Volatility and Growth: Credit Constraints and the Composition of Investment*

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Abstract

This paper examines how uncertainty and credit constraints affect the composition of investment and thereby volatility and growth. We develop a model where firms engage in two types of investment: a short-term one; and a long-term one, which contributes more to productivity growth. Because it takes longer to complete, long-term investment has a relatively less cyclical return but also a higher liquidity risk. The first effect ensures that the share of long-term investment to total investment is countercyclical when financial markets are perfect; the second implies that the share of long-term investment turns procyclical when firms face tight credit constraints. The contribution of the paper is thus to identify a novel propagation mechanism: through its effect on the cyclical composition of investment, tighter credit can lead to both higher volatility and lower mean growth. Evidence from a panel of countries provides support for these predictions.

JEL codes: E22, E32, O16, O30, O41, O57.
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1 Introduction

Business-cycle models give a central position to productivity and demand shocks, and the role of financial markets in the propagation of these shocks; but they typically take the entire productivity process as exogenous. Growth models, on the other hand, give a central position to endogenous productivity growth, and the role of financial markets in the growth process; but they focus on trends, largely ignoring shocks and cycles.

The broader goal of this paper is to build a bridge between the two approaches. Of course, ours is not the first attempt to do so. The novelty of this paper is in the particular mechanism we study: the interaction between uncertainty, credit frictions, and the allocation of savings between short-term and long-term investment opportunities. This choice is motivated by both empirical and theoretical considerations.

First, the data suggest that countries with tighter financial markets tend to have more volatile growth rates, but their investment rates are not more volatile. Prima facia, this fact seems inconsistent with propagation mechanisms that rely on credit constraints amplifying the impact of shocks on overall investment. Moreover, while there is a negative correlation between volatility and growth in the cross-section of countries, this relation does not appear to be channeled through the rate of investment. The data thus suggest that uncertainty has an effect on growth that goes beyond its effect on the overall rate of saving and investment.

Second, whereas most previous theoretical work has focused on the impact of credit constraints on the *ability* to invest, we are interested in understanding how the anticipation of liquidity risk affects the *willingness* to invest in long-term projects. By the mere fact that they take longer to complete, long-term investments are likely to face higher liquidity risk than short-term ones. At the same time, long-term investments are often the source, or the vehicle, of productivity growth.

Taken together, these observations suggest that the interaction between uncertainty, credit constraints, and the composition of investment may have important implications for both volatility and growth. The contribution of the paper is to show that this interaction leads to a novel propagation mechanism: even if it does not affect the cyclical behavior of the overall rate of investment, tighter credit can lead to both higher volatility and lower mean growth through its effect on the *cyclical composition* of investment.

In our model, firms engage in two alternative types of investment. *Short-term investment* takes relatively little time to build and therefore generates output (and liquidity) relatively fast. *Long-term investment* takes more time to complete, but also contributes more to productivity growth. The supply of savings is assumed to be constant, ensuring that in general equilibrium the overall rate of investment is also constant. This permits us to isolate the novel composition effects that are the core of our contribution from the standard neoclassical propagation mechanism that works through the response of aggregate saving and investment to shocks.

With perfect credit markets, the equilibrium composition of investment is dictated merely by an opportunity-cost effect. As long as shocks are not fully persistent, short-term returns are more procyclical than long-term returns. That is, the relative demand for long-term investment is higher in recessions than in booms. It follows that the fraction of savings allocated to long-term investment is countercyclical.

With sufficiently imperfect credit markets, instead, the fraction of savings allocated to long-term investment becomes procyclical. This is *not* because borrowing constraints limit the ability to invest as in standard credit-multiplier models; in our model the interest rate adjusts in equilibrium so that neither type of investment is constrained ex ante. Rather, it is because tighter constraints imply a higher risk that long-term investment will be interrupted by some (idiosyncratic) liquidity shock. Ex ante, this risk reduces the *willingness* to engage in long-term investment—and the more so in recessions, when firms expect liquidity to be scarce for a while.

Since long-term investment enhances productivity more than short-term investment, these results imply that the cyclical behavior of the composition of investment mitigates fluctuations when financial markets are perfect, but amplifies them when credit constraints are sufficiently tight. In other words, tighter credit raises the sensitivity of endogenous productivity to exogenous shocks. At the same time, tighter credit reduces the average propensity to engage in long-term productivity-enhancing investments by increasing the average level of liquidity risk involved in these investments. It follows that financial frictions contribute to both a lower mean rate of productivity growth and higher volatility.

Whereas we view the theoretical exercise as the key contribution of the paper, we also take a first pass at the empirical performance of the theory within a panel of 21 OECD countries over the 1960-2000 period.

We map the model to the data as follows. As a proxy for shocks, we consider innovations in commodity prices, weighted for each country by the contribution of these commodities to the country's net exports composition; because price fluctuations in international commodity markets are largely exogenous to each individual country, there is a good chance that our identification of exogenous shocks is valid. As a proxy for the share of long-term investment, we take the ratio of structural investment to total private investment; this seemed, to us, the best available option given data-availability and data-quality concerns. Finally, as a proxy for financial development, we take the ratio of private credit to GDP; this is the standard measure used in the literature.

We then proceed to test the model's key properties. First, we find that the impact of adverse commodity price shocks on the share of structural investment is more negative in countries with lower private credit. In contrast, we find no such effect in the case of the overall investment rate. Next, we document that the impact of an adverse shock on output growth is more negative in countries with lower private credit. Finally, we find this effect to survive the inclusion of the current and lagged values of investment in the set of controls. Although of varying statistical significance, these findings appear to support our thesis that credit frictions affect the propagation of shocks more through the composition of investment than through the overall rate of investment.

The rest of the paper is organized as follows. Section 2 reviews some facts that motivated our theoretical exercise and its relation to the pertinent literature. Section 3 introduces the model. Section 4 analyzes the equilibrium composition of investment. Section 5 derives the implications for growth and volatility. Section 6 contains the empirical analysis. Section 7 concludes.

2 Motivating background and related literature

In an influential paper, Ramey and Ramey (1995) document a negative correlation between the volatility and the mean rate of output growth in a cross-section of countries. They show that this correlation survives a variety of controls and go on to argue that it reflects a causal negative effect of uncertainty on growth.[1]

Such an effect is consistent with the one-sector neoclassical growth model if risk discourages the demand for investment more than it encourages the precautionary supply of savings. In an AK economy, for example, the general-equilibrium impact of aggregate risk on savings and thereby on growth is negative if the elasticity of intertemporal substitution is sufficiently high (Obstfeld, 1994; Jones, Manuelli and Stacchetti, 2000).[2] Alternatively, in a one-sector model with credit market imperfections, volatility may increase the likelihood of binding credit constraints and thereby reduce aggregate investment (e.g., Bernanke and Gertler, 1989). However, the observed correlation between volatility and growth does not seem to be consistent with either of these interpretations.

First, the negative effect of volatility persists even after controlling for the rate of investment. This is shown in columns 1-4 of Table 1, which re-estimate some of the basic specifications from Ramey and Ramey's (1995) in our data set: the point estimate of the volatility coefficient falls only by one tenth when the investment rate is included as an additional control. This suggests that the main channel through which uncertainty affects the trend of productivity might not be the overall propensity to save or invest.

Second, whereas there is suggestive evidence that credit access predicts both the mean and the volatility of the growth rate (see columns 5 and 6), a first pass at the data gives no indication that credit predicts the volatility of the aggregate investment rate. In our sample, the cross-country correlation between a country's ratio of private credit to GDP—the measure of financial development usually used in the literature—and the country's mean growth rate is 0.49, and the

[1] Complementary evidence is provided by Blattman, Hwang and Williamson (2004), Koren and Tenreyro (2004), and others. See, however, Chatterjee and Shukayev (2005) and Ramey and Ramey (2006) for a debate on how sensitive these findings are to the particular measurement of output growth.

[2] A similar result holds for idiosyncratic investment risk in the neoclassical growth model (Angeletos, 2007).

Table 1. Average growth, growth volatility and investment volatility

Dependent variable:	Average growth, 1960-2000				Growth volatility, 1960-2000		Investment volatility, 1960-2000	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
initial income	0.0018	-0.0095	-0.0060	-0.0096	-0.0116	-0.0048	-0.9397	-1.5256
	(0.88)	(-3.31)***	(-3.59)***	(-4.07)***	(-3.23)***	(-1.22)	(-2.18)**	(-2.63)**
growth volatility	-0.1269	-0.1158	-0.1129	-0.1007				
	(-2.10)**	(-1.27)	(-2.64)***	(-1.35)				
investment/GDP			0.0018	0.0013				
			(10.11)***	(5.64)***				
private credit					-0.0236	-0.0059	0.5770	2.3616
					(-2.09)**	(-0.52)	(0.43)	(1.41)
Controls:								
pop growth, sec enroll	no	yes	no	yes	no	yes	no	yes
Levine et al. policy set	no	yes	no	yes	no	yes	no	yes
R-squared	0.0779	0.4234	0.5395	0.6168	0.2411	0.4980	0.0523	0.3693
N	106	73	106	73	106	73	106	73

*Note: All regressors are averages over the 1960-2000 period, except for initial income and secondary school enrollment, which are taken for 1960. Growth and investment volatility are constructed as the standard deviation of annual growth and the share of total investment in GDP in the 1960-2000 period respectively. The Levine et al. policy set of controls includes government size as a share of GDP, inflation, black market premium, and trade openness. Constant term not shown. t-statistics in parenthesis. ***,**,* significant at 1%, 5%, and 10%.*

correlation between private credit and the variance of the growth rate is -0.42. By contrast, the correlation between private credit and the standard deviation of the ratio of investment to GDP is about zero (only -0.06). Moreover, when in columns 7 and 8 of Table 1 we repeat the same regressions as in columns 5 and 6 now using the standard deviation of the investment rate as the dependent variable, we find no relationship between the latter and the quality of the financial sector. This suggests that credit constrains might not affect the sensitivity of the overall rate of investment to shocks.

Taking together, these observations indicate that one should look beyond the standard transmission channel—the response of aggregate saving and investment—in order to understand how uncertainty and credit constraints affect the trend and the volatility of the growth process. The transmission mechanism that we investigate in this paper works through the share of saving that is allocated to long-term productivity-enhancing investments.

Of course, this is not the first paper to look at how financial frictions affects either trend growth or volatility. This has been the subject of a large literature, including Bernanke and Gertler (1989), Banerjee and Newman (1993), King and Levine (1993), Obstfeld (1994), Aghion and Bolton (1997), Kiyotaki and Moore (1997), Holmstrom and Tirole (1998), Aghion, Banerjee and Piketty (1999).[3] However, we depart from this earlier work by focusing on liquidity risk affects the cyclical composition of investment.

[3]See Levine (1997) for an excellent review and more references.

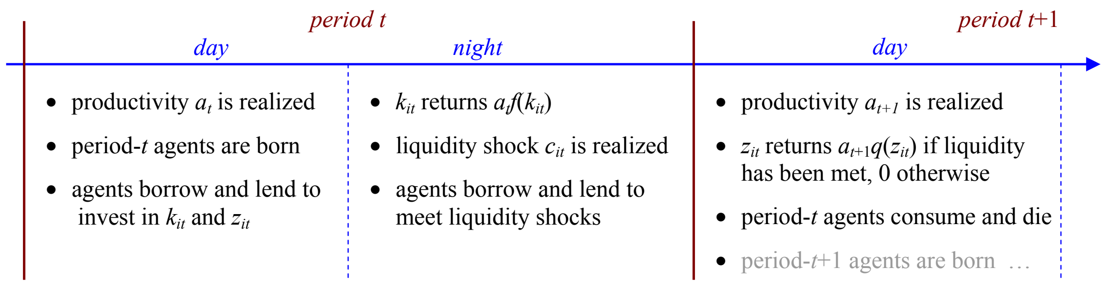

Figure 1: The life of an entrepreneur.

King and Rebelo (1993), Stadler (1990), and Jones, Manuelli and Stacchetti (2000) analyze the relation between volatility and growth within the AK class of models, but do not consider the cyclical behavior of the allocation of investment or the role of financial markets. Hall (1991), Gali and Hammour (1991), Aghion and Saint-Paul (1998), Barlevy (2004), Walde (2004), and Comin and Gertler (2004) do look at the allocation of investment across alternative uses, but only under the assumption of perfect credit markets.

Acemoglu and Zilibotti (1997) argue that lower levels of income, by constraining the ability to diversify sector-specific risks, may lead to both higher volatility and lower growth.[4] Caballero and Hammour (1994) examine the cleansing effect of recessions. Finally, Francois and Lloyd-Ellis (2003) consider a Schumpeterian growth model in which cycles are generated by firms' incentives to synchronize their innovations, as in Shleifer (1986). We share with these papers an interest in the co-determination of volatility and growth, but our interest in the interaction of credit constraints and the allocation of savings between short- and long-term investment, differentiates our work from this literature.

3 The model

There are overlapping generations of agents ("entrepreneurs"), who are indexed by i, are uniformly distributed over the segment $[0, 1]$, live two periods, and engage in two types of investment. Short-term investment produces at the end of the first period, whereas long-term investment produces at the end of the second period and only if a random liquidity shock, realized in between, is successfully met. The life of an entrepreneur is illustrated in Figure 1 and further explained below.

Productivity and exogenous shocks. Aggregate productivity has two components; the one is endogenous, the other is exogenous. We denote the endogenous component by T_t; we call it the level of "knowledge" and describe its determination later. We denote the exogenous component

[4]Koren and Tenreyro (2004), however, provide evidence suggesting that less developed countries specialize in sectors with relatively higher, not lower, risks.

by a_t; this is the source of aggregate uncertainty in the model. We assume that a_t follows a Markov process with support $[\underline{a}, \overline{a}] \subseteq \mathbb{R}_+$, unconditional mean normalized to 1, and conditional mean $\mathbb{E}_{t-1} a_t = a_{t-1}^{\rho}$; the coefficient $\rho \in (0,1)$ parametrizes the persistence of the exogenous shock.

Short-term and long-term investment. Consider an entrepreneur born in period t. In the beginning of her life, the entrepreneur receives an endowment of wealth, $W_{t,1}^i$, and decides how to allocate it between short-run investment, K_t^i, long-term investment, Z_t^i, and savings in the riskless bond, B_t^i. To ensure a balanced-growth path, we assume that the initial endowment and the costs of short-term and long-term investments are proportional to T_t. We then define $w_{t,1}^i \equiv W_{t,1}^i / T_t$, $k_t^i \equiv K_t^i / T_t$, $z_t^i \equiv Z_t^i / T_t$, and $b_t^i \equiv B_t^i / T_t$, to be the "detrended" levels of wealth, short-term investment, long-term investment, and bond holdings. We also assume that $w_{t,1}^i$ is constant across agents as well over time, which effectively fixes the supply of savings; without any further loss of generality we then normalize $w_{t,1}^i = 1$.[5] The initial budget thus reduces to

$$k_t^i + z_t^i + b_t^i \leq 1. \tag{1}$$

Short-term investment takes only one step to complete—the initial investment k_t^i—and produces at the end of the same period (period t). Its output is given by

$$\Pi_{t,1}^i = a_t T_t \pi(k_t^i), \tag{2}$$

where π is a neoclassical production function (i.e., $\pi' > 0 > \pi''$, $\pi'(0) = \infty$, and $\pi'(\infty) = 0$).

Long-term investment, on the other hand, takes two steps to complete—the initial investment Z_t^i incurred in the beginning of the first period, plus an additional random adjustment cost C_t^i incurred at the end of the first period—and produces at the end of the second period (period $t+1$). Let ℓ_t^i be an indicator variable that takes value 1 if the second step is successfully completed and 0 otherwise. The output of long-term investment is given by

$$\Pi_{t,2}^i = \begin{cases} a_{t+1} T_t q(z_t^i) + C_t^i & \text{if } \ell_t^i = 1 \\ 0 & \text{if } \ell_t^i = 0 \end{cases} \tag{3}$$

where q is also a neoclassical production function (i.e., $q' > 0 > q''$, $q'(0) = \infty$, and $q'(\infty) = 0$).

That $\Pi_{t,2}^i$ includes C_t^i is inessential; it ensures that long-term investment is always completed under complete markets and therefore models C_t^i as a pure liquidity shock. That $\Pi_{t,2}^i$ depends on T_t rather than T_{t+1} is also inessential; it only means that the endogenous component of the productivity of an entrepreneur depends on the knowledge available at the moment he is born

[5] Here we are ruling out any impact of credit constraints on the mean and the volatility of total investment. None of the results would be affected if we let $w_{t,1}^i$ (and hence total investment) be an increasing function of μ. On the other hand, that μ does not affect the volatility of the investment rate is justified simply by our choice of focus, but is also consistent with the evidence discussed in the introduction.

(period t) rather than at the moment he produces.[6] The assumption, on the other hand, that $\Pi^i_{t,2}$ (which is produced at $t+1$) depends on a_{t+1} while $\Pi^i_{t,1}$ (which is produced at t) depends on a_t is crucial; together with the assumption that a_t is mean-reverting, it ensures that the return to short-term investment is more cyclical than the return to long-term investment.

Liquidity risk. The detrended shock $c^i_t \equiv C^i_t/T_t$ is independently and identically distributed across agents and periods, with support $[0, \bar{c}]$, cumulative distribution function F, and density f. Unless otherwise stated, we assume for simplicity that F is isoelastic: $F(c) = (c/\bar{c})^{\phi}$, with $\phi > 0$.

Entrepreneur's payoff. The entrepreneur is risk neutral and consumes only in the last period of her life. Hence, expected life-time utility is simply $\mathbb{E}_t[W^i_{t,2}]$, where $W^i_{t,2} = \Pi^i_t + \left(\Pi^i_{t+1} - C^i_t\right)\ell^i_t + (1+r_t)B^i_t$ is the entrepreneur's final-period wealth and ℓ^i_t is an indicator variable such that $\ell^i_t = 1$ if the firm meets its liquidity shock and $\ell^i_t = 0$ otherwise. Equivalently, the entrepreneur maximizes $\mathbb{E}_t[w^i_{t,2}]$, where

$$w^i_{t,2} \equiv W^i_{t+1,2}/T_t = a_t\pi(k^i_t) + a_{t+1}q(z^i_t)\ell^i_t + (1+r_t)b^i_t. \tag{4}$$

Credit markets. Credit markets open twice every period. The "day" market takes place at the beginning of the period, after the realization of the aggregate shock a_t but before the realization of the idiosyncratic liquidity shock C^i_t. The "overnight" market takes place at the end of the period, after the realization of the liquidity shock.

In the day market the entrepreneur can borrow up to m times her initial wealth ($m \geq 0$). The ex ante borrowing constraint can thus be expressed as $k^i_t + z^i_t \leq \mu$, where $\mu \equiv 1 + m \geq 1$. Similarly, in the overnight market, the entrepreneur can borrow up to m times her end-of-current-period wealth, $X^i_t = a_t T_t \pi(k^i_t) + (1+r_t)B^i_t$, for the purpose of covering the liquidity cost C^i_t. Thus, the probability that the entrepreneur will be able to meet the liquidity shock and enjoy the fruits of his long-term investment is given by

$$p^i_t \equiv \Pr\left(C^i_t \leq \mu X^i_t\right) = \Pr\left(c^i_t \leq \mu x^i_t\right) = F\left(\mu x^i_t\right),$$

where $x^i_t \equiv X^i_t/T_t = a_t\pi(k^i_t) + (1+r_t)b^i_t$.

Finally, to simplify the analysis, we assume that wealth cannot be stored during the day, whereas overnight storage can take place at a one-for-one rate. Also assume that $\bar{c} \leq \underline{a}\pi(\hat{k}(\underline{a}))$, where $\hat{k}(a)$ is the solution to $a\pi'(\hat{k}) = a^{\rho}q'(1-\hat{k})$. 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

$$\int_i (k^i_t + z^i_t) = 1. \tag{5}$$

The second assumption ensures that the "overnight" interest rate is zero.

[6]The alternative assumption would introduce a complementarity in long-term investment across entrepreneurs, which would only increase its countercyclicality under complete markets and increase its procyclicality under tight constraints, thus leaving our main results unaffected.

Technological growth. To close the model, we need to specify the dynamics of T_t, the endogenous component of productivity. Assuming that the knowledge accumulated by one generation spills over to the next generation and identifying the knowledge produced by each entrepreneur in generation t with her realized productivity, the knowledge available to generation $t+1$ is

$$T_{t+1} = \int_i T_t q(z_t^i)\ell_t^i. \tag{6}$$

This is essentially the same as assuming that productivity growth is increasing in the level of productivity-enhancing investment, as usually done in endogenous-growth models.

Aggregate output. Aggregate output in period t is given by

$$Y_t = \int_i [W_{t,1}^i + \Pi_{t,1}^i] + \int_j \Pi_{t-1,2}^j \tag{7}$$

The first integral is the initial endowment of entrepreneurs born in the current period and the output of their short-term projects; the second integral is the output of (surviving) long-term projects undertaken by entrepreneurs born in the previous period. Using $W_{t,1}^i = T_t$ together with (2), (16) and (6), the above reduces to $Y_t = y_t T_t$ where

$$y_t = 1 + a_t \int_i \pi(k_t^i) + a_t.$$

Thus, controlling for capital, output is an increasing function of the contemporaneous shock a_t. Moreover, the impact of past shocks on output mirrors the one of past shocks on T_t.

Remarks. There are various interpretations of what the two types of investment and the liquidity shock may represent. The short-term investment might be putting money into one's current business, while long-term productivity-enhancing investment may be starting a new business. Or, the short-term investment may be maintaining existing equipment or buying a machine of the same vintage as the ones already installed, while the long-term investment is building an additional plant, building a research lab, learning a new skill, or adopting a new technology. Similarly, the liquidity shock might be an extra cost necessary for a newly-adopted technology to be adapted to evolving market conditions; or a health problem that the entrepreneur needs to deal with; or some other idiosyncratic shock that can ruin the entrepreneur's business unless she can repair the damage from it.[7] Finally, the shock a_t is modeled here as a productivity shock, but is meant to capture more broadly exogenous variation in firm profits (and hence in investment returns) that may originate in either supply- or demand-side conditions. For our empirical implementation, for example, we will identify a_t with shifts in international commodity prices.

[7] The fact that long-term productivity-enhancing investments such as starting a new business, learning a new skill, or adopting a new technology are largely intangible and non-verifiable underlies our assumption that a significant fraction of their value—for simplicity their entire value—may be lost in case the liquidity shock is not met.

4 Equilibrium composition of investment

In this section we analyze the effect of uncertainty and credit constraints 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.

4.1 Complete markets

When credit markets are perfect, entrepreneurs can always meet their liquidity shocks, ensuring that long-term investment pays out with probability one. Expected wealth is thus

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

which the entrepreneurs maximize with respect to (k_t^i, z_t^i, b_t^i) subject to the budget constraint (1).

Obviously, all entrepreneurs make identical choices and therefore we can drop the i superscripts. Since π and q are both strictly concave, the following first-order conditions are both necessary and sufficient for an optimal solution:

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

Hence, the marginal rate of substitution between the two types of investment satisfies

$$\frac{q'(z_t)}{\pi'(k_t)} = \frac{a_t}{\mathbb{E}_t a_{t+1}} = a_t^{1-\rho}. \tag{8}$$

The latter is increasing in a_t as long as $\rho < 1$, reflecting the fact short-term returns are more cyclical than long-term returns as long as there is some mean-reversion in a_t.

In equilibrium, the (day) interest rate r_t adjusts so that the demand for the bond is zero (i.e., equal to supply), or equivalently that the resource constraint is satisfied:

$$k_t + z_t = 1. \tag{9}$$

Combining the above with the optimality condition (8) gives the following characterization of the general-equilibrium effect of exogenous shocks on the composition of investment.

Proposition 1 *Consider the complete-markets case. There exists a function $z^* : [\underline{a}, \bar{a}] \to (0,1)$ such that $k_t = 1 - z^*(a_t)$ and $z_t = z^*(a_t)$. As long as $\rho < 1$, this function is decreasing. That is, the share of long-term investment decreases with the contemporaneous productivity shock.*

Since aggregate output, which is given by $Y_t = y_t T_t$ with $y_t = 1 + a_t \pi(k_t) + a_t$, is increasing in a_t, we can immediately restate this result in terms of the cyclical behavior of the composition of investment: the share of long-term investment is countercyclical under complete markets.

The logic behind this result is simple and is likely to extend to richer environments. As long as there is mean-reversion in the business cycle, profit in the immediate future—the return to short-term investment—is likely to be more sensitive to the contemporaneous state of the economy than the present value of profits anticipated further in the future—the return to long-term investment—and hence the relative demand for long-term investment is likely to be higher in recessions than in booms. In other words, the demand for both types of investment can be procyclical, but the demand for long-term investment is likely to be less so than that for short-term investment. This *opportunity-cost effect* is the core of our result that the fraction of long-term investment out of total investment is countercyclical under complete markets.

Note, however, that by imposing that the sum $k_t + z_t$ is acyclical we have abstracted from potential income effects. This is not essential as long as k_t and z_t tend to increase proportionally with total savings for given relative prices, which is the case if the production functions π and q have the same curvature. In this case, both k_t and z_t can increase with a positive shock in a_t if the supply of savings also increases, but it remains true that the ratio z_t in total investment decreases with a_t. More generally, however, whether a positive shock tilts the composition of investment away from long-term investment depends, not only on the opportunity-cost effect highlighted above, but also on the shape of the income-expansion path.

Finally, note that the model makes testable predictions about the composition of investment, but, by design, has nothing interesting to say about either the overall rate of investment out of output (i.e., $(k_t + z_t)/y_t$), or the rate of the two types of investment output (i.e., k_t/y_t or z_t/y_t). This is because the supply of savings and hence the overall investment rate are mechanically fixed in condition (9). The same will be true when we consider incomplete markets. Thus, in the empirical section we will focus on composition rather than level effects.

Example 1. Suppose that $\pi(k) = k^\alpha$ and $q(z) = z^\alpha,\ 0 < \alpha < 1$. Condition (8) then reduces to $(k_t/z_t)^{1-\alpha} = a_t^{1-\rho}$, which together with (9) implies

$$k_t = \frac{a_t^\eta}{1 + a_t^\eta} \quad \text{and} \quad z_t = \frac{1}{1 + a_t^\eta}, \tag{10}$$

where $\eta = (1-\rho)/(1-\alpha) > 0$. Hence, a positive shock in a_t raises k_t and decreases z_t. If we relax the assumption that the total saving rate is acyclical, and instead let $k_t + z_t = s_t = s(a_t)$ where s is an increasing function, then $k_t = [a_t^\eta/1 + a_t^\eta]s(a_t)$ and $z_t = [1/(1 + a_t^\eta)]s(a_t)$. Hence, now it is possible that both k_t and z_t increase with a_t, but it remains true that a higher a_t increases k_t/s_t and decreases z_t/s_t.

4.2 Incomplete markets

The previous section analyzed the equilibrium composition of investment under complete markets ($\mu = \infty$). We now turn to the case of incomplete markets ($\mu < \infty$).

Credit constraints limit an entrepreneur's borrowing capacity to a finite multiple of her current wealth in both periods of life. The entrepreneur's investment problem is thus given by

$$\max_{k_t^i, z_t^i, b_t^i} \left\{ a_t \pi(k_t^i) + \mathbb{E}_t a_{t+1} q(z_t^i) F(\mu[a_t \pi(k_t^i) + (1+r_t) b_t^i]) + (1+r_t) b_t^i \right\} \tag{11}$$

$$s.t. \qquad k_t^i + z_t^i + b_t^i \leq 1 \quad \text{ and } \quad k_t^i + z_t^i \leq \mu$$

where $F(\mu[a_t\pi(k_t^i) + (1+r_t)b_t^i])$ is simply the probability that $\ell_t^i = 1$ (i.e., that the liquidity shock will be met and long-term investment will pay out).

We assume that π, q, and F are such that the objective in (11) is strictly concave.[8] The first-order conditions are then both necessary and sufficient and all entrepreneurs make identical choices in equilibrium (so that we can again drop the i subscripts). The assumption of no storage within periods implies that the first constraint is never binding in equilibrium; by the resource constraint (5), we indeed have $k_t + z_t = 1 < \mu$. The first-order conditions with respect to k_t^i and z_t^i can then be expressed as follows:

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

where $x_t = a_t \pi(k_t) + (1+r_t) b_t$. The condition for k_t is obviously satisfied at

$$a_t \pi'(k_t) = 1 + r_t, \tag{12}$$

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

$$\mathbb{E}_t a_{t+1} q'(z_t) = (1+r_t) \left[\frac{1 + \mathbb{E}_t a_{t+1} q(z_t) f(\mu x_t) \mu}{F(\mu x_t)} \right]. \tag{13}$$

Thus, for any r_t, the demand for long-term investment is lower than that under complete markets.

In equilibrium, the interest rate r_t adjusts so that $b_t = 0$ and therefore $k_t + z_t = 1$ and $x_t = a_t \pi(k_t)$. Let $\bar{\mu} \equiv \bar{c} / \left(\bar{a}\pi(1)\right)$. Note that $\mu \leq \bar{\mu}$ suffices for $\mu x_t < \bar{c}$ to hold for all a_t, in which case $F(\mu x_t) < 1$, $f(\mu x_t) > 0$, and the term in brackets in (13) is strictly greater than one.

Proposition 2 *Consider the complete-markets case. There exists a function* $z : [\underline{a}, \bar{a}] \times \mathbb{R}^2 \to (0,1)$ *such that* $k_t = 1 - z(a_t; \mu, \phi)$ *and* $z_t = z(a_t; \mu, \phi)$. *As long as* $\mu < \bar{\mu}$, $z(a; \mu, \phi) < z^*(a)$ *for all* a. *That is, relative to complete markets, sufficiently tight credit constraints lead to a higher share of short-term investment* k_t, *a lower share of long-term investment* z_t, *and a higher interest rate* r_t, *for any realization of the shock* a_t.

[8] For this it suffices that all three functions be concave, with π or q strictly concave.

Next consider the cyclical behavior of investment. Using $F(\mu x_t) = (\mu a_t \pi(k_t)/\bar{c})^{\phi}$ along with (12), (13), and $\mathbb{E}_t a_{t+1} = a_t^{\rho}$, we infer that the equilibrium allocation of savings satisfies

$$\frac{q'(z_t)}{\pi'(k_t)} = \frac{a_t^{1-\rho-\phi}}{[\mu\pi(k_t)/\bar{c}]^{\phi}} + \phi\frac{q(z_t)}{\pi(k_t)} \tag{14}$$

Together with the resource constraint (9), the above implies that long-term investment z_t is increasing [respectively, decreasing] in a_t if $1-\rho-\phi<0$ [>0].

Proposition 3 *As long as $\mu < \bar{\mu}$ and $\phi > 1-\rho$, $z(a,\mu,\phi)$ is increasing in a for all a. That is, with sufficient tight credit constraints, the share of long-term investment increases with the contemporaneous productivity shock.*

Provided that y_t increases with a_t, this also means that the cyclical behavior of the composition of investment is the opposite of what it is under complete markets: now the share of long-term investment out of total investment is procyclical.[9]

The intuition for this result is quite simple. The opportunity-cost effect, which tends to make the relative demand for long-term investment countercyclical, is equally present under complete and incomplete markets. But a second effect emerges when $\mu \leq \bar{\mu}$. The probability that the liquidity shock will not be met is then positive in all states and, most importantly, is higher in a recession than in a boom. This *liquidity-risk effect* tends to make the relative demand for long-term investment procyclical. The condition $\phi > 1-\rho$ then ensures that this latter effect dominates: the opportunity-cost effect is weaker the higher the persistence ρ in the business cycle, whereas the liquidity-risk effect is stronger the higher the cyclical elasticity ϕ of the probability of meeting the liquidity shock.

Note that μ controls primarily the *average level* of liquidity risk, while ϕ controls its *cyclical elasticity*. Although the two parameters are unrelated in our model, lower levels of financial development may be associated with both a lower mean level and a greater cyclicality of liquidity risk. Moreover, in our model, the cyclicality of liquidity risk is also affected by μ when $\mu > \bar{\mu}$, for then a higher μ implies a larger region of a_t for which the liquidity risk becomes zero (and hence locally insensitive to fluctuations in a_t). For these reasons, in the empirical part of the paper, we will interpret lower financial development in the data with a combination of lower μ and higher ϕ in the model.

Finally, note that, as in the case of complete markets, the result in Proposition 3 relies on abstracting from income effects. In general, the reaction of the composition of investment to a positive shock will depend, not only on the opportunity-cost and liquidity-risk effects that we highlight in this paper, but also on the shape of the income expansion path. Nevertheless, we

[9] Since $y_t = [1 + a_t\pi(k_t) + a_t]$ and k_t decreases with a_t, we cannot rule out the possibility that Y_t decreases with a_t, even though this case seems pathological and does not occur in the examples we experiment with below.

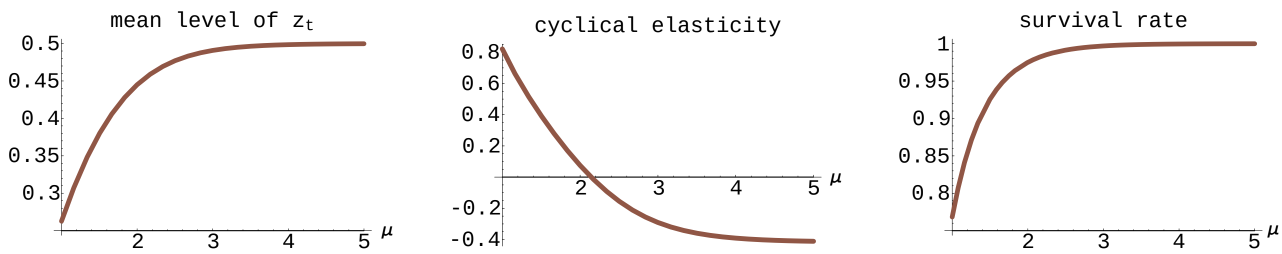

Figure 2: The effect of credit constraints (μ) on the mean level, the cyclical elasticity, and the survival rate of long-term investment.

expect the main insight to be quite robust: although the overall impact of a positive shock on the composition of investment may be ambiguous, the *interaction* effect with the level of financial development is likely to remain as in our model—that is, tighter credit constraints are likely to amplify the procyclicality (or reduce the countercyclicality) of long-term investment. This is because our result hinges on how credit constraint alter the cyclical behavior of the *relative* demand for the two types of investment.

Example 2. Suppose $\pi(k) = k^\alpha$, $q(z) = z^\alpha$, $\alpha < 1$, $\bar{c} = 1$, and $1 - \rho < \phi < (1-\alpha)/\alpha$.[10] Condition (14) then reduces to

$$\psi(z_t) = \mu^\phi a_t^{\phi+\rho-1}, \tag{15}$$

where $\psi(z) \equiv z^{1-\alpha}(1-z)^{-\phi\alpha}(1-(1+\phi)z)^{-1}$. Since $\psi(z)$ increases with z, whereas $\mu^\phi a^{\phi+\rho-1}$ increases with μ and a, condition (15) can be solved for z_t as an increasing function of μ and a_t.

Example 3. Suppose the same technologies as in the above example, but now let the distribution of c be log-normal, in which case the elasticity ϕ becomes endogenous. Figure 2 illustrates the impact of μ on the equilibrium level of long-term investment z_t, its cyclical elasticity $\partial \ln z_t / \partial \ln a_t$, and its survival rate, $\delta(a_t) = F(\mu a_t \pi(k_t))$ (all evaluated at the mean shock $a_t = 1$). In this example, too, tighter constraints lead to a lower and more procyclical share of long-term investment.

5 Amplification, volatility and growth

In this section, we use the results about the composition of investment to analyze how credit constraints affect aggregate volatility, mean growth, and the relation between the two.

[10]The assumption $\phi < (1-\alpha)/\alpha$ suffices for the objective in (11) to be strictly concave and therefore for the first-order conditions to be sufficient.

5.1 Complete markets

Under complete financial markets, productivity-enhancing investment is never interrupted. Hence, the growth rate of knowledge is

$$\frac{T_{t+1}}{T_t} = \gamma^*(a_t) \equiv q(z^*(a_t)),$$

where $z^*(a_t)$ is the complete-markets equilibrium share of long-term investment. Since the latter is decreasing in a_t, $\gamma^*(a_t)$ is also decreasing in a_t, and the following is immediate.

Corollary 1 *Under complete markets, the endogenous component of productivity growth is countercyclical and therefore mitigates the business cycle.*

Consider next the causal effect of volatility on growth. Whether a higher variance in a_t results in higher or lower mean growth ultimately depends upon the curvatures of q and z^*. In the Cobb-Douglas case (see below) it is easy to check that γ^* is necessarily convex at least in a neighborhood of the mean productivity shock. A small mean-preserving spread in a_t starting from zero variance then necessarily *increases* the mean rate of technological growth. In general, however, γ^* may have both convex and concave segments and therefore the complete-markets effect of volatility on growth is a priori ambiguous.

Example 1b. Consider the Cobb-Douglas example introduced in Section 3.1. Using $T_t = T_{t-1}q(z_{t-1})$ and condition (10), we have that aggregate output in period t is given by

$$Y_t = a_t T_t[\pi(k_t) + 1] = a_t T_t \left[\left(\frac{a_t^\eta}{1 + a_t^\eta} \right)^\alpha + 1 \right]$$

It is easy to check that Y_t/T_t is always increasing in a_t and it is also convex in a_t at least for a_t in the neighborhood of 1 (small shocks). It follows that the mean and variance of detrended output are negatively correlated at least when the support of a_t is small enough.

5.2 Incomplete markets

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

$$\frac{T_{t+1}}{T_t} = \gamma(a_t) \equiv q(z(a_t))\,\delta(a_t)$$

where $z(a_t)$ is equilibrium share of long-term investment and $\delta(a_t) \equiv F(\mu a_t \pi(1 - z(a_t)))$ is the equilibrium probability of covering the liquidity shock (which, since we have a continuum of agents with i.i.d. shocks, this is also equal to the equilibrium fraction of entrepreneurs who successfully overcome their liquidity shocks).[11] Clearly, $\mu < \bar{\mu}$ and $\phi > 1 - \rho$ suffice for $\delta(a_t) < 1$ and

[11] To simplify notation, we henceforth suppress the dependence of z, δ and γ on μ and ϕ.

$z(a_t) < z^*(a_t)$ to hold for all a_t, as well as for both $\delta(a_t)$ and $z_t(a_t)$ to be strictly increasing in a_t. It follows that $\gamma(a_t) < \gamma^*(a_t)$ for all a_t, and that $\gamma(a_t)$ is strictly increasing in a_t. Thus, ignoring again the uninteresting possibility that Y_t decreases with a_t, we have the following result.

Corollary 2 *Under sufficiently incomplete markets ($\mu < \bar{\mu}$ and $\phi > 1 - \rho$), the endogenous component of productivity growth is procyclical and therefore amplifies the business cycle. Moreover, productivity growth is strictly less than that under complete markets in all states.*

This amplification result contrasts with the mitigating effect of long-term investment under complete markets (Corollary 1). While under complete markets the opportunity-cost effect implies that long-term investment and therefore the endogenous component of productivity growth are countercyclical, under incomplete markets the liquidity-risk effect imputes procyclicality in productivity growth via two channels: by increasing the failure rate of long-term investments in recessions (ex-post effect); and by discouraging the demand for long-term investment in recessions (ex-ante effect).

Also note that amplification emerges even though the overall rate of investment is fixed by assumption; the channel here is the composition rather than the level of investment.

Consider now the relationship between volatility and growth. For any given variance in a_t, a reduction in μ can both increase the variance and reduce the mean of T_{t+1}/T_t. The negative cross-country correlation between growth volatility and mean growth observed in the data may therefore reflect a *spurious* correlation imputed by cross-country differences in financial development. Moreover, this negative correlation need not diminish once one controls for the level of aggregate investment since what matters is its composition.

The *causal* effect of exogenous volatility on mean growth, on the other hand, depends again on the curvatures of q and z, as well as that of δ. As with complete markets, the curvature of z is ambiguous. Moreover, the curvature of δ depends on the distribution of the liquidity shock. The causal effect of a mean-preserving spread in a_t on the mean of T_{t+1}/T_t thus remains ambiguous in general. Nevertheless, the following examples provide some insight into the causal effect of volatility on growth under incomplete credit markets.

Example 4. Suppose that the adjustment cost c is 0 with probability $p \in (0,1)$ and $\bar{c} > 0$ with probability $1 - p$. Suppose further that $z(a_t) = \hat{z} \in (0,1)$ for all a_t, that is, ignore the cyclicality in long-term investment. Normalizing $\pi(1-\hat{z}) = q(\hat{z}) = 1$, it follows that

$$\gamma(a_t) = \delta(a_t) = \begin{cases} 1 & \text{if } \mu a_t \geq \bar{c} \\ p & \text{if } \mu a_t < \bar{c} \end{cases}$$

When $\mu > \bar{c}$, firms face no liquidity risk in the absence of macroeconomic volatility (i.e., when $\underline{a} = \bar{a} = 1$) or, more generally, as long as volatility is small enough that $\underline{a} > \bar{c}/\mu$.[12] But as soon as

[12] Recall that the productivity shock a_t has unconditional mean 1 and support $[\underline{a}, \bar{a}]$.

$\underline{a} < \bar{c}/\mu$, a mean-preserving spread in a_t *decreases* mean growth by increasing the probability that the economy will be in a (sufficiently severe) slump where a positive fraction of firms fail to meet their liquidity shocks and complete their long-term investments.

When $\mu < \bar{c}$, on the other hand, only a fraction of firms succeed in completing their long-term investments in the absence of volatility or, more generally, as long as $\bar{a} < \bar{c}/\mu$. But, as soon as $\bar{a} > \bar{c}/\mu$, a mean-preserving spread in a_t now *increases* mean growth by increasing the probability that the economy will enter a sufficiently good boom where all long-term investments are completed.

This example highlights an important reason why the causal effect of volatility on growth may be non-monotonic under incomplete markets. When liquidity shocks and credit constraints are sufficiently severe that the mean probability of success is very low, higher volatility may increase mean growth by raising the chances for "resurrection"; otherwise higher volatility is likely to decrease mean growth by raising the chances for failure.

Example 5. Suppose that $z(a_t) = \hat{z}$ for all a_t, as in the previous example, but now let c be uniform over $[0, \bar{c}]$. Normalizing again $\pi(1 - \hat{z}) = q(\hat{z}) = 1$, we now have

$$\gamma(a_t) = \delta(a_t) = \min\{\mu a_t/\bar{c}, 1\}.$$

Whereas $\delta(\cdot)$ was S-shaped (i.e., convex for low a, concave for high a) in the previous example, now it is globally concave. In other words, the resurrection effect discussed above has now disappeared. It follows that a sufficiently large mean-preserving spread in a_t necessarily reduces mean growth. Furthermore, if $\mu > \bar{c}$, the negative effect of volatility on mean growth is higher the lower μ.

Example 6. Consider the same specification as in Example 3 of Section 3.2, but now assume that $\ln a_t$ follows a Gaussian $AR(1)$ and let σ denote the standard deviation of the innovations in a_t. Figure 3 illustrates how the mean and the standard deviation of the growth rate T_{t+1}/T_t vary with σ. The dashed lines represent complete credit markets ($\mu = \infty$), whereas the solid ones correspond to incomplete markets ($\mu < \infty$).

For any level of σ, incomplete markets are associated with lower growth and higher volatility than complete markets. Moreover, an increase in σ has a strong negative effect on mean growth under incomplete markets. This is explained by two factors. First, the average liquidity risk is relatively small, which ensures that the resurrection effect is weak. Second, since the survival probability $\delta(a)$ tends to be concave in a, the optimal level of long-term investment $z(a)$ also tends to be concave in a under sufficiently incomplete markets, whereas it is convex at least in a neighborhood of the mean productivity level under complete markets; the concavities of $z(a)$ and $\delta(a)$ then imply that an increase in σ tends to reduce the mean levels of z and γ.

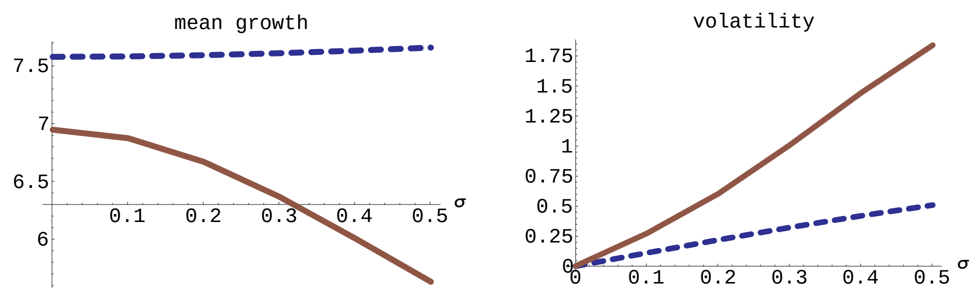

Figure 3: The effect of uncertainty (σ) on growth and volatility; dashed lines for perfect markets, solid lines for tight credit constraints.

6 Empirical analysis

In this section we use data on a panel of countries to test the key predictions of the model: that a lower level of financial development amplifies the impact of shocks on both the share of long-term investment and the rate of output growth—preferably without affecting their impact on the rate of investment.

For these purposes, we proxy the model's long-term investment z_t with the share of structural investment to total private investment; the model's exogenous disturbance a_t with a measure of net-export-weighted changes in international commodity prices; and the model's credit tightness μ with the ratio of private credit to GDP. We then proceed to identify the interaction effect of credit and shocks on the composition of investment, the overall rate of investment, and the growth rate using primarily country-variation in private credit and time-variation in commodity price shocks.

6.1 Data description

As a measure of financial development we use *private credit*, the value of credit extended to the private sector by banks and other financial intermediaries, as a share of GDP. This is a standard indicator in the finance and growth literature. It is usually preferred to other measures of financial development because it excludes credit granted to the public sector and funds provided from central or development banks. In robustness checks we also present results with measures of total liquid liabilities and the total capitalization of the stock market, both as a share of GDP. The data for all these measures come from Levine, Loyaza and Beck (2000).

We compute annual growth as the log difference of per capita income from the Penn World Tables, mark 6.1 (PWT). The measures of growth and volatility used in Tables 1 and 6 are the country-specific means and standard deviations of annual growth over the 1960-2000 period.

To study the responsiveness of the economy to exogenous shocks, we construct the following proxy for a_t. Using data on the international prices of 42 products between 1960 and 2000 from the International Financial Statistics Database of the IMF (IFS), we first calculate the annual percentage change of the price of each commodity. We then take a weighted average of price changes across all commodities. As weights, we use the average share of this commodity in a country's net exports in 1985, 1986, and 1987, as reported in the World Trade Analyzer (WTA).[13] Note that these weights are constant over time for a given country, but vary across countries. Commodity prices, on the other hand, vary in the time series. We thus obtain a country-by-year-specific measure, which we call *commodity-price shock*.[14]

To test whether there is any amplification effect of financial constraints, we examine the variation in the sensitivity of growth to commodity price shocks across different levels of financial development. To test the amplification channel described in the model, we need an empirical counterpart to what is long-term investment is in the model. We use the share of structural investment in total private investment.

Our data on structural investment cover 21 OECD countries over the 1960-2000 period from the Source OECD Economic Outlook Database Volume 2005. Structural investment consists of private investments in structures and housing, which are likely to be long-term investment projects.

When analyzing the reaction of the economy to shocks, we seek to isolate the effect of financial development from other institutional characteristics. For this purpose, when we study structural investment we control for overall rule of law in the economy using the index provided in La Porta, Lopez-de-Silanes, Shleifer and Vishny (1998).

Finally, the demographic data are from the PWT; the schooling data are from Barro and Lee (1997); and the various policy variables used in Table 1—i.e., the share of government spending in GDP, the inflation rate, the black-market exchange-rate premium, and the degree of openness to trade—are from Levine et al. (2000).

6.2 Impact of shocks on the composition and the rate of investment

Our model predicts that long-term growth-enhancing investment should respond less strongly to positive exogenous shocks in countries with more developed financial sectors. We test this prediction with annual data on the composition of investment and estimate the following specification:

$$\frac{LTI_{it}}{I_{it}} = const + \alpha \cdot credit_{it} + \sum_{j=0,1,2} (\delta_j + \gamma_j \cdot credit_{it}) \cdot shock_{i,t-j} + \beta \cdot X_{it} + \mu_i + \mu_t + \varepsilon_{it} \quad (16)$$

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

[14] In the model, a_t was meant to capture both supply and demand shocks. What is important for our theoretical results is only that a_t is exogenous, that it has a positive effect on firm returns, and that it is less than perfectly persistent. For the measure of commodity-price shocks we use, the first two properties are automatically satisfied if the economy is small enough to take international prices as given (which is likely to be true for most countries), whereas the last property is easily verified in the data. The autocorrelation coefficient for our measure of shocks in the panel of all countries with shock data is -0.0316.

The dependent variable (LTI_{it}/I_{it}) is the ratio of structural investment in total private investment. We measure financial development with a moving lagged average of private credit over the five years immediately preceding time t. The contemporaneous value of credit may vary with the business cycle and thus capture the impact of some other omitted cyclical variable. In contrast, the lagged average allows us to exploit the significant time variation in the level of financial development while also mitigating the concerns with omitted variable biases and endogeneity. The three shock variables correspond to the contemporaneous, 1-year lagged, and 2-year lagged commodity price shocks. The estimation of all lagged shock terms is possible because of the low autocorrelation in the commodity-price shocks.

To address the potential for omitted intransient country-level variables, we include country fixed effects and cluster errors by country. We also allow for year fixed effects to capture time trends affecting all countries in the sample. In all specifications we control for the level of GDP per capita, which has been averaged over the five years immediately preceding time t as private credit.

Table 2 summarizes our results. In line with our theoretical predictions, column 1 documents a negative coefficient on the interaction of private credit with the concurrent commodity price shocks. In columns 2 and 3 we address the possibility that our estimates capture the impact of some other institutional variable. Since overall rule of law is positively correlated with credit availability, if growth reacts less to adverse shocks in countries with stronger rule of law, the interaction term reported in column 1 may reflect the mitigating effect of rule of law rather than that of financial development. Similarly, financial development may reflect the effects of overall development and not a credit constraints channel. We thus include interactions of income per capita and the overall rule of law with the three shock terms to isolate an independent effect of financial institutions. Private credit continues to mitigate the impact of concurrent shocks on long term investment. Our findings suggest that financial development may also interact with older, twice-lagged shocks, but this effect is not always precisely estimated.

In columns 4 and 5 we limit our sample to country-year observations for which the absolute change in net-export weighted commodity prices is not greater than 100%. One motivation for this restriction is that extremely large shocks may signal structural changes in the economy, which our model is not appropriate to address; another is that the response of the economy might be quite non-linear in such extreme events. In this sub-sample, we find strong evidence of an important mitigating role of financial development in the transmission of concurrent, once- and twice-lagged shocks to long-term investment. All three interaction terms of interest enter negatively and are highly economically and statistically significant. For example, a one-standard deviation increase in the level of private credit is associated with a 0.05% reduction in the impact of a 1% adjustment in current and lagged shocks ($0.05\% = 0.26 \cdot (0.052 + 0.052 + 0.081)$).[15]

[15]We have also examined the sensitivity of our results to the lag structure of shocks. When we include only concurrent and once-lagged shocks, we continue to find that financial development interacts importantly with the

Table 2. The response of structural investment to commodity price shocks

Dependent variable: Share of private structural investment in total private investment

	Baseline specifications			Shocks less than 100%	
	(1)	(2)	(3)	(4)	(5)
shock $_t$	0.0072 (2.22)**	-0.0093 (-0.36)	-0.0012 (-0.03)	0.0262 (2.51)**	-0.2805 (-1.02)
shock $_{t-1}$	-0.0011 (-0.83)	-0.0357 (-1.25)	-0.0375 (-0.83)	0.0323 (2.80)**	-0.1401 (-0.58)
shock $_{t-2}$	0.0005 (0.36)	-0.0753 (-3.41)***	-0.1231 (-2.86)***	0.0291 (1.70)	-0.5478 (-1.23)
priv credit	0.0135 (0.32)	0.0152 (0.36)	0.0153 (0.36)	0.0189 (0.41)	0.0185 (0.40)
*priv credit*shock* $_t$	-0.0087 (-2.08)**	-0.0089 (-2.16)**	-0.0079 (-1.89)*	-0.0350 (-2.14)**	-0.0521 (-2.45)**
*priv credit*shock* $_{t-1}$	0.0024 (0.96)	0.0029 (1.15)	0.0033 (1.78)*	-0.0422 (-2.00)*	-0.0517 (-2.11)**
*priv credit*shock* $_{t-2}$	0.0004 (0.15)	-0.0007 (-0.24)	-0.0025 (-0.90)	-0.0465 (-1.71)	-0.0807 (-2.32)**
Controls:					
country, year FE	yes	yes	yes	yes	yes
income	yes	yes	yes	yes	yes
income interactions	no	no	yes	no	yes
rulelaw interactions	no	yes	yes	no	yes
abs(shock)<=1	no	no	no	yes	yes
R-squared	0.7884	0.7902	0.7904	0.7843	0.7855
# countries	21	21	21	21	21
N	728	728	728	603	603

Note: Annual 1960-2000 data, except where lost due to lags. shock $_t$*, shock* $_{t-1}$*, shock* $_{t-2}$ *refer to the contemporaneous, 1-year and 2-year lagged net-exports commodity price shock. Private credit and income are measured as moving lagged averages over (t-1, t-5). Columns 4 and 5 restrict the sample to observations with the absolute value of contemporaneous and lagged shocks less than 100%. All regressions include a constant term, country and year fixed effects, and cluster errors at the country level. t-statistics in parenthesis. ***,**,* significant at 1%, 5%, and 10%.*

Table 3. The response of structural investment to commodity price shocks: robustness

Dependent variable: Share of private structural investment in total private investment

Fin devt measure:	Private credit$_{1960\text{-}2000}$			Liquid liabilities		Market capitalization	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
shock $_t$	0.0097	0.0354	-0.5199	0.0381	-0.3155	0.0048	-0.4371
	(2.95)***	(3.00)***	(-0.85)	(2.99)***	(-1.21)	(0.38)	(-1.04)
shock $_{t-1}$	-0.0018	0.0450	0.1520	0.0445	-0.1623	0.0107	-0.4716
	(-1.04)	(2.74)**	(0.28)	(3.37)***	(-0.69)	(0.90)	(-1.32)
shock $_{t-2}$	0.0014	0.0647	-0.8674	0.0337	-0.5933	0.0002	-0.8542
	(0.45)	(4.59)***	(-2.28)**	(1.50)	(-1.48)	(0.02)	(-1.71)
fin devt				-0.0540	-0.0528	-0.0030	-0.0024
				(-0.93)	(-0.91)	(-0.05)	(-0.04)
*fin devt*shock $_t$*	-0.0121	-0.0444	-0.0665	-0.0578	-0.0892	-0.0187	-0.0267
	(-2.89)***	(-2.39)**	(-2.27)**	(-3.43)***	(-3.11)***	(-0.55)	(-0.77)
*fin devt*shock $_{t-1}$*	0.0032	-0.0523	-0.0522	-0.0620	-0.0728	-0.0428	-0.0547
	(1.26)	(-1.76)*	(-1.58)	(-3.10)***	(-2.90)***	(-1.48)	(-1.43)
*fin devt*shock $_{t-2}$*	-0.0005	-0.0869	-0.1127	-0.0541	-0.0949	-0.0532	-0.0659
	(-0.10)	(-4.79)***	(-4.89)***	(-1.56)	(-2.61)**	(-1.25)	(-1.25)
Controls:							
income; country, year FE	yes	yes	yes	yes	yes	yes	yes
income, rulelaw interactions	no	no	yes	no	yes	no	yes
abs(shock)<=1	no	yes	yes	yes	yes	yes	yes
R-squared	0.7816	0.7760	0.7769	0.7524	0.7555	0.7828	0.7864
# countries	21	21	21	19	19	19	19
N	764	639	639	537	537	374	374

*Note: Annual 1960-2000 data, except where lost due to lags. The measure of financial development is as indicated in the column heading. Financial development and income are averages over 1960-2000 in the first 3 columns, and moving lagged averages over (t-1, t-5) in columns 4-7. shock $_t$, shock $_{t-1}$, shock $_{t-2}$ refer to the contemporaneous, 1-year and 2-year lagged net-exports commodity price shock. All regressions include a constant term, country and year fixed effects, and cluster errors at the country level. t-statistics in parenthesis. ***,**,* significant at 1%, 5%, and 10%.*

The measure of private credit used in Table 2 is a moving lagged average over the preceding 5 years. While using this lagged average mitigates potential endogeneity or reverse causality issues, some bias may remain if shocks trigger slow changes in the level of private credit. For this reason, in columns 1-3 of Table 3 we check the robustness of our findings to a measure of financial development that varies only in the cross-section, not at all in the time-series: the country average of private credit over the entire period in the sample (1960-2000). Our results continue to hold, and in fact become statistically stronger. The interaction of private credit with the concurrent shock is always negative and significant, as is the interaction with twice-lagged shocks in the sample with non-extreme shocks.

In the rest of Table 3, we explore the robustness of our results to two alternative indicators of financial development: the volume of liquid liabilities or total stock market capitalization as a share of GDP. We find negative and significant point estimates on the interaction of liquid liabilities with

concurrent shocks. This result is robust to controlling for overall development or the rule of law, and obtains in both the entire sample and the sub-sample with shocks smaller than 100%.

all three shocks, but imprecisely estimated negative coefficients when we use market capitalization.[16]

Our theory predicts that credit constraints can modify the impact of shocks on the composition of investment, and thereby amplify volatility, *even if* they do not affect the impact of shocks on the aggregate rate investment. Clearly, the validity of our theory is not contradicted if we find evidence that credit constraints affect both the composition and the overall rate of investment. However, its empirical relevance is certainly strengthened if we find no effect on the overall rate of investment.

In Table 4 we thus examine whether lower levels of financial development predict a stronger impact of commodity-price shocks on the share of investment in total GDP across. The findings in the first three columns suggest that this is not the case: if anything, these findings favor a scenario where tighter credit dampens, rather than amplifies, the reaction of total investment to shocks. This finding directly contradicts models that focus on how credit constraint amplify the impact of shocks on the aggregate rate of investment, and strengthens our position that other channels, such as the composition of investment and endogenous productivity, are the key to understanding the amplification effects of credit constraints.

Finally, we test whether our results on the composition of investment change once we control for the overall rate of investment to GDP (which we can also think of as a proxy for the overall supply of savings). As columns 4-6 of Table 4 show, our main findings continue to hold: financial development mitigates the impact of shocks on long-run investment even after holding the overall level of investment fixed.

The empirical results we have reported so far proxy long-term investment with the share of structural investment to total investment. In a previous version of this paper and other unreported results, we also consider the share of R&D spending. The results we obtained were qualitatively similar, but their statistical significance was much less robust. We believe this was because of the very poor quality of R&D data in our sample: most countries in our sample report almost no R&D spending, but this does not mean that they engage in no long-term productivity-enhancing investments; it only means that cross-country variation in reported R&D spending is a very poor empirical measure for our purposes. This concern, however, disappears once one shifts attention from country-level data to *firm-level* data within a developed country—which is what Berman et al (2007) do.

In particular, these authors test the predictions of our model for the cyclical composition of investment using data for 13,000 French firms over the 1993-2004 period. As a proxy of a firm's access to external finance, they construct a binary variable that equals 1 if the firm has defaulted on its trade credits in the previous year; for any given firm, time-variation in this variable predicts lower probability of receiving a bank loan and smaller loan sizes. They then estimate an equation

[16] The reported results use a lagged moving average for liquid liabilities and market capitalization, and concentrate on shocks smaller than 100% in absolute value. Similar results obtain with country fixed averages or unrestricted shocks.

Table 4. Total investment vs. the composition of investment

Dependent variable:	Total investment / GDP			Structural inv / Total inv		
	(1)	(2)	(3)	(4)	(5)	(6)
investment / GDP				0.0002	0.0012	0.0013
				(0.10)	(0.44)	(0.50)
shock $_t$	0.062	-1.043	4.826	0.0072	0.0274	0.0013
	(0.29)	(-1.00)	(0.16)	(2.26)**	(2.53)**	(-1.00)
shock $_{t-1}$	-0.285	-2.493	16.434	-0.0010	0.0352	-0.1622
	(-3.34)***	(-2.93)***	(0.90)	(-0.96)	(3.44)***	(-0.62)
shock $_{t-2}$	0.280	-1.020	53.551	0.0005	0.0303	-0.6199
	(1.39)	(-0.80)	(2.10)**	(0.31)	(1.79)*	(-1.25)
priv credit	3.433	2.422	2.490	0.0127	0.0160	0.0152
	(1.76)*	(1.05)	(1.13)	(0.32)	(0.36)	(0.34)
*priv credit*shock $_t$*	-0.175	1.614	2.533	-0.0087	-0.0370	-0.0555
	(-0.60)	(1.10)	(1.52)	(-2.13)**	(-2.22)**	(-2.42)**
*priv credit*shock $_{t-1}$*	0.409	2.535	3.260	0.0023	-0.0452	-0.0561
	(3.57)***	(1.90)*	(2.45)**	(1.03)	(-2.20)**	(-2.14)**
*priv credit*shock $_{t-2}$*	-0.608	0.096	2.997	0.0005	-0.0466	-0.0847
	(-2.31)**	(0.05)	(1.61)	(0.18)	(-1.76)*	(-2.41)**
Controls:						
income; country, year FE	yes	yes	yes	yes	yes	yes
income, rulelaw interactions	no	no	yes	no	no	yes
abs(shock)<=1	no	yes	yes	no	yes	yes
R-squared	0.7324	0.7390	0.7458	0.7884	0.7855	0.7870
# countries	21	21	21	21	21	21
N	728	603	603	728	603	603

*Note: Annual 1960-2000 data, except where lost due to lags. The dependent variable in the first 3 columns is the share of investment in GDP for the sample with structural investment data. The dependent variable in columns 4-6 is the share of structural investment in total private investment. shock $_t$, shock $_{t-1}$, shock $_{t-2}$ refer to the contemporaneous, 1-year and 2-year lagged net-exports commodity price shock. Private credit and income are calculated as a moving lagged average over (t-1, t-5). Columns 2, 3, 5, and 6 restrict the sample to observations with the absolute value of contemporaneous and lagged shocks less than 100%. All regressions include a constant term, country and year fixed effects, and cluster errors at the country level. t-statistics in parenthesis. ***,**,* significant at 1%, 5%, and 10%.*

similar to (16), using the change in a firm's sales during the current, once- and twice-lagged period as proxies for firm-specific shocks. Then, in accordance with our theory's predictions, they find a strong negative interaction between the aforementioned proxy of a firm's access to external finance and the response of the firm's R&D investment share to these shocks. These results are robust to standard firm-level controls, obtain with both firm- and time-fixed effects, and survive instrumenting the shocks (the variation in sales) with firm-specific exchange-rate exposure measures.[17]

Taken together, the country-level evidence that we document here for structural investment and the firm-level evidence that Berman et al. (2007) document for R&D expenditures indicate that our model captures well the impact of credit constraints on the cyclicality of the composition of investment.

6.3 Impact of shocks on growth

So far we have documented that tighter credit amplifies the impact of shocks on the composition of investment, without amplifying their impact on the overall rate of investment. We now test whether tighter credit amplifies the impact of shocks on income and productivity growth.

For this purpose, we first examine the sensitivity of growth to shocks in an annual panel between 1960 and 2000. We estimate the following specification:

$$\Delta y_{it} = const + \alpha \cdot credit_{it} + \beta \cdot y_{it-2} + \sum_{j=0,1,2} (\delta_j + \gamma_j \cdot credit_{it}) \cdot shock_{i,t-j} + \mu_i + \mu_t + \varepsilon_{it}. \quad (17)$$

Here, y_{it} denotes annual growth for country i in time t (in logs). As before, the three shock variables correspond to the contemporaneous, 1-year lagged, and 2-year lagged commodity-price shocks. We continue to use a moving lagged average of private credit over the preceding 5 years as an indicator of financial development. We also continue to include country and year fixed effects in the estimation, and to cluster errors at the country level.

The first three columns of Table 5 show our baseline specification. In the full sample concurrent shocks enter negatively, but their effect is weakened in financially developed countries. However, when we restrict the sample to observations with data on the composition of investment in column 2, we find that once-lagged shocks boost growth today, and financial development mitigates this effect. This is precisely the result that our model predicts, and it obtains in the sample with shocks under 100% as well (column 3).

In the remainder of Table 5 we test whether these results reflect the impact of total investment. We include measures of concurrent, once- and twice-lagged investment as a share of GDP in the specification above, and find that our results are unchanged. This test serves an additional purpose, too. In the absence of a direct measure of TFP, controlling for the investment rate over a period of

[17] In further support of our theory, Berman et al. find that credit constraints increase the volatility of firm-level sales growth, complementing the related evidence we document for country-level output growth in the next section.

Table 5. The response of growth to commodity price shocks

Dependent variable: Annual GDP per capita growth

	Baseline specifications			Controlling for total investment / GDP		
	(1)	(2)	(3)	(4)	(5)	(6)
shock $_t$	-0.0028**	0.0007	-0.0033	-0.0027**	0.0014	-0.0028
shock $_{t-1}$	0.0002	0.0016**	0.0218*	0.0003	0.0008	0.0199*
shock $_{t-2}$	0.0021***	0.0013	0.0065	0.0020***	0.0009	0.0048
priv credit	0.0181	-0.0037	-0.0075	0.0198	-0.0049	-0.0093
	(2.10)**	(-0.45)	(-0.75)	(2.47)**	(-0.55)	(-0.92)
*priv credit*shock* $_t$	0.0046	-0.0002	0.0057	0.0046	-0.0010	0.0063
	(3.82)***	(-0.13)	(0.39)	(3.09)***	(-0.59)	(0.46)
*priv credit*shock* $_{t-1}$	-0.0026	-0.0048	-0.0302	-0.0032	-0.0036	-0.0273
	(-1.34)	(-4.63)***	(-2.38)**	(-1.61)	(-3.22)***	(-2.19)**
*priv credit*shock* $_{t-2}$	-0.0017	-0.0031	-0.0047	-0.0018	-0.0022	-0.0021
	(-1.04)	(-1.56)	(-0.59)	(-1.48)	(-1.28)	(-0.25)
Controls:						
abs(shock)<=1	no	no	yes	no	no	yes
struct invest sample	no	yes	yes	no	yes	yes
y_{t-2}	yes	yes	yes	yes	yes	yes
R-squared	0.1496	0.4102	0.4562	0.1830	0.4245	0.4676
# countries	109	21	21	109	21	21
N	3,104	727	602	3,104	727	602

*Note: Annual 1960-2000 data, except where lost due to lags. shock $_t$, shock $_{t-1}$, shock $_{t-2}$ refer to the contemporaneous, 1-year and 2-year lagged net-exports commodity price shock. Private credit is measured as a moving lagged average over (t-1, t-5). Columns 3 and 6 restrict the sample to observations with the absolute value of contemporaneous and lagged shocks less than 100%. Columns 2,3,5, and 6 restrict the sample to observations with data on structural investment. Columns 4-6 control for the current, 1-year and 2-year lagged values of total investment as a share of GDP. All regressions include a constant term, country and year fixed effects, and cluster errors at the country level. t-statistics in parenthesis. ***,**,* significant at 1%, 5%, and 10%.*

time and including a measure of GDP per capita is akin to controlling for total capital, and hence for isolating productivity improvements above and beyond capital accumulation. In support of our model, we find that this rough measure of TFP grows faster after adverse shocks in countries with more abundant credit. The effect of financial development is most pronounced at one lag.[18]

7 Concluding remarks

This paper identified a novel propagation mechanism in the impact of credit frictions on the cyclical composition of investment. We first showed how the share of long-term investment turns from countercyclical under complete markets to procyclical under sufficiently tight credit constraints. We then showed how through this channel credit frictions can lead to both lower mean growth and amplified volatility, even though they seem to have no effect on the impact of shocks on aggregate saving and investment. We finally provided some supporting empirical evidence.

The model we developed was stylized, and the empirical findings we provided were limited. We nevertheless hope that our findings draw more attention to the important interactions between credit constraints, short-run fluctuations and long-run growth that are channeled through the composition of investment.

A particularly interesting possibility was raised for situations where idiosyncratic liquidity risk increases with aggregate volatility: the causal effect of volatility on growth was then predicted to be more negative the tighter the credit constraints. This possibility may have important implications for welfare and policy: it suggests that the cost of business cycles can be higher in countries with lower financial development, as well as that stabilization policies can have more favorable growth effects in those same countries.

We thus close the paper by taking a first look at whether such a regularity is present in the data. In Table 6 we repeat the Ramey-Ramey regression with the addition of private credit and its interaction with volatility. We find that the negative impact of volatility on growth tends to be, indeed, stronger in countries with lower levels of private credit. This effect is economically important: in the specification of column 1, for example, a one-standard-deviation increase in the level of financial development reduces the negative growth impact of a 1% rise in volatility by -0.14%.[19] We conclude that further investigating the interaction between credit constraints, volatility and growth, and the implications of this interaction for macroeconomic policy, remains a fruitful direction for future research.

[18] All these findings are robust to the addition of the share of structural investment to the set of right-hand variables. When these variables are added, their effect is as in the model: for any given rate of investment, a higher fraction in structural investment tends to predict higher growth. (Results available upon request.)

[19] This effect is robust to controlling for demographics, policy variables, and the investment rate (columns 2, 4, and 5), but it looses significance if we control for a non-linear effect of private credit (columns 3 and 6).

Table 6. Growth, volatility and credit constraints

Dependent variable: Average GDP per capita growth, 1960-2000

	No investment			With investment		
	(1)	(2)	(3)	(4)	(5)	(6)
initial income	-0.0030	-0.0102	-0.0113	-0.0063	-0.0094	-0.0103
	(-1.51)	(-3.79)***	(-4.37)***	(-3.78)***	(-3.97)***	(4.42)***
growth volatility	-0.1606	-0.2571	-0.1373	-0.1725	-0.2182	-0.1344
	(-2.35)**	(-2.46)**	(-1.27)	(-3.15)***	(-2.37)**	(-1.40)
private credit	0.0144	-0.0045	0.0642	-0.0042	-0.0154	0.0361
	(1.20)	(-0.35)	(2.37)**	(-0.43)	(-1.33)	(1.43)
*volatility*private credit*	0.5204	0.7566	0.4579	0.4414	0.5755	0.3754
	(2.23)**	(2.50)**	(1.50)	(2.36)**	(2.14)**	(1.37)
investment/GDP				0.0015	0.0012	0.0010
				(7.59)***	(4.45)***	(4.03)***
Controls:						
pop growth, sec enroll	no	yes	yes	no	yes	yes
Levine et al. policy set	no	yes	yes	no	yes	yes
private credit^2	no	no	yes	no	no	yes
F-test (volatility terms)	0.0456	0.0268	0.3092	0.0082	0.0473	0.3215
F-test (credit terms)	0.0000	0.0019	0.0001	0.0026	0.1022	0.0109
R-squared	0.3558	0.5289	0.5837	0.5912	0.6444	0.6726
N	106	73	73	106	73	73

*Note: All regressors are averages over the 1960-2000 period, except for initial income and secondary school enrollment, which are taken for 1960. Growth volatility is constructed as the standard deviation of annual growth in the 1960-2000 period. The Levine et al. policy set of controls includes government size as a share of GDP, inflation, black market premium, and trade openness. Constant term not shown. t-statistics in parenthesis. ***,**,* significant at 1%, 5%, and 10%.*

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