Volatility and Growth: Financial Development and the Cyclical Composition of Investment*

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Abstract

This paper investigates how financial development affects the cyclical behavior of the composition of investment and thereby volatility and growth. We first consider an endogenous growth model in which firms engage in two types of investment, a short-term investment activity (physical capital) and a long-term growth-enhancing one (R&D). Under complete financial markets, R&D tends to be countercyclical, thus mitigating volatility, and mean growth tends to increase with volatility. These relations are reversed when firms face tight borrowing constraints: R&D becomes procyclical, thus amplifying volatility, and mean growth tends to decrease with volatility. Moreover, the tighter the credit constraints, the higher the sensitivity of R&D and growth to exogenous shocks. We next confront the model with cross-country data over the period 1960-2000. We find that a lower degree of financial development predicts a more negative relation between growth and volatility, a higher sensitivity of growth to shocks, and a more countercyclical R&D over total investment.

Keywords: Endogenous growth, fluctuations, cycles, composition of investment, R&D, credit constraints.

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1 Introduction

The idea that productivity growth and the business cycle are closely interrelated goes back at least to Schumpeter and Hicks in the 1940s-1950s.[1] Yet, it is only recently that empirical and theoretical attempts have been made at analyzing the relation between volatility and growth in more depth. Using cross-sectional data from 92 countries, Ramey and Ramey (1995) find a negative correlation between volatility and growth (the former measured by the standard deviation of annual per-capita GDP growth rates and the latter by the corresponding mean). The effect of volatility on growth remains negative when they control for various country-specific characteristics, as well as when they instrument volatility with arguably more exogenous variables, suggesting a possible causal relation from volatility to growth.[2] Columns (1)-(4) in Table 1 repeat their exercise in our data set.[3]

The most straightforward explanation for a negative relation between volatility and growth is risk aversion: more volatility means more investment risk, which tends to discourage investment and thereby slow down growth. This effect, however, may be partly or totally offset by the precautionary motive for savings: more volatility also means more income risk, which tends to raise precautionary savings and thereby reduce interest rates, which in turn encourages investment and boosts growth. As a result, the overall effect of volatility on growth is generally ambiguous. In the AK class of models, for example, Jones, Manuelli and Stacchetti (2000) show that the overall effect of volatility on investment and growth is negative only when the elasticity of intertemporal substitution is higher than one. The results in Angeletos (2003), on the other hand, suggest that, in economies in which capital does not exhaust all income, risk can have a negative overall impact on investment even when the elasticity of intertemporal substitution is substantially below one.

The simple neoclassical paradigm can thus explain the negative relation between volatility and growth through a negative effect on the level of investment. This hypothesis is tested in Columns

[1]Kaldor (1954) would already crticize the literature for failing to integrate business cycles with productivity growth: "As a pure cyclical model, the [neo-keynesian] oscillator model had little resemblance to the cyclical fluctuations in the real world, where successive booms carry production to successively higher levels."

[2]More recent work by Gavin and Hausmann (1996) and by the Inter-American Development Bank on volatility in Latin America also provides strong cross-country evidence of the detrimental effects of volatility on long-run growth, particularly in countries or subset of countries with low levels of financial development as measured by the ratio of bank credit to GDP.

[3]For data discription and variable definitions, see Section 5.

(4)-(8) of Table 1. Controlling for investment turns out to account for only a small fraction of the overall impact of volatility on growth. In the whole sample, for example, the coefficient on volatility falls only to -0.22 from -0.26 once the level of investment is included in the controls.[4] Therefore, the main channel through which volatility affects growth is *not* the level of investment.

[insert Table 1 here]

This paper provides a first attempt at filling the gap between the theory and the empirics of the relationship between volatility and growth. We propose that the main channel through which volatility affects growth is the *composition* of investment. We then explore how the impact of volatility interacts with the level of financial development and how the latter affects both the mean and the cyclical behavior of the composition of investment.

In the first part of the paper, we develop a simple endogenous-growth model in which agents (entrepreneurs) engage in two types of investment activity. The one type of investment takes little time to build and generates output relatively fast; the other takes more time to build, brings a return over a longer horizon, and contributes relatively more to productivity growth. When we turn to the data, we identify short-term investment as physical capital and long-term investment as R&D. The model, however, is not limited to R&D: long-term investments may also include entry of new firms, mergers and acquisitions, human capital, etc.

It is well understood that borrowing constraints may directly affect the cyclical behavior of the total demand for investment. However, in general equilibrium, the endogenous reaction of interest rates may partially or even fully offset this effect. For example, if the supply of savings remain constant, tighter borrowing constraint will lead to more volatile interest rates but not more volatile investment in general equilibrium. Yet, the cyclical composition of investment may vary in a way that amplifies the business cycle. A main contribution of the paper is to characterize the cyclical behavior of the composition of investment as a function of the level of financial development, and to analyze how this affects growth and volatility.

When markets are complete, we find the following patterns. First, the fraction of savings allocated to long-term investment (R&D) is countercyclical. This is because the return to short-term investment (capital) is more procyclical than the return to long-term investment, implying

[4] Similar results were obtained by Ramey and Ramey (1995).

that the opportunity cost of the latter is low during recessions and high during booms.[5] Second, the countercyclicality of R&D reduces the persistence and magnitude of the business cycle. Finally, more volatility is likely to be associated with higher mean rates of R&D and growth.

These effects are reversed once agents face sufficiently tight borrowing constraints. First, the fraction of savings allocated to long-term investment (R&D) becomes procyclical, the more so the tighter the borrowing constraints. We emphasize that this result is *not* because of R&D being less collateralizable than physical capital; we assume that agents face equally tight borrowing constraints with respect to either type of investment. Instead, this result is a direct consequence of the property that long-term investments take a longer time to build and therefore face more liquidity risk than short-term investments; the procyclicality in the liquidity risk may then more than offset the countercyclicality in the opportunity cost.

Second, the procyclicality of R&D now amplifies the business cycle, in contrast to the mitigating effect under complete markets. And the tighter the borrowing constraints, the higher the sensitivity of growth to exogenous shocks.

Third, because tighter borrowing constraints imply both lower and more procyclical levels of R&D, lower levels of financial development predict both lower mean growth rates and higher volatility levels. The negative relation between growth and volatility observed in the data may thus reflect variation in the level of financial development. Finally, for a given level of financial development, more volatility cause lead to less growth, and the more so the lower the degree of financial development.

In the second part of the paper, we confront the model with the data by testing whether lower levels of financial development[6] predict (i) a stronger negative impact of volatility on growth, (ii) a lower and more procyclical R&D as a fraction of total investment, and (iii) a higher sensitivity of R&D and growth to exogenous productivity or demand shocks.

We first look at the long-run response of growth to volatility in a cross-section of 70 countries over the period 1960-1995. We find that the mean annual growth rate is less sensitive to the

[5] This "opportunity-cost effect" was emphasized by Aghion and Saint-Paul (1991). Related is the "cleansing effect" of Caballero and Hammour (1994), in which case recessions are good times for reorganization.

[6] In the model, we parametrize the level of financial development by the ratio between firms' borrowing capacity and their current wealth; in the empirical analysis, we adopt the measures of financial development used in Levine et al (2000).

standard deviation of growth rates the higher the degree of financial development. This result is robust to controlling for the familiar policy and demographics variables in Levine et al (2000), as well as to alternative measures of financial development.

While the above results support our theoretical model, the standard deviation of annual growth may be a very coarse measure of exogenous volatility and in fact is itself endogenous. Moreover, we are interested not only in long-run growth but also in medium-term fluctuations. Hence, we next perform panel regressions of the response of growth rates to innovations in either the terms of trade shocks or an export-weighted index of commodity prices – these variables are likely to be good proxies for the exogenous shocks hitting different economies at different times. Looking at 5-year averages in a sample of 73 countries between 1960 and 1985, we find that an adverse terms-of-trade or commodity price shock has a smaller negative impact on growth in countries with higher financial development. This result is robust to alternative measures of current or lagged credit constraints.

The same picture emerges when we look at annual data. In particular, we find a strong response of growth to terms-of-trade or commodity price shocks lagged one and two years. Moreover, the coefficient on the interaction between lagged private credit and the shock is strong and significant, in line with our theoretical predictions. Most importantly, our measure of financial development does not subsume the role of other policies or institutions: the interaction between shocks and private credit remains significant once we control for intellectual property rights, government expenditures, inflation, and the black-market premium.

Finally, we look at the response of R&D to shocks. Data availability limits the analysis to an annual panel of 14 OECD countries over the period 1973-1997 and reduces the statistical significance of some results. Nevertheless, we find that the fraction of investment allocated to R&D is more sensitive to commodity price shocks the lower the level of financial development. On the other hand, total investment as a share of GDP does not respond much to commodity price shocks. These results suggest that the cyclical behavior of the composition of investment is indeed an important propagation channel.

The first attempts at analyzing the relation between volatility and growth within the AK class of models are King and Rebelo (1993), Stadler (1990), and more recently Jones, Manuelli and Stacchetti (2000). As pointed out above, however, these papers do not consider either the cyclical behavior of the allocation of investment between short-term (capital) and long-term (R&D) projects, or the role of financial development.[7]

More closely related to our approach are Hall (1991), Gali and Hammour (1991), and especially Aghion and Saint-Paul (1991,1998). These papers also consider in one form or another the composition of investment, but assume perfect capital markets and therefore obtain only opportunity-cost effects whereby long-term investments tend to be countercyclical.[8] Caballero and Hammour (1994), on the other hand, focus on how the structure of adjustment costs affects the "cleansing" effect of recessions, namely the distruction of the least productive firms in the market.

The role of financial development, on the other hand, has been the subject of a large literature, including Bernanke and Gertler (1989), Banerjee and Newman (1993), King and Levine (1993), Obstfeld (1994), Kiyotaki and Moore (1997), Acemoglu and Zilibotti (1997), Aghion, Banerjee and Piketty (1999), etc.[9] Although some of this earlier work has considered the impact of incomplete markets on the allocation of savings between different types of investment, we depart from this literature in two important aspects. First, we do not assume that some types of investment are subject to borrowing constraints more than others, in which case the effect of incomplete markets on the composition of investment is rather ad hoc; we instead derive the impact of financial development merely from its interaction with the horizon of investment. Second, we examine the effect on the *cyclical* behavior of the composition of investment and provide direct evidence for this effect.

The empirical findings of this paper are also novel and interesting on their own. To the best of our knowledge, the panel evidence regarding the sensitivity of growth to commodity price shocks is the first direct evidence for the multiplier effect of incomplete markets. Complemented with our evidence on the cyclical behavior of the composition of investment, our findings document that cross-country differences in financial development explain cross-country differences in the structure of business cycles.

Finally, the paper contributes to the RBC literature (e.g., Kydland and Prescott, 1982, King

[7] More recently, Francois and Lloyd-Ellis (**2003 or 2004**) have developed a Schumpeterian model that endogenizes both growth and volatility. They focus, however, on how the firms' incentive to coordinate the timing of innovation may **(result to) influence** aggregate volatility in a fashion similar to the "implementation cycles" of Shleifer (1986).

[8] However, Barlevy (2004) argues that innovation can be procyclical even under complete markets if present-value profits are more procyclical than the opportunity cost of R&D.

[9] See Levine (2004) for an excellent review of the literature on financial development.

and Rebelo, 1993) by providing a simple theory for the Solow residual. Whereas most of this literature treats the shocks on the technology frontier of the economy as purely exogenous, we partially endogenize the Solow residual by allowing productivity growth to depend on the composition of investment. Our results then imply that the degree of financial development may affect directly the volatility and the persistence of the Solow residual, or that "demand" shocks in one period may generate "productivity" shocks in subsequent periods. One thus needs to be cautious in the interpretation of the "exogenous" productivity shocks identified in the VAR and quantitative RBC literature (e.g., Gali and Rabanal, 2004, Chari, Kehoe, and McGrattan 2004).

The rest of the paper is organized as follows. Section 2 outlays the basic framework. Section 3 analyzes the effect of volatility and financial development on the composition of investment and the procyclicality of R&D. Section 4 analyzes their effects on productivity growth. Section 5 develops the empirical analysis. And finally, Section 6 concludes.

2 The Model

In any given period t, the economy is populated by a continuum of mass 1 of overlapping generations of two-period lived agents ("entrepreneurs"), who are indexed by i and uniformly distributed over $[0, 1]$. In the first period of her life, an entrepreneur decides how much to invest in short-term or long-term projects (physical capital versus R&D). Capital produces at the end of the first period. R&D, by contrast, produces at the end of the second period and only if the entrepreneur has spent additional resources to develop what was produced by the initial round of investment. At the end of the second period, the entrepreneur consumes her total life-time income and dies. Finally, productivity growth is driven by past aggregate R&D activity.

2.1 Aggregate productivity

Let T_t denote the aggregate stock of knowledge and A_t the aggregate productivity at date t. In the absence of aggregate uncertainty, productivity would coincide with the level of knowledge, namely $A_t = T_t$. We introduce aggregate uncertainty in the model by letting

$$\ln A_t = \ln T_t + \ln a_t \tag{1}$$

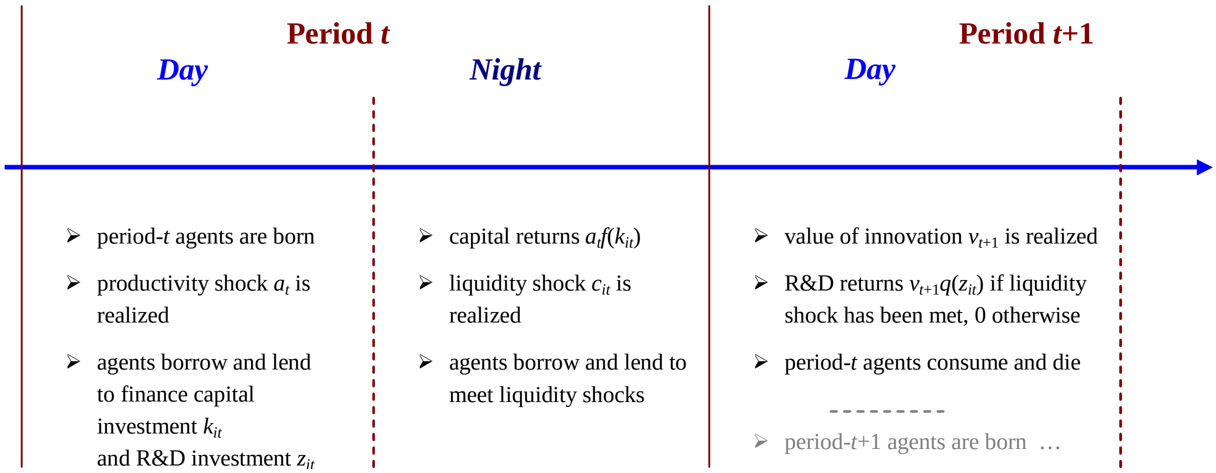

Figure 1: The life of an entrepreneur.

where a_t represents an exogenous aggregate productivity (or demand) shock in period t. We specify an $AR(1)$ process for the latter:

$$\ln a_t = \rho \ln a_{t-1} + \varepsilon_t, \quad \varepsilon_t \sim \mathcal{N}\left(-\sigma^2/2, \sigma^2\right),$$

so that $\rho \in [0,1)$ and $\sigma > 0$ measure the persistence and the volatility of the exogenous aggregate shock. Note that T_t can be interpreted as the "trend" in productivity and A_t as the Solow residual. Unlike the RBC framework, however, the latter is determined endogenously, in a way specified later.

2.2 Entrepreneurs

Each agent (entrepreneur) lives for two periods. She makes investment choices in the first period, produces in both the first and the second period, and consumes only in the second period. Her life-span is illustrated in Figure 1 and explained below.

Initial budget constraint. Consider an entrepreneur born in period t. In the beginning of life, the entrepreneur receives an endowment that is proportional to the inherited level of knowledge: $W_t^i = wT_t$ for some $w > 0$. In the first period of her life, the entrepreneur must decide on how to allocate her initial endowment between short-run investments, K_t^i, long-term investments, Z_t^i, and savings in the riskless bond, B_t^i. Her budget constraint is thus given by

$$K_t^i + Z_t^i + B_t^i \leq W_t^i.$$

To ensure a balanced-growth path, we assume that the costs of capital and R&D investments, like the initial endowment of each entrepreneur, are proportional to T_t, and denote with $k_t^i = K_t^i/T_t$, $z_t^i = Z_t^i/T_t$, and $b_t^i = B_t^i/T_t$ the "detrended" levels of capital, R&D, and bonds holdings. The initial budget constraint thus reduces to

$$k_t^i + z_t^i + b_t^i \leq w.$$

Short-term investment (capital). Short-term capital investment at date t generates income

$$\Pi_t^i = A_t \pi(k_t^i)$$

at the end of the same date. The production (or profit) function π satisfies the "neoclassical" assumptions $\pi' > 0 > \pi''$, $\pi'(0) = \infty$, and $\pi'(\infty) \leq 0$.

Long-term investment (R&D). Long-term investment at date t generates income only if the investment is successful in generating an innovation (or more generally, a potential source of productivity growth) by the end of period t, *and* the entrepreneur has implemented the innovation. This is important because the successful implementation of this innovation requires that the entrepreneur incurs a positive cost

$$C^i = c_t^i T_t$$

at the end of the period. For simplicity, we take c_t^i to be i.i.d. across entrepreneurs and across periods, with c.d.f. F and positive density f over $\mathbb{R}_+$.

Conditional on paying this cost, the income generated by long-term investment is

$$\Pi_{t+1}^i = V_{t+1} q(z_t^i) + C_t^i,$$

where $q(z_t^i)$ can be interpreted as the probability that R&D is successful and V_{t+1} as the value of a new innovation. The function q also satisfies the "neoclassical" assumptions $q' > 0 > q''$, $q'(0) = \infty$, and $q'(\infty) \leq 0$. Finally, the fact that Π_{t+1}^i includes C_t^i means that the survival cost does not affect the net return to R&D, which is simply $V_{t+1} q(z_t^i) > 0$, and therefore it is always optimal to pay the adjustment cost. Whether, however, the firm will be able to do so will depend on the efficiency of credit markets. In other words, C_t^i represents a pure *liquidity shock*.

Entrepreneur's objective. The entrepreneur is risk neutral and consumes only in the last period of her life. Hence, expected life-time utility is simply $\mathbb{E}_t[W^i_{t+1}]$, where

$$W^i_{t+1} = \Pi^i_t + \left(\Pi^i_{t+1} - C^i_t\right)\mathbb{I}^i_t + (1 + r_t)B^i_t \tag{2}$$

is the entrepreneur's final-period wealth and $\mathbb{I}^i_t$ is an indicator variable such that $\mathbb{I}^i_t = 1$ if the firm succeeds in paying for the implementation of the innovation and $\mathbb{I}^i_t = 0$ otherwise. It is convenient to normalize variables by the level of knowledge. It follows that the entrepreneur maximizes $\mathbb{E}_t[w^i_{t+1}]$, where

$$w^i_{t+1} = W^i_{t+1}/T_t = a_t\pi(k^i_t) + v_{t+1}q(z^i_t)\mathbb{I}^i_t + (1 + r_t)b^i_t \tag{3}$$

denotes the knowledge-adjusted final wealth and $v_{t+1} = V_{t+1}/T_t$ the knowledge-adjusted value of a new innovation.

Value of innovation. To complete our description of the entrepreneur's problem, we need to specify the value of a new innovation. Our main assumption here will be that the returns to R&D investment are less procyclical than the return to capital investments. This amounts to assuming that the correlation between $v_{t+1} = V_{t+1}/T_t$ and $a_t = A_t/T_t$ over the business cycle is less than one, which in turn is necessarily the case as long as the productivity shock is less than fully persistent and the value of innovation represents a present value of returns over a horizon extending beyond period t.[10] A special case is when $V_{t+1} = A_{t+1}$, in which case $\ln v_{t+1} = \rho \ln a_t + \varepsilon_{t+1}$. We shall be a little more general and let

$$\ln v_{t+1} = \theta \ln a_t + \xi_{t+1},$$

where ξ_{t+1} is a random shock and θ measures the procyclicality of the value of innovation. We let $\xi_{t+1} \sim \mathcal{N}\left(-\sigma^2_v/2, \sigma^2_v\right)$ so that the expected value of an innovation at date $t+1$ is simply expressed as

$$\mathbb{E}_t v_{t+1} = (a_t)^\theta. \tag{4}$$

Finally, to capture the idea that the value of an innovation is likely to be more procyclical the more persistent the productivity shock, we let $\theta = \theta(\rho)$ be increasing in ρ and $0 \leq \theta(0) < \theta(1) \leq 1$. This assumption, however, can be relaxed without affecting our results; the only important assumption

[10] That would be the case, for example, if we specify $V_{t+1} = \mathbb{E}_{t+1}\sum_{j=1}^{T} M_{t+j}A_{t+j}$, where $T > 1$ represents the horizon of a new innovation and M_{t+j} is the market discount factor.

is that the return to long-term investment (R&D) is less procyclical than the return to short-term investment (capital).

2.3 Credit markets

Credit markets open twice every period. The "day" market takes place in the beginning of the period and closes at the end of the period, *before* the realization of the R&D adjustment cost. The "overnight" market takes place at the end of the period, after the realization of the adjustment cost.

On the day market, an entrepreneur born at date t can borrow only up to m times her initial wealth. Thus she faces the borrowing constraint

$$k_t^i + z_t^i \leq \mu w,$$

where $\mu = 1 + m$. Similarly, on the overnight market, the entrepreneur can borrow up to μ times her end-of-current-period wealth x_t^i for the purpose of covering the implementation cost. Thus, her initial R&D investment this period will pay out next period if and only if

$$c_t^i \leq \mu x_t^i \equiv \mu \left[a_t \pi(k_t^i) + (1 + r_t)\, b_t^i \right].$$

The probability that the entrepreneur will be able to meet the liquidity shock and implement his innovation is given by

$$p_t^i \equiv \Pr\left(c_t^i \leq \mu x_t^i\right) \equiv F\left(x_t^i\right).$$

When performing comparative statics analysis in the next two sections, it will be useful to approximate the latter by the log-linear function

$$\ln p_t^i \approx \phi \ln \mu x_t^i,$$

where ϕ is the (local) elasticity of F. Both parameters μ and ϕ reflect the tightness of credit constraints: $\mu = \infty$ corresponds to perfect credit markets, whereas $\mu = 1$ corresponds to the absence of credit markets, and a lower μ between these two extremes corresponds to tighter credit-constraints or to a lower degree of financial development. Similarly, $\phi = 0$ means that the probability of surviving the R&D adjustment cost is independent of wealth, whereas a large ϕ corresponds to a high wealth sensitivity of this survival probability.

Finally, we close our model of the credit market by assuming that wealth cannot be stored during the day, whereas overnight storage can take place at a one-to-one rate. The first assumption implies that the "day" interest rate r_t will adjust so that the excess aggregate demand for the riskless bond in the day market is zero. This is equivalent to imposing the resource constraint

$$\int_i \left[k_t^i + z_t^i\right] = w.$$

The second implies that the "overnight" interest rate is bounded below by 0. We restrict the set of parameters so that in equilibrium

$$\int_i \left[c_t^i \mathbb{I}_t^i - a_t \pi\left(k_t^i\right)\right] \leq 0,$$

which in turn ensures that the "overnight" bond market clears at zero interest rate.

2.4 Endogenous technological change

To complete the model, we need to describe the growth process, which here boils down to specifying the dynamics of T_t. Like in other growth models with endogenous innovation,[11] we assume that knowledge accumulate at a rate proportional to the aggregate rate of innovation in the economy, namely:

$$\ln T_{t+1} - \ln T_t = \gamma \int_i q(z_t^i)\mathbb{I}_t^i di,$$

where $\mathbb{I}_t^i$ is as defined above, and $\gamma > 0$.

3 Cyclical composition of investment

In this section we analyze the effect of financial development on the level and the cyclical behavior of the two types of investment. We first consider the benchmark case of complete financial markets; we then contrast it with the case of tight credit constraints.

3.1 Complete Markets

In a complete financial market, entrepreneurs face no credit constraints that would prevent them from borrowing what is necessary in order to cover their R&D adjustment costs. This implies that

[11] See Aghion-Howitt (1998).

the R&D investment of an entrepreneur in her first period of life will always pay out next period in the form of future revenues v_{t+1}.

Expected wealth for entrepreneur i is thus

$$a_t \pi(k_t^i) + \mathbb{E}_t v_{t+1} q(z_t^i) + (1 + r_t) b_t^i,$$

which she will maximize over $\left(k_t^i, z_t^i, b_t^i\right)$ subject to the budget constraint

$$k_t^i + z_t^i + b_t^i \leq w_t^i.$$

Obviously, all entrepreneurs make identical choices. Dropping the i superscripts, we obtain the first-order conditions:

$$a_t \pi'(k_t) = 1 + r_t \quad \text{and} \quad \mathbb{E}_t v_{t+1} q'(z_t) = 1 + r_t.$$

It follows that

$$\frac{q'(z_t)}{\pi'(k_t)} = \frac{a_t}{\mathbb{E}_t v_{t+1}} = a_t^{1-\theta}. \tag{5}$$

In equilibrium, the (day) interest rate r_t adjusts so that total investment is acyclical:

$$k_t + z_t = w. \tag{6}$$

Combining the above with (5) implies that an increase in a_t reduces z_t and increases k_t. That is, the level of capital investment is procyclical and that of R&D investment is countercyclical. Note that the property that the *level* of R&D (z_t) is countercyclical in our model hinges on the assumption that the aggregate supply of savings (w) is acyclical. But even if aggregate savings were procyclical, R&D as a *fraction* of total investment ($z_t/(z_t + k_t)$) would likely remain procyclical. We thus conclude:

Proposition 1 *Under complete markets, the share of capital investment is procyclical, whereas the share of R&D is countercyclical. The share of R&D is more countercyclical the less persistent the aggregate shocks, or the longer the horizon of long-term investments.*

This is the opportunity cost effect already stressed by the existing literature on volatility and growth. Current profits are more sensitive to the contemporaneous state of the economy than the expected value of long-term investments. It follows then that k_t should be more procyclical than

z_t. In particular, during a recession entrepreneurs expect that production in the short run will not be very profitable, whereas the value of long-term (R&D) investments is less than perfectly correlated with the current state of the cycle. In the extreme case where aggregate shocks were not persistent at all, so that $\mathbb{E}_t a_{t+1}$ would remain constant over the business cycle, the demand for long-term investment z_t would also remain invariant over the cycle for given values of the interest rate. However, the interest rate would be procyclical, and therefore the demand for long-term investment, z_t, will be countercyclical in equilibrium. [12]

Example. Suppose that $\pi(k) = k^\alpha$ and $q(z) = z^\alpha,\ 0 < \alpha < 1$. Condition (5) then reduces to $(k_t/z_t)^{1-\alpha} = a_t^{1-\theta}$, which together with (6) implies

$$k_t = \frac{a_t^\eta}{1 + a_t^\eta} w \quad \text{and} \quad z_t = \frac{1}{1 + a_t^\eta} w,$$

where $\eta = (1-\theta)/(1-\alpha) > 0$. We immediately see that the equilibrium R&D investment z_t is decreasing in the realization a_t of the current productivity shock (in other words R&D is countercyclical), whereas capital investment k_t is procyclical. Moreover, z_t is globally convex in a_t when $\theta \geq \alpha$ and convex in a neighborhood of $a_t = Ea$ when $\theta < \alpha$, which in turn implies that increased volatility tends to increase mean R&D. This observation will prove useful when we examime the relation between volatility and growth.

3.2 Incomplete Markets

Credit constraints limit entrepreneurs' borrowing capacity to a finite multiple μ of their current wealth in both periods of their lifetime. At the beginning of period t, an entrepreneur born at date t faces the constraint:

$$k_t^i + z_t^i \leq \mu w.$$

And at the end of period t, the entrepreneur must satisfy the following constraint if she wants to survive until the next period:

$$c_t^i \leq \mu \left[a_t \pi(k_t^i) + (1 + r_t)\, b_t^i \right], \tag{7}$$

[12] Introducing persistence in the aggregate shock tends to mitigate this effect by inducing procyclicality in the demand for z_t. However, as long as productivity growth is mean-reverting, the demand for R&D investment z_t is less procyclical than the demand for capital investment k_t, and therefore less procyclical than the interest rate r_t, so that the equilibrium level of z_t remains countercyclical.

where $a_t\pi(k_t^i) + (1+r_t)b_t^i$ is her net wealth accumulated over period t.

Our assumption of no-storage within periods, implies that the first constraint is never binding in equilibrium.[13] Then, using (7) to substitute for the probability of survival in the entrepreneur's objective function, a new entrepreneur born at date t will choose her investment profile (k_t^i, z_t^i) so as to solve

$$\max_{k_t^i, z_t^i, b_t^i} \left\{a_t\pi(k_t^i) + \mathbb{E}_t v_{t+1} q(z_t^i) F\left(\mu\left[a_t\pi(k_t^i) + (1+r_t)b_t^i\right]\right) + (1+r_t)b_t^i\right\}$$

$$s.t. \qquad k_t^i + z_t^i + b_t^i \leq w.$$

Dropping superscripts once again, the first-order conditions with respect to k_t^i and z_t^i, can then be expressed as:

$$a_t\pi'(k_t) + \mathbb{E}_t v_{t+1} q(z_t) f(\cdot)\, \mu\left[a_t\pi'(k_t) - (1+r_t)\right] = 1 + r_t,$$

$$\mathbb{E}_t v_{t+1} q'(z_t) F(\cdot) - \mathbb{E}_t v_{t+1} q(z_t) f(\cdot)\, \mu\,(1+r_t) = 1 + r_t.$$

The condition for k_t is obviously satisfied at

$$a_t\pi'(k_t) = 1 + r_t, \tag{8}$$

which implies that the demand for k_t is not affected by credit constraints. The condition for z_t, on the other hand, reduces to

$$\mathbb{E}_t v_{t+1} q'(z_t) = (1+r_t)\left[\frac{1 + \mathbb{E}_t v_{t+1} q(z_t) f(\cdot)\, \mu}{F(\cdot)}\right]. \tag{9}$$

Since the term in brackets is greater than one, it follows that the demand for z_t is necessarily lower than under complete markets. In equilibrium, the interest rate r_t still adjusts so that $b_t = 0$ and $k_t + z_t = w$. It follows that

Proposition 2 *For any realization a_t, incomplete markets lead to a lower interest rate r_t, a higher capital investment k_t, and a lower R&D z_t as compared to complete markets.*

[13] We indeed have:

$$k_t^i + z_t^i = w < \mu w.$$

We now turn to the cyclical behavior of R&D over the business cycle. Let $\psi(x) \equiv f(x)\,x/F(x)$ denote the elasticity of F. Combining (8) and (9), and using the fact that $b_t = 0$ in equilibrium, we obtain:

$$\begin{aligned}\frac{q'(z_t)}{\pi'(k_t)} &= \frac{a_t}{\mathbb{E}_t v_{t+1}}\left[\frac{1}{F(\cdot)} + \frac{\mathbb{E}_t v_{t+1} q(z_t)\psi(\cdot)}{a_t \pi(k_t)}\right] \\ &= \frac{a_t^{1-\theta}}{F(\mu a_t \pi(k_t))} + \psi(\mu a_t \pi(k_t))\frac{q(z_t)}{\pi(k_t)}.\end{aligned}$$

Assuming that ψ is relatively stable over the business cycle, and given that the probability of meeting the R&D adjustment cost $F(\mu a_t \pi(k_t))$ is procyclical, then the ratio z_t/k_t is necessarily less countercyclical than under complete markets, and it may even become procyclical.

If we now use the log-linear approximation $\ln F(x) \approx \phi \ln x$ for some constant ϕ, the above condition turns into:

$$\frac{q'(z_t)}{\pi'(k_t)} \approx \frac{a_t^{1-\theta-\phi}}{[\mu\pi(k_t)]^{\phi}} + \phi\frac{q(z_t)}{\pi(k_t)} \tag{10}$$

From there, it follows that z_t/k_t is procyclical if and only if $\phi > 1-\theta$.[14] Moreover, the procyclicality of z_t increases with a higher ϕ, a lower μ, or a lower θ (or lower ρ). Recall that μ and ϕ both reflect the tightness of credit constraints. Indeed, z_t falls with either a reduction in μ or an increase in ϕ. We thus conclude:

Proposition 3 *Under sufficiently incomplete markets, the share of R&D z_t becomes procyclical, and the share of capital investment k_t becomes countercyclical. R&D investment z_t is less procyclical the less tight credit constraints, the less persistent the shocks, or the longer the horizon of long-term investment.*

Example. The following three figures illustrate the effect of credit constraints on the level of R&D, the cyclical variation of R&D, and the probability of survival. We assume that the distribution of c is lognormal, in which case of course the elasticity ϕ is not constant. We also assume $\pi(k) = k^{\alpha}$, $q(z) = z^{\alpha}$, $\alpha = 1/3$, and let μ vary between 1 (meaning no credit) and 5 (meaning a credit line as large as four times the entrepreneur's income). Figure 2 depicts the equilibrium level of z_t, evaluated at the mean productivity level ($a_t = 1$). Figure 3 depicts the equilibrium cyclical elasticity of z_t (also evaluated at $a_t = 1$). In particular, this figure implies that

[14] In the case of a (locally) uniform distribution, $\phi = 1$ so that this condition is automatically satisfied.

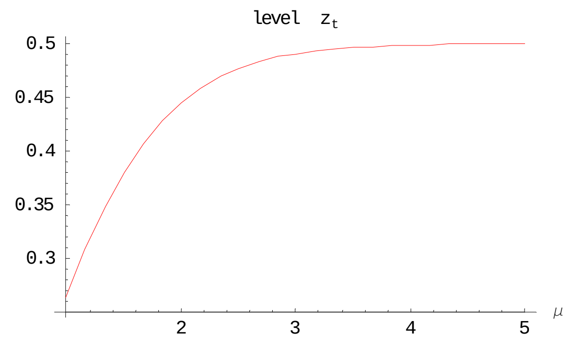

Figure 2: The effect of incomplete markets on the level of R&D.

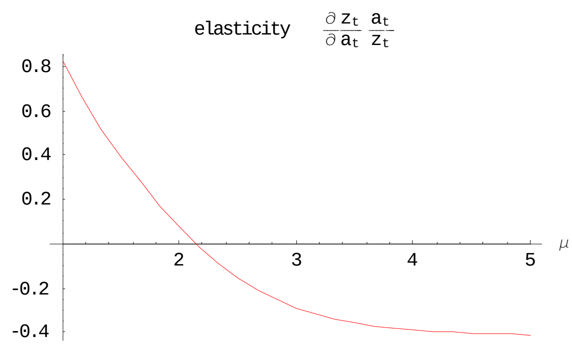

Figure 3: The effect of incomplete markets on the cyclical elasticity of R&D.

for μ sufficiently small, z_t is increasing in a_t ($\frac{dz_t}{da_t} > 0$), in other words R&D investment becomes procyclical whereas it is countercyclical for μ sufficiently large. This, together with the fact that R&D investment must lie in the interval $[0, w_t]$, implies that z_t must be not only increasing but also partly concave over this interval, which in turn points to the possibility of a negative correlation between volatility and mean R&D and therefore mean productivity growth (see the next section). Finally, Figure 4 depicts the equilibrium probability of meeting the liquidity shock (also evaluated at $a_t = 1$). We see that a reduction in μ leads to lower R&D, more procyclical R&D, and lower probability of meeting the liquidity cost.

4 Amplification, volatility, and growth

In this section we use our findings above on the relation between financial development and the cyclical behavior of the two types of investment to analyze the correlation between volatility and

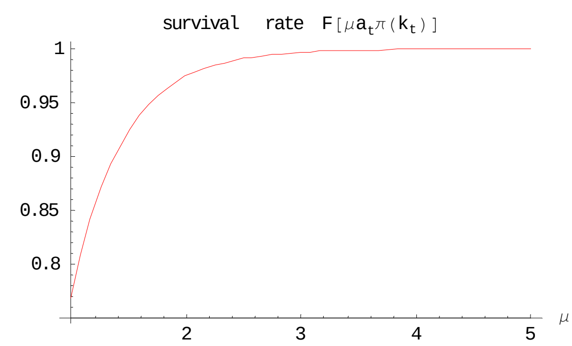

Figure 4: The effect of incomplete markets on the probability of meeting the liquidity risk.

growth, first under complete financial markets and then with tight credit constraints.

4.1 Complete markets

Under complete financial markets, entrepreneurs can always meet their R&D adjustment costs by borrowing whatever additional resources are necessary to cover those costs. Thus, all firms born at date t innovate with the same probability $q(z)$. But then, our endogenous growth assumption in Section 2 above implies that the growth rate of technology in this case, is equal to:

$$g_t \equiv \ln T_{t+1} - \ln T_t = \gamma q\left(z(a_t)\right),$$

where $z(a_t)$ is the (complete-markets) equilibrium level of R&D analyzed in Section 3.1. In particular we saw that $z(a_t)$ is monotonic in a_t, which in turn implies that a higher variance in a_t will translate into a higher volatility in the growth rate g_t. Whether a higher variance in a_t will result in higher or lower mean growth, will ultimately depend upon the curvatures of $q(.)$ and $z(.)$. In general, $z(.)$ may have both convex and concave segments. However, as we already pointed out in the previous section, $z(a)$ is decreasing in a and satisfies the Inada conditions $\lim_{a\to 0} z(a) = w$ and $\lim_{a\to\infty} z(a) = 0$. It follows that at least at the two extremes of the interval $[0, w]$ the equilibrium R&D investment $z(a)$ is convex (in the Cobb-Douglas example analyzed in Section 3.1, we could also show that $z''(a) < 0$ at the mean value of a). This in turn implies that a large increase in the variance of a_t should increase the mean rate of R&D.

Proposition 4 *Under complete markets, technological growth is countercyclical and therefore mitigates the business cycle. Moreover, the effect of volatility on growth is generally ambiguous but* *likely positive.*

4.2 Incomplete markets

We now reintroduce credit constraints, which prevent entrepreneurs from investing more than μ times their end-of-first-period wealth in order to meet their R&D adjustment costs. Since only those firms that can meet their adjustment costs are able to innovate and thereby contribute to aggregate productivity growth, the growth rate of technology is now given by:

$$g_t \equiv \ln T_{t+1} - \ln T_t = \gamma q\left(z(a_t)\right)\delta(a_t)$$

where $z(a_t)$ is the (incomplete-markets) equilibrium level of R&D and

$$\delta(a_t) \equiv F\left(\mu a_t \pi\left(w - z(a_t)\right)\right)$$

is the equilibrium probability of meeting the R&D adjustment costs. As we discussed in the previous section, when μ is sufficiently low, $z(a_t)$ is likely to be increasing in a_t. We also argued that since $z(a_t)$ is bounded between 0 and w, it is also likely to be "on average" concave in a_t. Since $q(z)$ is concave in z, $q(z(a_t))$ is even more likely to be concave in a_t. Similarly, $\delta\left(a_t\right)$ is increasing a_t and bounded between 0 and 1, which suggests that $\delta(a_t)$ is also likely to be "on average" concave in a_t. All this will contribute to making the growth rate g_t a concave function of a_t, so that mean growth is now more likely to fall in response to an increase in the variance of a_t.

The above would explain a negative *causal* effect of volatility on growth, which is stronger the tigther the credit constraints. At the same time, tigher credit constraints are associated with both lower growth and higher volatility, which would explain a negative *spurious* relation between the (endogenous) levels of volatility and growth. We summarize these results in the following proposition.

Proposition 5 *Under incomplete markets, technological growth is procyclical and amplifies the business cycle, the more so the tigther the credit constraints. Moreover, volatility and growth tend to be negatively related, the more so the tigther the credit constraints.*

We next present two illustrative examples, one that numerical and another that can be solved analytically.

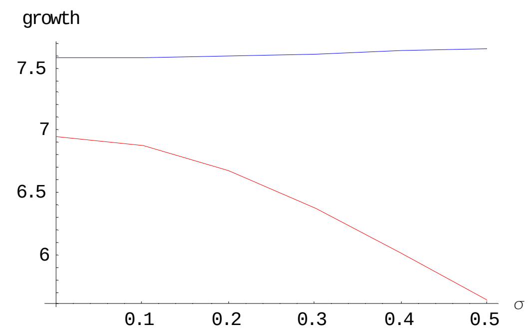

Figure 5: The effect of exogenous productivity risk on growth (blue line = complete markets, red line = incomplete markets)

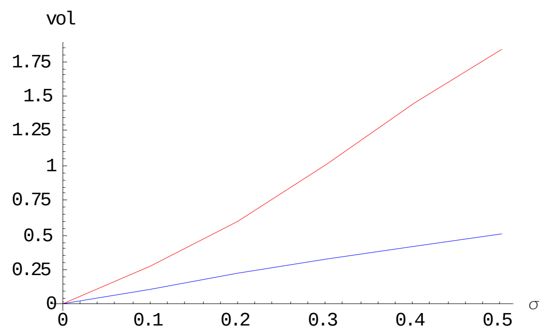

Figure 6: The effect of exogenous productivity risk on aggregate volatility (blue line = complete markets, red line = incomplete markets)

Example. Figures 5-7 illustrate the effect of credit constraints on the mean growth rate, the level of volatility, and the relation between volatility and growth, in the special case analyzed in Section 3.2 and described in Figures 2-4. Figure 5 shows how the mean of the growth rate of the economy (*growth*) varies with the standard deviation of the exogenous shock (σ). Figure 6 shows how the standard deviation of the growth rate of the economy (*vol*) varies with the standard deviation of the exogenous shock (σ). Finally, figure 7 depicts the implied relation between *growth* and *vol* as σ varies exogenously. The blue lines represents complete markets, whereas the red lines correspond to incomplete markets. For any level of σ, incomplete markets are associated with lower growth and higher volatility than complete markets. Moreover, the relation between growth and volatility is almost flat under complete markets, but strongly negative under incomplete markets.

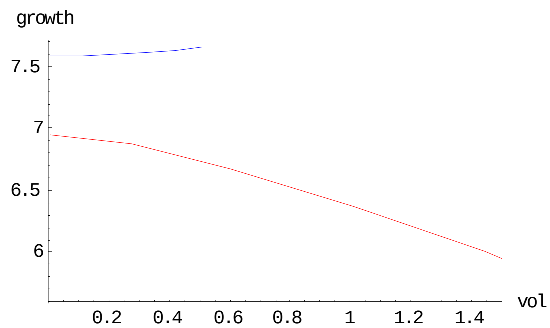

Figure 7: The relation between growth and volatility (blue line = complete markets, red line = incomplete markets)

Example. Assume linear technologies, a random walk for the exogenous shock, and a (locally) uniform distribution for the R&D adjustment cost: $\pi(k) = k$, $q(z) = \lambda z$, and $\rho = \theta = \phi = 1$.Then, (10) reduces to

$$\lambda = \frac{1}{\mu a_t k_t} + \frac{\lambda z_t}{k_t},$$

which, together with $k_t + z_t = w$, implies that the equilibrium level of R&D is given by

$$z(a_t) = \frac{\lambda w - (\mu a_t)^{-1}}{1+\lambda}.$$

It then immediately follows that $z'(a) > 0 > z''(a)$, and that z increases with μ. Thus, equilibrium R&D investments are procyclical and a convex function of the realization of the productivity shock a. Next, the probability of surviving the R&D adjustment cost, is given by:

$$F(\mu a_t \pi(k_t)) = \delta(a_t) = \frac{1 + \mu a_t w}{1+\lambda},$$

which is increasing and linear in a_t and μ. Finally, combining the equilibrium probability of innovation with the probability of surviving the R&D adjustment cost, the average rate of knowledge growth is given by:

$$g(a_t) = \gamma q\left(z(a_t)\right)\delta(a_t) = \gamma\lambda \frac{[1 + \mu a_t w][\lambda w - (\mu a_t)^{-1}]}{(1+\lambda)^2}.$$

It is easy to check that $g'(a) > 0 > g''(a)$, and that $g(a)$ increases with μ. The concavity of g implies a negative relation between volatility and growth. What is more, it is easy to show that, not only $\partial g(a)/\partial\mu > 0$, which means that tighter credit constraints reduce growth for every realization of a, but also $\partial g'(a)/\partial\mu < 0 < \partial g''(a)/\partial\mu$, which means that growth $g(a)$ becomes both more sensitive to the shock a and more concave in a as credit constraint become tighter. By implication, the lower the degree of financial development, the stronger the negative effect of exogenous volatility on mean growth.

4.3 R&D Spillovers

In our analysis so far we abstracted from any kind of spillovers in R&D activities among firms in order to highlight the direct implications of financial development on individual R&D investments. But now suppose that the value of an innovation increases with the aggregate level of R&D during the same period.

In particular, suppose that the value of innovation in period $t+1$ is proportional to the level of technology in period $t+1$ rather than that in period t :

$$V_{t+1} = \widetilde{v}_{t+1} T_{t+1} \quad \text{and} \quad \ln \widetilde{v}_{t+1} = \theta \ln a_t + \upsilon_{t+1},$$

where $\theta \in (0, \rho)$ again measures the procyclicality in the value of innovation and υ_{t+1} is a random shock. It follows that the final wealth of the firm is now given by

$$w^i_{t+1} \equiv \frac{W^i_{t+1}}{T_t} = a_t \pi(k^i_t) + v_{t+1} q(z^i_t) \mathbb{I}^i_t + (1 + r_t) b^i_t,$$

where $v_{t+1} \equiv V_{t+1}/T_t$ now satisfies

$$\ln v_{t+1} = \gamma z(a_t) + \theta \ln a_t + \upsilon_{t+1}.$$

That is, the normalized value of an innovation for the individual now increases with the aggregate rate of innovation. This spillover effect generates a macroeconomic complementarity in R&D investment: The optimal level of R&D for the individual is a positive function of the anticipated aggregate growth rate. In the general equilibrium, the aggregate growth rate is in turn a positive function of how much R&D individuals pursue. But how does this macroeconomic complementarity interact with the business cycle?

Under complete markets, R&D and technological growth tend to be countercyclical because of the opportunity-cost effect. Therefore, if the economy enters a recession, agents anticipate that innovation and technological progress will be *high* in the near future. In the presence of an aggregate demand externality or knowledge spillover, the anticipation of higher growth in the future feeds back to an even higher R&D in the present. Therefore, under complete markets, the macroeconomic complementarity in R&D reinforces the *countercyclicality* of technological growth and further *mitigates* the business cycle.

The conclusions become quite different when firms are credit-constrained. As we discussed, R&D and technological growth become procyclical. When the economy enters a recession, agents anticipate that innovation and technological progress will be *low* in the near future. The anticipation of lower growth in the future now feeds back to an even lower incentive to do R&D in the present. Therefore, with credit constraints, the macroeconomic complementarity in R&D reinforces the *procyclicality* of technological growth and thereby further *amplifies* the business cycle.

Proposition 6 *The existence of knowledge externalities increases the countercyclicality of technological growth and further mitigates the business cycle when markets are complete, whereas it increases the procyclicality of technological growth and further amplifies the business cycle when markets are sufficiently incomplete.*

5 Empirical Analysis

The model presented above makes testable predictions for the relation between volatility and growth, the sensitivity of output to exogenous shocks, and the cyclical behavior of the composition of investment. Our main predictions can be summarized as follows:

1. The level of financial development affects the relationship between aggregate volatility and mean growth (or mean R&D investment). When firms face tighter credit constraints, the relationship tends to become more negative (or less positive).

2. The level of financial development predicts the sensitivity of growth to past exogenous shocks. When firms face tighter constraints, growth becomes more sensitive to exogenous shocks, especially lagged ones.

3. The level of financial development predicts the cyclicality of R&D and other knowledge-intensive investments. As a fraction of GDP or total investment, R&D tends to be counter-

cyclical in the absence of credit constraints, but becomes increasingly procyclical as credit constraints tighten.

Below we test each of these predictions in turn and find strong empirical support for all three claims. In a cross-section of 70 countries we first show that average per capita growth over the 1960-1995 period is less sensitive to volatility the more credit is available to the private sector. To address the second prediction, we next consider the response of per capita growth to changes in the terms of trade and an export-weighted measure of commodity price shocks. We find that exogenous shocks to growth are mitigated in countries with better developed financial systems. Finally, in an annual panel of 14 OECD countries we observe that R&D as a share of total investment responds more countercyclically to lagged commodity price shocks the more private credit is available. On the other hand, total investment as a share of GDP does not exhibit this pattern, suggesting that the effect of shocks on future growth is truly channeled through reallocations towards more long-run investments and not simply through increased total investment. Our results are robust to the inclusion of different demographic and policy controls, as well as to alternative measures of financial development.

5.1 Data

Our data is relatively standard and readily available. Annual growth is computed as the log difference of per capita income obtained from the Penn World Tables mark 6.1 (PWT). We construct a measure of aggregate volatility by taking the country-specific standard deviation of annual growth over the 1960-1995 period.

As a measure of financial intermediation we use private credit, the value of loans by financial intermediaries to the private sector divided by GDP. Data for 71 countries on 5-year interval averages between 1960 and 1995 (1960-1964, 1965-1969, etc.) was first compiled by Levine, Loyaza and Beck (2000); an annual dataset was more recently prepared and made available by Levine on his webpage. Levine et al (2000) argue that private credit should be the preferred measure of financial development because it excludes credit granted to the public sector and funds coming from central or development banks. We also conduct sensitivity analysis with two alternative measures of credit constraints, liquid liabilities and bank assets. The first is defined as currency plus demand and interest-bearing liabilities of banks and non-bank financial intermediaries divided by GDP; the second gives the value of all loans by banks but not other financial intermediaries.

When analyzing the response of growth to shocks we first consider terms of trade shocks, available as five-year averages between 1960 and 1985 from the Barro-Lee (1997) dataset. Changes in the terms of trade reflect export-weighted changes in export prices net of import-weighted changes in import prices, quoted in the same currency. Arguably, exchange rate fluctuations may be endogenous to the growth process and therefore regressions of growth on terms of trade shocks may be subject to reverse causality and produce biased coefficient estimates. We therefore also construct an annual index of export-weighted commodity price shocks using data on the international prices of 42 products between 1960 and 2000 available from the International Financial Statistics (IFS) Database of the IMF. We first calculate the annual inflation/deflation rate for each commodity. We then average the share of that commodity in a country's exports in 1985, 1986, and 1987 as reported in the World Trade Analyzer (WTA).[15] Finally, we sum across all commodities' price changes using the corresponding export shares as weights, and obtain an annual shock index for all 70 countries between 1960 and 2000.

For the analysis on the transmission channel of credit constraints, we also need data on long term versus short-run investments. We consider R&D as a share of total investment. Unfortunately, data availability limits our sample to 14 OECD countries between 1973-1997 for which the OECD reports spending on research and development in the ANBERD database. Data on investment as a share of GDP is easily obtainable from the PWT. We also try out other ways of distinguishing between investments of different horizons, such as structural investment versus equipment, IT imports as a share of total imports, and the R&D embodied in capital imports as a share of total capital imports (the latter was constructed from data in Caselli and Wilson (2003)).

In the growth regressions below we follow Ramey and Ramey (1995) and Levine et al (2000) in controlling for population growth, initial secondary school enrollment, and a set of four policy variables (the share of government in GDP, inflation, the black market exchange rate premium, and openness to trade). We use demographics data from the PWT and the policy conditioning set in Levine et al (2000). When analyzing both growth and R&D we also control for property rights (*property*) and intellectual property rights (*ipr*). The former is broad measure from various editions of the Fraser Institute's Economic Freedom of the World database, while the latter is a

[15] These were the earliest years for which complete data was available at the country-commodity level.

narrower index constructed by Ginarte and Park (1997). We use the data as compiled by Caselli and Wilson (2003) for every fifth year between 1970 and 1995 for *ipr* and between 1970 and 1990 for *property*; to construct an annual panel we fill in the data by imposing a constant growth rate for each 5-year interval.

5.2 Growth, volatility, and credit in the cross-section

We start by exploring the relationship between volatility, credit constraints and growth in a cross-section of 70 countries. To test the first prediction of the model we estimate the following specification:

$$\begin{aligned} growth_i &= \alpha_0 + \alpha_1 \cdot y_i + \alpha_2 \cdot volatility_i + \alpha_3 \cdot credit_i + \\ &+ \gamma \cdot credit_i \cdot volatility_i + \beta \cdot X_i + \varepsilon_i \end{aligned} \tag{11}$$

We take $growth_i$ and $credit_i$ to be the average annual growth and private credit for country i between 1960 and 1995, and we expect $volatility_i$ to enter negatively. y_i is initial 1960 per capita income, and X_i is a vector of country specific controls. We are interested in the interaction γ between volatility and private credit, and we predict $\gamma > 0$ since more credit to the private sector should make growth less sensitive to volatility.

`[insert Table 2 here]`

Table 2 presents our results. We find a strong direct negative effect of volatility on long term growth of –0.41 and a significant positive coefficient on the interaction term of 0.011 (Column (1)). In this sample private credit varies from 4% to 141%, with a mean of 38% and a standard deviation of 29%. A one standard deviation increase in the level of financial development would therefore reduce the impact of a 1% rise in volatility from a 0.41% fall in the growth rate to -0.09% $(= -0.41 + 0.011 \cdot 29)$. This effect is significant in economic terms not only because of the large variation in private credit in the cross section, but also because there have been substantial changes in the level of financial development within a single countrybover the last few decades: For example, in the United States private credit almost tripled between 1960 and 1995, steadily rising from 50% to 140%. For many other countries the level of private credit both moved up and down significantly during the same period. As Column (2) shows, our result is robust to the inclusion of demographic and human capital controls, as well as measures of property rights protection and the Levine et al (2000) policy variables.

For sufficiently high levels of private credit (which we observe for many OECD countries) our results predict that the overall contribution of volatility to economic growth becomes positive. Moreover, for intermediate levels of private credit this gross contribution may be close to zero. Without accounting for the direct and interacted effects of financial development, regressing long run growth on volatility alone could thus produce an insignificant coefficient. This may explain why Ramey and Ramey (1995) find a strong negative effect of volatility on growth in the full cross-section but a non-significant one in the OECD sample. In Columns (3) and (4) we estimate (11) for the OECD countries only and find coefficients similar to those we found for the entire sample.[16]

Levine et al (2000) document a strong positive association between growth and financial development. Interestingly, when we interact the latter with volatility we observe an insignificant main effect of private credit (Table 2, any specification). Without pushing our results too far, we surmise that mitigating the response to volatility and exogenous shocks may be the most important transmission channel for the effects of deeper credit markets. In fact, when we study the response of annual growth to lagged terms of trade and commodity price shocks below we also observe an insignificant direct effect of financial development. Although our theoretical setup does not preclude the existence of other channels through which financial development affects growth, the results here suggest our model captures a key feature of the role of credit constraints.

Table 2 Columns (5) and (6) show that the growth impact of both volatility itself and its interaction with private credit are little affected by the inclusion of investment as a control. Risk arguably affects savings rates and investment, and investments fuel growth. However, controlling for the ratio of investment to GDP reduces the coefficient on volatility by only 20%, suggesting that 80% of the total effect of volatility on growth is via a channel other than the rate of investment.

`[insert Table 3 here]`

Table 3 examines the cross-country variation in the ratio of investment to GDP and the fraction of R&D in total investment. We estimate (11) with the investment variables on the left hand side; this effectively gives the first stage regression behind the reduced form specification in (11). Consistently with the results in Table 2, more volatility is found to have a small negative effect

[16] Because of the small sample size (22 or 19 countries) including the full controls set in Column (4) makes it difficult to estimate these coefficients precisely, but their point estimates are quite stable across specifications.

on the rate of total investment (Columns (1) through (3)).[17] In contrast, volatility has a large negative effect on the R&D intensity of investment (Columns (4) through (6)). Moreover, the private credit interaction term has a stronger positive effect on R&D than on total investment, as expected from our theory. Most of these effects are imprecisely estimated, presumably because of the small sample size or cross-country variation within the OECD. However, they anticipate our results on the responsiveness to shocks in the panel regressions below.

`[insert Table 4 here]`

Our main results are robust to alternative measures of financial development. Table 4 repeats the analysis from the first two columns in Table 2 with liquid liabilities and bank assets. In the last two columns of Table 4 we also consider the initial 1960 value of private credit in place of its 1960-1995 average. All coefficients remain significant and quantitatively similar across these specifications. We have also checked our results for sensitivity with respect to different measures of human capital, as well as initial 1960 vs. average 1960-1995 values for all controls (results not reported).[18]

5.3 Sensitivity of growth to shocks

We next estimate the sensitivity of growth to exogenous shocks, exploring both the cross-section and time-series variation in the panel. We first consider the medium run, and average data over 5-year period intervals in a cross-section of over 70 countries to estimate the following specification:

$$\begin{aligned} growth_{it} &= \alpha_0 + \alpha_1 \cdot y_{it} + \alpha_2 \cdot shock_{it} + \alpha_3 \cdot credit_{it} + \\ &\quad + \gamma \cdot credit_i \cdot shock_{it} + \beta \cdot X_{it} + \mu_i + \varepsilon_{it} \end{aligned} \tag{12}$$

Here we take $growth_{it}$ and $credit_{it}$ to be the average annual growth and private credit for country i in period t, where a period is defined as 5 consecutive non-overlapping years between 1960 and 1985. y_{it} is beginning of period per capita income, and X_{it} is a vector of controls. As a measure of

[17] In our model, the supply of savings was exogenously fixed, which implied that borrowing constraints had no effect on the overall level of investment in general equilibrium. With endogenous savings, however, borrowing constraints may affect both the composition and the overall level of investment.

[18] In particular, our results are robust to replacing secondary school enrollment with the average years of schooling in the population above 25 years of age, or with a Mincerian-returns-based measure of human capital.

$shock_{it}$ we consider both the average terms of trade shock and the average commodity price shock for the period. We expect a terms-of-trade improving shock to stimulate growth, and therefore α_2 to be positive. Similarly, we anticipate a positive direct *level* effect of financial development, thus $\alpha_3 > 0$.[19] We are interested in the interaction term γ, which captures the *amplification* effect of financial development, and we predict $\gamma < 0$: more credit to the private sector should make growth less sensitive to exogenous shocks or even reverse the overall effect of the shock. In the estimation we allow for country specific fixed effects.

`[insert Table 5 here]`

In Table 5 we show evidence for the expected significant positive effect of shocks on medium run growth. We also observe a strong negative coefficient on the interaction term, although it is only significant when we consider changes in the terms of trade. This result is robust to alternative measures of financial development and to using a 1-period lagged value of private credit. Because of the substantial time-series variation in private credit it is not surprising that using its initial 1960 value produces an insignificant interaction term.

Looking at 5-year intervals is useful because we do not need to take a stand on the exact frequency at which our amplification channel operates. It is possible, however, that by averaging over 5-year intervals we are smoothing commodity-price shocks too much. Moreover, one would expect tigther credit constraints to amplify the reaction of growth to lagged shocks more than its reaction to contemporaneous shocks, since productivity growth today is driven by investment activity in the past. For these reasons, we now move to an annual panel and study the impact of lagged commodity-price shocks on growth and their interaction with financial development.

[19] Note that financial development has a positive *level* effect on growth even in the absence of aggregate shocks, because tighter credit constraints increase the liquidity risk associated with idiosyncratic shocks and thereby reduce the average level of R&D as a fraction of investment.

Table 6 reports our results from estimating the following specification in an annual panel of 44 countries between 1960 and 2000:[20]

$$\begin{aligned} growth_{it} &= \alpha_0 + \delta_0 \cdot shock_{it} + \delta_{-1} \cdot shock_{it-1} + \delta_{-2} \cdot shock_{it-2} + \\ &\quad + \gamma_0 \cdot credit_{i\_} \cdot shock_{it} + \gamma_{-1} \cdot credit_{i\_} \cdot shock_{it-1} + \gamma_{-2} \cdot credit_{i\_} \cdot shock_{it-2} + \\ &\quad + \alpha_c \cdot credit_{i\_} + \alpha_y \cdot y_{it} + \alpha_t \cdot year + \mu_i + \varepsilon_{it} \end{aligned} \tag{13}$$

Now $growth_{it}$ is annual growth, y_{it} is initial per capita income, μ_i is a country fixed effect, the three $shock_{i\_}$ variables are the contemporaneous, 1-year and 2-year lagged commodity price shocks, and $credit_{i\_}$ is private credit measured in a period that varies across different specifications. In Column (1) of Table 6 we abstract from the time-series variation in financial development and estimate (13) with the initial 1960 value of private credit. We find that tighter credit constraints result in higher sensitivity to shocks, as predicted. All three shocks enter positively and very significantly, while all interaction terms receive a negative coefficient. Note that the contemporaneous interaction term is not significant; this is consistent with the idea that shocks and credit constraints affect the composition of contemporaneous investment, which in turn affects growth with a lag. Older shocks have a stronger influence on growth today, but they are also dampened by the availability of credit to a larger extent. For example, a 10% beneficial shock two years ago (roughly the standard deviation of $shock_{it}$ in this sample) would translate into a direct gain of 0.007% ($= 0.0664 \cdot 0.10$) annual growth today. At this sample's mean 42% share of private credit in GDP, however, the direct effect of the shock would be overturned by the interaction term: -0.01% ($= -0.2446 \cdot 0.10 \cdot 0.42$). Thus, credit availability plays an economically significant role in the response of growth to exogenous shocks.

`[insert Table 6 here]`

The rest of Table 6 shows that our results persist when we put less weight on the time-series variation in private credit. In Columns (2) and (3) we use lagged values of credit, averaged respectively over the immediately preceding five years and over the 5-year interval that ended five years ago.[21] Fixing each country's private credit at its average 1960-2000 value also produces

[20] For consistency, we limit the sample to the 44 countries for which we have data on private credit in 1960 in all columns of Table 6.

[21] The latter precludes the possibility of private credit responding to shocks since the relevant time periods for the two variables do not overlap. Note that when we use the $(t-1, t-5)$ average value of private credit, its $t-1$ value

significant coefficients of the correct sign. We have checked our results for robustness to alternative measures of financial development, as well as to including lagged growth among the controls (results not reported).[22]

[insert Table 7 here]

One concern with the results above may be that some other institutional variable that is positively associated with private credit may also interact with the commodity price shock. For example, if intellectual property rights are highly positively correlated with credit availability, then long-term investment may flourish under a negative shock because of the favorable property rights protection environment and not because of financial development. If so, then omitting *ipr* from the control set may bias the coefficients on all credit terms upwards (in absolute value). Table 7 Column (1) reproduces our main result from Table 6, while Column (2) shows that it is robust to the inclusion of *ipr* and *ipr* interacted with shocks. Our results also survive the inclusion of other institutional variables and their interactions with shocks such as the size of government and the black market premium (results not reported). However, accounting for the broader measure of property rights in Columns (3) and (4) dilutes the effects of private credit but makes *ipr* terms significant. We are not sure how to explain this result, but it is possible that property rights protection affects growth through its effect on credit extended to the private sector.

5.4 Cyclicality in R&D and investment

The final link that remains to be established is the interaction of financial development with the cyclicality of R&D and total investment with respect to exogenous shocks. Using annual data on 14 OECD countries between 1973 and 1997 we estimate two first-stage regressions behind specification

may have responded to the shock at time $t-2$. This may explain why the interaction term with $shock_{it-1}$ is not significant in Column (2) if shock really only enters linearly.

[22] When we include growth lagged 1- and 2-years, the 2-year lagged direct and interaction shock terms lose significance. A plausible explanation is that growth yesterday has had time to respond to shocks up to $t-2$ and only the $t-1$ shock remains to be passed through.

(13), namely

$$\begin{aligned} R\&D/I_{it} &= \alpha_0 + \delta_0 \cdot shock_{it} + \delta_{-1} \cdot shock_{it-1} + \delta_{-2} \cdot shock_{it-2} + \\ &+ \gamma_0 \cdot credit_{i\_} \cdot shock_{it} + \gamma_{-1} \cdot credit_{i\_} \cdot shock_{it-1} + \gamma_{-2} \cdot credit_{i\_} \cdot shock_{it-2} + \\ &+ \alpha_c \cdot credit_{i\_} + \alpha_y \cdot y_{it} + \alpha_t \cdot year + \mu_i + \varepsilon_{it} \end{aligned} \tag{14}$$

and

$$\begin{aligned} I/Y_{it} &= \alpha_0 + \delta_0 \cdot shock_{it} + \delta_{-1} \cdot shock_{it-1} + \delta_{-2} \cdot shock_{it-2} + \\ &+ \gamma_0 \cdot credit_{i\_} \cdot shock_{it} + \gamma_{-1} \cdot credit_{i\_} \cdot shock_{it-1} + \gamma_{-2} \cdot credit_{i\_} \cdot shock_{it-2} + \\ &+ \alpha_c \cdot credit_{i\_} + \alpha_y \cdot y_{it} + \alpha_t \cdot year + \mu_i + \varepsilon_{it} \end{aligned} \tag{15}$$

Now the dependent variables of interest are R&D as a share of total investment ($R\&D/I_{it}$) and investment as a fraction of GDP (I/Y_{it}) for country i in year t. As before, we include a linear trend and country fixed effects, and let the three $shock_{i\_}$ variables be the contemporaneous, 1-year and 2-year lagged commodity price shocks.

[insert Table 8 here]

Table 8 Column (5) shows our results from estimating (14) using the moving average of private credit over the immediately preceding five years. In line with our model, we find that all coefficients on the $shock_{i\_}$ variables are positive, while the interaction terms with private credit enter negatively. Two-year lagged shocks are the only significant ones, perhaps suggesting that the reallocation of investment itself takes place with a lag. To gauge the importance of credit constraints, note that R&D is procyclical for low levels of financial development but a value for private credit of 60% (= 0.74/1.25) is enough to make long-term investment countercyclical with respect to twice-lagged shocks. In fact, we observe such high levels of loan availability for many countries in our sample of 70, with their number tripling to 36 between 1974 and 1999. Our results on the response of $R\&D/I$ to shocks are robust to controlling for both *ipr* and *property* (and their interactions with shocks), as well as to using the five-year lagged 5-year average of private credit (Columns (6)–(8)).

In contrast to our findings above, the share of total investment in GDP does not become more procyclical as credit constraints tighten (Table 8, Columns (1) – (4)). Shocks do not appear to be a consistent source of either stimuli or disincentives for total investment, and their interaction with private credit tends to be insignificant and not stable across different specifications. If anything, financial development may magnify the procyclicality of I/Y, judging by the only significant (and positive) interaction coefficients in Columns (2) and (4). In brief, we interpret the evidence in support of our theory that credit availability helps redirect resources towards long-term projects (such as R&D) during a downturn, translating into improved growth a year or two later.

Our model makes predictions about short-run versus long-run investment allocation that extend to other types of investment but research and development. To test our results on the transmission channel of credit constraints we take three alternative cuts at investment (results not reported). Our strongest results are for the response of structural investment to lagged shocks. We distinguish housing/construction (long-run) from machinery and equipment (short-run), and we obtain data on the share of structural in total investment for 20 OECD countries between 1960 and 2000. We find that the fraction of long-horizon investment is countercyclical but becomes (more) procyclical when credit constraints tighten, as our model predicts. We observe the same behavior for the share of office and computing machines in total imports, another potential measure of long-term investments.[23] Finally, we were able to replicate the results with an imputed measure of the share of R&D embodied in capital equipment imports using data from Caselli and Wilson (2003). However, our findings with this measure were not stable across specifications, plausibly because of the limitations of the data.[24] While these three different measures of long-run versus short-run investments suffer from different imperfections (for example, office machines may actually be used immediately and therefore considered short-horizon), we consider these findings to be broadly consistent with our earlier conclusions.

We conclude that the results presented in Tables 1 through 8 provide convincing evidence for the three main predictions of our model about the response of growth to aggregate volatility and exogenous shocks, the cyclicality of long-run investment, and financial development.

[23] Surprisingly, however, the only statistically significant relationships we observe with computer imports are for shocks lagged by 5 to 10 years.

[24] For example, we were only able to construct an imputed value for the R&D embodied in capital imports for every fifth year between 1980 and 1995, which left us with roughly 60 countries and 3 data points per country. This made allowing for a linear trend or country fixed effects difficult and prevented an analysis with annual lagged shocks.

6 Concluding remarks

This paper investigated how financial development affects the impact of macroeconomic volatility or trade shocks on the composition of investment and on long-run productivity growth. We first considered a simple model in which agents engage in two types of investment, a short-term production investment and a long-term growth-enhancing investment. We identified the former as physical capital and the latter as R&D. We found that a lower degree of financial development implies a more negative correlation between macroeconomic volatility and growth, a higher sensitivity of growth to shocks, and a more procyclical ratio of R&D over total investment. We then confronted the model with cross-country panel data and found that the theoretical predictions were confirmed by the empirical analysis.

The model is highly stylized, but we expect our results to extend to more general frameworks as long as two key ingredients are preserved – namely, the distinction between short-term and long-term investments, and the presence of credit constraints. Indeed, one interesting direction for future research would be to embed these two ingredients in a full-fledged RBC model and examine in more detail the implications of our analysis for the endogenous cyclical behavior of the Solow residual and the impulse responses to productivity and demand shocks.

For the empirical part of the paper, we identified long-term investment with R&D. This is appropriate for investigating the impact of volatility on medium- and long-run growth, but R&D is perhaps less relevant as an amplification channel in business-cycle frequency. For the latter, it may be more appropriate to look at other kinds of long-term investment, such as structures or entry of new firms.

Finally, turning to policy implications, our analysis suggests that the impact of countercyclical fiscal policy on volatility and growth ought to be higher the lower the degree of financial development in a country. In the presence of nominal rigidities, financial development may also affect the extent to which a countercyclical monetary policy or a flexible exchange-rate regime can be stabilizing and therefore growth-enhancing. We plan to explore these issues in future research.[25]

[25] See Aghion, Bacchetta, Ranciere and Rogoff (2004) on exchange rate regimes.

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Table 1. Ramey-Ramey revisited

Dependent variable: avg. growth, 1960-1995	No investment				With investment			
	Whole sample		OECD countries		Whole sample		OECD countries	
Independent variable:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
initial income	-0.0019	-0.0175	-0.0110	-0.0258	-0.0094	-0.0163	-0.0123	-0.0258
	(-0.69)	(-5.66)***	(-3.49)***	(-7.47)***	(-3.89)***	(-5.98)***	(-4.25)***	(-6.99)***
volatility	-0.2796	-0.2641	0.0370	-0.2939	-0.1829	-0.2208	0.0142	-0.2899
	(-2.63)***	(-2.78)***	(0.22)	(-1.44)	(-2.14)**	(-2.63)**	(0.09)	(-1.33)
investment/GDP					0.1742	0.0963	0.0662	0.0058
					(6.47)***	(3.96)***	(2.43)**	(0.17)
pop growth		-0.0085		-0.0011		-0.0075		-0.0008
		(-3.53)***		(-0.39)		(-3.54)***		(-0.25)
sec school enrollment		0.0116		0.0050		0.0015		0.0047
		(0.89)		(0.90)		(0.13)		(0.77)
government size		-0.00020		-0.00019		-0.00025		-0.00014
		(-0.58)		(-0.51)		(-0.82)		(-0.29)
inflation		0.0003		-0.0011		0.0002		-0.0010
		(2.45)**		(-1.83)^		(1.89)*		(-1.07)
black market premium		-0.0127		-0.0414		-0.0123		-0.0382
		(-1.61)		(-0.44)		(-1.78)*		(-0.37)
trade openness		0.00012		-0.00008		0.00010		-0.00008
		(2.25)**		(-1.45)		(2.14)**		(-1.30)
intell property rights		0.0003		-0.0019		0.0004		-0.0018
		(0.14)		(-0.70)		(0.21)		(-0.57)
property rights		0.0030		0.0004		0.0018		0.0006
		(2.67)***		(0.35)		(1.74)*		(0.37)
R-squared	0.0969	0.6018	0.4194	0.9367	0.4472	0.7013	0.5515	0.9370
N	70	59	24	19	70	59	24	19

*Note: Dependent variable is average growth over the 1960-1995 period. All regressors are averages over the 1960-1995 period, except for intellectual and property rights which are for 1970-1995 and 1970-1990 respectively. Initial income and secondary school enrollment are taken for 1960. Constant term not shown. t-statistics in parenthesis. ***,**,*,^ significant at the 1%, 5%, 10% and 11% respectively.*

Table 2. Growth, volatility and credit constraints: basic specification

Dependent variable: avg. growth, 1960-1995

	No investment				With investment			
	Whole sample		OECD countries		Whole sample		OECD countries	
Independent variable:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
initial income	-0.0071	-0.0174	-0.0177	-0.0256	-0.0103	-0.0159	-0.0173	-0.0256
	(-2.56)**	(-5.77)***	(-6.69)***	(-6.32)***	(-4.10)***	(-5.70)***	(-6.55)***	(6.01)***
volatility	-0.4129	-0.5098	-0.5165	-0.5196	-0.3012	-0.4245	-0.5446	-0.5607
	(-3.06)***	(-3.33)***	(-1.73)*	(-1.14)	(-2.52)**	(-2.98)***	(-1.83)*	(-1.16)
private credit	-0.00005	-0.00016	-0.00019	-0.00006	-0.00008	-0.00020	-0.00021	-0.00008
	(-0.29)	(-0.98)	(-1.26)	(-0.29)	(-0.60)	(-1.34)	(-1.39)	(-0.37)
*volatility*private credit*	0.0113	0.0090	0.0080	0.0040	0.0069	0.0069	0.0083	0.0049
	(2.59)**	(2.15)**	(1.67)^	(0.63)	(1.76)*	(1.78)*	(1.73)^	(0.72)
investment/GDP					0.1420	0.0857	0.0270	0.0218
					(4.68)***	(3.20)***	(1.13)	(0.63)
pop growth		-0.0081		0.0005		-0.0076		0.0018
		(-3.55)***		(0.17)		(-3.64)***		(0.48)
sec school enrollment		0.0037		0.0064		-0.0040		0.0056
		(0.28)		(1.15)		(-0.33)		(0.92)
government size		-0.00001		0.00006		-0.00013		0.00027
		(-0.04)		(0.14)		(-0.43)		(0.51)
inflation		0.0003		-0.0004		0.0002		0.0001
		(2.78)***		(-0.52)		(1.91)*		(0.11)
black market premium		-0.0072		-0.0380		-0.0082		-0.0218
		(0.91)		(-0.34)		(-1.14)		(-0.18)
trade openness		0.00011		-0.00004		0.00009		-0.00003
		(2.06)**		(-0.62)		(1.98)*		(-0.36)
intell property rights		0.0013		-0.0015		0.0018		-0.0007
		(0.50)		(-0.50)		(0.76)		(-0.22)
property rights		0.0023		0.0003		0.0018		0.0009
		(1.94)*		(0.23)		(1.64)^		(0.57)
F-test (volatility terms)	0.0103	0.0051	0.2462	0.4122	0.0489	0.0105	0.2157	0.4580
F-test (credit terms)	0.0001	0.0310	0.0690	0.3993	0.0814	0.2120	0.1125	0.3875
R-squared	0.3141	0.6576	0.7894	0.9534	0.4889	0.7212	0.8049	0.9569
N	70	59	22	19	70	59	22	19

*Note: Dependent variable is average growth over the 1960-1995 period. All regressors are averages over the 1960-1995 period, except for intellectual and property rights which are for 1970-1995 and 1970-1990 respectively. Initial income and secondary school enrollment are taken for 1960. Constant term not shown. t-statistics in parenthesis. P-values from an F-test of the joint significance of volatility terms (volatility and volatility*credit) and credit terms (credit and volatility*credit) reported. ***,**,*,^ significant at the 1%, 5%, 10% and 11% respectively.*

Table 3. Credit constraints and the response of investment to volatility

Dependent variable:	Investment/GDP			R&D/investment		
Independent variable:	(1)	(2)	(3)	(4)	(5)	(6)
initial income	0.0433	0.0224	-0.0176	0.4709	0.3895	-1.3195
	(4.52)***	(2.28)**	(-1.16)	(1.60)	(1.26)	(-0.68)
volatility	-0.5553	-0.7868	-0.9946	-5.63	-22.10	-12.39
	(-1.46)	(-1.64)^	(-1.29)	(-0.53)	(-0.69)	(-0.24)
private credit		0.0003	0.0005		-0.0023	-0.0068
		(0.47)	(0.58)		(-0.20)	(-0.29)
*volatility*private credit*		0.0309	0.0246		0.1784	0.1354
		(1.99)*	(1.17)		(0.46)	(0.18)
pop growth			-0.0059			0.2237
			(-0.51)			(0.40)
sec school enrollment			0.0896			1.0506
			(1.37)			(0.64)
government size			0.0014			0.0964
			(0.83)			(1.13)
inflation			0.0011			-0.0951
			(2.20)**			(-0.41)
black market premium			0.0122			14.92
			(0.31)			(0.33)
trade openness			0.0002			-0.0054
			(0.58)			(-0.59)
intell property rights			-0.0059			0.5914
			(-0.45)			(0.78)
property rights			0.0057			-0.0104
			(0.98)			(-0.06)
R-squared	0.3471	0.5100	0.5770	0.2310	0.3382	0.8856
N	70	70	59	15	15	14

*Note: Dependent variable is investment as a share of GDP or R&D as a share of investment, averaged over the 1960-1995 and 1973-1997 period respectively. All regressors are averages over the 1960-1995 period, except for intellectual and property rights which are for 1970-1995 and 1970-1990 respectively. Initial income and secondary school enrollment are taken for 1960 in columns (1)-(3) and 1970 in columns (4)-(6). Constant term not shown. t-statistics in parenthesis. ***,**,*,^ significant at the 1%, 5%, 10% and 11% respectively.*

Table 4. Growth, volatility and credit constraints: sensitivity analysis

Dependent variable: avg. growth, 1960-1995								
Credit constraints var.:	private credit		liquid liabilities		bank assets		private $credit_{1960}$	
Independent variable:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
initial income	-0.0071	-0.0174	-0.0062	-0.0166	-0.0076	-0.0173	-0.0042	-0.0146
	(-2.56)**	(-5.77)***	(-2.93)***	(-5.90)***	(-2.95)***	(-5.59)***	(-1.36)	(-5.46)***
volatility	-0.4129	-0.5098	-0.6781	-0.5554	-0.6441	-0.4981	-0.5722	-0.1904
	(-3.06)***	(-3.33)***	(-3.72)***	(-2.97)***	(-4.03)***	(-2.78)***	(-3.71)***	(-1.52)
credit	-0.00005	-0.00016	0.00000	-0.00004	-0.00016	-0.00021	-0.00048	-0.00023
	(-0.29)	(-0.98)	(-0.03)	(-0.22)	(-0.88)	(-0.96)	(-1.97)**	(-1.27)
*volatility*credit*	0.0113	0.0090	0.0122	0.0077	0.0162	0.0085	0.0204	0.0083
	(2.59)**	(2.15)**	(2.96)***	(1.90)*	(3.41)***	(1.61)^	(3.07)***	(1.74)*
Controls:								
pop growth, sec enroll	no	yes	no	yes	no	yes	no	yes
Levine et al controls	no	yes	no	yes	no	yes	no	yes
property rights	no	yes	no	yes	no	yes	no	yes
R-squared	0.3141	0.6576	0.5058	0.6864	0.3924	0.6328	0.2263	0.7232
N	70	59	70	59	70	59	60	52

*Note: Dependent variable is average growth over the 1960-1995 period. All regressors are averages over the 1960-1995 period, except for intellectual and property rights which are for 1970-1995 and 1970-1990 respectively. Initial income and secondary school enrollment are taken for 1960. In columns (7) and (8) the initial 1960 value of private credit is used. Private credit is defined as the value of credits by financial intermediaries to the private sector, divided by GDP. Liquid liabilities represents currency plus demand and interest-bearing liabilities of banks and non-bank financial intermediaries, dividided by GDP. Bank assets is the value of all credits by banks (but not other financial intermediaries). The Levine et al. controls include the share of government in GDP, inflation, trade openness, and the black market premium. Property rights refer to both intellectural and overall property rights. Constant term not shown. t-statistics in parenthesis. ***,**,*,^ significant at the 1%, 5%, 10% and 11% respectively.*

Table 5. The response of growth to terms of trade and commodity price shocks: 5-year averages

Dependent variable: 5-year avg. growth

	Terms of trade shocks				Price commodity shocks			
	private $credit_t$		initial credit	lagged credit	private $credit_t$		initial credit	lagged credit
	OLS	FE	FE	FE	OLS	FE	FE	FE
Independent variable:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
initial income	-0.0063	-0.0757	-0.0670	-0.0899	-0.0076	-0.0701	-0.0592	-0.0751
	(-2.02)**	(-8.06)***	(-7.22)***	(-7.12)***	(-2.68)***	(-8.34)***	(-6.92)***	(-7.00)***
shock	0.1402	0.1383	0.1062	0.1640	0.1297	0.1243	0.1462	0.1234
	(3.07)***	(3.60)***	(2.31)**	(3.65)***	(2.43)**	(2.68)***	(2.45)**	(2.36)**
private credit	0.0143	0.0177		0.0145	0.0264	0.0387		0.0325
	(1.71)*	(1.09)		(0.64)	(3.61)***	(3.21)***		(1.99)**
*private credit*shock*	-0.3226	-0.3509	-0.0539	-0.3599	-0.2263	-0.2119	-0.4207	-0.2065
	(-1.89)*	(-2.24)**	(-0.23)	(-1.78)*	(-1.22)	(-1.33)	(-1.44)	(-0.99)
Controls:								
pop growth, sec enroll	yes	yes	yes	yes	yes	yes	yes	yes
R-squared	0.0696				0.0867			
R-squared within		0.3296	0.3418	0.3608		0.2723	0.2650	0.2519
R-squared between		0.0419	0.0287	0.0320		0.0403	0.0322	0.0516
# countries (groups)		73	57	70		72	57	72
N	323	323	277	255	388	388	331	321

*Note: Dependent variable is average growth over 5-year intervals in the 1960-1985 period. Terms of trade shock is defined as the growth of export prices less the growth of import prices. Commodity price shocks are export-weighted changes in the price of 42 commodities. Both shocks are averaged over the corresponding 5-year interval. Private credit is concurrent 5-year average, initial 1960-1964 average or lagged (t-5,t-1) average as indicated in the column heading. Constant term not shown. t-statistics in parenthesis. ***,**,*,^ significant at the 1%, 5%, 10% and 11% respectively.*

Table 6. The response of growth to commodity price shocks: annual panel data, fixed effects

Dependent variable: annual growth	private credit$_{1960}$	(t-5,t-1) avg credit	(t-10,t-6) avg credit	1960-2000 avg credit
Independent variable:	(1)	(2)	(3)	(4)
$shock_t$	0.0390	0.0356	0.0427	0.0449
	(1.87)*	(1.87)*	(2.19)**	(2.03)**
$shock_{t-1}$	0.0610	0.0508	0.0612	0.0959
	(2.84)***	(2.58)***	(3.02)***	(4.25)***
$shock_{t-2}$	0.0664	0.0772	0.0789	0.0701
	(3.04)***	(3.86)***	(3.77)***	(3.06)***
priv credit		0.0038	0.0092	
		(0.45)	(0.83)	
priv credit$shock_t$*	-0.1291	-0.0699	-0.0929	-0.1011
	(-1.14)	(-1.06)	(-1.27)	(-1.30)
priv credit$shock_{t-1}$*	-0.2314	-0.1039	-0.1326	-0.2845
	(-1.97)**	(-1.53)	(-1.71)*	(-3.57)***
priv credit$shock_{t-2}$*	-0.2446	-0.1915	-0.1929	-0.1671
	(-2.05)**	(-2.81)***	(-2.39)**	(-2.07)**
Controls:				
initial income	yes	yes	yes	yes
linear trend	yes	yes	yes	yes
R-squared within	0.0403	0.0395	0.0374	0.0457
R-squared between	0.0298	0.0182	0.0086	0.0316
# countries (groups)	44	44	44	44
N	1653	1516	1306	1653

*Note: Dependent variable is annual growth. Annual 1960-2000 data, except where lost due to lags. Panel fixed effects estimation. $Shock_t$, $shock_{t-1}$, $shock_{t-2}$ refer to the contemporaneous, 1-year and 2-year lagged commodity price shock, as defined in the text. All regressions include a constant term and a linear trend, and control for initial income. Initial 1960 or lagged average value used for private credit, as indicated in the column heading. Columns (2)-(4) limit the sample to countries for which we have initial credit values. t-statistics in parenthesis. ***,**,* significant at the 1%, 5% and 10% respectively.*

Table 7. The response of growth to commodity price shocks: annual panel data, property rights

Dependent variable: annual growth				
Independent variable:	(1)	(2)	(3)	(4)
$shock_t$	0.0390	-0.0030	-0.0136	-0.0810
	(1.87)*	(-0.07)	(-0.42)	(-1.72)*
$shock_{t-1}$	0.0610	0.1096	0.0352	0.1281
	(2.84)***	(2.53)**	(1.06)	(2.64)***
$shock_{t-2}$	0.0664	0.0546	0.0322	0.0606
	(3.04)***	(1.24)	(0.96)	(1.24)
priv credit$shock_t$*	-0.1291	-0.1149	-0.0627	-0.2068
	(-1.14)	(-1.00)	(-0.43)	(-1.29)
priv credit$shock_{t-1}$*	-0.2314	-0.2479	-0.0620	0.1194
	(-1.97)**	(-2.08)**	(-0.41)	(0.71)
priv credit$shock_{t-2}$*	-0.2446	-0.2364	0.0095	0.0278
	(-2.05)**	(-1.96)**	(0.06)	(0.17)
intell rights$shock_t$*		0.0196		0.0585
		(1.14)		(1.98)**
intell rights$shock_{t-1}$*		-0.0227		-0.0797
		(-1.30)		(-2.62)***
intell rights$shock_{t-2}$*		0.0054		-0.0221
		(0.31)		(-0.73)
prop rights$shock_t$*			0.0080	0.0058
			(1.76)*	(1.21)
prop rights$shock_{t-1}$*			-0.0047	-0.0008
			(-1.00)	(-0.15)
prop rights$shock_{t-2}$*			-0.0083	-0.0054
			(-1.78)*	(-1.08)
Controls:				
initial income	yes	yes	yes	yes
linear trend	yes	yes	yes	yes
R-squared within	0.0403	0.0420	0.0531	0.0629
R-squared between	0.0298	0.0314	0.0012	0.0014
# countries (groups)	44	43	28	28
N	1653	1623	1064	1064

*Note: Dependent variable is annual growth. Annual 1960-2000 data, except where lost due to lags. Panel fixed effects estimation. $Shock_t$, $shock_{t-1}$, $shock_{t-2}$ refer to the contemporaneous, 1-year and 2-year lagged commodity price shock, as defined in the text. All regressions include a constant term and a linear trend, and control for initial income. Initial 1960 value of private credit used throughout. t-statistics in parenthesis. ***,**,* significant at the 1%, 5% and 10% respectively.*

Table 8. The response of investment to commodity price shocks: annual panel data, fixed effects

Dependent variable:	Investment/GDP				R&D/investment			
Credit and prop rights:	(t-5,t-1) avg			(t-10,t-6) avg	(t-5,t-1) avg			(t-10,t-6) avg
Independent variable:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$shock_t$	-2.56	-9.19	-27.60	-9.14	0.2629	0.7217	0.5945	0.2863
	(-0.21)	(-0.20)	(-0.59)	(-0.85)	(0.65)	(0.52)	(0.58)	(0.79)
$shock_{t-1}$	10.06	22.58	47.85	12.61	0.0547	1.0157	0.4940	0.0642
	(0.82)	(0.47)	(1.00)	(1.16)	(0.14)	(0.70)	(0.48)	(0.18)
$shock_{t-2}$	-7.56	111.51	148.02	-13.19	0.7429	-1.0500	0.0350	0.8298
	(-0.65)	(3.09)***	(3.89)***	(-1.20)	(1.94)*	(-0.97)	(0.04)	(2.24)**
priv credit	1.83	-0.17	-1.71	5.93	-0.0583	0.0078	-0.0685	-0.0735
	(1.32)	(-0.11)	(-0.77)	(3.72)***	(-1.29)	(0.17)	(-1.41)	(-1.37)
priv credit$shock_t$*	11.54	9.81	8.43	23.25	-0.3734	-0.2190	-0.2459	-0.4368
	(0.62)	(0.39)	(0.34)	(1.40)	(-0.61)	(-0.29)	(-0.45)	(-0.78)
priv credit$shock_{t-1}$*	-2.23	0.14	-16.62	-3.42	-0.0871	-0.0220	0.0518	-0.1722
	(-0.12)	(0.01)	(-0.69)	(-0.20)	(-0.14)	(-0.03)	(0.10)	(-0.30)
priv credit$shock_{t-2}$*	26.09	40.46	2.85	38.12	-1.2544	-1.2025	-1.1847	-1.5159
	(1.46)	(2.06)**	(0.14)	(2.08)**	(-2.12)**	(-2.04)**	(-2.75)***	(-2.45)**
intell rights		-3.35	-4.27			0.2276	0.1233	
		(-2.70)***	(-2.91)***			(6.11)***	(3.87)***	
intell rights$shock_t$*		1.35	5.05			-0.1462	0.1216	
		(0.09)	(0.28)			(-0.32)	(0.31)	
intell rights$shock_{t-1}$*		-5.27	-13.09			-0.3558	-0.2452	
		(-0.34)	(-0.71)			(-0.76)	(-0.61)	
intell rights$shock_{t-2}$*		-40.58	-26.12			0.5785	0.0894	
		(-3.25)***	(-1.91)*			(1.54)	(0.30)	
prop rights			0.39				-0.0037	
			(1.54)				(-0.68)	
prop rights$shock_t$*			1.02				-0.1037	
			(0.19)				(-0.87)	
prop rights$shock_{t-1}$*			0.62				0.0141	
			(0.12)				(0.13)	
prop rights$shock_{t-2}$*			-8.14				0.0478	
			(-2.00)**				(0.54)	
Controls:								
linear trend	yes	yes	yes	yes	yes	yes	yes	yes
R-squared within	0.2535	0.2581	0.2295	0.2848	0.5053	0.5804	0.6228	0.5084
R-squared between	0.0519	0.1470	0.1016	0.0635	0.2292	0.1518	0.2325	0.2227
# countries (groups)	14	14	13	14	14	14	13	14
N	337	291	221	331	338	291	221	332

*Note: Dependent variable is investment as a share of GDP or R&D as a share of investment. Annual 1973-1997 data, except where lost due to lags. Panel fixed effects estimation. Shockt, shockt-1, shockt-2 refer to the contemporaneous, 1-year and 2-year lagged commodity price shock, as defined in the text. Lagged (t-10,t-6) or (t-5,t-1) average used for private credit, as indicated in the column heading. All regressions include a constant term and a linear trend. t-statistics in parenthesis. ***,**,* significant at the 1%, 5% and 10% respectively.*