. See Figure 1.

Region 2 For intermediate levels of F, $\mu_{jt} \to \mu_j^*$ but $z_{jt} \to z_j^{**} < z_j^*$. Higher financial development shifts H_j^2 upwards, and can have a positive marginal effect on industry growth rates along the convergence path, and also on the limit z_j^{**}. See Figure 2.

Region 3 For sufficiently low levels of F, $z_{jt} \to 0$, and productivity growth converges to a value below g_j that is increasing in F. Greater financial development within this range would still have a positive effect on productivity growth, although it would remain below g_j in the long run.[14] See Figure 3.

[13] In Region 1, then H_j^1 and H_j^2 cross *above* the 45° line: $v \geq \frac{\kappa_j n(\mu_j^*)}{(1+r)z_j^*}$. In Region 2, H_j^1 and H_j^2 cross *below* the 45° line, and $\frac{\partial H_j^2(z)}{\partial z}|_{z=0} > 1$: $v \in \left(\frac{g_{jt}-1}{(1+r)\tilde{\mu}_j'(0)g_{jt}}, \frac{\kappa_j n(\mu_j^*)}{(1+r)z_j^*}\right)$. In Region 3, then $\frac{\partial H_j^2(z)}{\partial z}|_{z=0} \leq 1$: $v \leq \frac{g_{jt}-1}{(1+r)\tilde{\mu}_j'(0)g_{jt}}$.

[14] To see this, observe that productivity growth equals $g_j \frac{z_{j,t+1}}{z_{jt}}$ and that, in Region 3, $\lim_{t\to\infty} \frac{z_{j,t+1}}{z_{jt}} = \lim_{t\to\infty} \frac{\tilde{\mu}_{jt}}{z_{j,t-1}} + \frac{1}{g_j} = \frac{v(1+r)}{1-\alpha_x} \frac{1}{\kappa_j n'(0)} + \frac{1}{g_j}$, where v is increasing in F.

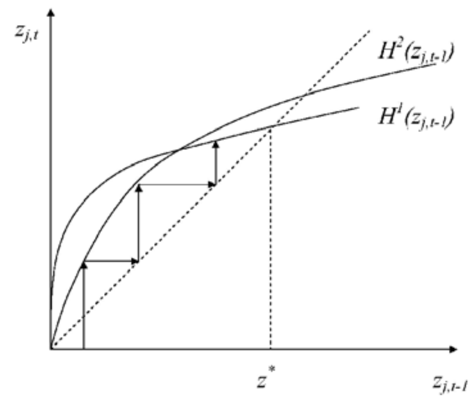

Figure 1 – Industry productivity dynamics, Region 1. The function $H^1(\cdot)$ crosses $H^2(\cdot)$ an odd number of times in the range $(0, z^*)$.

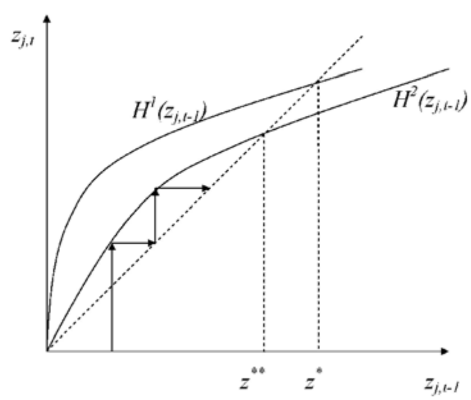

Figure 2 – Industry productivity dynamics, Region 2. The function $H^1(\cdot)$ crosses $H^2(\cdot)$ an even number of times (or zero times) in the range $(0, z^{**})$.

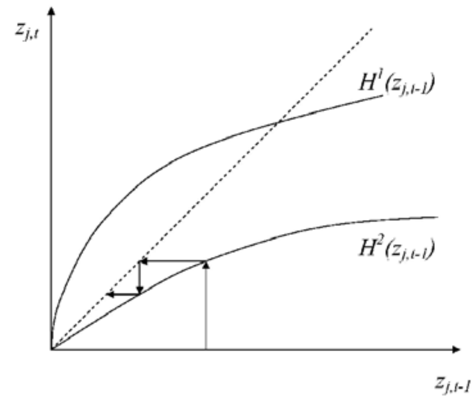

Figure 3 – Industry productivity dynamics, Region 3.
If $H^1(\cdot)$ and $H^2(\cdot)$ cross, it is above z_j^*, and $H^2(\cdot)$ has no fixed point other than zero.

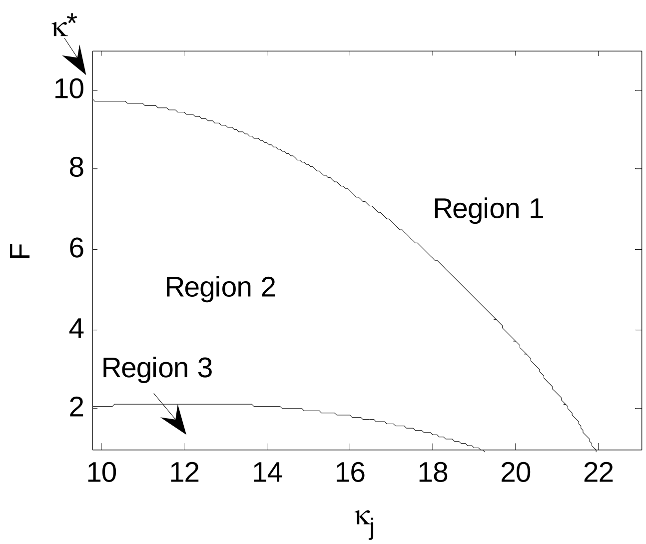

Figure 4 – Productivity dynamics for different values of the borrowing limit $v(F, A_j)$ and the research cost parameter κ_j, for $\kappa_j \geq \kappa^*$. Industry R&D intensity is negatively related to the parameter κ_j. The line between the areas denoted Region 1 and Region 2 represents the boundary $\bar{F}_j$, and the line between the areas denoted Region 2 and Region 3 represents the boundary $\underline{F}_j$.

For each industry j, there is a value $\underline{F}_j$ such that industry j falls in Region 3 for $F \leq \underline{F}_j$, and a value $\bar{F}_j$ such that industry j falls in Region 2 for $F \in \left(\underline{F}_j, \bar{F}_j\right)$. $\bar{F}_j$ is determined by optimal R&D spending in the benchmark economy so that, when $\kappa_j \geq \kappa^*$ (where κ^* is defined in Lemma 1), $\bar{F}_j$ is negatively related to κ_j. The lower the optimal amount of R&D in a given industry j, the less likely it is to be finance-constrained for a given borrowing limit v. See Figure 4 for an illustration.[15]

B Industry growth

How do industry productivity dynamics translate into industry growth? Define $G_{jt} = \frac{q_{j,t+1}c_{j,t+1}}{q_{jt}c_{jt}}$ as the growth factor of industry j, where $c_{j,t}$ is consumption of good j and $q_{j,t}$ is its price. The expression $G_{jt}/G_{j',t}$ then denotes the growth of industry j relative to industry j'.

As in Ngai and Pissarides (2007), preferences imply that relative industry growth satisfies:

$$\frac{G_{jt}}{G_{j',t}} = \left(\frac{q_{j,t+1}/q_{jt}}{q_{j',t+1}/q_{j',t}}\right)^{1-\varepsilon}$$

Hence, to understand the implications of the productivity dynamics discussed above for industry growth, we need to derive the relationship between relative prices and relative productivity values. If price changes equal inverse productivity changes, as in the model, then:

Proposition 1 ***(Structural Change)*** *In equilibrium, differences in productivity growth rates across industries can be decomposed into differences in the growth rates of their technological frontiers g_j and differences in the rates of change of $z_{j,t}$ – the productivity growth rates of industries relative to their technological frontiers:*

$$\frac{G_{jt}}{G_{j't}} = \left(\frac{z_{j,t+1}}{z_{j',t+1}} / \frac{z_{jt}}{z_{j',t}}\right)^{\varepsilon-1} \times \left(\frac{g_j}{g_{j'}}\right)^{\varepsilon-1} \tag{22}$$

The ratio $\frac{z_{j,t+1}}{z_{jt}}$ represents *convergence* of productivity in industry j to its technological frontier. Hence, industries grow or shrink relative to each other depending on the value of the elasticity of substitution parameter ε, on relative rates of expansion of their technological frontiers, and on relative rates of convergence of different industries to their respective technological frontiers.

[15] The parameters are $\alpha_l = 0.3$, $\alpha_x = 0.69$, $\chi = 1.5$, $\sigma = 0.5$, $\tilde{n}_j(\mu) = -\kappa_j \log(1-\mu)$, $\varepsilon = 1.5$, $v(F_k, A_j) = F$.

C Aggregate growth

In this section we characterize aggregate growth in a less financially developed economy, and later turn to industry growth implications.

A sufficient condition for equilibrium existence is that the entrepreneur's share of income $1 - \alpha_l - \alpha_x$ is not too large.

Proposition 2 ***(Existence)*** *There exists a number $\bar{\alpha} < 1 - \alpha_x$ such that if $\alpha_l > \bar{\alpha}$ then there exists a unique equilibrium for any initial conditions $\{z_{jt}\}_{j=1}^{J}$ and any F. In any such equilibrium $N_t^r \geq N_t^e$, and the economy converges towards a balanced growth path in which the rate of aggregate growth is constant.*

Recall that Y_t is the level of GDP, and G_t is its growth factor. Let Y_t^* and G_t^* be the level and growth factor of GDP in the benchmark economy, respectively. For given initial conditions, financial development may affect G_t so long as *any single industry* is financially constrained. To characterize the long run effect of F we classify limiting behavior as follows:

Definition 5 *In a* ***development trap,*** $\lim_{t\to\infty} \frac{G_t}{G_t^*} = 1$ *and* $0 < \lim_{t\to\infty} \frac{Y_t}{Y_t^*} < 1$

Definition 6 *In a* ***development sink,*** $\lim_{t\to\infty} \frac{G_t}{G_t^*} < 1$

In a development *trap*, an economy converges to the benchmark economy in terms of growth rates, but not GDP levels. In a development *sink*, an economy falls steadily behind the benchmark economy, converging neither in levels nor in growth rates.

As $t \to \infty$ there is one industry the nominal share of which converges to unity. If $\varepsilon > 1$ then this industry will be $\arg\max_j \left\{\lim_{t\to\infty} \frac{z_{j,t+1}}{z_{jt}} g_j\right\}$, and if $\varepsilon < 1$ then this industry will be $\arg\min_j \left\{\lim_{t\to\infty} \frac{z_{j,t+1}}{z_{jt}} g_j\right\}$.

Proposition 3 ***(Convergence I)*** *In equilibrium there are threshold levels of financial development $\bar{F}$ and $\underline{F}$ such that*

i) the model economy converges to the benchmark economy for $F \in [\bar{F}, \infty)$,

ii) the model economy falls into a development trap for $F \in [\underline{F}, \bar{F})$, where $\lim_{t\to\infty} \frac{Y_t}{Y_t^*}$ is decreasing in F;

iii) the model economy falls into a development sink if $F \in [0, \underline{F})$.

Define $j^* = \arg\max_j g_j$, so j^* is the industry with *the fastest rate of expansion of the technological frontier.*[16]

[16] Over the past four decades, according to Jorgensen, Ho, Samuels and Stiroh (2007), at the 3-digit SIC level this is Computing and Office Machinery, at least within Manufacturing. Within Services, it is Depository Institutions.

Proposition 4 ***(Convergence II)*** *If* $\varepsilon > 1$, $\bar{F} = \bar{F}_{j^*}$, *and* $\underline{F} = \underline{F}_{j^*}$.

Propositions 3 and 4 state conditions under which the model economy may fall into a development trap or a development sink in the long run. While statements (i)-(iii) in Proposition 3 are similar to the "convergence club" results of Aghion et al (2005), the underlying mechanisms are more complicated. In a single-industry context, financial development affects growth by reducing the gap between productivity growth in the developing economy and the rate of expansion of the technological frontier. In our multi-industry context, the same mechanism operates at the *industry* level but, in addition, aggregate growth rates are affected by equilibrium patterns of structural change, as industry shares of output change over time. In particular, if $\varepsilon > 1$, resources are shifted away from industries with relatively slower productivity growth, so that an economy falls into a development *trap* if and only if *the industry with the fastest rate of expansion of its technological frontier falls into Region* 2 (as defined in Lemma 3). Similarly, if $\varepsilon > 1$, an economy falls into a development *sink* if and only if *the industry with the fastest rate of expansion of its technological frontier falls into Region* 3.

D Industry growth and patterns of structural change

Next we explore the implications of industry productivity dynamics for patterns of structural change. Structural change is understood as changes in the shares of GDP of different industries. If the growth rate of industry j is more rapid than that of industry j', then the share of GDP of industry j rises relative to that of j'. Thus, analyzing the implications of financial development for structural change is equivalent to studying the implications of financial development for industry growth.

Proposition 1 implies that structural change is determined by industry differences in frontier productivity growth g_j and by industry differences in rates of productivity convergence to that frontier. Define $\gamma_j \equiv z_{j,t+1}/z_{jt}$ at a given date t, and for given initial conditions $\{z_{jt}\}_{j=1}^{J}$. Note that the industry productivity growth factor equals $\gamma_j g_j$ and recall from Proposition 1 that, if $\varepsilon > 1$, productivity growth maps monotonically into industry growth in nominal terms. We assume henceforth that $\varepsilon > 1$.[17]

[17] In the model, the assumption that $\varepsilon > 1$ is required for productivity growth differences to map positively into industry growth differences. In section *IV* we report evidence that is consistent with this assumption. Nonetheless, it is worth considering the behavior of the model if $\varepsilon < 1$. In this case, it would be the industry with the *lowest* rate of productivity growth that dominates in the long run, so that this would be the industry to determine whether or not the economy falls into a development trap or sink. This industry might be the one with the lowest value of g_j – however, in the case of a development sink, if financial constraints are sufficiently severe that a given industry diverges permanently from its productivity frontier, this industry might grow even more slowly than the industry with the lowest g_j and hence eventually dominate instead.

Lemma 3 shows that γ_j depends both on the industry research cost parameter κ_j and on industry $j's$ ability to raise funds A_j. Since g_j is independent of financial development, analyzing the implications of financial development for structural change is equivalent to studying the interactions between financial development F and the industry parameters κ_j and A_j.

Consider a financially constrained industry. It is straightforward to show that financial development accelerates convergence ($\frac{\partial \gamma_j}{\partial F} \geq 0$). In our model, financial development disproportionately increases growth rates in industries with low ability to raise funds A_j, as well as industries with low κ_j (R&D intensive industries).

Proposition 5 ***(Ability and industry growth)*** *In the model, financial development leads to a greater acceleration in convergence rates in industries with a low ability to raise external funds (*$\frac{\partial^2 \gamma_j}{\partial F \partial A_j} \leq 0$*).*

Proposition 6 ***(R&D cost and industry growth)*** *In the model, financial development leads to a greater acceleration in convergence rates in industries with a low R&D cost parameter (*$\frac{\partial^2 \gamma_j}{\partial F \partial \kappa_j} \leq 0$*).*

There are two effects driving the result in Proposition 6.

- The R&D cost function itself depends on κ_j. For lower values of κ_j, a given decrease in R&D spending yields a larger decrease in μ_{jt}, and hence a greater deceleration in convergence rates. We call this the *need* effect.

- To the extent that firms do not perform successful R&D, their position relative to the productivity frontier deteriorates at rate g_j. Since $\frac{\partial g_j}{\partial \kappa_j} < 0$ in the empirically relevant range, this particularly affects R&D intensive industries. We call this the *convergence* effect.

Figure 5 illustrates the patterns of structural change implied by Proposition 6. Consider two economies with different levels of financial development – one is financially constrained and the other one is not. Otherwise, assume that they have the same initial conditions – i.e. the same values of z_{j0} for all industries j. Productivity growth in a financially constrained economy is lower than in an unconstrained economy, particularly in industries with the most rapid expansion of the technological frontier. Consequently, industry differences in productivity growth rates are *smaller* than in a financially constrained economy. Both financially unconstrained and financially constrained economies converge to the same optimal industry structure in the long run (unless the latter falls into a development sink). However, since structural change is driven by productivity growth differences, convergence to this long run optimal structure will be *more rapid* in the case of a more financially developed economy.

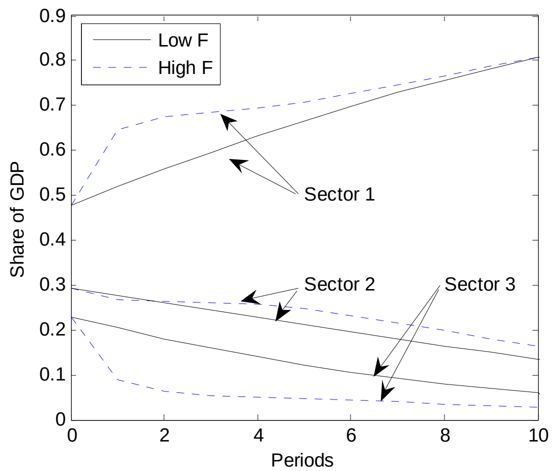

Figure 5 – Structural change in a model economy with three industries. The dotted line represents a financially unconstrained economy, and the solid line represents a financially constrained economy. Sector 1 has the lowest value of κ_j and Sector 3 has the highest.

To further illustrate the implications of delayed structural change, consider the following well-known feature of developing economies. Imbs and Wacziarg (2003) and Koren and Tenreyro (2007) find that, as countries grow, specialization tends to decrease up until a certain point, after which specialization increases once more. The model economy is capable of displaying this pattern. Consider a less financially developed economy that starts out relatively undiversified, specializing in certain industries as a result of resource endowments. If these are industries *other* than those that would eventually grow to dominate the economy, it may display a "U" shaped specialization pattern over time.[18] Figure 6 represents industry specialization in a parameterization of the model that displays this U-shaped pattern for a 3-sector economy that is initially dominated by the slowest-growing industry.

[18] This pattern of "stages of diversification" is typically interpreted in terms of the diversification of productive risk in a small open economy. The model shows that even a closed economy without aggregate uncertainty may display this pattern.

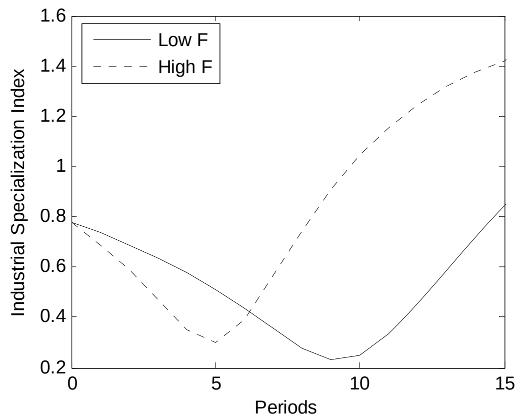

Figure 6 – Patterns of industrial specialization along the growth path. The index of specialization is the coefficient of variation among industry shares of GDP, as in Imbs and Wacziarg (2003). The coefficient of variation is defined as the standard deviation divided by the mean.

IV Empirical Analysis

In the remainder of the paper, we examine the empirical underpinnings and implications of the model. First, we use a second order linear approximation of equilibrium industry dynamics to derive a regression specification that links industry growth to its determinants implied by the model. This specification encompasses the differences-in-differences regression specification in Rajan and Zingales (1998), as well as other related work on financial development and industry growth. Then, we examine the empirical relationship between industry level R&D intensity, the need to raise external funds, and the ability to raise funds, to verify the empirical underpinnings of the model. Finally, we estimate the specification suggested by the model.

A Decomposing Industry Growth

According to Equation (22), relative industry growth rates can be decomposed into a part that is due to the movement of the technological frontier, and a part due to relative industry convergence rates. Let G_{jk} be the growth factor of industry value added, and let z_{jk} be the relative productivity of industry j in country k. Also, let $\gamma_{jk}(F, z_{jk}, \kappa_j, A_j)$ be the growth rate of z_{jk}, referred to earlier as the rate of industry productivity convergence. Fixing an arbitrary industry j' as a benchmark, and suppressing time indices, (22) can be written:

$$\log G_{jk} = B_j + B_k + (\varepsilon - 1) \log \gamma_{jk} (F, z_{jk}, \kappa_j, A_j) \tag{23}$$

where $B_j = (\varepsilon - 1) \log g_j$ and $B_k = \log G_{j',k} - (\varepsilon - 1) \log \gamma_{j',k} - (\varepsilon - 1) \log g_{j'}$.

To obtain a specification for an industry growth regression, we decompose γ_{jk} using a second-order Taylor approximation. Equation (23) becomes:

$$\begin{aligned} \log G_{jk} &= B_j + B_k + \beta_{F,RND} F_k \times RND_j + \beta_{F,A} F_k \times A_j + \beta_{F,z} F_k \times z_{jk} \\ &\quad + \beta_{RND,z} RND_j \times z_{jk} + \beta_{F,z} A_k \times z_{jk} + \beta_z z_{jk} + \beta_{z^2} z_{jk}^2 + \epsilon_{jk}. \end{aligned} \tag{24}$$

Here z_{jk} is an indicator of industry j's *initial condition* in country k (how far it is from the technological frontier) and RND_j is research intensity in industry j, which is negatively related to κ_j. Variables B_j and B_k are industry and country dummies, that include all first- and second-order derivatives of $\gamma_{jk} (F, z_{jk}, \kappa_j, A_j)$ with respect to country and industry variables (note that this is not the same as the country and industry dummies in (23)). The remaining coefficients relate to *cross*-derivatives among country and industry variables, or to derivatives with respect to initial conditions.[19]

In what follows, we will measure industry initial conditions z_{jk} as the difference between the share of industry j in country k and the share of industry j in the benchmark economy. Thus, $z < 0$ implies that the industry is likely to expand along the growth path, whereas $z > 0$ implies that it it likely to shrink. Then:

- The coefficient $\beta_{F,RND}$ indicates whether financial development affects industries differently, depending on their R&D intensity. Based on Proposition 6, we expect that $\beta_{F,RND} > 0$, as κ_j is inversely related to RND_j.

- The coefficient $\beta_{F,A}$ indicates whether financial development affects industries differently, depending on their ability to raise external funds. Based on Proposition 5, we expect that $\beta_{F,A} < 0$.

- β_z and β_{z^2} account for differences in initial conditions. If countries converge towards the industry structure of the benchmark economy, industries with $z < 0$ should be growing, and $z > 0$ shrinking, at rates that increase with the distance from that structure. Hence, we expect that $\beta_z < 0$ and possibly $\beta_{z^2} > 0$.

- The coefficient $\beta_{RND,z}$ indicates whether being closer to the technological frontier affects industries differently depending on their R&D intensity. $\beta_{RND,z} < 0$ would in-

[19] See the technical appendix for details.

dicate that, for a given initial condition z_{jk}, research-intensive industries converge faster.[20]

- The coefficient $\beta_{A,z}$ indicates whether being close to the technological frontier affects industries differently depending on their ability to raise external funds. $\beta_{A,z} < 0$ would indicate that, for a given initial condition z_{jk}, more "able" industries converge faster.

- The coefficient $\beta_{F,z}$ indicates whether financial development affects industries differently depending on their position relative to the technological frontier. $\beta_{F,z} < 0$ would indicate that financial development makes convergence more rapid particularly for industries that are further away from their share in the benchmark economy.

It is worth noting that the regression specification in Rajan and Zingales (1998) is closely related to equation (24). Their specification is:

$$\log G_j^k = B_j + B_k + \beta_{F,RND} F_k \times D_j + \beta_{Share} Share_{jk} + \epsilon_{jk} \tag{25}$$

where D_j is their measure of *external finance dependence* and $Share_{jk}$ is the manufacturing share of industry j in the GDP of k. Equation (25) is a restricted form of equation (24), assuming that the second order terms other than $\beta_{F,RND}$ equal zero, replacing RND_j with external finance dependence, and using $Share_{jk}$ as a proxy for z_{jk}. The specification in Fisman and Love (2007) is similar to (25), with D_j replaced with a measure of US growth (GR_j).[21] The specification in Ilyina and Samaniego (2008) is also similar except that research intensity, rather than finance dependence, is interacted with financial development. The fact that previous research finds positive and significant coefficients for the interaction term of each of these variables with financial development validates the model structure, within which all three variables – RND_j, D_j and GR_j – are positively related. In what follows, we verify that these correlations are indeed positive and that the full specification suggested by the model is consistent with the data.

B Country data

Industry growth is measured using value added growth, as reported in the Industrial Statistics Database (INDSTAT3) provided by the United Nations Industrial Development

[20] If the share of industry j in country k is bigger (smaller) than that in the benchmark economy, the industry share converges to the benchmark by shrinking (growing). Hence, *industry growth* should depend negatively on the relative position z_{jk}. The model has no prediction for the sign of $\beta_{RND,z}$, $\beta_{A,z}$ nor $\beta_{F,z}$.

[21] Fisman and Love (2007) interpret the benchmark industry growth rate as a short term factor: without detracting from their analysis, we find that the industry correlation between their measure for the 1980s and 1990s is 84 percent, suggesting that there is a long-term component also.

Organization (UNIDO). The data cover the period 1990-1999, but for robustness we also examine the period 1980-1989.[22] We use the same sample of 41 countries as Rajan and Zingales (1998), Fisman and Love (2007) and Ilyina and Samaniego (2008).

Financial development is measured in several ways. Our benchmark measure is the domestic private credit-to-GDP ratio (CRE). Domestic credit data is line 32d in the International Financial Statistics (IFS) database of the International Monetary Fund. CRE is a standard measure of financial deepening, used in the finance and growth literature as an indicator of financial development since at least King and Levine (1993). For each country, the measures of financial deepening were averaged over the relevant decade in order to reduce the effects of short-term fluctuations in economic or financial market conditions.[23]

For robustness, the paper also considers two kinds of financial development measures other than deepening:

- Outcome-based measures such as bank overhead in 1990 ($BANK$), and the interest rate margin in 1990 ($MARG$), both drawn from Beck, Demirgüç-Kunt and Levine (2000). Larger values of $BANK$ and $MARG$ are associated with lower financial development, so they are multiplied by minus one.

- Survey-based measures, such as the perceived access to loans ($ACCS$) and financial market sophistication ($SOPH$), as reported by World Economic Forum (2008). ACCS grades responses to the question "how easy is it to obtain a bank loan in your country with only a good business plan and no collateral?" on a scale of 1-7. SOPH grades responses to the question "the level of sophistication of financial markets in your country is (1=lower than international norms, 7=higher than international norms)."

C Industry data

Industry measures are constructed for the 28 manufacturing industries in INDSTAT3. We seek measures of financing and research activity that are not themselves affected by financing constraints. We use data on publicly traded US firms.

We measure the observed **need for external finance** D_j using the share of expenditures that is not financed by cash flow from operations. As in Rajan and Zingales (1998), cash flow from operations is defined as cash flow from operations plus changes in payables minus changes in receivables plus changes in inventories, and is computed using DATA 110 and DATA 2, 3 and 70 (or DATA 302, 303 and 304 if 2, 3, 70 are unavailable). The question

[22] Data before 1980 and after 1999 in INDSTAT3 is very partial.

[23] We assume that a period equals one decade, to abstract from short-run factors.

is how to measure expenditures. While Rajan and Zingales (1998) examine only capital expenditures (DATA 128), we consider research expenditures as well (DATA 46).[24] Thus, our measure of D_j is similar to the Rajan and Zingales (1998) measure of external finance dependence, except that it also includes research expenditures, as suggested by the model. Expenditures and cash flow are summed up over the relevant decade (the 1980s or the 1990s) to compute the firm-level measures, and the median firm value is used as an index of industry level financing need D_j.

We measure **"benchmark" industry growth** using the growth rate in sales at the median firm in each industry in Compustat (DATA 12), following Fisman and Love (2007) (GR_j).[25] Since the model predicts that productivity growth and industry growth are positively related in the benchmark economy, we check this prediction using measures of these two variables from Jorgenson et al (2007). They report industry (value-added) growth and total factor productivity growth in 76 private industries in the United States over the period 1960-2004, including industries from both manufacturing and non-manufacturing.

Research intensity (RND_j) is defined as R&D expenditures (DATA 46) divided by total expenditures (defined as DATA 46 plus DATA 128). Again, the industry measure of RND is the median firm value.

We also examine indicators of the industry-specific **ability to raise external funds** A_j, again using publicly traded firms in the United States. In particular, we use two proxies for A_j:

- Better collateralizability of a firm's assets tends to improve its ability to raise external funds in a less financially developed economy, see Kiyotaki and Moore (1997). This suggests that one proxy for A_j might be "asset fixity" (FIX_j). We measure FIX_j as a ratio of fixed assets to total assets in Compustat (DATA 8 divided by DATA 6), following Braun and Larraín (2005). FIX_j at the industry level is the median firm value.

- Greater asymmetric information, on the other hand, may hinder the ability of firms to raise external funds. Barron, Kim, Lim and Stevens (1998) and Thomas (2002) suggest that variability in earnings forecasts may indicate more heterogeneity of information across analysts concerning future profitability of a particular firm ($ASYM_j$). Hence, we take $ASYM_j$ to be a measure of *in*ability. Corporate earnings forecasts are avail-

[24] Double counting is not a problem as research spending includes only current expenditures, not capital expenditures. We do not include labor expenditures (DATA 41) because reporting is sparse: such a measure had only one firm in 8 out of 28 industries, and was not deemed reliable as a result.

[25] We also used industry growth in the US as reported in INDSTAT3, as well as the industry fixed effect in a regression of industry growth on country and industry dummies, as suggested by equation (22).

able from the Institutional Brokers' Estimate System (IBES). We use long-term (3-5 years ahead) forecasts because the return to a current research project is not likely to materialize in the near term. Again, we average the measure for each firm over the 1990s and take the median firm value to be the industry-level measure of $ASYM_j$.

The related literature measures **initial conditions** z_{jk} using the share of industry j in the manufacturing value added of country k. We use the share of industry j in the manufacturing value added of country k, minus the share of industry j in the manufacturing value added of the United States (drawn from INDSTAT3), as an indicator of how far the industry has yet to converge to the current industry frontier.[26] However, results are the same using either approach.

All measures of financial development and industry indicators (such as R&D intensity) are normalized.

D Empirical validity of model assumptions

We wish to verify that certain assumptions of the model are empirically valid. These include the fact that R&D intensity in the benchmark economy is positively related to the need for external finance, and the fact that R&D intensity is positively related to the rate of industry growth in the benchmark economy. In addition, we explore whether or not R&D intensity is related to measures of the ability to raise external funds.

R&D and the need for external funds: The cross-industry correlation between RND_j and D_j is positive and high. Moreover, this is true not just at the industry level but also at the firm level. The result also holds if we measure the need for external finance using the Rajan and Zingales (1998) measure of external finance dependence. See Tables 1 and 2.

R&D and the ability to raise external funds: Measures of ability are negatively linked to RND_j. At the firm level, the measure FIX_j is strongly negatively correlated[27] with RND_j, whereas $ASYM_j$ is positively correlated with RND_j. At the industry level, the same is the case except that $ASYM_j$ is not significantly related to RND_j. Hence, we move ahead using FIX_j as a measure of ability, leaving $ASYM_j$ aside in the industry analysis.[28]

[26] We also used the industry share times industry dummies, to allow convergence rates to differ across industries.

[27] We also measure fixity in two other ways. We excluded cash and recievables from the definition of "total assets", as these are arguably not productive assets per se. We also computed FIX_j using only firms that do not conduct R&D, as what we are interested in is the ability of the firm to raise funds for research through its non R&D-assets. All measures of FIX_j were highly correlated amongst themselves, and results were broadly similar.

[28] $ASYM_j$ may be a weak indicator because of a tendency among analysts not to deviate too much from the consensus.

R&D and industry growth: The model assumes that R&D intensity is positively related to industry growth in the benchmark country, and we find that this is also the case in the data. For productivity growth differences to map into industry growth differences in the model economy requires that $\varepsilon > 1$ among the industries in question. One way for us to assess this is using equation (23). If $\varepsilon > 1$, equation (23) implies that the industry fixed effect B_j in a country-industry growth regression should be positively related to growth in industry j in the benchmark country GR_j. Table 2 shows that the data support the prediction that B_j and GR_j are related across manufacturing industries.

Industry growth and productivity growth: Equation (22) indicates that, in the benchmark economy, industry value added growth rates and productivity growth rates should be positively correlated in the benchmark economy, provided that $\varepsilon > 1$. Jorgenson et al (2007) report industry value-added growth and productivity growth rates for the United States (1960-2004). The correlation between these two variables is 0.84 in the full sample of 76 industries; within manufacturing it is 0.97, and within services and other industries it is 0.35. All values are positive and significant at the 5 percent level or better (Spearman rank correlations, which are less sensitive to outliers, are also positive and significant).

Furthermore, equation (22) indicates that, in the benchmark economy, ε equals one plus the coefficient obtained from regressing value added growth on TFP growth in the benchmark economy. Thus, we can estimate ε from the Jorgenson et al (2007) data. Using all industries, we find that $\varepsilon = 3.21$ (s.d. 0.167), or $\varepsilon = 2.08$ (s.d. 0.176) if we exclude two outliers. Among 32 manufacturing industries, the estimate is $\varepsilon = 3.75$ (s.d. 0.125), and using 44 services and other industries it is $\varepsilon = 1.85$ (*s.d.* 0.355). In all cases, the estimate is significantly greater than unity.

Productivity growth and R&D: We can also compute R&D intensity for the industry breakdown of Jorgenson et al (2007).[29] The correlation between RND and TFP growth is 0.39 and the correlation between RND and industry growth is 0.47, both of which are significant at the 1 percent level. This finding supports our focus on the parameter range over which R&D intensity and productivity growth are positively related, as per Lemma 1.

E Cross-country industry growth regressions

Finally, we estimate equation (24). Results using financial deepening as a measure of financial development are reported in Table 3. We report heteroskedasticity-consistent standard errors. The upshot is that there is a strong, significant interaction between R&D intensity and financial development. This result is robust to using different measures of financial

[29] For these purposes we measure R&D intensity over the entire post-war era. We lose 12 industries because no firms in Compustat report the corresponding industry codes.

development. Ability (as measured by FIX_j) does not interact significantly with financial development in the full specification. However, Table 1 indicates that RND_j and FIX_j are strongly negatively correlated. Hence we estimate (24) twice more, first without the terms for FIX_j, and again without the terms for RND_j – see Tables 4 and 5. The results point to a strong positive interaction of RND_j with financial development, and a weaker (negative) interaction of FIX_j with financial development. Both of these signs are consistent with model predictions.[30] For robustness, we also repeat the regression with industry indicators, country financial development (as measured by CRE), and country-industry growth data measured during the 1980s instead of the 1990s, finding the same results.

Regarding the other terms in the regressions, it is interesting that $\beta_z < 0$ and $\beta_{z^2} > 0$, consistent with a trend towards a uniform industry structure across countries. The remaining interaction terms $\beta_{RND,z}, \beta_{A,z}$ and $\beta_{F,z}$ are generally not significant and are of unstable sign.

We conclude that the evidence supports the structure and predictions of the model. R&D intensive industries grow relatively faster in more financially developed economies, and so do industries with low asset collateralizability. Given the high negative correlation between RND_j and FIX_j, we interpret this as providing some support for the ability channel – whereby research investments have a weaker ability to raise funds than other kinds of investments.[31]

V Conclusion

We present a model in which financial development and industry characteristics such as the cost of research jointly determine industry growth rates. In equilibrium, financial development disproportionately increases growth in industries that are more R&D intensive. Equilibrium industry dynamics in the model economy maps into well-known empirical specifications of the link between finance and industry growth, providing new insights into the interpretation of these regressions in terms of the effect of financial development on convergence through technology transfer.

[30] We also obtained these results when measuring R&D intensity as the average research spending divided by net sales as reported by the National Science Foundation, and also the median R&D intensity divided by sales in Compustat.

[31] In our growth regressions, we replaced RND_j with our measures of D_j and GR_j to see whether we could attribute the interaction of RND_j with F_k to either of the model channels: coefficients were of the correct sign but not significant except for D_j when $BANK_j$ was the measure of financial development. We also repeated the analysis using data from the 1980s (for which only the financial development measure CRE was available), finding that the interaction of D_j was significant as in Rajan and Zingales (1998), although the interaction of RND_j was more so, as in Ilyina and Samaniego (2008). Thus, it appears that none of the measures of need, ability and frontier growth on their own fully capture the possibly complex interactions between R&D and financial development.

Interestingly, depending on initial conditions, the model can replicate the well known pattern of structural change observed by Imbs and Wacziarg (2003) and Koren and Tenreyro (2007), that diversification first increases and subsequently decreases over time as countries develop. This pattern of "stages of diversification" is typically interpreted in terms of the diversification of productive risk in a small open economy. The paper shows that even a closed economy without aggregate uncertainty may display this pattern, if initial conditions skew a country's industry composition away from the industries that dominate in the long run as a matter of productivity-induced structural change. By diminishing industry differences in rates of technical progress, the effect of financial underdevelopment is to slow the process of productivity-driven structural change.

We see several directions for future work. First, the model abstracts from international trade. This keeps our framework closer to standard growth models and demonstrates that growth-theoretic considerations can account for the industry growth phenomena described in the paper. Still, an open-economy extension could be useful for understanding the impact of financial development on trade patterns, as well as the role of trade mechanisms in the process of structural change. Second, ours is a model of the impact – not the sources – of financing constraints. A model with physical capital and explicit informational frictions might allow for the endogenization of ability in the manner of Kiyotaki and Moore (1997). Third, the greater sensitivity of R&D-intensive industries to financial frictions suggests that they may be particularly vulnerable to shocks through the financial accelerator mechanism of Bernanke, Gertler and Gilchrist (1996), something that would be interesting to study in a stochastic environment.

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Table 1 -- Regression of financial variables on RND at the firm level

This table shows the results of regressing external finance dependence (D), asset fixity (FIX) and asymmetric information (ASYM) on R&D intensity (RND) at the firm level. Results are reported without industry fixed effects, with industry fixed effects, and with industry fixed effects for Manufacturing and Non-manufacturing firms separately. Results are reported for the 1990s. All variables are normalized by their means and standard deviations, so coefficients can be interpreted as correlations. Standard errors are in parentheses. One, two and three asterisks represent statistical significance at the 10, 5 and 1 percent levels respectively.

	1	2	3	4	5	6
D(j)	**0.314*** **		**-**	**0.218*** **	**0.243*** **	**0.194*** **
	(0.033)			(0.027)	(0.035)	(0.029)
FIX(j)	-	**-0.599*** **	-	**-0.562*** **		**-0.548*** **
		(0.028)		(0.027)	-	(0.028)
ASYM(j)	-		**0.281*** **	-	**0.191*** **	**0.070*** **
			(0.033)		(0.035)	(0.029)
Obs	893	893	893	893	893	893
R^2	0.099	0.359	0.079	0.405	0.130	0.409

Table 2 -- Correlations between different industry measures

This table shows correlations between industry measures of R&D intensity, financial need, financial ability or industry growth. D(j) is the need for external finance in industry j as measured in this paper. RZ(j) is the external finance dependence measure of Rajan and Zingales (1998). FIX(j) is the share of fixed assets in total assets. ASYM(j) is the dispersion of analyst long-term growth forecasts. GUS(j) is sales growth at the median firm in Compustat, as in Fisman and Love (2007). β(j) is the industry fixed effect in a cross country industry growth regression on country and industry dummies. Standard errors are in parentheses. Variables are measured during the 1990s. One, two and three asterisks represent statistical significance at the 10, 5 and 1 percent levels respectively.

	D(j)	RZ(j)	FIX(j)	ASYM(j)	GR(j)	β(j)
RND(j)	**0.654*** **	**0.677*** **	**-0.523*** **	0.160	**0.710*** **	**0.413** **
	(0.148)	(0.144)	(0.167)	(0.206)	(0.138)	(0.179)
D(j)		**0.799*** **	-0.123	0.077	**0.613*** **	**0.388** **
		(0.118)	(0.195)	(0.204)	(0.155)	(0.181)
RZ(j)			-0.232	0.003	**0.860*** **	**0.367* **
			(0.191)	(0.209)	(0.100)	(0.182)
FIX(j)				0.116	**-0.400** **	-0.186
				(0.206)	(0.180)	(0.193)
ASYM(j)					0.003	0.130
					(0.205)	(0.206)
GR(j)						**0.464** **
						(0.174)

Table 3 -- Interaction of R&D intensity and Ability measures with financial development in country-industry growth regressions.

This table presents the panel regression estimation results of equation (24). The dependent variable is the growth rate of industry j in country k. RND(j) is the R&D intensity of industry j; FinDev(k) is financial development in country k; z(j,k) is a measure of technology gap for industry j located in country k. Country and industry dummies are omitted for brevity. Standard errors are reported in parentheses. Standard errors are corrected for heteroskedasticity using the method of White (1980). Financial development is measured in five ways: CRE is private credit/GDP; MARG is the interest rate margin; BANK is the ratio of bank overhead to assets; ACCS is access to credit as measured using a survey of executives; and SOPH is the sophistication of the financial system as measured using a survey of executives. CRE80 is CRE measured in the 1980s, all other variables are measured in the 1990s. Sources: IMF, Compustat, UNIDO, Beck et al (2002), World Economic Forum (2008). Standard errors are in parentheses. One, two and three asterisks represent statistical significance at the 10, 5 and 1 percent levels respectively.

Regression specification	CRE	MARG	BANK	ACCS	SOPH	CRE80
RND(j) × FinDev(k)	**0.046****	**0.063*****	**0.063*****	**0.052****	**0.049***	**0.049*****
	(0.020)	(0.022)	(0.021)	(0.026)	(0.026)	(0.019)
RND(j) × z(j,k)	0.664	0.479	0.471	**1.87***	1.62	1.10
	(0.819)	(0.813)	(0.801)	(0.991)	(0.996)	(1.01)
FIX(j) × FinDev(k)	0.001	-0.002	-0.018	-0.020	-0.019	0.016
	(0.021)	(0.022)	(0.024)	(0.029)	(0.030)	(0.025)
FIX(j) × z(j,k)	-0.036	-0.026	-0.025	0.800	0.437	-0.402
	(0.760)	(0.857)	(0.847)	(0.936)	(0.950)	(1.32)
z(j,k) × FinDev(k)	-0.832	0.044	0.212	0.480	0.791	-0.425
	(0.612)	(0.934)	(0.479)	(0.460)	(0.496)	(0.539)
z(j,k)	**-4.35*****	**-3.98*****	**-4.01*****	**-5.82*****	**-6.03*****	**-3.14*****
	(0.924)	(0.946)	(0.949)	(1.15)	(1.16)	(0.695)
$z(j,k)^2$	**13.3****	**13.6****	**13.6****	**15.9****	**16.8****	7.14
	(6.12)	(6.61)	(6.62))	(6.85)	(6.79)	(4.66)
R^2	0.305	0.307	0.308	0.307	0.307	0.392
Obs	968	968	968	699	699	1084

Table 4 -- Interaction of R&D intensity with financial development in country-industry growth regressions.

This table presents the panel regression estimation results of equation (24). The dependent variable is the growth rate of industry j in country k. RND(j) is the R&D intensity of industry j; FinDev(k) is financial development in country k; z(j,k) is a measure of technology gap for industry j located in country k. Country and industry dummies are omitted for brevity. Standard errors are reported in parentheses. Standard errors are corrected for heteroskedasticity using the method of White (1980). Financial development is measured in five ways: CRE is private credit/GDP; MARG is the interest rate margin; BANK is the ratio of bank overhead to assets; ACCS is access to credit as measured using a survey of executives; and SOPH is the sophistication of the financial system as measured using a survey of executives. CRE80 is CRE measured in the 1980s, all other variables are measured in the 1990s. Sources: IMF, Compustat, UNIDO, Beck et al (2002), World Economic Forum (2008). Standard errors are in parentheses. One, two and three asterisks represent statistical significance at the 10, 5 and 1 percent levels respectively.

Regression specification	**CRE**	**MARG**	**BANK**	**ACCS**	**SOPH**	**CRE80**
RND(j) × FinDev(k)	**0.046*** **	**0.064*** **	**0.079*** **	**0.062*** **	**0.059*** **	**0.047*** **
	(0.018)	(0.020)	(0.019)	(0.022)	(0.022)	(0.018)
RND(j) × z(j,k)	0.681	0.492	0.490	**1.45* **	**1.41* **	**1.37** **
	(0.696)	(0.682)	(0.672)	(0.835)	(0.844)	(0.646)
z(j,k) × FinDev(k)	-0.825	0.038	0.108	0.640	**0.931** **	-0.367
	(0.611	(0.934)	(0.425)	(0.441)	(0.462)	(0.464)
z(j,k)	**-4.34*** **	**-3.98*** **	**-3.99*** **	**-5.91*** **	**-6.10*** **	**-3.29*** **
	(0.923)	(0.934)	(0.936)	(1.15)	(1.15)	(0.464)
$z(j,k)^2$	**13.2*** **	**13.6*** **	**13.6*** **	**19.2*** **	**18.9*** **	**7.23* **
	(4.91)	(5.03)	(5.03)	(5.50)	(5.24)	(4.31)
R^2	0.305	0.307	0.308	0.305	0.306	0.391
Obs	968	968	968	699	699	1084

Table 5 -- Interaction of Ability with financial development in country-industry growth regressions.

This table presents the panel regression estimation results of equation (24). The dependent variable is the growth rate of industry j in country k. FIX(j) is the share of fixed assets in total assets; FinDev(k) is financial development in country k; z(j,k) is a measure of technology gap for industry j located in country k. Country and industry dummies are omitted for brevity. Standard errors are reported in parentheses. Standard errors are corrected for heteroskedasticity using the method of White (1980). Financial development is measured in five ways: CRE is private credit/GDP; MARG is the interest rate margin; BANK is the ratio of bank overhead to assets; ACCS is access to credit as measured using a survey of executives; and SOPH is the sophistication of the financial system as measured using a survey of executives. CRE80 is CRE measured in the 1980s, all other variables are measured in the 1990s. Sources: IMF, Compustat, UNIDO, Beck et al (2002), World Economic Forum (2008). Standard errors are in parentheses. One, two and three asterisks represent statistical significance at the 10, 5 and 1 percent levels respectively.

Regression specification	**CRE**	**MARG**	**BANK**	**ACCS**	**SOPH**	**CRE80**
FIX(j) × FinDev(k)	-0.026	-0.032	**-0.050****	**-0.052****	**-0.050****	0.009
	(0.018)	(0.021)	(0.022)	(0.025)	(0.025)	(0.025)
FIX(j) × z(j,k)	-0.567	-0.602	-.523	-0.295	-0.571	-0.926
	(0.663)	(0.730)	(0.732)	(0.910)	(0.897)	(1.06)
z(j,k) × FinDev(k)	-0.867	-0.319	-0.038	0.545	**0.913***	-0.737
	(0.621)	(0.526)	(0.487)	(0.472)	(0.511)	(0.546)
z(j,k)	**-3.93*****	**-3.81*****	**-3.85*****	**-5.24*****	**-5.43*****	**-2.58*****
	(0.903)	(0.921)	(0.923)	(1.11)	(1.12)	(0.617)
$z(j,k)^2$	**12.6***	**13.9****	**13.7****	**15.0***	**15.5****	3.36
	(6.51)	(6.84)	(6.94)	(7.87)	(7.49)	(4.80)
R^2	0.302	0.302	0.303	0.299	0.301	0.356
Obs	968	968	968	699	699	1084

A Resource constraints

Because of the production structure in (8), for any unit of good j used in consumption, an additional volume of good j is required for the production of customized intermediates. This volume depends upon the amount of intermediates used $x_{jt}(i)$ and on the number of units of j required, which averages $(\mu_{jt} + 1 - \chi\mu_{jt})$. From the firm's first order conditions, the number of units of j demanded as intermediates per unit of output is $\frac{\int x_{jt}(i)di}{y_{jt}} = \frac{\alpha_x}{\chi}$. Hence, for each unit of good j produced, the number of units of j used to produce intermediates is $I_{jt} = (\mu_{jt} + 1 - \chi\mu_{jt}) \frac{\alpha_x}{\chi}$.

If c_{jt} units of good j are consumed, then $c_{jt}I_{jt}$ units of j are required as intermediates to produce them. In turn, each of the $c_{jt}I_{jt}$ units of j used to make intermediates itself requires a similar proportion I_{jt} for intermediate use. As a result, market clearing requires that:[31]

$$M_{jt}y_{jt} = c_{jt}\frac{1}{1 - I_{jt}}. \tag{26}$$

where M_{jt} is the number of firms in industry j. This is also the feasibility condition for each final good: $M_{jt}y_{jt}$ is gross output of good j, whereas $c_{jt}\frac{1}{1-I_{jt}}$ is both intermediate and final demand.

In any period, there is quantity 2 of labor available in the economy. Labor demand is entrepreneurial labor $\sum_j M_{jt}$, production labor $\sum_j M_{jt}l_{jt}$ and labor in research $\sum_j M_{jt}\kappa_j n(\mu_{jt})/z_{jt}$. Thus

$$2 \geq N_t^r + \sum_j M_{jt}(1 + l_{jt}) + \sum_j M_{jt}\kappa_j n(\mu_{jt})/z_{jt} \tag{27}$$

Suppose each agent has a name i on the interval $[t, t+1)$, where t is their date of birth. Let b_{it} be the savings of agent i at date t. Market clearing for financial markets requires that

$$\int_{i\in[t,t+1)} b_{it}di = 0. \tag{28}$$

The feasibility constraint for the economy is that spending should not exceed output, i.e.:

$$Y_t^R \geq \sum_j q_{jt}c_{jt} + \sum_j M_{jt}\pi_{jt}\mu_{jt} - \sum_j M_{jt}\kappa_j n(\mu_{jt})/z_{jt}.$$

[31] An alternative interpretation is that $(\mu_{jt} + 1 - \chi\mu_{jt}) \int x_{jt}(i)\, di$ is "foregone output," so that final output for a given firm is $y_{jt}[1 - I_{jt}]$. Thus, final consumption of j is $c_{jt} = M_{jt}y_{jt}[1 - I_{jt}]$ and, in this case too, equation (26) holds.

B Proofs

Proof of Lemma 2. There is perfect competition in goods markets, so the demand function for intermediates is

$$x_{jt}(i) = Z_{jt}(i)\left(\frac{\alpha_x l_{jt}^{\alpha_l}}{\chi}\right)^{\frac{1}{1-\alpha_x}}. \tag{29}$$

For labor, the firm's first order condition is

$$\alpha_l q_{jt} y_{jt} = l_{jt} w_t \tag{30}$$

Let labor be the numeraire, so that $w_t = 1$. Placing (29) into (8), we have

$$y_{jt} = Z_{jt} l_{jt}^{\frac{\alpha_l}{1-\alpha_x}} \zeta$$

where $\zeta = \left(\frac{\alpha_x}{\chi}\right)^{\frac{\alpha_x}{1-\alpha_x}}$ So, using (30),

$$\alpha_l q_{jt} Z_{jt} l_{jt}^{\frac{\alpha_l}{1-\alpha_x}-1} \zeta = w \tag{31}$$

This implies that $\alpha_l q Z_{jt} l_{jt}^{\frac{\alpha_l}{1-\alpha_x}-1} / w_t = 1$ in all industries.

Allowing new entrepreneurs to choose their sector of entry implies that expected profits in all sectors are equal, so

$$\begin{aligned} \Theta_{jt} &= q_{jt} y_{jt} (1 - \alpha_l - \alpha_x) \\ &= q_{jt} Z_{jt} l_{jt}^{\frac{\alpha_l}{1-\alpha_x}} \zeta (1 - \alpha_l - \alpha_x) \end{aligned}$$

is constant across industries. This implies that l_{jt} is also equal across sectors, as

$$l_{jt} = \alpha_l \Theta_{jt} / (1 - \alpha_l - \alpha_x)$$

and hence

$$\Theta_{jt} = q_{jt} Z_{jt} \left[\frac{\alpha_l \Theta_{jt}}{1 - \alpha_l - \alpha_x}\right]^{\frac{\alpha_l}{1-\alpha_x}} \zeta (1 - \alpha_l - \alpha_x).$$

Note that this implies that $q_{jt} Z_{jt}$ is constant across industries. $\Theta_{jt} = F(q_{jt} Z_{jt})$, and $l_{jt} = G(q_{jt} Z_{jt}) = G_1 (q_{jt} Z_{jt})^{G_2}$. Since $\Theta_{jt} = \Theta$ at all dates ($\Theta = 1$), we have that $q_{jt} Z_{jt} = \psi^*$, where

$$\psi^* = \left[\alpha_l^{\alpha_l}\zeta^{1-\alpha_x}\left(\frac{1-\alpha_l-\alpha_x}{\Theta}\right)^{1-\alpha_x-\alpha_l}\right]^{-\frac{1}{1-\alpha_x}}.$$

Hence optimal labor input l^* is $l^* = \alpha_l/(1-\alpha_l-\alpha_x)$. Profits from a successful innovation are

$$\begin{aligned}\pi_{jt}(i) &= Z_{jt}^*(i)\left(\frac{\alpha_x (l^*)^{\alpha_l}}{\chi}\right)^{\frac{1}{1-\alpha_x}}[\chi-1]\,q_{jt} \\ &= \left(\frac{\alpha_x (l^*)^{\alpha_l}}{\chi}\right)^{\frac{1}{1-\alpha_x}}[\chi-1]\,\psi^*/\tilde{z}_{jt}\end{aligned}$$

so $\pi_{jt}(i) = \pi/z_{jt}$where

$$\pi = \left(\frac{\alpha_x (l^*)^{\alpha_l}}{\chi}\right)^{\frac{1}{1-\alpha_x}}[\chi-1]\,\psi^*.$$

■

Proof of Lemma 1. The result concerning κ^{**} follows from the fact that $n'(0) > 0$ so that for sufficiently large κ_j $\pi < \kappa_j n'(\mu)$ for all $\mu \geq 0$ so it is not profitable to conduct research. If $\kappa_j < \kappa^{**}$, μ_j^* is given by the condition $\pi = \kappa_j n'(\mu^*)$ so that:

$$\mu_\kappa^* = -\frac{n'(\mu^*)}{\kappa_j n''(\mu^*)} < 0 \text{ if } n' > 0, n'' > 0.$$

Total R&D spending in the benchmark economy is $\kappa_j n\left(\mu_j^*\right)/z_j^*$ so, suppressing asterisks,

$$\begin{aligned}\frac{d\kappa_j n(\mu)/z}{d\kappa_j} &= \frac{\sigma+1}{(\sigma\mu+1)}\left[n(\mu) - \frac{[n'(\mu)]^2}{n''(\mu)}\right] \\ &\quad +\mu_\kappa \sigma\kappa_j n(\mu)\frac{\sigma+1}{(\sigma\mu+1)^2}\end{aligned}$$

Since $\mu_\kappa < 0$, the sign of this derivative hinges on the sign of:

$$X(\kappa_j) \equiv \frac{d\kappa_j n(\mu)}{d\kappa_j} = n(\mu) - \frac{[n'(\mu)]^2}{n''(\mu)}$$

Note that $\lim_{\kappa_j\to\kappa^{**}} \mu_j^* = 0$, so that

$$\lim_{\kappa_j\to\kappa^{**}} X(\kappa_j) = -\frac{[n'(0)]^2}{n''(0)} < 0$$

On the other hand, $\lim_{\kappa_j\to 0}\kappa_j n\left(\mu_j^*\right)/z_j^* = 0$ also, so that there exists $\kappa^* > 0$ such that

R&D intensity and κ_j are strictly negatively correlated if $\kappa_j \in [\kappa^*, \kappa^{**}]$ (and equal to zero if $\kappa_j > \kappa^{**}$), so R&D intensity, μ_j^* and g_j^* are positively correlated in this range. ■

Proof of Lemma 3. First, note that in a constrained environment agents who do research will save all their income from their youth, as they are below the optimal R&D investment and the R&D cost function is strictly convex.

Let $\omega_{jk} = v_{jk}(1+r)$. Note that $H^2(0) = 0$ and

$$\begin{aligned} H_z^2(z) &= \omega_{jk}\tilde{\mu}_j'(\omega_{jk}z_{j,t-1}) + \frac{\left[1-\tilde{\mu}_j(\omega_{jk}z_{j,t-1})\right]}{g_{jt}} - \frac{\omega_{jk}\tilde{\mu}_j'(\omega_{jk}z_{j,t-1})}{g_{jt}}z_{j,t-1} \\ &= \omega_{jk}\tilde{\mu}_j'(\omega_{jk}z_{j,t-1})\left[1-\frac{1}{g_{jt}}z_{j,t-1}\right] + \frac{\left[1-\tilde{\mu}_j(\omega_{jk}z_{j,t-1})\right]}{g_{jt}} > 0 \end{aligned}$$

which is positive because $g > 1$ and $z < 1$. Then,[32] $H_z^2(0) = \omega_{jk}\tilde{\mu}_j'(0) + \frac{1}{g_{jt}}$, which is positive and finite as $\lim_{z\to 0}\tilde{\mu}_j'(\omega_{jk}z_{j,t-1}) > 0$.

For concavity of H_2 need $H_{zz}^2 < 0$.

$$\begin{aligned} H_{zz}^2(z) &= \omega_{jk}^2\tilde{\mu}_j''(\omega_{jk}z_{j,t-1})\left[1-\frac{1}{g_j}z_{j,t-1}\right] \\ &\quad -2\frac{\omega_{jk}\tilde{\mu}_j'(\omega_{jk}z_{j,t-1})}{g_j} \end{aligned}$$

which is negative if $\left[1-\frac{1}{g_{jt}}z_{j,t-1}\right] > 0$. This holds as $g > 1$ and $z^* < 1$, so $z < 1$.

$$\omega_{jk} = \frac{g_{jt} - \left[1-\tilde{\mu}_j(0)\right]}{\tilde{\mu}_j'(0)\,g_{jt}}$$

$$\omega_{jk} = \frac{g_{jt}-1}{\tilde{\mu}_j'(0)\,g_{jt}}$$

As for $H^1(z)$, note that

$$\tilde{z}_t' = \left[\frac{\pi/\tilde{z}_t}{\kappa} - \tilde{z}_t'\frac{\pi\tilde{z}_{t-1}}{\kappa\tilde{z}_t^2}\right]\tilde{\mu}'\left[\frac{\pi\tilde{z}_{t-1}/\tilde{z}_t}{\kappa}\right]\left(1-\frac{1}{g_{jt}}z_{j,t-1}\right) + \frac{\left[1-\tilde{\mu}\left[\frac{\pi\tilde{z}_{t-1}/\tilde{z}_t}{\kappa}\right]\right]}{g_{jt}}. \tag{32}$$

so

$$\tilde{z}_t' = \frac{\frac{\pi/\tilde{z}_t}{\kappa}\tilde{\mu}'\left[\frac{\pi\tilde{z}_{t-1}/\tilde{z}_t}{\kappa}\right]\left(1-\frac{1}{g_{jt}}z_{j,t-1}\right) + \frac{\left[1-\tilde{\mu}\left[\frac{\pi\tilde{z}_{t-1}/\tilde{z}_t}{\kappa}\right]\right]}{g_{jt}}}{1+\frac{\pi\tilde{z}_{t-1}}{\kappa\tilde{z}_t^2}\tilde{\mu}'\left[\frac{\pi\tilde{z}_{t-1}/\tilde{z}_t}{\kappa}\right]} > 0. \tag{33}$$

[32] Observe that $1-\frac{1}{g_j}z_{j,t-1} > 0$ as $z_{j,t-1} < z_j^*$ and $\frac{1}{g_j}z_j^* = \frac{\mu_j^*}{g_j-1+\mu_j^*} < 1$.

Setting $z_{t-1} = 0$,

$$\tilde{z}' = \frac{\pi/\tilde{z}_t}{\kappa}\tilde{\mu}'(0) + \frac{1}{g_{jt}} = \infty. \tag{34}$$

Note that $H^1(z_t)$ crosses the 45° line at only one positive number. Using (18), setting $z_{t-1} = z_t$ yields a linear equation with a single solution. ■

Proof of Proposition 1. Suppressing the time subscript, suppose spending on consumption is s_c. Across goods, demand is

$$c_i = s_c\left(\frac{\xi_i}{q_i}\right)^{\varepsilon}\left[\sum_{j=1}\xi_j^{\varepsilon}q_j^{1-\varepsilon}\right]^{-1} \tag{35}$$

Then

$$\frac{c_i}{c_j} = \left(\frac{\xi_i}{\xi_j}\right)^{\varepsilon}\left(\frac{q_j}{q_i}\right)^{\varepsilon}, \tag{36}$$

so total expenditure is $s_c = \sum_{j=1} q_j c_j = q_i c_i \sum_{j=1}\left(\frac{\xi_j}{\xi_i}\right)^{\varepsilon}\left(\frac{q_j}{q_i}\right)^{1-\varepsilon}$ which implies

$$c_j = s_c\left(\frac{\xi_j}{q_j}\right)^{\varepsilon}\left[\sum_{j=1}\xi_j^{\varepsilon}p_j^{1-\varepsilon}\right]^{-1}. \tag{37}$$

The static maximum is $\left(\sum_j \xi_j c_j^{\frac{\varepsilon-1}{\varepsilon}}\right)^{\frac{\varepsilon}{\varepsilon-1}} = c_i\left(\sum_j \xi_j\left(\frac{c_j}{c_i}\right)^{\frac{\varepsilon-1}{\varepsilon}}\right)^{\frac{\varepsilon}{\varepsilon-1}}$. Using (36) and (37), we have

$$\left(\sum_j \xi_j c_j^{\frac{\varepsilon-1}{\varepsilon}}\right)^{\frac{\varepsilon}{\varepsilon-1}} = s_c\left(\sum_j \xi_j^{\varepsilon}q_j^{1-\varepsilon}\right)^{\frac{1}{\varepsilon-1}}. \tag{38}$$

Add this over all the agents regardless of income.

In equilibrium $\tilde{M}_{jt}y_{jt} = c_{jt}$ where $\tilde{M}_{jt}$ is the number of firms in industry j that produces exactly the quantity of good j *not used to make intermediates*, so combining (30) with (35) and suppressing t we get

$$\tilde{M}_j l_j w_t = \alpha_l q_{jt} s\left(\frac{\xi_i}{q_i}\right)^{\varepsilon}\left[\sum_{j=1}\xi_j^{\varepsilon}q_j^{1-\varepsilon}\right]^{-1}$$

Define $\Lambda_t^{j,j'}$ as the share in nominal consumption of sector j divided by that of sector j':

$$\Lambda_t^{j,j'} = \frac{q_{jt}c_{jt}}{q_{j't}c_{j't}}$$

$$\frac{q_{jt}\left(\frac{\xi_j}{q_j}\right)^{\varepsilon}}{q_{j't}\left(\frac{\xi_{j'}}{q_{j'}}\right)^{\varepsilon}} = \frac{\tilde{M}_j l_j}{\tilde{M}_j l_{j'}} = \frac{\tilde{M}_j}{\tilde{M}_j} \equiv \Lambda_t^{j,j'} \tag{39}$$

The expression $\Lambda_{t+1}^{j,j'}/\Lambda_t^{j,j'}$ then denotes the growth rate of industry j relative to industry j', so:

$$\begin{aligned}
\frac{\Lambda_{t+1}^{j,j'}}{\Lambda_t^{j,j'}} &= \left(\frac{q_{jt+1}/q_{jt}}{q_{j't+1}/q_{j't}}\right)^{1-\varepsilon} \\
&= \left(\frac{Z_{jt+1}/Z_{jt}}{Z_{j't+1}/Z_{j't}}\right)^{\varepsilon-1}
\end{aligned}$$

This last step comes from the following. Define $P_t^{j,j'}$ as relative productivities. We have that

$$P_t^{j,j'} = \left[\frac{Z_{jt}}{Z_{j't}}\right] = \left[\frac{l_{jt}^{\alpha_l \frac{1}{1-\alpha_x}-1}}{l_{j't}^{\alpha_l \frac{1}{1-\alpha_x}-1}} \frac{q_{jt}}{q_{j't}}\right]^{-1}$$

So, defining $P_{t+1}^{j,j'}/P_t^{j,j'}$ as the growth in the productivity gap *between sectors* j and j', if $l_{jt} = l^* \forall j, t$ then

$$\begin{aligned}
P_{t+1}^{j,j'}/P_t^{j,j'} &= \left[\frac{q_{jt+1}}{q_{j't+1}}\right]^{-1} \div \left[\frac{q_{jt}}{q_{j't}}\right]^{-1} \\
&= \left(\frac{q_{jt+1}/q_{jt}}{q_{j't+1}/q_{j't}}\right)^{-1}
\end{aligned}$$

which is negatively related to relative price changes. Putting things in terms of the technology gap,

$$P_{t+1}^{j,j'}/P_t^{j,j'} = \left(\frac{Z_{jt+1}}{Z_{j't+1}} / \frac{Z_{jt}}{Z_{j't}}\right) = \left(\frac{z_{jt+1}}{z_{j't+1}} / \frac{z_{jt}}{z_{j't}}\right) \times \left(\frac{g_j}{g_{j'}}\right)$$

so $\frac{\Lambda_{t+1}^{j,j'}}{\Lambda_t^{j,j'}} = \left(\frac{z_{jt+1}}{z_{j't+1}} / \frac{z_{jt}}{z_{j't}}\right)^{\varepsilon-1} \times \left(\frac{g_j}{g_{j'}}\right)^{\varepsilon-1}$. Finally, it follows from the definitions of $\Lambda_t^{j,j'}$ and G_{jt} that growth in relative shares $\Lambda_{t+1}^{j,j'}/\Lambda_t^{j,j'}$ equals relative industry growth rates $G_{jt}/G_{j't}$. ■

Proof of Proposition 2. Equation (36) gives the relative shares of consumption, and hence relative numbers of firms that produce final goods given a sequence for q_{jt}. Since $q_{jt} = \psi^* Z_{jt}^{-1}$, the path of q_{jt} is known at all dates. As shown in the text, any producer of final goods requires $\left(\mu_{jt} + 1 - \chi\mu_{jt}\right) \frac{\chi}{\alpha_x}$ times its final output in units of good j to produce intermediates $x_{jt}(i)$, which pins down the ratio of firms in a given industry M_{jt} relative to those that produce goods for final use $\tilde{M}_{jt}$. Hence we know the number of firms down to a multiplicative factor, as in the working version of Samaniego (2009). In equilibrium, linear preferences and the labor endowment of the economy imply that:

$$2 = N_t^r + (1 + l^*) \sum_j M_{jt} + \sum_j M_{jt} \kappa_j n \left(\mu_{jt}\right) / z_{jt} \tag{40}$$

We require that the multiplicative constant that satisfies this equation allows $N_t^r + M_t < 1$. Now, we know that $\sum_j M_{jt} \kappa_j n \left(\mu_{jt}\right) / z_{jt} > \sum_j M_{jt} \min_j \left\{\kappa_j n \left(\mu_j^*\right) / z_j^*\right\}$ and $\sum_j M_{jt} \Pi_{jt} < \max_j \Pi_j^* M_t$. Moreover, since $N_t^r = \sum_j M_{jt} \Pi_{jt}$ we know that

$$N_t^r < \max_j \Pi_j^* M_t$$

so

$$\begin{aligned} N_t^r + M_t &< \max_j \Pi_{jt}^* M_t + M_t \\ &= M_t \left[\max_j \Pi_j^* + 1\right] \end{aligned}$$

Hence, we wish to find sufficient conditions so that:

$$M_t \left[\max_j \Pi_j^* + 1\right] \leq 1$$

We know that

$$2 > M_t \left[\max_j \Pi_j^* + (1 + l^*) + \min_j \left\{\kappa_j n \left(\mu_j^*\right) / z_j^*\right\}\right]$$

so a sufficient condition is that

$$2 \left[\max_j \Pi_j^* + 1\right] \leq \max_j \Pi_j^* + (1 + l^*) + \min_j \left\{\kappa_j n \left(\mu_j^*\right) / z_j^*\right\}$$

Is there some parameter that guarantees this? As $\alpha_l \to 1 - \alpha_x$, $l^* \to \infty$, so this is satisfied for sufficiently large values of α_l.

Also we require that $N_t^r \geq M_t$. A sufficient condition would be that the profits from R&D are always above one for all j, for all initial conditions, or that $\min_j \Pi_{jt} > 1$. Note that:

$$\Pi_{jt} = \min \left\{\pi \mu_j^* - \kappa_j n \left(\mu_j^*\right), \pi \mu_j (N) - N\right\}$$

Also,

$$\pi = \left(1 - \frac{1}{\chi}\right) \frac{\alpha_x}{(1 - \alpha_l - \alpha_x)}$$

hence, as $\alpha_l \to 1-\alpha_x$, $\pi \to \infty$. The researcher gets

$$\pi\mu_j(N)/z_{jt} - N$$

and $N > W = (1+r)w = 1+r$, so for constrained industries we need

$$\pi n^{-1}\left(\frac{1+r}{\kappa_j}\right) - (1+r) > 1$$

which is satisfied as long as α_l is sufficiently close to $1-\alpha_x$.

Alternatively, it may be that some industries are not finance-constrained even with $N=1$. Then, we require

$$\Pi_{jt} = \frac{(\chi-1)\alpha_x}{(1-\alpha_l-\alpha_x)}\mu_j^*/z_{jt} - n_j\left(\mu_j^*\right)/z_{jt} > 1$$

Since $\mu^* = n'^{-1}\left(\frac{\pi}{\kappa_j}\right)$, this becomes

$$\frac{(\chi-1)\alpha_x}{(1-\alpha_l-\alpha_x)}n'^{-1}\left(\frac{\left(1-\frac{1}{\chi}\right)}{\kappa_j}\frac{\alpha_x}{(1-\alpha_l-\alpha_x)}\right)$$
$$-n_j\left(n'^{-1}\left(\frac{\left(1-\frac{1}{\chi}\right)}{\kappa_j}\frac{\alpha_x}{(1-\alpha_l-\alpha_x)}\right)\right) > z_{jt}$$

Under the stated assumptions, Π_{jt} is increasing in π, so that again this inequality is satisfied as long as α_l is sufficiently close to $1-\alpha_x$.

That the economy should converge to a balanced growth path follows from the fact that μ_{jt} converges to a constant in all industries. Proposition 1 then implies (as in Ngai and Pissarides (2007)) that, as $t \to \infty$, there is one industry the nominal share of which converges to unity – which will be $\arg\max_j \left\{\lim_{t\to\infty} \frac{z_{j,t+1}}{z_{jt}} g_j\right\}$ if $\varepsilon > 1$ and $\arg\min_j \left\{\lim_{t\to\infty} \frac{z_{j,t+1}}{z_{jt}} g_j\right\}$ if $\varepsilon < 1$. ■

Proof of Propositions 3 **and** 4**.** Follows from the analysis of Regions $1-3$. ■

Proof of Proposition 5**.** Some preliminary derivations. Note that if $\tilde{n}_j(\mu) = \kappa_j n(\mu)$, then $\tilde{\mu}(x) = n^{-1}\left(\frac{x}{\kappa_j}\right)$, so

$$\begin{aligned}
\tilde{\mu}'(x) &= \frac{1}{\kappa_j}\frac{dn^{-1}(z)}{dx}|_{z=x/\kappa_j} \\
\tilde{\mu}'(x) &= \frac{1}{\kappa_j}\left[\frac{dn(\mu)}{dx}\right]^{-1} \\
\tilde{\mu}''(x) &= \left(\frac{1}{\kappa_j}\right)^2 \frac{d^2 n^{-1}(z)}{dx^2}|_{z=x/\kappa_j} < 0.
\end{aligned}$$

There are two effects intermediating between changes in F_k and changes in Z_j. First,

$$\gamma_{FA} = \left[\frac{1}{z_{j,t-1}} - \frac{1}{g_{jt}}\right]\left(\omega_{FA}(F,A)\, z\tilde{\mu}'(\omega(F,A)\, z) + \omega_A(F,A)\,\omega_F(F,A)\, z^2\tilde{\mu}''(\omega(F,A)\, z|\kappa)\right)$$

Both terms have the same sign, I think, as $\omega_{FA}(F, A(\kappa)) < 0$ and $\tilde{\mu}''(\omega(F, A(\kappa))\, z) < 0$. Presumably $\left[\frac{1}{z_{j,t-1}} - \frac{1}{g_{jt}}\right] > 0$, so γ_{FA} is negative. If we have measures of *in*ability, the coefficients should be positive. ∎

Proof of Proposition 6. If (F, A) are such that the industry is in Region 1, then the derivative is zero. Hence, suppose that (F, A) puts the industry in Regions 2 or 3. Note that

$$\gamma_{jt} = \tilde{\mu}_j(\omega(F,A)\, z_{j,t-1})\left[\frac{1}{z_{j,t-1}} - \frac{1}{g_j}\right] + \frac{1}{g_j}, \tag{41}$$

$$\Rightarrow \gamma_F = \omega_F(F,A)\, z\tilde{\mu}_j'(\omega(F,A)\, z)\left[\frac{1}{z} - \frac{1}{g_j}\right]. \tag{42}$$

Deriving this expression with respect to κ yields $\frac{\partial^2\gamma_{jk}}{\partial F_k \partial\kappa_j} = Q_1 + Q_2$, where

$$Q_1 = (1+r)\, v_F(F,A)\, z_j \frac{d\tilde{\mu}_j'([(1+r)\, v(F,A_j)\, z_j])}{d\kappa}\left[\frac{1}{z_j} - \frac{1}{g_j}\right] < 0.$$

$$Q_2 = \frac{\partial g_j}{\partial\kappa_j}(1+r)\, v_F(F,A)\, z_j\tilde{\mu}'[(1+r)\, v(F,A_j)\, z_j]\frac{1}{g_j^2} < 0.$$

To verify that $\frac{d\tilde{\mu}_j'(x)}{d\kappa} < 0$, $\tilde{\mu}_j(x) = \tilde{\mu}\left(\frac{x}{\kappa}\right)$, $\tilde{\mu}_j'(x) = \frac{1}{\kappa}\tilde{\mu}'\left(\frac{x}{\kappa}\right)$ and

$$\frac{d\tilde{\mu}_j'(x)}{d\kappa} = -\frac{1}{\kappa^2}\tilde{\mu}'\left(\frac{x}{\kappa}\right) + \frac{1}{\kappa}\tilde{\mu}''\left(\frac{x}{\kappa}\right) < 0.$$

∎

C Parameters

The parameters in Figure 5 are $\alpha_l = 0.5$, $\alpha_x = 0.49$, $\chi = 1.5$, $\sigma = 0.1$, $\tilde{n}_j(\mu) = -\kappa_j \log(1-\mu)$, $\kappa_j \in \{8, 11, 14\}$, $\varepsilon = 3$, $\xi_j \in \{0.364, 0.364, 0.273\}$, $v = F$, $F \in \{1, 13\}$. The initial conditions are $z_0 = [0.45, 0.40, 0.50]$. Parameters are the same in Figure 6, except that $z_0 = [0.15, 0.34, 0.5]$.

D Empirical specification

Recall that $z_{jt} = H_j(z_{j,t-1})$. Then,

$$\gamma_{jk} = H_j(z_{j,t-1})/z_{j,t-1} = \frac{\mu_{jt}}{z_{j,t-1}} + \frac{[1-\mu_{jt}]}{g_{jt}}$$

H_j is a kinked function. Define $\hat{\mu}_j(.)$ as a smooth approximation to μ_{jt}. $\hat{\mu}_j(\omega z)$ is twice-differentiable and strictly increasing up to the value of F in the benchmark country. Also, $\hat{\mu}'_j(\omega z) = 0$ for higher values of ω, but $\left\|\hat{\mu}_j(\omega z) - \mu_{jt}\right\| < \epsilon$ for some small $\epsilon > 0$ (this approach is as in Aghion et al (2005)). Then let

$$\Gamma(F, \kappa, A, z) = \frac{\hat{\mu}_j(\omega z)}{z_{j,t-1}} + \frac{[1-\hat{\mu}_j(\omega z)]}{g_{jt}}$$

so that Γ is a smooth approximation to γ. We take a second order Taylor approximation of the function Γ around some industry with $\kappa_j = \kappa^*, A_j = A^*$, evaluated at some level of financial development F^* and initial conditions z^* (such as those corresponding to the benchmark country):

$$\begin{aligned}
\Gamma(F, \kappa, A, z) \simeq\ & \Gamma(F^*, \kappa^*, A^*, z^*) + \Gamma_z(F^*, \kappa^*, A^*, z^*)(z - z^*) \\
& + \Gamma_F(F^*, \kappa^*, A^*, z^*)(F - F^*) \\
& + \Gamma_\kappa(F^*, \kappa^*, A^*, z^*)(\kappa - \kappa^*) \\
& + \Gamma_A(F^*, \kappa^*, A^*, z^*)(A - A^*) \\
& + \frac{1}{2}\Gamma_{zz}(F^*, \kappa^*, A^*, z^*)(z - z^*)^2 \\
& + \frac{1}{2}\Gamma_{FF}(F^*, \kappa^*, A^*, z^*)(F - F^*)^2 \\
& + \frac{1}{2}\Gamma_{\kappa\kappa}(F^*, \kappa^*, A^*, z^*)(\kappa - \kappa^*)^2 \\
& + \frac{1}{2}\Gamma_{AA}(F^*, \kappa^*, A^*, z^*)(A - A^*)^2
\end{aligned}$$

$$
\begin{aligned}
&+\frac{1}{2}\Gamma_{\kappa\kappa}\left(F^*,\kappa^*,A^*,z^*\right)\left(\kappa-\kappa^*\right)^2 \\
&+\frac{1}{2}\Gamma_{AA}\left(F^*,\kappa^*,A^*,z^*\right)\left(A-A^*\right)^2 \\
&+\Gamma_{zF}\left(F^*,\kappa^*,A^*,z^*\right)\left(z-z^*\right)\left(F-F^*\right) \\
&+\Gamma_{z\kappa}\left(F^*,\kappa^*,A^*,z^*\right)\left(z-z^*\right)\left(\kappa-\kappa^*\right) \\
&+\Gamma_{F\kappa}\left(F^*,\kappa^*,A^*,z^*\right)\left(F-F^*\right)\left(\kappa-\kappa^*\right) \\
&+\Gamma_{FA}\left(F^*,\kappa^*,A^*,z^*\right)\left(F-F^*\right)\left(A-A^*\right) \\
&+\Gamma_{zA}\left(F^*,\kappa^*,A^*,z^*\right)\left(z-z^*\right)\left(A-A^*\right) \\
&+\Gamma_{\kappa A}\left(F^*,\kappa^*,A^*,z^*\right)\left(\kappa-\kappa^*\right)\left(A-A^*\right)
\end{aligned}
$$

where Γ_x equals the derivative of Γ with respect to x and Γ_{xy} equals the derivative of Γ with respect to x and y. This reduces to:

$$
\begin{aligned}
\Gamma\left(F,\kappa,A,z\right) \;=\;& B_j+B_k+\beta_z z_{jk}+\beta_{z^2}z_{jk}^2+\beta_{z\kappa}z_{jk}\kappa_j+\beta_{zA}z_{jk}A_j \\
&+\beta_{Fz}F_k z_{jk}+\beta_{F\kappa}F_k\kappa_j+\beta_{FA}F_kA_j+\epsilon_{jk}
\end{aligned} \tag{43}
$$

as all terms except those involving interactions and the initial conditions z_{jk} are country- or industry-specific and will be soaked up by industry and country indicator variables (B_j and B_k). The remaining terms are interaction terms, multiplied by their cross-derivatives.

Now, recall that research intensity is some function of κ, so $\kappa = f\left(RND\right)$ where $f' < 0$ over the range of interest. Then, again using a Taylor approximation,

$$
\kappa_j \simeq f\left(RND^*\right) - f'\left(RND^*\right)RND^* + f'\left(RND^*\right)RND_j \tag{44}
$$

where $RND^* = f^{-1}\left(\kappa^*\right)$. Using equation (44) to replace κ_j with RND_j yields an equation of the same form as (43) except that all the interaction terms involving κ_j become interaction terms involving RND_j, and these terms have the opposite sign of the interaction terms involving κ_j:

$$
\begin{aligned}
\Gamma\left(F,\kappa,A,z\right) \;=\;& B_j+B_k+\beta_z z_{jk}+\beta_{z^2}z_{jk}^2+\beta_{z,RND}z_{jk}RND_j+\beta_{zA}z_{jk}A_j \\
&+\beta_{Fz}F_k z_{jk}+\beta_{F,RND}F_kRND_j+\beta_{FA}F_kA_j+\epsilon_{jk}
\end{aligned} \tag{45}
$$

Noting that $\log\gamma \simeq \gamma - 1$, replacing the expression for $\log\gamma$ in equation (23) with (45) yields equation (24).

E Alternative Model Specifications

A Equilibria in which $N_t^e \geq N_t^r$

We have focused on parameters under which entrepreneurs are on the short end of the market in equilibrium ($N_t^e < N_t^r$). In this case, the value of starting a firm is constant over time and across industries. Since the entrepreneur's share of profits is constant too, changes over time in relative prices equal inverse changes in relative productivities. If $N_t^e \geq N_t^r$, then some of the equilibrium returns from R&D would accrue to entrepreneurs. Let us refer to this possibility as "research pass-through." With research pass-through, changes over time in goods prices would reflect both changes over time in productivity and (to some extent) changes over time in the returns to R&D. This would also be true if we had a single agent both creating firms and conducting research, rather than distinguishing between entrepreneurs and researchers. For a given R&D expenditure, profits are higher in R&D intensive industries (lower κ_j) as the rate of success μ_j is higher for a given amount of R&D spending. Also, for a given *change* in R&D expenditure (resulting from a loosening of financing constraints), profits will increase more in R&D intensive industries, *caeteris paribus*. Since prices adjust so that entrepreneurs are indifferent between industries, research pass-through implies that R&D intensive industries display disproprotionately large declines in their output prices in financially developed economies. Hence, allowing for research pass-through should strengthen the results in Proposition 6, as relaxing financial constraints would once again particularly cheapen goods in research-intensive industries. While research pass-through is a phenomenon of interest, its presence renders the model no longer analytically tractable.

B Multiple limiting industries

It is straightforward to extend the model to allow several industries to persist in the limit (as opposed to just one). For example, suppose that the set of J industries is split into $N \geq 1$ broad sectors (e.g. manufacturing vs. services), $\{J_1, ..., J_N\}$, where $\cup_{n=1}^N J_N = J$. Then, let agents have the following preferences:

$$c_t = \left[\prod_{n=1}^{N} \frac{c_{nt}}{\eta_n}\right]^{\eta_n}, \quad \sum_{n=1}^{N} \eta_n = 1, \tag{46}$$

where

$$c_{nt} = \left[\sum_{j \in J_n} \xi_{nj} c_{jt}^{\frac{\varepsilon_n - 1}{\varepsilon_n}}\right]^{\frac{\varepsilon_n}{\varepsilon_n - 1}}, \quad \sum_{j=1}^{J} \xi_{nj} = 1. \tag{47}$$

Then it is straightforward to show that our analysis applies in this context except that the limiting structure of an economy without financing constraints would feature N industries. The share of GDP of each sector is constant over time and equal to η_n, but there would be structural change within each sector. If $\varepsilon_n > 1$ $\forall n$, then the limiting industry *within each sector* would be the industry with the highest rate of frontier productivity growth. For example, as discussed in Section IV, if we interpret broad sectors as manufacturing vs. services the data of Jorgenson et al (2007) indicate that for both sets of industries value added growth is positively correlated with industry TFP growth, consistent with the assumption that $\varepsilon_n > 1$. For this environment Propositions 5 and 6 would continue to hold among industries within the same sector. This is also true if preferences across the output of broad sectors have constant but non-unitary elasticity of substitution.