

A Multi-industry Model of Growth with Financing Constraints

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Abstract

We develop a general equilibrium multi-industry model in which firms use external funds to conduct productivity-enhancing R&D. Industries differ in terms of research costs, which lead them to different optimal research expenditures. In the model, more R&D-intensive industries require more external funding, and tend to grow relatively faster in more financially developed environments – consistent with empirical evidence. As a result, industry composition and the level of financial development have joint implications for aggregate growth and for equilibrium patterns of structural change. Aggregate growth in a financially underdeveloped economy converges to that in a frictionless benchmark economy, so long as its fastest-growing industry is not financially constrained. We show that equilibrium industry dynamics in the model can be approximated using a differences-in-differences industry growth regression that links financial development to industry growth.

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1 Introduction

The empirical evidence suggests a link between financial development and economic growth. Moreover, the impact of financial development appears to vary significantly across industries.¹

The finance-growth link has been modeled extensively, but mainly in a one-sector context.² A multi-industry model of the finance-growth nexus is desirable for several reasons. First, a multi-sector framework is required to understand the *aggregate* implications of differences in industry growth rates due to financial development. The industry evidence is viewed as being less subject to potential endogeneity problems than aggregate analysis of the growth-finance link, yet its aggregate implications remain unexplored. Second, industry growth differences necessarily result in *structural change*, and patterns of structural change along the economy's growth path can only be characterized in a multi-sector framework. Third, such a framework would be useful for identifying different *channels* through which financial development affects industry growth.

This paper develops a model in which agents raise external funds to pursue R&D that allows them to move closer to the productivity frontier in each industry. Industries differ in terms of the cost of research activity, and in terms of the tightness of financing constraints. The cost of research is increasing in the gap between the current state of technology and the frontier, as in Jovanovic and Nyarko (1996). In the model, optimal R&D spending determines the *need* for external funds and the growth rate of the industry productivity frontier, consistent with empirical evidence. The extent to which agents are *able* to borrow may vary across industries, and is determined by the level of financial development as well as by industry characteristics. Industry growth differences emerge from the interaction of industry parameters and financial development. We use the equilibrium behavior of the model to characterize these interactions, and to derive aggregate implications. A key element of the model that allows us to derive analytical results is the presence of a "benchmark" economy, where there are no financing constraints and to which other economies may or may not converge in equilibrium.

We adopt a research-based growth framework for several reasons. First, there

¹Rajan and Zingales (1998) find that industries that draw more on external funds tend to grow relatively slower in financially underdeveloped economies. Other studies of the impact of finance on industries include Carlin and Meyer (2003), Claessens and Laeven (2003) and Klingebiel, Kroszner and Laeven (2007). See Levine (2005) for a survey of the literature on finance and growth.

²See for instance Greenwood and Jovanovic (1990), Bencivenga and Smith (1991), De la Fuente and Marín (1996), Morales (2003), Aghion, Howitt and Mayer-Foulkes (2005) – the latter being the most closely related.

is a pervading sense that country differences in aggregate output are mainly due to productivity differences – see Easterly and Levine (2001). Second, Cohen and Levinthal (1990) and Griffith, Redding and Van Reenen (2004) find that a key function of research activity is the adoption of technologies developed elsewhere, even in developed economies. Third, Carlin and Meyer (2003), Hall (2005) and others show that research activity is highly sensitive to the financial environment. This evidence suggests that financial development could affect aggregate outcomes through its impact on the ability of firms to absorb knowledge by conducting research, as proposed in Aghion, Howitt and Mayer-Foulkes (2005). Since industries are known to differ widely in terms of research activity, this suggests that the process of technology transfer may be key to understanding why there are *industry differences* in the impact of financial development on growth.

Our results are as follows. Financially constrained economies can fall into a development *trap* – whereby an economy fails to converge to the level of GDP in a financially unconstrained economy – as well as a development *sink*, whereby it may diverge in growth rates as well. The trap and sink feature in the related one-sector model of Aghion, Howitt and Mayer-Foulkes (2005), where financial constraints may allocate fewer resources to R&D than are necessary for convergence to the frontier. However, the reasons behind these results in a multi-industry context are different. If a given industry falls behind its technological frontier (due to institutional or other factors), this need not affect aggregate outcomes in the long-run if resources are reallocated to *other* industries in response. As in Ngai and Pissarides (2007), long-term structural change in our model is driven by differences in industry productivity growth rates so that, after a point, the economy becomes increasingly specialized.³ Thus, aggregate incomes converge for all countries except those in which financial development is low enough that the industry that dominates in the long run in the benchmark economy is financially constrained. Reasonable parameterizations of the model suggest that, among manufacturing industries, the industry that dominates in the long run is the one that experiences the most rapid productivity growth.

Another contribution of our model is to distinguish between several *channels* through which R&D and financial development might interact in the process of convergence.

³Given the importance of research for technology transfer, the Ngai and Pissarides (2007) mechanism is a natural candidate for analyzing structural change resulting from the finance-growth interaction. This is, to our knowledge, the first study of the potential policy implications of their mechanism. There are other possible reasons for structural change, including non-homothetic preferences as in Kongsamut, Rebelo and Xie (2001) and differences in input shares as in Acemoglu and Guerrieri (2008): how they might interact with financial development is an open question.

- *Need*: R&D intensive industries tend to be more dependent on external finance, which means that any limit on borrowing is more likely to "bind" in R&D intensive industries.
- *Catch-up*: R&D intensive industries are known to experience more rapid productivity growth. Thus, a reduction of R&D activity may lead firms in such industries to fall disproportionately far behind the frontier, so that credit constraints limiting R&D may especially delay convergence in such industries.
- *Ability*: R&D-intensive industries may be intrinsically less able to raise funds. There is no presumption in the model that ability and research activity are linked, but the literature often assumes this – for example, because R&D generates intangible assets, which are inherently difficult to collateralize, or because it is subject to problems of asymmetric information.

Each of these channels leads financial underdevelopment to suppress growth particularly in research-intensive industries. The resulting patterns of structural change provide an account for the empirical finding in Rajan and Zingales (1998) – that industries that draw most on external funds 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, we show that the differences-in-differences regression specifications in these papers can be interpreted as Taylor approximations to the equilibrium dynamics of the model economy. We find that industry R&D intensity (as measured among publicly-traded firms in the United States) interacts with several measures of financial development, as predicted by the model. However, we also find a strong relationship at the industry and firm levels between R&D intensity and measures of the ability to raise external funds. We conclude that R&D intensive industries grow disproportionately faster in financially developed economies, at least partly because financial development overcomes intrinsic difficulties they experience with raising funds.

Section 2 introduces the model, and Section 3 characterizes the equilibrium dynamics of industry productivity change and aggregate growth. Section 4 explores the relationship between the model and industry growth data.

2 Economic Environment

Time is discrete and indexed by $t \in \mathbb{N}$. The model economy produces $J \in \mathbb{N}$ types of final good. There is a world productivity frontier Z_{jt}^* for the production of each

good j , which expands over time by an industry-specific factor $g_j > 1$. Knowledge spillovers are unlimited in the sense that the technological frontier in industry j is the same in all countries: however, each firm can adopt the frontier technology only by means of research activity. Thus, R&D determines the firm's ability to absorb knowledge, as in Cohen and Levinthal (1990) and Griffith, Redding and Van Reenen (2004).

Agents live for two periods. When they are young, they supply labor to a competitive market, and choose to become entrepreneurs, researchers, or to remain workers when old. Entrepreneurs may establish a firm in any industry, hire workers and purchase research services. Researchers may use borrowed funds to conduct firm-specific R&D. If research succeeds, the firm moves closer to the technological frontier. However, there is a limit on how much researchers can borrow, and this limit is increasing in the level of financial development.

The industry productivity frontier is common to all: however, 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 for the firm they are matched with.

2.1 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. The discount factor is $\beta < 1$.

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

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

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

An agent born in period t solves

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

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

$$U(c_t, l_t) = c_t - \lambda l_t. \quad (3)$$

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:

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

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:

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

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

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

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

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

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

2.2 Production

2.2.1 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

$$y_{jt} = l_{jt}^{\alpha_l} \int_0^1 Z_{jt}(i)^{1-\alpha_x} x_{jt}(i)^{\alpha_x} di, \quad (4)$$

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 also. A firm's average productivity is defined as:

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

When a new firm is established, it randomly imitates a firm that was active in the previous period, as in Luttmer (2007) or Gabler and Licandro (2008).

2.2.2 Intermediate goods

Intermediate goods need to be customized to enable a given firm to use these goods 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 intermediate⁴ 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 potential 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, production will take place under perfect competition, also at price $p_{jt}(i) = \chi q_{jt}$.

Profits from production are:

$$\theta_{jt} = \max_{l_{jt}, x_{jt}} \left\{ q_{jt} y_{jt} - w_t l_{jt} - \int x_{jt}(i) p_{jt}(i) di \right\} \quad (5)$$

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

⁴Since $x_{jt}(i)$ requires good j for its production, this cost structure may be interpreted in at least three ways: (1) literally in terms of intermediate use of good j , in which case the assumption is consistent with the fact that input-output 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 $y_{jt} - \int [\mu_{jt}(i) + \chi(1 - \mu_{jt}(i))] x_{jt}(i) di$ where $\mu_{jt}(i) = 1$ if research on i was successful and $\mu_{jt}(i) = 0$ otherwise.

$$\pi_{jt} = x_{jt}(i)(\chi - 1)q_{jt}. \quad (6)$$

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 leading 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 , "average" productivity at the firm level evolves according to:

$$Z_{jt} = Z_{jt}^* \mu_{jt} + Z_{j,t-1} (1 - \mu_{jt}) \quad (7)$$

Define the firm's **relative productivity** 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, (7) can be rewritten:

$$z_{jt} = \mu_{jt} + \frac{(1 - \mu_{jt})}{g_j} z_{j,t-1}. \quad (8)$$

2.3 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. Then, agents are matched according to the function

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

where N_t^e is the number of entrepreneurs and N_t^r is the number of researchers. In the remainder of the paper we focus on the case in which $N_t^e \leq N_t^r$, and derive conditions under which this holds in equilibrium.⁵

Researchers are able to customize intermediates for the firm they are matched with. Customized intermediates are used at the frontier productivity $Z_{j,t}^*$, 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} . The research cost equals $\tilde{n}_j(\mu_{jt})/z_{j,t-1}$ units of labor⁶ so that, as in Jovanovic and Nyarko (1996), the research cost is increasing in the gap between the current state of technology and the frontier – which is larger for lower $z_{j,t-1}$.

Industries vary in terms of the R&D cost function $\tilde{n}_j(\cdot)$. Specifically, we assume that there is an industry-specific parameter $\kappa_j > 0$ that scales the cost of research, so $\tilde{n}_j(\mu_{jt}) = \kappa_j n(\mu_{jt})$. The function $n(\cdot)$ satisfies $n(0) = 0$ and $\lim_{\mu \rightarrow 1} n(\mu) = \infty$. 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} . This does not necessarily mean that κ_j is positively linked to equilibrium research intensity, as this will also depend on the optimal choice of μ_{jt} in each industry. However, in the data research intensity and productivity growth rates are positively correlated and later we show that, over the parameter range that yields this property, κ_j is *negatively* related to R&D intensity.

If π_{jt} is the revenue from research success in any given intermediate variety i , a researcher chooses μ to maximize

$$\begin{aligned} \Pi_{jt} &= \max_{\mu} \{ \pi_{jt} \mu - \tilde{n}_j(\mu) / z_{j,t-1} \} \\ &\quad s.t. \\ &\quad \tilde{n}_j(\mu) / z_{j,t-1} \leq L_t \end{aligned} \tag{9}$$

where L_t are the funds available to the researcher to pay for labor (through savings or credit).

⁵Thus, researchers do not know which industry they will end up in, and may end up unmatched. Under this assumption, the value of starting a firm always equals 1 and, since the entrepreneur's share of profits is constant, changes over time in relative prices equal inverse changes in relative productivities. This assumption enables analytical characterization of the model in transition.

⁶This labor must be hired, because the researcher's labor was already used to create the lab.

Let W_t be a researcher's wealth. An agent can borrow only up to some multiple $v \geq 1$ of her wealth. Thus, $L_t = vW_t$. Since in their youth researchers earn at most w_t , their wealth when old is $W_t \leq w_t(1+r)$.

The borrowing limit v may vary across countries and industries. Specifically, let $v = v(F, A_j)$, where F is the level of financial development and A_j is an index of industry-specific technological characteristics.

Definition 1 *Parameter F is the level of **financial development**, representing the quality of institutions that enable transparency and disclosure, so that a higher level of financial development improves access to external finance for any industry j , i.e., $\frac{\partial v(F, A_j)}{\partial F} > 0$ for any A_j (defined below).⁷*

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 can be interpreted as a reduced form of the features of the production function such as factor intensities, factor elasticities or input characteristics. For example, in the model of Kiyotaki and Moore (1997), industries that use more fixed assets may have less difficulties raising external funds in a financially underdeveloped country because durable assets can serve as collateral. See Ilyina and Samaniego (2008) for a survey of the 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.

2.4 Technological frontier

We assume the existence of a "*leading economy*", where financial development is at some level F^* that is sufficiently high that credit constraints are not binding in any

⁷Aghion, Howitt and Mayer-Foulkes (2005) derive a credit constraint of this form on the basis of a moral hazard problem. In this case, higher F implies that it is more costly for borrowers to withhold the returns from research.

industry. If financing constraints are non-binding, the solution to (9) is such that $\mu_{jt} \rightarrow \mu_j^*$ and $z_{jt} \rightarrow z_j^*$. We assume also that in the *leading economy* $\mu_{jt} = \mu_j^*$, $z_{jt} = z_j^* \forall j, t$. For all other countries, initial conditions are such that $z_{j0} \leq z_j^* \forall j$.

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

$$g_j = \sigma \mu_j^* + 1, \sigma > 0. \quad (10)$$

Thus, R&D is carried out to produce output using the frontier level of knowledge, but in the leading economy research also has the effect of pushing the frontier forward, via spillovers from applied research.

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

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 leading economy: $D_j \equiv \frac{\kappa_j n(\mu_j^*)/z_j^* + l_{jt} + \int x_{jt}(i)p_{jt}(i)di - W}{\kappa_j n(\mu_j^*)/z_j^* + l_{jt} + \int x_{jt}(i)p_{jt}(i)di}$, where W is the amount of internal funds.*

Hence, R&D intensity and the need for external funds are positively related, i.e., higher RND_j entails higher D_j . Moreover, it can be shown that for certain values of parameter κ_j , R&D intensity is positively linked to productivity growth in the leading economy, consistent with the evidence in Terleckyj (1980) and others:

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 later on will be shown to be empirically relevant in that it is consistent with a positive empirical relationship between research spending and productivity growth across industries.

2.5 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 $\Theta_{jt} = \Theta_t \forall j$. Suppose that $N_t^r \geq N_t^e$. Old agents are

indifferent between research and entrepreneurship, so that $\Theta_t = \frac{\sum_j M_{jt}\Pi_{jt}}{N_t^r}$ and, since 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, we require that

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

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

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

The total value of final goods produced in any industry is

$$V_{jt} = q_{jt}c_{jt}$$

and total income from research is $V_t^R = \sum_j M_{jt}\pi_{jt}\mu_{jt} - \sum_j M_{jt}\kappa_j n(\mu_{jt})/z_{jt}$. It is straightforward to verify that $Y_t^R = \sum_j V_{jt} + V_t^R$.

Current national income accounting procedures do not count R&D as part of GDP. In the discussion that follows, we assume that aggregate output is measured by $Y_t = \sum_j M_{jt}q_{jt}c_{jt}$. This approach will simplify our discussion. We return to the alternative notion of GDP later.

Feasibility and market clearing constraints are reported in Appendix A.

3 Model Equilibrium

This section derives the aggregate equilibrium behavior of the model economy, based on the impact of financing constraints on industry productivity dynamics.

3.1 Equilibrium research and productivity

We begin by characterizing the effect of credit constraints on equilibrium research activity. If the number of researchers is greater than or equal to the number of entrepreneurs ($N_t^r \geq N_t^e$), then the returns to entrepreneurship $\Theta_t = 1$. With the production technology exhibiting decreasing returns to scale, this condition determines the equilibrium link between goods prices and industry productivity.

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 accumulated wealth W_t , where for now we suppress the dependence of v upon F and A_j . Equivalently, since $W_t \leq 1 + r$, the entrepreneur is constrained if

$$\tilde{n}_j(\mu_j^*) > z_{j,t-1}v(1+r). \quad (11)$$

Characterizing equilibrium industry productivity dynamics amounts to characterizing the dynamics of a firm that invests the optimal level of research input, and the dynamics of a firm that devotes all available financial resources to research.

Let $\tilde{\mu}_j(\cdot)$ be the inverse of $\tilde{n}_j(\cdot)$. Suppose that v is very large – large enough that credit constraints do not bind. Optimal investment is given by the first order condition to problem (9). Relative productivity z_{jt} follows the law of motion $z_{jt} = H_j^1(z_{j,t-1})$ where, using (8), the function H_j^1 is given implicitly by

$$z_t = \tilde{\mu} \left(\frac{\pi z_{j,t-1}}{\kappa_j z_{j,t}} \right) + \frac{\left[1 - \tilde{\mu} \left(\frac{\pi z_{j,t-1}}{\kappa_j z_{j,t}} \right) \right]}{g_j} z_{j,t-1}. \quad (12)$$

Also, z_{jt} converges to the steady state value z_j^* where, using (8) and (10),

$$z_j^* \equiv \frac{\sigma \mu_j^* + 1}{\sigma + 1} < 1 \quad (13)$$

Suppose now that researchers devote their entire savings towards research. Then, $\mu_{jk} = \tilde{\mu}_j(v(1+r)z_{j,t-1})$. Productivity dynamics in this case are given by $z_{jt} = H_j^2(z_{j,t-1})$ where again using (8),

$$H_j^2(z_{j,t-1}) = \tilde{\mu} \left(\frac{v(1+r)z_{j,t-1}}{\kappa_j} \right) + \frac{\left[1 - \tilde{\mu} \left(\frac{v(1+r)z_{j,t-1}}{\kappa_j} \right) \right]}{g_{jt}} z_{j,t-1}. \quad (14)$$

Finally, since investment will not exceed the optimum,

$$z_{jt} = H_j(z_{j,t-1}) \equiv \min \{ H_j^1(z_{j,t-1}), H_j^2(z_{j,t-1}) \} \quad (15)$$

The function $H_j(z_{j,t-1})$ determines the link between credit 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 , whereas $H_j^2(\cdot)$ is strictly increasing in v for all $z_{j,t-1}$.
- (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 $z_{j,t-1} \in \{0, z^{**}\}$.
- (v) for sufficiently low v , $\lim_{z \rightarrow 0} \frac{dH_j^1(z)}{dz} > \lim_{z \rightarrow 0} \frac{dH_j^2(z)}{dz}$.

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

Region 1 For sufficiently high levels of F , $\mu_{jt} \rightarrow \mu_j^*$ and $z_{jt} \rightarrow z_j^*$. 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 , $\mu_{jt} \rightarrow \mu_j^*$ but $z_{jt} \rightarrow z_j^{**} < z_j^*$. 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 , $z_{jt} \rightarrow 0$, and productivity growth converges to a value below g_j that is increasing in F . Greater financial development within this range has a positive effect on *long-term* rates of productivity growth.⁸ See Figure 3.

⁸To see this, observe that productivity growth equals $g_j \frac{z_{j,t+1}}{z_{jt}}$ and that, in Region 3, $\lim_{t \rightarrow \infty} \frac{z_{j,t+1}}{z_{jt}} = \lim_{t \rightarrow \infty} \frac{\tilde{\mu}_{jt}}{z_{j,t-1}} + \frac{1}{g_j} = \frac{v(1+r)}{1-\alpha_x} \frac{1}{\kappa_j n'(0)} + \frac{1}{g_j}$, where v is increasing in F .

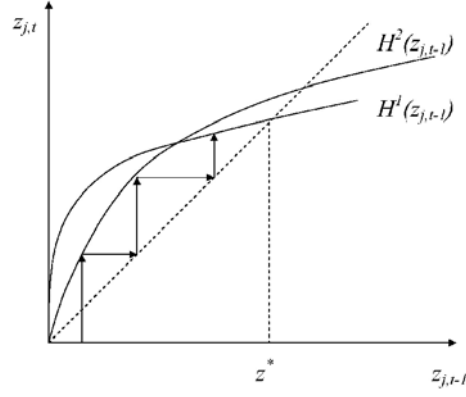


Figure 1 – Industry productivity dynamics, Region 1.
The function $H^1(\cdot)$ crosses $H^2(\cdot)$ an odd number of times in the range $(0, z^*)$.

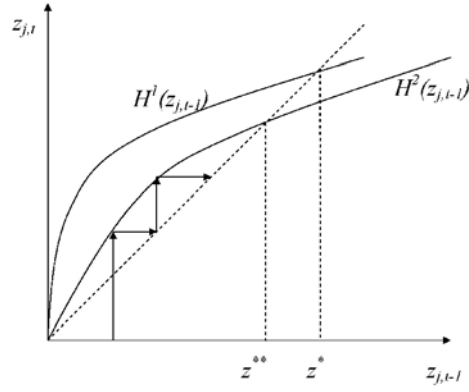


Figure 2 – Industry productivity dynamics, Region 2.
The function $H^1(\cdot)$ crosses $H^2(\cdot)$ an even number of times (or zero times) in the range $(0, z^{**})$.

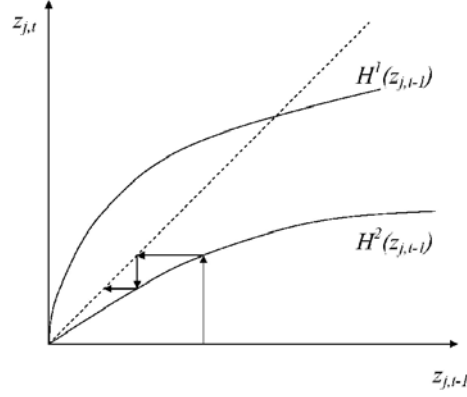


Figure 3 – Industry productivity dynamics, Region 3.
 If $H^1(\cdot)$ and $H^2(\cdot)$ cross, it is above z_j^* , and $H^2(\cdot)$ has no fixed point other than zero.

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 $F \in (\underline{F}_j, \bar{F}_j)$.⁹ When $\kappa_j \geq \kappa^*$, $\bar{F}_j$ is negatively related to κ_j , so that R&D intensive industries are more likely to be credit-constrained for a given borrowing limit v . This is because $\bar{F}_j$ is defined precisely by whether or not optimal R&D spending is attainable in the long run. Interestingly, if ability is constant, the relationship between κ_j and $\underline{F}_j$ is non-monotonic – see the left panel of Figure 4 for an illustration.. However, the data will later indicate a negative relationship between measures of ability and of research intensity (as is commonly assumed), suggesting a positive link between κ_j and A_j . In this case, $\underline{F}_j$ too may be decreasing in κ_j . This is displayed in the right-hand panel of Figure 4.¹⁰

⁹In 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 $\frac{\partial H_j^2(z)}{\partial z}|_{z=0} > 1$: $v \in \left(\frac{g_{jt}-1}{(1+r)\bar{\mu}_j'(0)g_{jt}}, \frac{\kappa_j n(\mu_j^*)}{(1+r)z_j^*} \right)$. In Region 3, then $\frac{\partial H_j^2(z)}{\partial z}|_{z=0} \leq 1$: $v \leq \frac{g_{jt}-1}{(1+r)\bar{\mu}_j'(0)g_{jt}}$.

¹⁰The parameters are $\alpha_l = 0.3$, $\alpha_x = 0.69$, $\chi = 1.5$, $\sigma = 0.5$, $\tilde{n}_j(\mu) = -\kappa_j \log(1 - \mu)$, $\varepsilon = 1.5$, $v(F_k, A_j) = (\eta F_k^v + (1 - \eta) A_j^v)^{1/v}$ and $A_j = \kappa_j$. We set $v = 1.5$. In the left panel $\eta = 1$ and in the right panel 0.97.

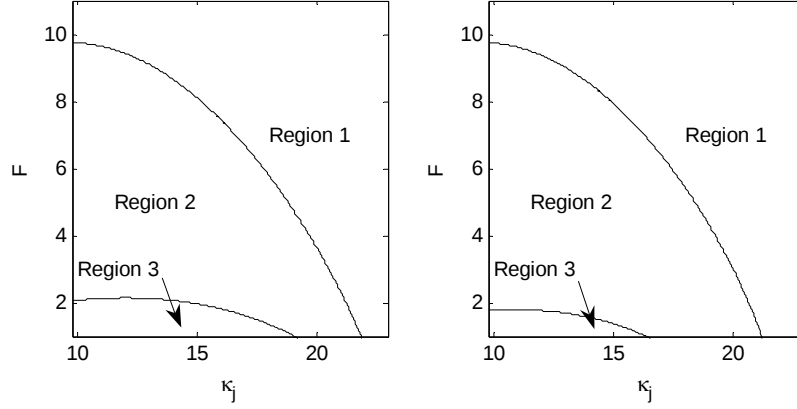


Figure 4 – Productivity dynamics for different values of the borrowing limit $v(F, A_j)$ and the research cost parameter κ_j , for $\kappa_j \geq \kappa^*$. Industry R&D intensity is negatively related to the parameter κ_j . The left panel assumes no relationship between κ_j and ability A_j . In the right panel A_j is positively related to 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 $\underline{F}_j$. Both lines are tilted downwards when ability A_j is linked to κ_j , so a strong enough link can lead $\underline{F}_j$ to be monotonic, as in the right panel.

3.2 Industry growth

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

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

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

Hence, solving the implications of the model for industry growth is equivalent to deriving the relationship between relative prices and relative productivities.

Proposition 1 *In equilibrium, for any $\varepsilon \neq 1$, there is structural change at the level of each industry such that*

$$\frac{G_{jt}}{G_{j't}} = \left(\frac{z_{j,t+1}}{z_{j',t+1}} / \frac{z_{j,t}}{z_{j',t}} \right)^{\varepsilon-1} \times \left(\frac{g_j}{g_{j'}} \right)^{\varepsilon-1} \quad (16)$$

As a share of GDP, industries grow or shrink relative to each other depending on the value of the elasticity of substitution ε and on relative productivity changes. Equation (16) decomposes industry productivity growth differences into differences in frontier growth rates – which are exogenous to the developing economy – and differences in convergence rates $\frac{z_{j,t+1}}{z_{j,t}}$.

3.3 Aggregate growth

Now we derive the aggregate implications of our industry level results.

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 *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 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 leading economy, respectively. For given initial conditions, financial development may affect G_t so long as *any single industry* is financially constrained. However, to characterize the long run effect of F we define:

Definition 5 *An economy is in a development **trap** if $\lim_{t \rightarrow \infty} \frac{G_t}{G_t^*} = 1$ and $0 < \lim_{t \rightarrow \infty} \frac{Y_t}{Y_t^*} < 1$.*

Definition 6 *An economy is in a development **sink** if $\lim_{t \rightarrow \infty} \frac{G_t}{G_t^*} < 1$.*

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

As in Ngai and Pissarides (2007), as $t \rightarrow \infty$ there is one industry the nominal share of which converges to unity – which will be $\arg \max_j \left\{ \lim_{t \rightarrow \infty} \frac{z_{j,t+1}}{z_{jt}} g_j \right\}$ if $\varepsilon > 1$

and $\arg \min_j \left\{ \lim_{t \rightarrow \infty} \frac{z_{j,t+1}}{z_{jt}} g_j \right\}$ if $\varepsilon < 1$. Define $j^* = \arg \max_j g_j$, so j^* is the industry with the highest rate of technical progress.¹¹

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

- i) an economy converges to the leading economy for $F \in [\bar{F}, \infty)$,*
- ii) an economy falls into a development trap for $F \in [\underline{F}, \bar{F})$, where $\lim_{t \rightarrow \infty} \frac{Y_t}{Y_t^*}$ is decreasing in F ;*
- iii) an economy falls into a development sink if $F \in [0, \underline{F})$.*

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

In the long run, Propositions 3 and 4 state conditions under which the economy may fall into a development trap or a development sink, which are similar to the "convergence clubs" of Aghion et al (2005).

However, the conditions under which financial development might affect long run growth rates are different in a multi-industry context. In this model, aggregate growth rates are affected not only by productivity differences across industries, but also by long run patterns of structural change. In particular, if $\varepsilon > 1$, resources shift away from industries with slow productivity growth, so that an economy falls into a development *trap* if and only if *the industry with the highest rate of technical progress falls in Region 2*. Similarly, if $\varepsilon > 1$, an economy falls into a development *sink* if and only if *the industry with the highest rate of technical progress falls in Region 3*.

3.4 Industry growth and patterns of structural change

Next we explore the implications of industry productivity dynamics for patterns of industry growth. To address this question, we analyze the impact of the industry's *ability* to raise external funds A_j and of the industry's *need* to raise external funds D_j on convergence dynamics for different initial levels of financial development F .

The following definitions will be useful in mapping the model into the data. Define $\gamma_j \equiv z_{j,t+1}/z_{jt}$ at a given date t , and for given initial conditions. Note that the industry productivity growth factor equals $\gamma_j g_j$. Recall from Proposition 1 that, if $\varepsilon > 1$, this maps monotonically into industry growth in nominal terms. We assume henceforth that $\varepsilon > 1$ and discuss the case of $\varepsilon < 1$ at the end of the paper.

¹¹Over the past four decades, according to the NBER productivity database, at the 3-digit SIC level this would be Computing and Office Machinery,

Consider a financially constrained industry. It is straightforward to show that $\frac{\partial \gamma_j}{\partial F} \geq 0$. We are interested in how the impact of financial development depends on industry parameters – in particular, the ability to draw on external funds A_j and the R&D cost parameter κ_j , which underlies both R&D intensity and the need to draw on external funds. It turns out that 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).

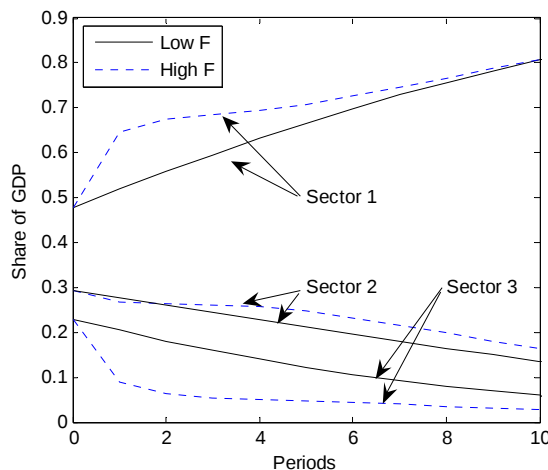


Figure 5 – Structural change in a model economy with three industries. The dotted line represents a financially unconstrained economy, and the solid line represents a financially constrained economy. Sector 1 has the lowest value of κ_j and Sector 3 has the highest.

Proposition 5 $\frac{\partial \gamma_j}{\partial F}$ is negatively related to ability A_j ($\frac{\partial^2 \gamma_j}{\partial F \partial A_j} \leq 0$).

Proposition 6 $\frac{\partial \gamma_j}{\partial F}$ is negatively related to the R&D cost parameter κ_j ($\frac{\partial^2 \gamma_j}{\partial F \partial \kappa_j} \leq 0$).

Hence, $\frac{\partial \gamma_j}{\partial F}$ is positively related to R&D intensity and to the need for external finance D_j , as well as to industry frontier growth g_j .

To distinguish among two channels underlying the result in Proposition 6, we can write $\frac{\partial^2 \gamma_{jk}}{\partial F_k \partial \kappa_j} = Q_1 + Q_2$, where the terms are written out in the appendix:

- Term Q_1 reflects the fact that the R&D cost function itself depends on κ_j . For lower values of κ_j , a change in available funds yields a larger change in R&D output (in terms of μ_{jt}), and hence a larger deceleration in convergence rates. We call this the *need* effect.
- Term Q_2 reflects the fact that the frontier growth path for any given industry varies systematically with κ_j . To the extent that firms do not perform successful R&D, their industry position relative to the frontier deteriorates at rate g_j . Since $\frac{\partial g_j}{\partial \kappa_j} < 0$ in the empirically relevant range, $Q_2 < 0$. We call this the *catch-up* effect.

The need effect is related to the finding of Rajan and Zingales (1998) that an interaction term between country financial development and the observed tendency of an industry to draw on external funds in a relatively frictionless environment carries a positive coefficient in an industry growth regression. From Lemma 1, this tendency is negatively related to κ_j .

The catch-up effect is related to the finding of Fisman and Love (2007) that an interaction term between country financial development and the observed industry growth rate in a relatively frictionless environment carries a positive coefficient in an industry growth regression. From Lemma 1, the industry growth rate is negatively related to κ_j .

There is a third possible channel of interaction between research activity and financial development. As mentioned, it is commonly thought that research projects face particular difficulties in raising external funds. This could be simply a statistical relationship, or could be linked to some (un-modelled) features of research-intensive industries, such as the intangibility of assets or asymmetric information. In terms of the model, this would imply a positive relationship between κ_j and A_j . In that case, the interaction between ability A and financial development F in Proposition 5 also implies that, $\frac{\partial \gamma_j}{\partial F}$ is positively related to R&D intensity, because R&D intensity is negatively related to ability A_j . We call this the *ability* effect.

Figure 5 displays the patterns of structural change implied by Proposition 6 for two different levels of financial development but the same initial conditions.¹² Structural change due to productivity growth is delayed in less financially developed economies, as growth is disproportionately lowered in those industries which would otherwise grow most rapidly: after about ten periods the structures of the two economies are similar, but in transition they may be quite different for a time.

¹²The parameters 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 $z_0 = [0.15, 0.34, 0.5]$.

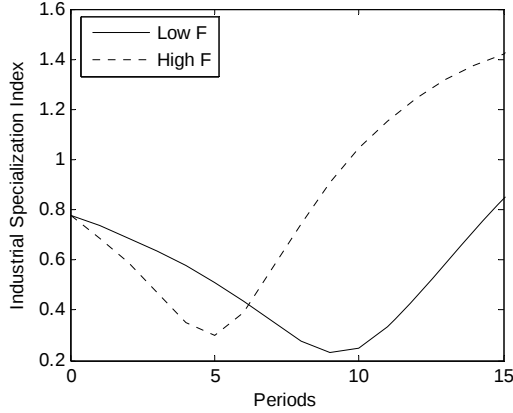


Figure 6 – Patterns of industrial specialization along the growth path. The index of specialization is the coefficient of variation among industry shares of GDP, as in Imbs and Wacziarg (2003).

To 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 develop, industrial specialization in terms of industry shares of manufacturing tends to decrease up until a certain point, after which specialization increases once more. The model economy is capable of displaying this pattern. Consider an economy that starts out relatively undiversified, specializing in certain industries as a result of resource endowments. If these are industries *other* than those that eventually grow to dominate the economy as a result of long-term structural change, the economy may display a "U" shaped specialization pattern over time. Industries with more rapid productivity growth gradually expand to dominate the economy: however, if those industries are initially relatively small, this will lead specialization to decrease until those industries have expanded enough to overtake other sectors.¹³ 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. Since financial development compresses industry productivity growth rates – suppressing growth especially in industries with the highest rates of frontier growth – structural change

¹³This 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.

resulting from industry differences in productivity growth rates is delayed. This pattern may occur regardless of the level of financial development: however, in a less financially-developed economy, industry differences in rates of technical progress are diminished, so that the process of structural transformation is drawn out over time as in Figure 6.

4 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 the model's equilibrium industry growth dynamics to derive a suggested regression specification. The specification is closely related to the differences-in-differences regression in Rajan and Zingales (1998), as well as other related work on financial development and industry growth. Then, we examine the empirical links between industry level R&D intensity, the need to raise external funds, and the ability to raise funds, as these links are important for verifying the structure of the model. Finally, we estimate the specification suggested by the model.

4.1 Decomposing Industry Growth

According to Equation (16), 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 distance from the knowledge frontier of industry j in country k . Also, let $\gamma_{jk}(F, z_{jk}, \kappa_j, A_j)$ be the growth rate of z_{jk} . Fixing an arbitrary industry j' as a benchmark, and suppressing time indices, (16) can be written:

$$\log G_{jk} = B_j + B_k + (\varepsilon - 1) \log \gamma_{jk}(F, z_{jk}, \kappa_j, A_j) \quad (17)$$

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 to equation (17). Recall that research activity in the leading economy and κ are negatively related in cross section. Hence, we can approximate equation (17) as:

$$\begin{aligned} \log G_{jk} = & B_j + B_k + \beta_{F,RND} F_k \times RND_j + \beta_{F,A} F_k \times A_j + \beta_{F,z} F_k \times z_{jk} \quad (18) \\ & + \beta_{RND,z} RND_j \times z_{jk} + \beta_{F,z} A_k \times z_{jk} + \beta_z z_{jk} + \beta_{z^2} z_{jk}^2 + \epsilon_{jk}. \end{aligned}$$

Here z_{jk} is an indicator of industry j 's initial condition in country k and RND_j is research intensity in industry j . Variables B_j and B_k are industry and country

dummies, that capture first order derivatives of $\gamma_{jk}(F, z_{jk}, \kappa_j, A_j)$ with respect to country and industry variables, as well as second order derivatives. The remaining coefficients relate to *cross*-derivatives among country and industry variables, or to derivatives with respect to initial conditions. See Appendix C for details.

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 leading economy. Thus, $z < 0$ implies that the industry is likely to expand along the growth path, whereas $z > 0$ implies that it is 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 $\beta_{F,A} < 0$.
- The coefficient $\beta_{RND,z}$ indicates whether R&D intensive industries are more or less likely to converge, for a given gap. The model has no prediction for the sign of $\beta_{RND,z}$: however, $\beta_{RND,z} < 0$ would indicate that, for a given gap z , research-intensive industries converge faster.
- The coefficient $\beta_{A,z}$ indicates whether industries with high financing ability are more or less likely to converge, for a given gap. The model has no prediction for the sign of $\beta_{A,z}$: however, $\beta_{A,z} < 0$ would indicate that, for a given gap z , more "able" industries converge faster.
- The coefficient $\beta_{F,z}$ indicates whether the rate of industry convergence is dependent on the level of financial development, as suggested by the model. The model does not predict the sign of $\beta_{F,z}$: however, $\beta_{F,z} < 0$ would indicate that financial development makes convergence more rapid particularly for industries that are further away from their share in the leading economy.
- β_z and β_{z^2} account for differences in initial conditions. If countries converge towards the industry structure of the leading economy, industries with $z < 0$ should be growing, and $z > 0$ shrinking, at rates that increase with the distance (see Figure 5). Hence, we expect that $\beta_z < 0$ and possibly $\beta_{z^2} > 0$.

It is worth noting that the regression specification in Rajan and Zingales (1998) is closely related to equation (18). They run the following industry growth regression:

$$\log G_j^k = \beta_j + \beta_k + \beta_{F,RND} F_k \times D_j + \beta_{Share} Share_{jk} + \epsilon_{jk} \quad (19)$$

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 . This is a restricted form of equation (18), assuming that the second order terms other than $\beta_{F,RND}$ equal zero, and replacing RND_j with external finance dependence. It also assumes that $Share_{jk}$ is an index of z_{jk} . The specification in Fisman and Love (2007) is identical to (19), replacing D_j with a measure of US growth (GR_j).¹⁴ The specification in Ilyina and Samaniego (2008) is also similar except that research intensity, rather than finance dependence, is interacted with financial development. Since the model suggests that all three of these variables (RND_j , D_j , GR_j) are positively related, the fact that all three papers find positive and significant coefficients for $\beta_{F,RND}$ validates the model structure. However, these correlations need to be verified, and (18) is more general than (19). Hence, in what follows, we verify that the full specification suggested by the model is indeed consistent with the data.

4.2 Data on countries

Industry growth is measured using the Industrial Statistics Database (INDSTAT3) provided by the United Nations Industrial Development Organization (UNIDO). The data cover the period 1990-1999. 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 using 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 development, used in the finance and growth literature since at least King and Levine (1993). For each country, financial development was averaged over the 1990s in order to reduce the effects of short-term fluctuations in economic or financial market conditions. Thus, we assume that a period equals one decade, to abstract from shorter-run factors.

For robustness, the paper also considers two kinds of measures of financial development other than deepening.¹⁵ The first kind includes outcome-based measures

¹⁴Fisman 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 fully 84%, suggesting that there is a long-term component also.

¹⁵Financial deepening in the model economy depends on initial conditions as well as F_k . We regressed financial deepening for the 41 countries on the 28 values of industry initial conditions z , and then tested whether the coefficients on z were jointly significantly different from zero. When there were no other dependent variables, an F-test accepted the null hypothesis with a P-value of 0.385. This suggests that initial conditions do not have a significant effect on deepening – possibly because a substantial fraction of deepening represents finance that is enabled by the institutions of

that are not themselves measures of financial deepening – specifically, measures of bank overhead in 1990 (*BANK*), and measures of the interest rate margin in 1990 (*MARG*), both drawn from Beck et al (2000). Larger values of each of these measures are associated with lower financial development, so they are multiplied by minus one.

The second kind of measure is survey-based. The World Economic Forum (2008) reports annual values for the perceived access to loans (*ACCS*) and financial market sophistication (*SOPH*) based on surveys of executives.¹⁶ These are not available for all countries, but the advantage is that the responses should be less affected by non-monotonicities in the development-deepening relationship.

4.3 Data on industries

Industry measures are constructed for the 28 manufacturing industries in INDSTAT3, using data on publicly traded firms in the United States. We seek measures of financing and research activity that are not themselves affected by financing constraints, and the depth, sophistication and transparency of US public financial markets may approximate the required environment in the absence of crisis conditions.

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 is how to measure expenditures. Rajan and Zingales (1998) examine only capital expenditures (DATA 128). However, it is important for the model to also consider research expenditures (DATA 46).¹⁷ Thus, our measure of D_j is similar to the Rajan and Zingales (1998) measure of external finance dependence, except that it also accounts for 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 use the median firm value as an index of industry D_j .

Research intensity (RND_j) is defined as R&D expenditures (DATA 46) divided

financial development but that is directed towards households, or towards uses other than R&D.

¹⁶ACCS 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)."

¹⁷We are not worried about double counting as research spending includes only current 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.

by total expenditures (defined as DATA 46 plus DATA 128). Again, the industry measure of RND is the median firm value.

We measure "benchmark" industry growth using the growth rate in sales at the median firm in each industry in Compustat (DATA 12), as suggested by Fisman and Love (2007) (GR_j).¹⁸

We also examine indicators of the ability of firms to use their assets as collateral, i.e. measures of $v(F, A_j)$ where F is the level of financial development faced by publicly traded firms in the United States.

First, several authors such as Kiyotaki and Moore (1997) have underlined the role of fixed assets in serving as collateral for loans. This suggests that one measure of A_j might be "asset fixity" (FIX_j), measured using the ratio of fixed assets to total assets in Compustat (DATA 8 divided by DATA 6), as in Braun and Larraín (2005). We measure FIX_j at the industry level using the median firm in each industry in Compustat.

Second, theory suggests that asymmetric information may hinder the ability of firms to raise external funds. Barron et al (1998) and Thomas (2002) argue that variability in analyst forecasts of earnings-price ratios may indicate more heterogeneity of information sets concerning a particular firm ($ASYM_j$). We take $ASYM_j$ as a measure of *inability*. These forecasts are available from the Institutional Brokers' Estimate System (IBES). Available forecasts are both short-term and long-term: we make use of long-term forecasts because the return to a current research project is not likely to materialize for many years. Again, we average the measure for each firm over the 1990s and take the median firm in each industry.

The related literature measures initial conditions using the industry share of manufacturing value added. We use the industry share minus the US industry share (drawn from INDSTAT3), as an indicator of how far the industry has yet to converge. However, results are insensitive to either approach.

All measures of financial development are normalized by their means and standard deviations. Industry indicators (such as R&D intensity) are also normalized by their means and standard deviations. In the tables that follow, one, two and three asterisks represent statistical significance at the 10%, 5% and 1% levels respectively.

¹⁸We 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 (16).

4.4 Empirical relationships among variables

First, we need to verify that certain assumptions of the model are empirically valid. One of these is that R&D intensity in the leading economy is positively related to the need for external finance. The second regards measures of ability. The third is that R&D intensity is positively related to the rate of industry growth in the leading country. The aim is to provide evidence for the existence of the three channels above relating research intensity to financial factors (need, ability and catch-up).

We find that RND_j and D_j are related: the cross-industry correlation between RND_j and D_j equals 0.85. Moreover, this is true not just at the industry level but also at the firm level, and not just for manufacturing industries but also for service sector industries, even controlling for industry fixed effects.¹⁹ See Tables 1 and 2.

TABLES 1 AND 2 ABOUT HERE

Measures of ability are also linked to RND_j . At the firm level, the measure FIX_j is strongly negatively correlated²⁰ 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.²¹

The R^2 of an industry regression of D_j , FIX_j and GR_j on RND_j is fully 68%. This suggests that need, ability and catch-up (as captured by the above measures) account for much – though not all – of the variation in research intensity across industries, providing the empirical background for the decomposition of any interaction between research and finance into separate effects.

For productivity growth differences to map into industry growth differences in the model economy requires that $\varepsilon > 1$ for the industries in question. One way for us to assess this is using equation (16). If $\varepsilon > 1$, equation (16) implies that the industry fixed effect B_j in an industry growth regression should be positively related

¹⁹Ilyina and Samaniego (2008) find that the same is true using the Rajan and Zingales (1998) measure of external finance dependence, which does not use R&D spending in its computation.

²⁰We also measure fixity in two other ways. We excluded cash and receivables 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 other activities. All measures of FIX_j were highly correlated amongst themselves, and results were broadly similar.

²¹When we did include $ASYM_j$ in the industry growth regressions, its interaction with financial development was never statistically significant. $ASYM_j$ may be a weak indicator of asymmetric information because analysts with views that strongly diverge from the median may under-report this divergence out of career concerns.

to growth in the leading country GR_j . Table 2 shows that the data support the prediction that B_j and GR_j are related. The model assumes that R&D intensity is positively related to industry growth in the leading country, and we find that this is also the case in the data.

4.5 Industry growth regressions

Results using financial deepening as a measure of financial development are reported in Table 3. 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 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 (18) 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 the model predictions.²² For robustness, we also repeated the regression with industry and country data for 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 $\beta_{z2} < 0$, consistent with a trend towards a uniform industry structure, with more rapid convergence the more the industry structure deviates from that in the US. The interaction terms $\beta_{RND,z}$, $\beta_{A,z}$ and $\beta_{F,z}$ are generally not significant and are of unstable sign: this is not inconsistent with the model as it does not predict the sign of any of these terms.

TABLES 3, 4 AND 5 ABOUT HERE

We conclude that the evidence supports the prediction of the model that R&D intensive industries grow relatively faster in more financially developed economies, and more tentatively that industries with low asset collateralizability grow relatively slower. There is also support for the ability channel – whereby research investments have a weaker ability to raise funds than other kinds of investments.²³

²²We also obtained these results when measuring R&D intensity as the average research spending divided by net sales as reported by the NSF, and also the median R&D intensity divided by sales in Compustat.

²³In 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

4.6 Discussion and extensions

The assumption $\varepsilon > 1$ is important to ensure that productivity dynamics map monotonically into output dynamics. If $\varepsilon < 1$ then some of the implications of our results for relative industry growth would be reversed – in particular, rapid industry productivity growth would map into relatively *slow* industry growth.

If $\varepsilon < 1$, some of our results concerning development traps would be affected too. 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 from the productivity frontier, it might grow even more slowly than the industry with the lowest g_j and hence eventually dominate instead. In this case, the distribution of ability A_j might matter for long run income convergence patterns, as it could play a role in the selection of the industry with the lowest rate of productivity growth in a given financially constrained economy.

It is worth noting that empirical work on industry growth builds on data for manufacturing industries, due to data limitations. Our model has been developed with an eye towards this literature. The model predicts a pattern of structural change leading to the increasing dominance of one industry over others: however, the share of manufacturing in U.S. GDP has been relatively constant over time. The model is simple to extend to be consistent with this feature of the data, without overturning our convergence results. For example, suppose that preferences are given by $c_t = c_{mt}^\eta c_{nt}^{1-\eta}$, where $c_{mt} = \left[\sum_{j=1}^J \xi_j c_{jt}^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}}$ is manufacturing and c_{nt} is non-manufacturing. The manufacturing share of GDP would be constant and equal to η , but the *composition* of manufacturing (and hence productivity growth in manufacturing) would vary over time in accordance with the model.

In the model economy, we have measured GDP without including R&D spending. This reflects common national accounting practice. However, if R&D spending were also counted, there are two reasons why it would not affect the results. The first is that R&D spending is small compared to the rest of GDP. The second is that industries with high productivity growth are those with high R&D spending. Hence,

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, although the interaction of RND_j was moreso. Thus, it appears that none of the measures of need, ability and "catch-up" on their own fully capture the possibly complex interactions between R&D and financial development.

as the share of GDP of these industries expands, their share of GDP accounting for R&D intensity expands also when $\varepsilon > 1$, so that counting R&D as part of GDP further underscores our results.

The model so far abstracts from international trade. If global goods markets are integrated, industry growth differences reflect not just changes in the domestic economy but changes in the economy's export patterns. Indeed, Beck (2002) finds evidence consistent with an influence of financial development on export patterns. A model with trade could be complicated by the possibility of international borrowing to finance current consumption in transition, but simplified in that the assumption $\varepsilon > 1$ might not be necessary – since industry productivity growth differences across countries might translate into differences in changes in shares of the industry at the world level, which could overcome the influence of country-level structural change due to ε . We leave this interesting extension for future work.

5 Concluding remarks

We present a multi-industry model of the link between financing constraints and economic growth. The model embodies the finding that the need to raise external funds appears related to research intensity. Equilibrium industry growth 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.

Interestingly, depending on parameters, 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. 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 at least two useful directions for future work. First, an open economy extension could be useful for understanding the impact of financial development on trade flows. Second, a model with productive risk might allow to study more carefully the theory of "stages of diversification." Third, our model assumes that the ability to raise funds is an exogenous industry factor, whereas a model with explicit informational frictions and with physical capital might allow for the endogenization

of ability.

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A Resource constraints

Because of the production structure in (4), 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:²⁴

$$M_{jt}y_{jt} = c_{jt} \frac{1}{1 - I_{jt}}. \quad (20)$$

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

$$2 \geq N_t^r + \sum_j M_{jt}(1 + l_{jt}) + \sum_j M_{jt}\kappa_j n(\mu_{jt})/z_{jt} \quad (21)$$

²⁴An 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 (20) holds.

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

$$\int_{i \in [t, t+1)} b_{it} di = 0. \quad (22)$$

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

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

B Proofs

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

$$x_{jt}(i) = Z_{jt}(i) \left(\frac{\alpha_x l_{jt}^{\alpha_x}}{\chi} \right)^{\frac{1}{1-\alpha_x}}. \quad (23)$$

For labor, the firm's FOC is

$$\alpha_l q_{jt} y_{jt} = l_{jt} w_t \quad (24)$$

Let labor be the numeraire, so that $w_t = 1$. Placing (23) into (4), 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 (24),

$$\alpha_l q_{jt} Z_{jt} l_{jt}^{\frac{\alpha_l}{1-\alpha_x}-1} \zeta = w \quad (25)$$

This implies that $\alpha_l q_{jt} Z_{jt} l_{jt}^{\frac{\alpha_l}{1-\alpha_x}-1} / w_t = 1$ 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 $\pi_{jt}(i) = \pi / \tilde{z}_{jt}$ 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 leading economy is $\kappa_j n(\mu_j^*)/z_j^*$ 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 $\lim_{\kappa_j \rightarrow \kappa^{**}} \mu_j^* = 0$, so that

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

On the other hand, $\lim_{\kappa_j \rightarrow 0} \kappa_j n(\mu_j^*)/z_j^* = 0$ 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

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

which is positive because $g > 1$ and $z < 1$. Then,²⁵ $H_z^2(0) = \omega_{jk} \tilde{\mu}'_j(0) + \frac{1}{g_{jt}}$, which is positive and finite as $\lim_{z \rightarrow 0} \tilde{\mu}'_j(\omega_{jk} z_{j,t-1}) > 0$.

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

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

²⁵Observe that $1 - \frac{1}{g_j} z_{j,t-1} > 0$ as $z_{j,t-1} < z_j^*$ and $\frac{1}{g_j} z_j^* = \frac{\mu_j^*}{g_j - 1 + \mu_j^*} < 1$.

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 $z < 1$.

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

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

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

$$\tilde{z}'_t = \left[\frac{\pi/\tilde{z}_t}{\kappa} - \tilde{z}'_t \frac{\pi \tilde{z}_{t-1}}{\kappa \tilde{z}_t^2} \right] \tilde{\mu}' \left[\frac{\pi \tilde{z}_{t-1}/\tilde{z}_t}{\kappa} \right] \left(1 - \frac{1}{g_{jt}} z_{j,t-1} \right) + \frac{[1 - \tilde{\mu} \left[\frac{\pi \tilde{z}_{t-1}/\tilde{z}_t}{\kappa} \right]]}{g_{jt}}. \quad (26)$$

so

$$\tilde{z}'_t = \frac{\frac{\pi/\tilde{z}_t}{\kappa} \tilde{\mu}' \left[\frac{\pi \tilde{z}_{t-1}/\tilde{z}_t}{\kappa} \right] \left(1 - \frac{1}{g_{jt}} z_{j,t-1} \right) + \frac{[1 - \tilde{\mu} \left[\frac{\pi \tilde{z}_{t-1}/\tilde{z}_t}{\kappa} \right]]}{g_{jt}}}{1 + \frac{\pi \tilde{z}_{t-1}}{\kappa \tilde{z}_t^2} \tilde{\mu}' \left[\frac{\pi \tilde{z}_{t-1}/\tilde{z}_t}{\kappa} \right]} > 0. \quad (27)$$

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

$$\tilde{z}' = \frac{\pi/\tilde{z}_t}{\kappa} \tilde{\mu}'(0) + \frac{1}{g_{jt}} = \infty. \quad (28)$$

Note that $H^1(z_t)$ crosses the 45° line at only one positive number. Using (12), 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

$$c_i = s_c \left(\frac{\xi_i}{q_i} \right)^\varepsilon \left[\sum_{j=1} \xi_j^\varepsilon q_j^{1-\varepsilon} \right]^{-1} \quad (29)$$

Then

$$\frac{c_i}{c_j} = \left(\frac{\xi_i}{\xi_j} \right)^\varepsilon \left(\frac{q_j}{q_i} \right)^\varepsilon, \quad (30)$$

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

$$c_j = s_c \left(\frac{\xi_j}{q_j} \right)^\varepsilon \left[\sum_{j=1} \xi_j^\varepsilon q_j^{1-\varepsilon} \right]^{-1}. \quad (31)$$

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 (30) and (31), we have

$$\left(\sum_j \xi_j c_j^{\frac{\varepsilon-1}{\varepsilon}}\right)^{\frac{\varepsilon}{\varepsilon-1}} = s_c \left(\sum_j \xi_j^\varepsilon q_j^{1-\varepsilon}\right)^{\frac{1}{\varepsilon-1}}. \quad (32)$$

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 (24) with (29) 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' :

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

$$\frac{q_{jt} \left(\frac{\xi_j}{q_j}\right)^\varepsilon}{q_{j't} \left(\frac{\xi_{j'}}{q_{j'}}\right)^\varepsilon} = \frac{\tilde{M}_j l_j}{\tilde{M}_{j'} l_{j'}} = \frac{\tilde{M}_j}{\tilde{M}_{j'}} \equiv \Lambda_t^{j,j'} \quad (33)$$

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

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

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,

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

so $\frac{\Lambda_{t+1}^{j,j'}}{\Lambda_t^{j,j'}} = \left(\frac{z_{jt+1}/z_{jt}}{z_{j't+1}/z_{j't}} \right)^{\varepsilon-1} \times \left(\frac{g_j}{g_{j'}} \right)^{\varepsilon-1}$. 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 (30) 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 $(\mu_{jt} + 1 - \chi \mu_{jt}) \frac{\chi}{\alpha_x}$ 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:

$$2 = N_t^r + (1 + l^*) \sum_j M_{jt} + \sum_j M_{jt} \kappa_j n(\mu_{jt}) / z_{jt} \quad (34)$$

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

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

so a sufficient condition is that

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

Is there some parameter that guarantees this? As $\alpha_l \rightarrow 1 - \alpha_x$, $l^* \rightarrow \infty$, 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:

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

Also,

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

hence, as $\alpha_l \rightarrow 1 - \alpha_x$, $\pi \rightarrow \infty$. 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 credit constrained even with $N = 1$. Then, we require

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

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

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

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

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

and

$$\tilde{\mu}''(x) = \left(\frac{1}{\kappa_j} \right)^2 \frac{d^2 n^{-1}(z)}{dx^2} \Big|_{z=x/\kappa_j} < 0.$$

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 inability, 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

$$\gamma_{jt} = \tilde{\mu}_j(\omega(F, A) z_{j,t-1}) \left[\frac{1}{z_{j,t-1}} - \frac{1}{g_j} \right] + \frac{1}{g_j}, \quad (35)$$

so that

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

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

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

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

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 Empirical specification

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

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

where H_j is a kinked function.

Define $\hat{\mu}_j(\cdot)$ 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 leading country. Also, $\hat{\mu}'_j(\omega z) = 0$ for higher values of ω , but $\|\hat{\mu}_j(\omega z) - \mu_{jt}\| < \epsilon$ for some small $\epsilon > 0$ (this approach is as in Aghion et al (2005)).

Then let

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

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 leading country):

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

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 . Noting that $\log(x) \simeq x$, this reduces to equation (18), 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.

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

This table shows the results of regressing external finance dependence (N), 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.

	1	2	3	4	5	6
N(j)	0.314*** (0.033)	-		0.218*** (0.027)	0.243*** (0.035)	0.194*** (0.029)
FIX(j)	-	-0.599*** (0.028)	-	-0.562*** (0.027)	-	-0.548*** (0.028)
ASYM(j)	-		0.281*** (0.033)	-	0.191*** (0.035)	0.070*** (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. $N(j)$ is the need for external finance in industry j . $FIX(j)$ 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). $\beta(j)$ is the industry fixed effect in a cross country industry growth regression on country and industry dummies.

	$N(j)$	$FIX(j)$	$ASYM(j)$	$GUS(j)$	$\beta(j)$
$RND(j)$	0.857*** (0.101)	0.428** (0.200)	0.854*** (0.102)	-0.437** (0.176)	-0.155 (0.199)
$N(j)$		-0.232 (0.191)	-0.168 (0.200)	0.857*** (0.101)	0.367* (0.182)
$FIX(j)$			0.531*** (0.172)	-0.387** (0.181)	-0.186 (0.192)
$ASYM(j)$				-0.286 (0.194)	-0.097 (0.203)
$GUS(j)$					0.476*** (0.172)

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 (18). 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; $z(j,k)$ 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. CRED is private credit/GDP; MARG is the interest rate margin; BANK is the ratio of bank overhead to assets; ACCS is access to credit, and SOPH is the sophistication of the financial system. CRE80 is CRE measured in the 1980s, all other variables are measured for the 1990s. Sources: IMF, Compustat, UNIDO, Beck et al (2002), World Economic Forum (2008).

Regression specification	CRE	MARG	BANK	ACCS	SOPH	CRE80
$RND(j) \times FinDev(k)$	0.046** (0.020)	0.063*** (0.022)	0.063*** (0.021)	0.052** (0.026)	0.049* (0.026)	0.049*** (0.019)
$RND(j) \times z(j,k)$	0.664 (0.819)	0.479 (0.813)	0.471 (0.801)	1.87* (0.991)	1.62 (0.996)	1.10 (1.01)
$FIX(j) \times FinDev(k)$	0.001 (0.021)	-0.002 (0.022)	-0.018 (0.024)	-0.020 (0.029)	-0.019 (0.030)	0.016 (0.025)
$FIX(j) \times z(j,k)$	-0.036 (0.760)	-0.026 (0.857)	-0.025 (0.847)	0.800 (0.936)	0.437 (0.950)	-0.402 (1.32)
$z(j,k) \times FinDev(k)$	-0.832 (0.612)	0.044 (0.934)	0.212 (0.479)	0.480 (0.460)	0.791 (0.496)	-0.425 (0.539)
$z(j,k)$	-4.35*** (0.924)	-3.98*** (0.946)	-4.01*** (0.949)	-5.82*** (1.15)	-6.03*** (1.16)	-3.14*** (0.695)
$z(j,k)^2$	13.3** (6.12)	13.6** (6.61)	13.6** (6.62)	15.9** (6.85)	16.8** (6.79)	7.14 (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 (18). 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; $z(j,k)$ 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. CRED is private credit/GDP; MARG is the interest rate margin; BANK is the ratio of bank overhead to assets; ACCS is access to credit, and SOPH is the sophistication of the financial system. CRE80 is CRE measured in the 1980s, all other variables are measured for the 1990s. Sources: IMF, Compustat, UNIDO, Beck et al (2002), World Economic Forum (2008).

Regression specification	CRE	MARG	BANK	ACCS	SOPH	CRE80
$RND(j) \times FinDev(k)$	0.046*** (0.018)	0.064*** (0.020)	0.079*** (0.019)	0.062*** (0.022)	0.059*** (0.022)	0.047*** (0.018)
$RND(j) \times z(j,k)$	0.681 (0.696)	0.492 (0.682)	0.490 (0.672)	1.45* (0.835)	1.41* (0.844)	1.37** (0.646)
$z(j,k) \times FinDev(k)$	-0.825 (0.611)	0.038 (0.934)	0.108 (0.425)	0.640 (0.441)	0.931** (0.462)	-0.367 (0.464)
$z(j,k)$	-4.34*** (0.923)	-3.98*** (0.934)	-3.99*** (0.936)	-5.91*** (1.15)	-6.10*** (1.15)	-3.29*** (0.464)
$z(j,k)^2$	13.2*** (4.91)	13.6*** (5.03)	13.6*** (5.03)	19.2*** (5.50)	18.9*** (5.24)	7.23* (4.31)
R^2	0.305	0.307	0.308	0.305	0.306	0.391
Obs	968	968	968	699	699	108450

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

This table presents the panel regression estimation results of equation (18). 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; $z(j,k)$ 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, and SOPH is the sophistication of the financial system. 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).

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