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 cyclical 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 it also has 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 this share may turn 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 the model's key predictions.

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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 theory of the *joint* determination of growth and volality. Of course, ours is not the first attempt to do so.[1] The novelty of our approach rests in the particular propagation mechanism that we consider: we study how financial frictions impact the *composition* of investment over the business cycle, and the implications that this in turn has for both volatility and growth.

Theory. 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 quickly. *Long-term investment* takes more time to complete, but also contributes more to productivity growth. By design, the overall supply of capital goods does not vary over the business cycle. This permits us to isolate the novel composition effects that are the core of our contribution from more conventional propagation mechanisms that work through the response of aggregate saving and overall investment to the underlying business-cycle shocks.

With perfect credit markets, the equilibrium composition of investment is dictated merely by an opportunity-cost effect. As long as shocks are mean reverting, 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 capital allocated to long-term investment opportunities is countercyclical.

With sufficiently tight credit constraints, this fraction turns procyclical. This is *not* because credit constraints limit the ability to invest as in standard credit-multiplier models: in equilibrium, neither type of investment is constrained ex ante. Rather, it is because tighter constraints imply a higher probability that long-term investment will be interrupted by a liquidity shock. Ex ante, the anticipation of this risk reduces the *willingness* to engage in long-term investment—and the more so in recessions, when firms expect liquidity to remain relatively scarce for a while.

The first main prediction of our model is therefore that tighter credit constraints contribute to a more procyclical share of long-term investment. We view this result regarding the cyclical composition of investment as the core theoretical contribution of our paper. This result in turn generates two additional sets of predictions.

[1] For other contributions in this direction, see Acemoglu and Zilibotti (1997), Caballero and Hammour (1994), Comin and Gertler (2006), Francois and Lloyd-Ellis (2003), Jones, Manuelli and Stacchetti (2000), King and Rebelo (1993), Stadler (1990), Obstfeld (1994), and Walde (2004).

Because long-term investment enhances productivity more than short-term investment, tighter credit constraints also induce procyclicality in the growth rate of the economy. In particular, the cyclical behavior of the composition of investment mitigates fluctuations when financial markets are perfect, but amplifies them when credit constraints are sufficiently tight. This amplification effect is therefore the second main prediction of our paper. At the same time, because tighter credit constraints increase the liquidity risk involved in long-term investments, they reduce the average propensity to engage in such investments. In so doing, they also reduce the mean growth rate of the economy. This growth effect is the third main prediction of our paper.

Combined, these results mean that financial frictions contribute to both lower mean growth and higher volatility. Importantly, what drives these results is not the cyclical behavior of aggregate saving and investment, as in most other models of financial frictions, but rather the cyclical composition of investment. Our paper thus makes a distinct contribution towards understanding the *joint* determination of growth and volatility in the cross-section of countries.

Empirics. We examine the empirical performance of the theory within a panel of 21 OECD countries over the 1960-2000 period. As a proxy for our model's business-cycle shocks, we consider innovations in commodity prices, weighted by the contribution of these commodities to each country's net exports. This measure of shocks is appealing because price fluctuations in international commodity markets are largely exogenous to each individual economy. As a proxy for the share of long-term investment, we take the ratio of structural investment to total private investment. This measure captures long-term projects that are likely to be productivity-enhancing, and has systematically been collected for a large sample of countries over a 40-year period.[2] Finally, as a proxy for the potential tightness of credit constraints, we use the ratio of private credit to GDP. This is a standard measure of financial development in the finance-and-growth literature, and provides substantial time-series and cross-sectional variation in our panel.

Using these empirical proxies, we find strong support for our model's key predictions. First, the impact of shocks on the share of structural investment is greater in countries at lower levels of financial development. By contrast, no such effect is observed for the overall investment rate. Second, tighter credit amplifies the effects of shocks on output growth. Moreover, this result is not driven by the aggregate investment rate. Finally, financially underdeveloped countries feature less growth, more volatility, and a more strong negative correlation between growth and volatility.

Related literature. The growth and volatility effects of credit frictions have, of course, been the subject of a voluminous literature, including Aghion, Banerjee and Piketty (1999), Aghion and Bolton (1997), Banerjee and Newman (1993), Bernanke and Gertler (1989), King and Levine (1993), and Kiyotaki and Moore (1997); see Levine (1997) for an excellent review and more references. We depart from this earlier work by studying how liquidity risk affects the cyclical composition of

[2]While R&D expenditure is another natural proxy for long-term productivity-enhancing investments, we opted away from it because of the poor quality of the cross-country R&D data. See the remark at the end of Section 6.2.

investment as opposed to the overall rate of investment. Many other papers—including Acemoglu and Zilibotti (1997), Aghion and Saint-Paul (1998), Barlevy (2004), Comin and Gertler (2004), Hall (1991), Gali and Hammour (1991), Koren and Tenreyro (2007), and Walde (2004)—do look at the allocation of investment across alternative uses; but they do not consider the impact of credit frictions and liquidity risk as our paper. Finally, Chevalier and Scharfstein (1996) propose a theory of countercyclical markups whose mechanics resemble those of our theory, once appropriately re-interpreted.[3]

Layout. The rest of the paper is organized as follows. Section 2 reviews some empirical and theoretical considerations that motivate our exercise. Section 3 introduces the model. Section 4 analyzes the equilibrium composition of investment, while Section 5 derives the implications for growth and volatility. Section 6 contains the empirical analysis. Section 7 concludes.

2 Some motivating background

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 admits a causal interpretation.[4] Our paper is about the *joint* determination of volatility and growth, rather than the *causal* effect of the former on the latter. Nevertheless, the findings in Ramey and Ramey (1995) provide a certain motivation and guidance for our own theoretical and empirical explorations.

An negative effect of volatility on growth is consistent with the one-sector neoclassical growth model if risk discourages demand for investment more than it encourages the precautionary supply of savings, which is typically the case if the elasticity of intertemporal substitution is sufficiently high (Obstfeld, 1994; King and Rebelo, 1993; Jones, Manuelli and Stacchetti, 2000). A similar result can be obtained within the neoclassical growth model for the case of idiosyncratic investment risk (Angeletos, 2007). Such an effect is also consistent with models featuring financial frictions in the tradition of Bernanke and Gertler (1989): higher volatility may increase the likelihood of binding credit constraints and thereby reduce investment.

However, none of these stories seems to explain the observed negative correlation between volatility and growth. If these stories were the key behind this correlation, one would expect that controlling for the aggregate rate of investment would remove most of this correlation. As shown in columns 1-4 of Table 1, that's not the case. In these columns, we re-estimate some of the basic

[3]That paper argues that young firms have an incentive to keep their markups low in the hope of building up higher market shares, but this effect is likely to lower when bankruptcy risk is higher. The similarity to our paper then rests on re-interpreting the choice of a low markup as a long-term investment and the bankruptcy risk as liquidity risk.

[4]Complementary evidence is provided by Blattman, Hwang and Williamson (2004), Koren and Tenreyro (2007), 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.

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	0.002	-0.010	-0.006	-0.010	-0.012	-0.005	-0.940	-1.526
	(0.88)	(-3.31)***	(-3.59)***	(-4.07)***	(-3.23)***	(-1.22)	(-2.18)**	(-2.63)**
growth volatility	-0.127	-0.116	-0.113	-0.101				
	(-2.10)**	(-1.27)	(-2.64)***	(-1.35)				
investment/GDP			0.002	0.001				
			(10.11)***	(5.64)***				
private credit					-0.024	-0.006	0.577	2.362
					(-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	0.078	0.423	0.540	0.617	0.241	0.498	0.052	0.369
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%.*

specifications from Ramey and Ramey (1995) in our dataset. The point estimate of the volatility coefficient falls only by one tenth when the investment rate is included as an additional control. The data therefore suggest that the observed negative relation between volatility and growth is *not* channeled through the overall rate of saving and investment.

Morevoer, whereas there is suggestive evidence that credit access predicts both the mean and the volatility of the growth rate,[5] 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 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. Once again, this suggests that the volatility effects of credit constrains are *not* channeled through the overall rate of investment.

Taken together, these observations indicate that one should look beyond the standard transmission channel—the response of aggregate saving and investment—in order to understand the interaction of effect of uncertainty and credit constraints on growth and volatility. Our approach

[5]If we include credit in the regressions of columns 1-4, then its effect on mean growth is positive, as standard in the literature. Its effect on growth volatility, on the other hand, is negative, as shown in columns 5 and 6.

then rests on shifting focus from the average rate of investment to its composition.

3 The model

We consider a closed economy that is populated by overlapping generations of a single type of agents, whom we call "entrepreneurs". Each generation consists of a unit mass of entrepreneurs. Each entrepreneur lives for three periods and is endowed with one unit of labor in each period of her life. There is a single consumption good and two types of capital goods.

Consider an entrepreneur born in period t. Her labor endowment, measured in efficiency units, is denoted by H_t. We can think of H_t as the stock of human capital, skills, and other know-how that an entrepreneur has acquired by the time she starts engaging in productive activities. To simplify the analysis, we assume that this stock is fixed over the productive life of an entrepreneur and exogenous to her production choices. At the same time, we allow the growth rate of H_t to depend on the general equilibrium of the economy through a certain type of intergenerational spillover effects, similar in spirit to those in Lucas (1988); we specify these spillover effects later on. Finally, the preferences of this entrepreneur are given by

$$U_t = C_{t,t} + \beta C_{t,t+1} + \beta^2 C_{t,t+2} \tag{1}$$

where $C_{t,t+n} \geq 0$ denotes her consumption during period $t+n$, for $n \in \{0,1,2\}$, and $\beta > 0$ is her discount factor.

In the first period of her life (period t), the entrepreneur has access to two CRS technologies that permit her to transform her effective labor to either of the two types of capital goods. In the subsequent two periods of her life, the entrepreneur has no more access to this capital-producing technology, but she can now use her stock of capital goods along with her endowment of labor to produce a consumption good under some other CRS technology. In particular, both types of investment have to be installed during the first period of the entrepreneur's life (period t) and cannot be reallocated afterwards, but the one type becomes productive in the second period of her life (period $t+1$), while the other type becomes productive in the third period of her life (period $t+2$). In what follows, we interpret the former type of capital as *short-term investment* and the latter one as *long-term investment*.

Consider first the production of capital goods. Since labor is the only input used in the production of the capital goods, the CRS assumption means that the corresponding production functions are linear. Let the technology of producing the short-term capital goods be $K_t = \theta_{k,t} H_{k,t}$, where $H_{k,t}$ is the amount of effective labor allocated to this technology, $\theta_{k,t}$ is the corresponding productivity, and K_t is the produced amount of short-term capital goods. Similarly, let the technology of producing the long-term capital goods be $Z_t = \theta_{z,t} H_{z,t}$, where $H_{z,t}$ is the amount of effective labor allocated to this technology, $\theta_{z,t}$ is the corresponding productivity, and K_t is the produced

amount of short-term capital goods. We abstract from shocks to these productivities and, without any further loss of generality, we set $\theta_{k,t} = \theta_{z,t} = \theta$ for some fixed $\theta > 0$.[6]

Consider, next, the production of the consumption good. As mentioned already, short-term investment produces the consumption good with only a one-period lag. Thus, an entrepreneur who is born in period t produces the following amount of the consumption good in period $t+1$:

$$Y_{t,t+1} = A_{t+1}F(K_t, H_t) \tag{2}$$

where A_{t+1} is an exogenous aggregate productivity shock, K_t is the stock of short-term capital goods that the entrepreneur installed in period t, H_t is her effective labor, and F is a neoclassical production function. For simplicity, we assume that F is Cobb-Douglas: $F(K, H) = K^{\alpha}H^{1-\alpha}$, for some $\alpha \in (0, 1)$.

Long-term investment, on the other hand, takes one additional period in order to produce the consumption good. During this extra time, the entrepreneur may face an idiosyncratic "liquditiy" risk. By this we mean the following. In period $t+1$, the entrepreneur is hit by an idiosyncratic shock, denoted by $L_{t+1} \geq 0$. This shock identifies a random expense, in terms of the consumption good, that the entrepreneur must incur in order to guarantee that her long-term investment remains intact. In particular, if the entrepreneur succeeds in covering this random expense, then she is able to produce the following amount of the consumption good in period $t+2$:

$$Y_{t,t+2} = A_{t+2}F(Z_t, H_t), \tag{3}$$

where A_{t+2} is the aggregate productivity shock in period $t+2$, Z_t is the stock of long-term capital goods that the entrepreneur installed in period t, and H_t is her effective labor. If, instead, the entrepreneur fails to cover this expense, then her long-term capital goods become obsolete and therefore her output in period $t+2$ is zero. We henceforth call this situation the "failure" or "liquidation" of the entrepreneur's long-term investment.[7]

We further assume that, if the entrepreneur covers the liquidity shock in period $t+1$, she recovers fully the associated expense in period $t+2$ along with any foregone interest: conditional on paying L_{t+1} in period $t+1$, she receives $\beta^{-1}L_{t+1}$ in period $t+2$. This assumption guarantees that this shock does not affect the net present value of the long-term investment of the entrepreneur; it only affects the intertemporal pattern of its gross costs and benefits.[8] This assumption thus permits us

[6] In equilibrium, all entrepreneurs will choose the same levels of short-term and long-term investment (because they have identical preferences, they face the same technologies and distribution of shocks, and their investment problem is strictly convex). For this reason, and to simplify the notation, we do not index individual investment choices by the identity of the entrepreneur, and instead use K_t and Z_t to denote either individual or aggregate investment choices. However, one has to keep in mind that each entrepreneur is subject to an idiosyncratic liquidity risk, which implies that different entrepreneurs may end up with different realized incomes even though they make identical choices.

[7] The fact that we model "failure" or "liquidation" as full, rather than partial, depreciation is only for simplicity.

[8] Here, we anticipate the fact that, because preferences are linear, the equilibrium interest rate will be $R_t = \beta^{-1}$.

to identify the shock L_{t+1} as a pure liquidity shock: the presence of this shock has no effect on equilibrium allocations when markets are complete, but starts playing a crucial role once markets are incomplete. That being said, our key results do not hinge on this assumption. What is essential for our purposes is only that this shock induces a countercyclical liquidity risk when markets are incomplete; whether it may also happen to affect the present value of investment is of secondary importance, which is why we find it best to abstract from this effect.

In particular, we specify the financial structure of the economy as follows. First, we assume that the entrepreneurs can trade only a riskless short-term bond. Second, we impose an ad-hoc borrowing constraint that requires that the net borrowing of an entrepreneur in the first or second period of her life does not exceed a multiple μ of her contemporaneous income (where $\mu \geq 0$). It follows that we can write the budget and borrowing constraints of the entrepreneur in these periods as follows: for the first period,

$$C_{t,t} + q_t(K_t + Z_t) = q_t\theta H_t + B_{t,t} \quad \text{and} \quad B_{t,t} \leq \mu q_t H_t, \tag{4}$$

where $C_{t,t}$ is her first-period consumption, q_t is the unit price of capital goods at date t, $q_t(K_t + Z_t)$ is her purchases of capital goods, $B_{t,t}$ is her first-period borrowing (or saving, if this number is negative), and $q_t\theta H_t$ is her income from the production and sale of capital goods, while for the second period,

$$C_{t,t+1} + L_{t+1}e_{t,t+1} = Y_{t,t+1} + B_{t,t+1} - (1 + R_t)B_{t,t} \quad \text{and} \quad B_{t,t+1} \leq \mu Y_{t,t+1}, \tag{5}$$

where $C_{t,t+1}$ is her second-period consumption, L_{t+1} is the liquidity shock, $e_{t,t+1}$ is an indicator function that takes the value 1 if the entrepreneur covers this shock and 0 otherwise, $B_{t,t+1}$ is her second-period borrowing, $Y_{t,t+1}$ is her income from short-term investment, and R_t is the risk-free rate between periods t and $t+1$. In the third period, on the other hand, we impose that no further borrowing is allowed because the entrepreneur will die after this period. Her budget constraint is thus given by

$$C_{t,t+2} = (Y_{t,t+2} + \beta^{-1}L_{t+1})e_{t+1} + (1 + R_{t+2})B_{t,t+1}, \tag{6}$$

where $C_{t,t+2}$ is her third-period consumption, $Y_{t,t+2}$ is her income from long-term investment and $\beta^{-1}L_{t+1}$ is the recovery of the previous-period liquidity expense.

To close the model, we need to specify the dynamics of the stock of human capital (H_t), the stochastic process of the aggregate productivity shock (A_t) and the idiosyncratic liquidity shock (L_t). We do so as follows.

For the stock of human capital (or level of know-how), we assume the following law of motion:

$$H_{t+1} = \Gamma(H_t, \tilde{Z}_t, K_t)$$

where $\tilde{Z}_t$ denotes the amount of long-term investment that survives the liquidity shock (to be determined in equilibrium) and where the function Γ is continuous and increasing in all its arguments.

To guarantee a balanced-growth path, we assume that Γ is homogenous of degree 1. We further assume that, for any H and any given sum $Z+K$, $\Gamma(H,Z,K)$ increases with the ratio Z/K. With this assumption we seek to capture the idea that many long-term investments such as education, firm entry, R&D, and the like appear to be relatively more conducive to productivity growth than short-term investments in working capital, machines, and the like. This in turn will permit us to spell out the potential implications of our results for the dynamics of growth without going into the deeper micro-foundations of productivity growth.

Next, for the productivity shock, we assume that its logarithm follows an AR(1) process:

$$\log A_t = \rho \log A_{t-1} + \log \nu_t \tag{7}$$

where ν_t is the innovation in the productivity shock—a random variable that is i.i.d. over time, with mean normalized to $\mathbb{E}[\nu_t] = 1$, positive higher moments, and compact support $[\nu_{min}, \nu_{max}]$, with $0 < \nu_{min} < \nu_{max} < \infty$—and where $\rho \in (0,1)$ parameterizes the persistence of the productivity shock. The key property we seek to capture with this specification is that the business cycle features both some persistence ($\rho > 0$) and some mean-reversion ($\rho < 1$). This is essential for our argument. The log-linearity, instead, is not essential; it only buys us some tractability in computing conditional expectations for future productivity shocks.

Finally, for the liquidity shock, we assume that it grows in proportion to H_t so as to guarantee that the economy admits a balanced growth path along which the impact of the liquidity risk does not vanish as the economy grows. Formally, we let $\ell_{t+1} \equiv L_{t+1}/H_t$ denote the "normalized" level of the liquidity shock and impose that the distribution of ℓ_{t+1} is invariant over time; we then let $[0, \ell_{max}]$ be the support of this distribution and Φ its c.d.f..[9] We further impose that $\ell_{max} > A_{max} F(\theta, 1)$, where ℓ_{max} and $A_{max} \equiv \nu_{max}/(1-\rho)$ are, respectively, the maximum possible realizations of the liquidity shock and of the productivity shock; as it will become clear, this restriction guarantees that the entrepreneur will fail to meet the maximal liquidity shock when credit markets are sufficiently tight (μ is sufficiently small). Finally, to maintain tractability, we impose a power-form specification: $\Phi(\ell) = (\ell/\ell_{max})^{\phi}$ when $\ell < \ell_{max}$, for some $\phi > 0$, and $\Phi(\ell) = 1$ when $\ell \geq \ell_{max}$.[10]

[9] An alternative specification of the liquidity shock that would also guarantee the existence of such a balanced-growth path is one that specifies the shock L_{t+1} as proportional to the level Z_{t+1} of the enterpreneur's long-term investment. In this case, the exogenous, stationary shock would be given by $\ell_{t+1} \equiv L_{t+1}/Z_{t+1}$. Furthermore, thanks to the CRS property of the production function, one could then interpret the probability that $L_{t+1} \leq X_{t+1}$ interchangeably either as the probability that the entire long-term investment of the entrepreneur survives to period $t+2$, or as the *fraction* of her long-term capital stock that survives to period $t+2$. Finally, because this specification retains the key property of our model, namely that the liquidity risk is countercyclical, it also does not affect the core of our key predictions. However, this specification is more cumbersome analytically, which is why we opted for the simpler one we have assumed.

[10] As it will become clear, the parameter ϕ, which identifies the elasticity of Φ, governs the cyclical elasticity of the

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 the 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. Finally, the fact that long-term productivity-enhancing investments such as starting up a new business, learning a new skill, adopting a new technology, or undertaking a new R&D project are largely intangible and non-verifiable may justify our implicit assumption that a large portion of these investments is not collateralizable—and hence that these investments may get disrupted by liquidity shocks even if they have positive net present value. In this regard, although we abstract from the micro-foundations of liquidity constraints, we are essentially building on the insights of the related literature on moral hazard and credit constraints, such as Holmstrom and Tirole (1998) and Aghion, Banarjee and Piketty (1999). Indeed, note that the latter paper provides a microfoundation of the particular borrowing constraint we assume in this paper.

4 Equilibrium composition of investment

In this section we analyze the equilibrium composition of investment, starting first with the case where markets are perfect and then moving to the case where credit constraints are binding. Our model is designed so that the characterization of the equilibrium composition of investment can be derived without characterizing the equilibrium dynamics of H_t. This highlights that the core contribution of our paper regards the cyclical composition of investment. We will spell out the implications of our results for output volatility and growth in a subsequent section.

4.1 Complete markets

Suppose that credit markets are perfect and consider an entrepreneur born in period t. Because the entrepreneur can borrow as much as she wishes in the second period of her life, she can always meet her liquidity shock, should she find it desirable to do so. Because of the linearity of preferences, the equilibrium interest rate is pinned down by $R_t = \beta^{-1}$. It follows that the net present value of meeting the liquidity shock is $(Y_{t,t+2} + \beta^{-1}L_{t+1}) - R_{t+1}L_{t+1} = Y_{t,t+2} = A_{t+2}F(Z_t, H_t) \geq 0$, which guarantees that it is always optimal for the entrepreneur to meet her liquidity shock.

liquidity risk faced by the entrepreneur. When the elasticity of Φ is not constant, our equilibrium characterization can be interpreted as a log-linear approximation around the steady state.

Next, the budget constraints along with the fact that $R_t = \beta^{-1}$ imply that the present value of the entrepreneur's consumption—also her lifetime utility—is pinned down by the following:

$$\begin{aligned} U_t &= C_{t,t} + \beta C_{t,t+1} + \beta^2 C_{t,t+2} \\ &= q_t(\theta H_t - K_t - Z_t) + \beta(Y_{t,t+1} - L_{t+1}) + \beta^2(Y_{t,t+2} + \beta^{-1} L_{t+1}) \\ &= q_t(\theta H_t - K_t - Z_t) + \beta A_{t+1} F(K_t, H_t) + \beta^2 A_{t+2} F(Z_t, H_t) \end{aligned}$$

We infer that the optimal investment problem of the entrepreneur can be reduced to the following:

$$\max_{K_t, Z_t} \mathbb{E}_t \left[\beta A_{t+1} F(K_t, H_t) + \beta^2 A_{t+2} F(Z_t, H_t) - q_t K_t - q_t Z_t \right]$$

Let $k_t \equiv K_t / H_t$ and $z_t \equiv Z_t / H_t$ denote the "normalized" levels of short- and long-term investment. We can then restate the entrepreneur's problem as follows:

$$\max_{k_t, z_t} \mathbb{E}_t \left[\beta A_{t+1} f(k_t) + \beta^2 A_{t+2} f(z_t) - q_t k_t - q_t z_t \right]$$

Because f is strictly concave, the solution to the above problem, for given q_t, is uniquely pinned down by the following first-order conditions:

$$\beta \mathbb{E}_t[A_{t+1} f'(k_t)] = q_t \quad \text{and} \quad \beta^2 \mathbb{E}_t[A_{t+2} f'(z_t)] = q_t. \tag{8}$$

That is, the entrepreneur equates the marginal cost of the two types of investment (the price q_t) with their expected marginal profit.

The individual entrepreneur takes the price of capital goods, q_t, as exogenous to her choices. In equilibrium, however, this price adjusts to make sure that the aggregate excess demand for capital goods is zero. In other words, the equilibrium investment levels must satisfy the resource constraint $K_t + Z_t = \theta H_t$, where, recall, θ is the productivity of new-born entrepreneurs in the production of capital goods. Equivalently, the normalized levels must satisfy

$$k_t + z_t = \theta.$$

Combining this with (8), we infer that the equilibrium composition of investment is pinned down by the following condition:

$$\mathbb{E}_t[A_{t+1} f'(\theta - z_t)] = \beta \mathbb{E}_t[A_{t+2} f'(z_t)] \tag{9}$$

This condition has a straightforward interpretation: it equates the marginal value of long-term investment (on the right-hand side) with its opportunity cost (on the left-hand side).

To complete the characterization of the equilibrium, we only need to ensure that there are enough aggregate resources to pay for the liquidity shocks in each period. To do so, we henceforth impose that the parameters of the economy satisfy $l_{mean} < A_{min} f(\theta - z_{max})$, where z_{max} is the solution to condition (8) when $A_t = A_{min}$, and where A_{min} and l_{mean} are, respectively, the minimum productivity level and the mean liquidity shock.[11] We then reach our first main result.

[11] Alternatively, we could relax this parameter restriction and instead permit consumption to be negative.

Proposition 1 *Suppose that credit markets are perfect.*

(i) The equilibrium exists and is unique.

(ii) There exists a continuous function $z^* : \mathbb{R}_+ \to (0, \theta)$ *such that the equilibrium levels of short-term and long-term investment are given, respectively, by* $k_t = \theta - z^*(A_t)$ *and* $z_t = z^*(A_t)$.

(iii) The function z^* *is strictly decreasing. That is, the share of long-term investment decreases with a positive innovation in productivity.*

Proof. By the AR(1) specification of the process for the productivity shock, we have that $\mathbb{E}_t[A_{t+1}] = \mathbb{E}_t[\nu_{t+1} A_t^\rho] = A_t^\rho$ and $\mathbb{E}_t[A_{t+2}] = \mathbb{E}_t[\mathbb{E}_{t+1}[A_{t+2}]] = \mathbb{E}_t[A_{t+1}^\rho] = \mathbb{E}_t[(v_{t+1} A_t^\rho)^\rho] = \chi A_t^{\rho^2}$, where $\chi \equiv \mathbb{E}[\nu_t^\rho] > 0$. Rearranging condition (9), and using the aforementioned facts, we get that the equilibrium z_t is pinned down by the following equation:

$$\frac{f'(z_t)}{f'(\theta - z_t)} = \frac{\mathbb{E}_t[A_{t+1}]}{\beta \mathbb{E}_t[A_{t+2}]} = \frac{A_t^{\rho(1-\rho)}}{\beta \chi}$$

Note that the left-hand side of the above equation is continuous and decreasing in z_t, while the right-hand side is continuous and increasing in A_t. Furthermore, the left-hand side tends to $+\infty$ (respectively, 0) as $z_t \to 0$ (respectively, θ). Parts (ii) and (iii) then follow from the Implicit Function Theorem. Finally, part (i) follows from part (ii) along with the fact that the assumption $l_{mean} < A_{min} f(\theta - z_{max})$, where $z_{max} = z^*(A_{min})$, guarantees that consumption is positive in all states. **QED**

The logic behind this result is very basic and hence likely to extend to richer environments. As long as there is mean-reversion in the business cycle, profits anticipated in the near future are likely to be more pro-cyclical than profits anticipated in the distant future. Moreover, the return to short-term investment depends more heavily on profits in the near future, while the return to long-term investment depends more heavily on profits in the distant future. It follows that the return of short-term investment is likely to be more procyclical than the return to long-term investment and, therefore, the composition of investment is likely to shift towards a relatively higher share of long-term investment during recessions than during booms.

At the core of this result is a particular type of *opportunity-cost effect*: the opportunity cost of long-term investment, in terms of forgone short-term investment opportunities, is higher in booms than in recessions. This opportunity-cost effect, which induces countercylicality in the share of long-term investment, is present independently of whether credit markets are perfect or not; but once markets are imperfect, an additional, countervailing effect emerges. We move on to identify this additional effect in the next section.

Remark. Proposition 1 stated the cyclical properties of the composition of investment in terms of its co-movement with the productivity shock. However, it is straightforward to translate these properties in terms of the co-movement of the two types of investment with aggregate output (which

is the canonical definition of cyclical properties). To see this, note that the equilibrium level of GDP, evaluated in units of the consumption good, can be written as follows:

$$GDP_t = A_t f(k_{t-1}) + A_t f(z_{t-2}) + q_t k_t + q_t z_t. \tag{10}$$

The first two terms on the right-hand side capture the value added of the consumption sector, while the last two terms capture the value added of the investment sector. Clearly, the first two terms increase with a positive innovation in A_t. By Proposition 1 and the fact that $q_t = \mathbb{E}[A_{t+2}]f'(z_t)$ in equilibrium, we have that q_t also increases with a positive innovation in A_t. Since $k_t + z_t = \theta$ is constant, we conclude that GDP_t, too, increases with a positive innovation in A_t. It follows that the contemporaneous covariance between GDP and the share of long-term investment is indeed negative.

4.2 Incomplete markets

Consider now the case where credit markets are imperfect. Once again, the linearity of preferences guarantees that $R_t = \beta^{-1}$. But now the entrepreneur is not completely indifferent about the timing of her consumption and the pattern of her borrowing and saving. In particular, because the probability of failing to meet the liquidity shock is positive, the entrepreneur finds it strictly optimal to consume zero in the first period of her life—for doing so maximizes the availability of funds in the second period and thereby minimizes the probability of failure. Furthermore, whenever the entrepreneur has enough funds herself in the second period to cover her liquidity shock, or can borrow enough funds to meet this goal, she will always find it optimal to do so. It follows that the entrepreneur covers her liquidity shock if and only if $L_{t+1} \leq X_{t+1}$, where

$$X_{t+1} \equiv (1+\mu)Y_{t,t+1} + R_t q_t(\theta H_t - K_t - Z_t).$$

The latter measures the total liquidity available to the entrepreneur during period $t+1$: it is given by the income of the entrepreneur in that period, plus the maximal borrowing that is available to her in that period, plus any savings from the (net) sale of capital goods in the previous period.

Combining the aforementioned observations with the budget constraints, we infer that the present value of the entrepreneur's consumption—also her lifetime utility—is pinned down by the following:

$$C_{t,t} + \beta C_{t,t+1} + \beta^2 C_{t,t+2} \quad = \quad q_t(H_t - K_t - Z_t) + \beta A_{t+1} F(K_t, H_t) + \beta^2 A_{t+2} F(Z_t, H_t) e_{t+1}$$

where $e_{t+1} = 1$ if $L_{t+1} \leq X_{t+1}$ and $e_{t+1} = 0$ if $L_{t+1} > X_{t+1}$. Letting $x_{t+1} \equiv X_{t+1}/H_t$, we can thus state the entrepreneur's problem as follows:

$$\max_{k_t, z_t} \mathbb{E}_t \left[\beta A_{t+1} f(k_t) + \beta^2 \lambda_{t+1} A_{t+2} f(z_t) - q_t k_t - q_t z_t \right]$$

where $\lambda_{t+1} \equiv \Phi(x_{t+1})$ is the probability that the entrepreneur will have enough funds to cover the liquidity shock. Equivalently, $1-\lambda_{t+1}$ measures the "liquidity risk" faced by the entrepreneur: it is the probability that long-term investment will become obsolete due to the unavailability of enough liquidity in period $t+1$.

The first-order condition of the entrepreneur's problem with respect to k_t gives

$$\beta \mathbb{E}_t[A_{t+1} f'(k_t)] + \beta^2 \mathbb{E}_t[\tfrac{\partial \lambda_{t+1}}{\partial k_t} A_{t+2} f(z_t)] = q_t,$$

while the one with respect to z_t gives

$$\beta^2 \mathbb{E}_t[\lambda_{t+1} A_{t+2} f'(z_t)] + \beta^2 \mathbb{E}_t[\tfrac{\partial \lambda_{t+1}}{\partial z_t} A_{t+2} f(z_t)] = q_t.$$

Combining these two first-order conditions gives the following arbitrage condition between the two types of investment:

$$\mathbb{E}_t[A_{t+1} f'(k_t)] = \beta \mathbb{E}_t[(1-\tau_{t+1}) A_{t+2} f'(z_t)], \tag{11}$$

where

$$\tau_{t+1} \equiv (1-\lambda_{t+1}) + \left(\tfrac{\partial \lambda_{t+1}}{\partial k_t} - \tfrac{\partial \lambda_{t+1}}{\partial z_t}\right) \tfrac{f(z_t)}{f'(z_t)} \tag{12}$$

The quantity τ_{t+1}, which is isomorphic to a tax on the return of long-term investment, identifies the wedge that credit frictions introduce between the two types of investment. Understanding the cyclical properties of this wedge is the key to understanding how credit frictions impact the cyclical composition of investment. In what follows we thus seek to gain further insight in the equilibrium determination of this wedge.

We start by observing that the wedge τ_{t+1} comprises two terms. The first term captures the probability of failure; the second term captures the marginal change in this probability caused by a reallocation of investment from the long-term opportunity to the short-term one. The first term would emerge even if the probability of failure were exogenous to the choices of the entrepreneur; the second term, instead, highlights the endogeneity of the liquidity risk. When $x_{t+1} > \ell_{max}$ (that is, when the entrepreneur has enough liquidity to meet even the highest possible liquidity shock), both terms are zero and the wedge vanishes. When, instead, $x_{t+1} < \ell_{max}$, the probability of failure is positive. Furthermore,[12]

$$\tfrac{\partial \lambda_{t+1}}{\partial k_t} - \tfrac{\partial \lambda_{t+1}}{\partial z_t} = \Phi'(x_{t+1})(1+\mu) A_{t+1} f'(k_t)/\ell_{max} > 0, \tag{13}$$

which means that shifting a unit of capital from the long-term to the short-term investment opportunity necessarily reduces the probability of failure; this is simply because such a shift increases the available liquidity in period $t+1$. It follows that τ_{t+1} is strictly positive whenever $x_{t+1} < \ell_{max}$.

[12] Note that $x_{t+1} = (1+\mu) A_{t+1} f(k_t) + R_t q_t(\theta - k_t - z_t)$, implying that $\frac{\partial \lambda_{t+1}}{\partial k_t} = \Phi'(x_{t+1})[(1+\mu) A_{t+1} f'(k_t) - R_t q_t]$ and $\frac{\partial \lambda_{t+1}}{\partial z_t} = \Phi'(x_{t+1})[-R_t q_t]$, which in turn give condition (13).

We henceforth restrict attention to situations where credit constraints are sufficiently tight that the liquidity risk and the associated wedge are bounded away from zero. That is, we assume that the equilibrium satisfies $x_{t+1} < \ell_{max}$, so that $\lambda_{t+1} < 1$ and $\tau_{t+1} > 0$. Note then that, while this is an assumption on equilibrium objects, it is easy to find a restriction on the exogenous parameters of the economy that guarantees that this assumption holds. In particular, this is the case if we let $\mu < \bar{\mu}$, where $\bar{\mu} > 0$ solves $(1 + \bar{\mu})A_{max}f(\theta) = \ell_{max}$.

Finally, we consider the cyclical properties of this wedge. Using $x_{t+1} = (1 + \mu)A_{t+1}f(k_t)$ into condition (13), we get that $\frac{\partial \lambda_{t+1}}{\partial k_t} - \frac{\partial \lambda_{t+1}}{\partial z_t} = \phi\lambda_{t+1}\frac{f'(k_t)}{f(k_t)}$. Substitution this into (12), we infer that condition (11) can be restated as follows:

$$\mathbb{E}_t\left[A_{t+1}f'(\theta - z_t)\left(1 + \beta\phi\lambda_{t+1}\frac{A_{t+2}f(z_t)}{A_{t+1}f(k_t)}\right)\right] = \beta\mathbb{E}_t\left[\lambda_{t+1}A_{t+2}f'(z_t)\right] \tag{14}$$

To gain further insight, let us momentarily ignore the underlying uncertainty about aggregate productivity. We can then drop the expectation operators from both conditions (11) and (14). Since the two conditions are equivalent, we infer that the wedge is also given by

$$\tau_{t+1} = 1 - \frac{\lambda_{t+1}}{1 + \beta\phi\lambda_{t+1}\frac{A_{t+2}f(z_t)}{A_{t+1}f(k_t)}},$$

which is decreasing in λ_{t+1} and increasing in the ratio $\frac{A_{t+2}f(z_t)}{A_{t+1}f(k_t)}$. Intuitively, one would expect the probability of survival λ_{t+1} to be higher in a boom, because of the improved availability of liquidity. One would also expect the ratio $\frac{A_{t+2}f(z_t)}{A_{t+1}f(k_t)}$ to be lower in a boom, because of the mean-reversion in the business cycle. One would thus expect the wedge τ_{t+1} to be lower in a boom than in a recession.

Other things equal, this countercyclicality of the wedge τ_t would tend to boost long-term investment during a boom. However, the opportunity-cost effect that we encountered under complete markets is still present and contributes in the opposite direction. Therefore, one would expect the share of long-term investment to be procyclical if and only if the countercyclicality of the wedge τ_{t+1} is sufficiently strong to offset the countervailing opportunity-cost effect. We verify these intuitions in the following proposition, which is our second main result.

Proposition 2 *Suppose that credit constraints are sufficiently tight that the liquidity risk is non-zero in all states of nature, which is necessarily the case if $\mu < \bar{\mu}$.*

(i) The equilibrium exists and is unique.

(ii) There exists a continuous function z such that the equilibrium composition of investment is given by $k_t = \theta - z(A_t, \mu)$ and $z_t = z(A_t, \mu)$.

(iii) This function satisfies $z(A, \mu) < z^*(A)$ for all (A, μ), and is decreasing in μ. That is, credit constraints depress the share of long-term investment below its complete-market value, and the more so the tighter they are.

(iv) Suppose further that $\phi > 1 - \rho$. Then the function $z(A, \mu)$ is increasing in A. That is, the share of long-term investment increases with a positive innovation in productivity.

Proof. By the assumption that $\mu < \bar{\mu}$ or, more generally, that the liquidity risk is non-zero, we have that $x_{t+1} < \ell_{max}$ and $\lambda_{t+1} = (x_{t+1}/\ell_{max})^{\phi}$, where $x_{t+1} = (1+\mu)A_{t+1}f(k_t)$ and $k_t = \theta - z_t$. Using these facts, we can restate (14) as follows:

$$\mathbb{E}_t\left[A_{t+1}f'(k_t)\left(1+\beta\phi\ell_{max}^{-\phi}(1+\mu)^{\phi}A_{t+1}^{\phi-1}f(k_t)^{\phi-1}A_{t+2}f(z_t)\right)\right] = \beta\mathbb{E}_t\left[\ell_{max}^{-\phi}(1+\mu)^{\phi}A_{t+1}^{\phi}f(k_t)^{\phi}A_{t+2}f'(z_t)\right]$$

Next, using the log-linear AR(1) specification of the productivity shock to compute the various expectations involved in the above condition, we can rewrite this condition as follows:

$$A_t^{\rho}f'(k_t)\left(1+\beta\phi\delta(1+\mu)^{\phi}A_t^{\rho(\phi-1)}f(k_t)^{\phi-1}A_t^{\rho^2}f(z_t)\right) = \beta\delta(1+\mu)^{\phi}A_t^{\rho\phi}f(k_t)^{\phi}A_t^{\rho^2}f'(z_t),$$

where δ is a positive constant defined by $\delta \equiv \ell_{max}^{-\phi}\mathbb{E}[\nu_t^{\rho+\phi}]$. Finally, rearranging the above gives the following:

$$\frac{f'(z_t)}{f'(\theta-z_t)} = \frac{A_t^{\rho(1-\rho-\phi)}}{\beta\delta(1+\mu)^{\phi}f(\theta-z_t)^{\phi}} + \phi\frac{f(z_t)}{f(\theta-z_t)} \tag{15}$$

Note that the left-hand side is continuous and decreasing in z_t, while the right-hand side is continuous and increasing in z_t. Furthermore, the right-hand side is continuous and decreasing in μ; it is continuous in A_t; and it is increasing in A_t [resp., decreasing] if and only if $1-\rho-\phi > 0$ [resp., $1-\rho-\phi < 0$]. Parts (ii), (iii) and (iv) then follow from the Implicit Function Theorem. Finally, part (iii) implies that, for all (A,μ), $z(A,\mu) < z_{max} \equiv z^*(A_{min})$. Along with the assumption $l_{mean} < A_{min}f(\theta - z_{max})$, this guarantees that consumption is positive in all states. Part (i) then follows from this fact together with part (ii). **QED**

The property that the share of long-term investment is lower than under complete markets is a direct implication of our result that $\tau_{t+1} > 0$, namely that the liquidity shock introduces a positive wedge between the marginal products of the long-term and the short-term investment. As mentioned already, this wedge reflects, not only the positive probability that the long-term investment will get disrupted by a sufficiently high liquidity shock, but also the consequent precautionary motive for short-term investment.

Part (iii) of the above proposition then extends this result by showing that the share of long-term investment decreases mononotinically with the tightness of the borrowing constraints. Intuitively, as credit constraints become tighter, the probability of disruption increases and the precautionary motive gets reinforced, implying that long-term investment is further depressed.

Turning to the cyclical behavior of the composition of investment, we first note that this is governed by two conflicting effects. On the one hand, a positive productivity shock raises the opportunity cost of long-term investment (the marginal product of short-term investment). This *opportunity-cost* effect, which is equally present under complete and incomplete markets, pushes the economy to shift resources away from long-term investment during a boom. On the other hand, a positive productivity shock also improves the availability of liquidity, thereby reducing the

probability of disruption, the precautionary motive for short-term investment, and the wedge τ_{t+1}. This *liquidity-risk* effect, which emerges only when markets are incomplete, pushes the economy in the opposite direction: it motivates entrepreneurs to invest relatively more in long-term projects during a boom.

Part (iv) of the above proposition establishes that the liquidity-risk effect dominates if and only if ϕ is sufficiently high relative to $1-\rho$. Intuitively, this is because a higher ϕ strengthens the liquidity-risk effect by raising the cyclical elasticity of the liquidity risk, while a higher ρ dampens the opportunity-cost effect by increasing the persistence of the business cycle.[13]

Comparing the result of Proposition 2 with that of Proposition 1, we conclude that the share of long-term investment turns from countercyclical under complete markets to procyclical when two conditions are satisfied: credit constraints are tight enough that they are always binding ($\mu < \hat{\mu}$); and the implied liquidity risk is sufficiently procyclical ($\phi > 1-\rho$). This result thus provides us with a very sharp contrast between complete and incomplete markets—a sharp contrast that best illustrates the theoretical contribution of our paper. In what follows, we discuss how our results need to be qualified if one of the above two conditions fails– the sharpness is then somewhat lost, but the essence remains intact.

4.3 Discussion

When the conditions $\mu < \bar{\mu}$ and $\phi > 1-\rho$ are violated, the sharp contrast between complete and incomplete markets that we obtained in the preceding analysis is lost. In particular, when μ is high enough, the borrowing constraint stops binding for sufficiently high productivity shocks, and the liquidity risk vanishes for these states. The share of long-term investment is then locally decreasing with the productivity shock, at least for an upper range of the state space. When, on the other hand, ϕ is less than $1-\rho$, the share of long-term investment is countercyclical no matter whether the credit constraint is binding or not.

Nevertheless, a weaker version of our result survives. As long as μ is low enough that the probability of disruption is positive for a non-empty subset of the state space, the liquidity-risk effect that we discussed earlier remains present for this same subset of the state space: it might vanish for sufficiently high states, and it might never be strong enough to offset the conflicting opportunity-cost effect, but it always contributes some procyclicality in the share of long-term investment *relative* to the complete-markets case. In this sense, credit frictions may not always turn the countercycality of long-term investment upside down, but they do tend to mitigate it.

Finally, note that as long as the liquidity risk is bounded away from zero (which is necessarily the case when $\mu < \bar{\mu}$), the cyclical elasticity of the liquidity risk is pinned down by ϕ alone, while

[13] This intuition suggest that ρ should not be interpreted too literally as the autocorrelation of the exogenous shock, but rather more generally as the persistence of the impulse response of output to the underlying shock.

μ matters only for the level of the liquidity risk. This explains why the cyclical properties of the composition of investment in the above proposition are governed solely by a comparison of ϕ with ρ and not by μ. However, when the liquidity risk vanishes in some states (which is the case for μ sufficiently high), then μ starts mattering also for the cyclical elasticity of the liquidity risk. In particular, a lower μ implies a smaller range of A_t for which the liquidity risk vanishes, and therefore a larger subset of the state space for which the procyclical liquidity-risk effect is present.

Combining these observations, we conclude that the core theoretical prediction of our paper can be stated as follows.

Main Prediction. *Other things equal, tighter credit constraints make it more likely that the share of long-term investment increases with a positive productivity shock.*

We expect this prediction to extend well beyond the specific model of this paper, for it rests only on two highly plausible properties: that long-term investment is relatively more sensitive to liquidity risk, by the mere fact that it takes longer to complete; and that liquidity risk is more severe in recessions than in booms. We will test this prediction in Section 6 below.

5 Reinterpretation and additional results

In this section we provide a re-interpretation of the productivity shock that illustrates that our insights need not be unduly sensitive to the details of the underlying business-cycle shocks, while also facilitating our subsequent empirical investigation. We then proceed to study the predictions that our theory makes regarding the dynamics of output growth.

5.1 Reinterpreting the productivity shock

In our model, the source of the business cycle is a TFP shock. However, one should not take this too literally. Rather, the productivity shock in our model is meant to capture more broadly a variety of supply and demand shocks that may cause variation in firm profits and thereby in the returns of the two types of investment. For example, in our empirical analysis, we seek to re-interpret the productivity shock as a particular type of terms-of-trade shock, because we find this to be best from the perspective of econometric identification. We now present a variant of our model that justifies this re-interpretation.

The economy is now open to international trade. In particular, the economy continues to produce a single consumption good, but can now export this good to the rest of the world and can import from it a variety of other consumption goods. In addition, the economy imports a particular intemediate input—think of it as oil—that is used in the production of the domestic good.

Consider an entrepreneur born in period t. Re-interpret $C_{t,t+n}$ as a CES composite of all the goods the entrepreneur consumes and let $P_{c,t}$ denote the price index of this composite relative to

the domestic good. Next, let $P_{m,t}$ denote the price of the aforementioned imported intermediate input relative to the domestic good; let M_t denote the quantity of this input that the entrepreneur purchases; and let the technologies the entrepreneur uses to produce the domestic good in periods $t+1$ and $t+2$ be given, respectively, by

$$Y_{t,t+1} = (M_{t+1})^{1-\eta}(A_{t+1}F(K_t, H_t))^{\eta} \quad \text{and} \quad Y_{t,t+2} = (M_{t+2})^{1-\eta}(A_{t+2}F(Z_t, H_t))^{\eta}$$

Finally, let $\tilde{Y}_{t,t+n}$ denote the real value (in terms of the consumption composite) of the net income that the entrepreneur enjoys in period $t+n$ once she has optimized over the use of the imported input:

$$\tilde{Y}_{t,t+n} \equiv \frac{1}{P_{c,t+1}} \max_{M_{t+n}} [Y_{t,t+n} - P_{m,t+n}M_{t,t+n}].$$

It is straightforward to characterize the optimal use of the intermediate input and thereby to show that

$$\tilde{Y}_{t,t+1} = \tilde{A}_{t+1}F(K_t, H_t) \quad \text{and} \quad \tilde{Y}_{t,t+1} = \tilde{A}_{t+2}F(Z_t, H_t),$$

where

$$\tilde{A}_t \equiv \eta P_{c,t}^{-1} P_{m,t}^{-\frac{1-\eta}{\eta}} A_t$$

is a composite of the productivity shock and the relative prices of the imported goods. We can then repeat the entire analysis of our baseline model simply by replacing $Y_{t,t+n}$ with $\tilde{Y}_{t,t+n}$, and A_t with $\tilde{A}_t$. Therefore, we can indeed reinterpret a positive productivity shock as a reduction in the relative price of either the imported consumption goods or the imported intermediate input—that is, as a positive shock to the country's terms of trade.

Of course, this exact equivalence between productivity and terms-of-trade shock may not hold in richer models.[14] Rather, the purpose of the above example is to clarify that we wish to take the productivity shock only as a metaphor for a variety of aggregate shocks that may affect firm profits and investment returns. The choice of our empirical proxy for these shocks will then be guided primarily by econometric considerations.

5.2 Propagation and amplification

We now study the predictions of our model for the endogenous component of productivity, as captured by the H_t. Recall that the law of motion for H_t is assumed to be $H_{t+1} = \Gamma(H_t, \tilde{Z}_t, K_t)$, where Γ is homogeneous of degree 1 and where $\tilde{Z}_t$ is the amount of long-term investments that survive the liquidity shock. Using this along with the facts that, in equilibrium, $\tilde{Z}_t = \lambda_{t+1}Z_t$, $Z_t = z_t H_t$, and $K_t = (\theta - z_t)H_t$, we infer the equilibrium growth rate of H is given by

$$\frac{H_{t+1}}{H_t} = \gamma(z_t, \lambda_{t+1})$$

[14] For example, if there is both a tradeable and a non-tradeable sector, a terms-of-trade shock will increase returns in the tradeable sector much like a productivity shock, but will also cause a reallocation across the two sectors that is unlike the symmetric effect of an aggregate productivity shock.

where the function γ is defined by $\gamma(z,\lambda) \equiv \Gamma(1,\lambda z,\theta - z)$. Furthermore, by the assumption that $\Gamma(H,Z,K)$ increases with Z for given K and that it increases with the ratio Z/K for given $Z+K$, we have that the function γ is increasing in both its arguments. Using these observations along with our results regarding the cyclical composition of investment, we reach the following characterization of the growth rate of the efficiency of labor.

Proposition 3 *(i) There exist functions h^* and h such that $H_{t+1}/H_t = h^*(A_t)$ when markets are complete and $H_{t+1}/H_t = h(A_t,\nu_{t+1},\mu)$ when markets are incomplete (where ν_{t+1} denotes the innovation in productivity between periods t and $t+1$).*

(ii) Suppose $\mu < \bar{\mu}$, or more generally that the liquidity risk is bounded away from zero. Then, $h(A_t,\nu_{t+1},\mu)$ is necessarily lower than $h^*(A_t)$, it is increasing in μ, and it is increasing in ν_{t+1}. That is, the endogenous component of productivity growth is lower under incomplete markets than under complete markets, and the more so the lower μ or the lower the innovation in productivity.

(ii) Suppose further that $\phi > 1-\rho$. Then, $h(A_t,\nu_{t+1},\mu)$ is increasing in A_t. In contrast, $h^*(A_t)$ is necessarily decreasing in A_t. That is, the endogenous component of productivity growth increases with the beginning-of-period productivity under incomplete markets, whereas it decreases with it under complete markets.

Proof. Part (i) follows from our preceding discussion, letting

$$h^*(A) \equiv \gamma(z^*(A),1) \quad \text{and} \quad h(A,\nu,\mu) \equiv \gamma(z(A,\mu),\lambda(A,\nu,\mu))$$

where $\lambda(A,\nu,\mu) \equiv \Phi((1+\mu)A^\rho \nu f(\theta - z(A,\mu))$ identifies the equilibrium probability of survival. Part (ii), on the other hand, follows from combining the monotonicity of γ with the properties that $z(A,\mu) < z^*(A)$ and $\lambda(A,\nu,\mu) < 1$ (from part (i) of Proposition 2) and the observation that $\lambda(A,\nu,\mu)$ increases with ν. Finally consider part (iii). The claim that $h^*(A_t)$ decreases with A_t follows directly from the result that $z^*(A_t)$ is decreasing in A_t (from Proposition 1) and the monotonicity of γ. Turning to the incomplete-markets growth rate, we know (from Proposition 2) that $z_t = z(A_t,\mu)$ increases with both A_t and μ. It is possible to show that $\lambda_t = \lambda(A_t,\nu_{t+1},\mu)$ also increases with A_t and μ. Towards this goal, rewrite condition (15) as follows:

$$\frac{f'(z_t)}{f'(\theta - z_t)} - \phi \frac{f(z_t)}{f(\theta - z_t)} = \frac{A_t^{\rho(1-\rho)}}{\beta\delta\lambda_{t+1}\nu_{t+1}^{-\phi}}$$

Note then that the left-hand side is decreasing in z_t, and thereby decreasing in A_t and μ, while the right-hand side is increasing in A_t and independent of μ. It follows that λ_{t+1} is indeed increasing in A_t and μ, as claimed. The monotonicity of γ then implies that $h(A_t,\nu_{t+1},\mu)$ is also increasing in A_t and μ. **QED**

This result follows from the combination of our earlier results regarding the composition of investment with the property that long-term investments are relatively more conducive to productivity growth than short-term ones. While we have only assumed the latter property, rather than

derive it from deeper micro-foundations, we nevertheless think that this assumption is both highly plausible and empirically relevant. Furthermore, note that this result would only be re-inforced if we let the rate of productivity growth depend on the fraction of long-term investments that survive, as opposed to its entire level; the property that some long-term investments get disrupted would then further depress the growth rate of H, while the property that this fraction is countercyclical would further strengthen the procyclicality of the growth rate of H under incomplete markets. Finally, translating this result in terms of GDP growth, we reach the following two testable predictions:

Auxiliary predictions. *(i) In the short run, tighter credit constraints amplify the response of output to exogenous business-cycles shocks. (ii) In the long run, they lead to lower mean growth.*

The second prediction is consistent with prior work studying the empirical cross-country relationship between measures of financial development and the long-run growth rate. The first one, on the other hand, will be an important part of our own empirical investigation in Section 6.

5.3 On the relationship between volatility and growth

Combining these last two predictions, we infer that countries with tighter credit constraints should experience *both* lower and more volatile growth rates. Thus, as long as one fails to control for the tightness of credit constraints, our model predicts that one should find a negative partial cross-country correlation between growth and volatility.

This observation provides one possible interpretation of the empirical findings of Ramey and Ramey (1995) through the lens of our model: the negative cross-country correlation between growth and volatility observed in the data may reflect a *spurious* correlation induced by unmeasured cross-country differences in financial development, rather than any causal effect of uncertainty on growth. Moreover, this negative correlation need not diminish once one controls for the level of aggregate investment, for what matters is its composition.

Another possible interpretation of the aforementioned empirical relationship through the lens of our model rests on the *causal* effect of uncertainty on the composition of investment, and thereby on productivity growth. Unfortunately, we have been unable to provide any general result on this front because the comparative statics of the equilibrium with respect to the variance of the productivity shock are quite complex and involve various additional effects. However, the following discussion sheds some light on why it is quite plausible that more volatility may cause a lower mean growth rate within the context of our model.

As long as credit constraints are neither too tight nor too loose, we expect them to bind for sufficiently low productivity shocks but not for sufficiently high shocks. This makes it quite likely that the probability of survival, λ_{t+1}, is a concave function of the productivity shock—and therefore that the mean level of this probability decreases with a mean-preserving spread in the productivity

shock. In other words, we expect higher aggregate volatility to increase the mean level of the idiosyncratic liquidity risk. But then we also expect higher volatility to depress the growth rate of the economy, both by reducing the demand for long-term investments (an ex-ante effect) and by reducing the survival rate of such long-term investment (an ex-post effect).

Furthermore, as long as credit constraints are neither too tight nor too loose, we expect the share of long-term investment, z_t, to be an increasing function of the productivity shock when the shock is sufficiently low (so that the borrowing constraint binds), and a decreasing function of it when the shock is sufficiently high (so that the borrowing constraint does not bind). In this sense, we expect the share of long-term investment to be a concave function of the productivity shock, much like the probability of survival. But then we also expect the mean level of long-term investment to fall when volatility is higher, once again contributing to lower growth.

The combination of these observations makes us believe that a negative causal effect of volatility on mean growth is quite likely within the context of our model. However, we need to qualify this prediction with the following important observation. If the credit constrains are sufficiently tight that the probability of survival is zero (or nearly zero) even for the mean productivity shock, then a mean preserving spread in the productivity shock may actually increase the mean probability of survival, and thereby stimulate long-term investment and growth. In essence, average conditions in the economy are then so dire that higher volatility stimulates the economy by increasing the likelihood of "resurrection".

While this resurrection effect is theoretically possible, we do not expect it to be particularly relevant in practice: if the average situation were so dire, agents would probably have opted to avoid the liquidity risk altogether, perhaps by taking some other option that is not allowed in our model (such as abstaining completely from entrepreneurial activity and investment). We therefore expect that the most likely scenario is one where more volatility increases the average liquidity risk, thereby further distorting the composition of investment and depressing productivity growth.

6 Empirical analysis

In this section, we use data on a panel of 21 OECD countries to provide evidence in support of the key predictions of the model. We proxy for the long-term investment rate z_t in the model with the share of structural investment in total private investment; the exogenous disturbance ν_t with a measure of net-export-weighted changes in international commodity prices; and the credit tightness parameter μ with the ratio of private credit to GDP. We identify the interaction effect of credit and shocks on growth, the composition of investment, and the overall investment rate, using primarily the cross-country variation in private credit and the time-series variation in commodity price shocks.

6.1 Data description

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 test the amplification channel in our theory, we need an empirical counterpart to long-term, productivity-enhancing investment in the model. Such systematic cross-country and time-series data are typically not available for a large panel of countries. We thus use the share of structural investment in total private investment for 21 OECD countries over the 1960-2000 period, from the Source OECD Economic Outlook Database Volume 2005.

We believe that structural investment is an appropriate empirical proxy for z_t in our model because it consists of private investments in structures and housing, which are likely to be long-term investment projects. Furthermore, these investments are likely to contribute to output growth. In unreported results, we have confirmed that a higher share of structural investment in periods t, $t-1$ and $t-2$ is associated with a higher growth rate of output between t and $t+1$, controlling for initial GDP per capita, country- and year fixed effects. In particular, our estimates imply that a one-standard-deviation increase in the share of structural investment has a cumulative effect of 0.8% on subsequent growth. This is quite substantial compared to the average annual growth rate in our sample, 2.6%. Moreover, these results are robust to conditioning on the current and lagged overall investment rate.

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 stock market capitalization, both as a share of GDP. These data come from Levine, Loyaza and Beck (2000).

There is significant cross-sectional and time-series variation in financial development in the panel. Appendix Table 1 reports the 1960-2000 average and standard deviation of private credit for each of the 21 countries in our sample. The mean value of private credit as a share of GDP in the panel is 0.66, with a standard deviation of 0.36. For the average country, the standard deviation of private credit over this 40-year period reaches 0.22. Similarly, the standard deviation of private credit in the cross-section of country averages is 0.27. This variation allows us to identify the differential effect of shocks on the economic growth of countries at different levels of financial development.

Finally, to study the responsiveness of growth and investment to exogenous shocks, we construct the following proxy for ν_t in our model. Using data on the international prices of 42 commodities

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 c, $\triangle P_{ct}$. We then exploit 1985-1987 data on countries' exports and imports by product from the World Trade Analyzer (WTA) to obtain commodity weights.[15] Each country-product specific weight is equal to the net exports of that commodity, divided by the country's total net exports, NX_{ic}/NX_i. Note that these weights are constant over time for a given country, but vary across countries. Commodity prices, on the other hand, vary over time but not in the cross-section. For each country i and year t, we thus construct a weighted commodity-price shock using each commodity's share in net exports as weights:

$$Shock_{it} = \sum_c \frac{NX_{ic}}{NX_i} \triangle P_{ct}.$$

Note that a positive commodity-price shock means that a country can import certain inputs at lower prices and export some of its products at higher prices. Putting aside how this affects cross-sector allocations, this terms-of-trade improvement can be interpreted within the model as a positive ν_t shock, since ν_t is meant to capture innovations to both supply and demand. Note also that an economy can experience large shocks even if it is not a big commodity producer or exporter, since what is decisive for our measure is net exports.[16] Moreover, even if a country maintains relative trade balance overall and NX_i is low, a substantial rise in commodity prices can result in a large shock if the country is a big net commodities importer or exporter.

It is important for our theoretical results that ν_t be exogenous, that it have a positive effect on firm returns, and that it be 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 commodity prices as given, which is likely to be true for most countries in our sample. The last property is easily verified in the data: the autocorrelation coefficient of shocks in the panel of all countries with shock data is -0.032, and 0.058 for the 21 economies with data on structural investment.

Commodity-price shocks vary substantially in our sample. As reported in Appendix Table 2, the average shock in the panel is -0.05, with a standard deviation of 1.17. Most countries experience big fluctuations in shocks over time, and the mean country recorded a 0.60 standard deviation in 1960-2000. The standard deviation of country averages in the cross-section is also large, 0.26. Combined with the variation in financial development across countries and over time, this dispersion in commodity-price shocks allows us to identify the main amplification mechanism in the model.

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

[16] Note also that the commodity weights for a given country do not sum to 1, but to the share of net exports of all commodities in total net exports. This reflects the fact that countries differ in their overall exposure to commodity price shocks.

When analyzing the reaction of the economy to shocks, we seek to isolate the effect of financial development from that of other institutional characteristics. For this reason, we also control for the overall rule of law using the index provided in La Porta et al. (1998). The demographic data are from the PWT and the schooling data are from Barro and Lee (1997). Finally, the various policy variables used in Table 1—that is, 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 rate of investment

Our model predicts that long-term growth-enhancing investment should respond less 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:

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

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 concerns about 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 commodity-price shocks.[17]

To control for omitted intransient country characteristics, 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 presents our main findings. In line with our theoretical predictions, column 1 documents a negative coefficient on the interaction of private credit with the concurrent commodity-price shock. Since financial development is positively correlated with overall development and countries' institutional environment more generally, we need to confirm that our results reflect a credit constraints channel. In column 2, we thus include interactions of income per capita and the overall rule of law with the three shock terms to isolate the independent effect of credit availability. Private credit continues to mitigate the impact of concurrent shocks on long-term investment.

[17] For 11 of the 21 countries, this autocorrelation is in the [-0.10, 0.10] range. The autocorrelation exceeds 0.20 in absolute value only for 2 countries.

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)	(6)
priv credit	0.0135	0.0153	0.0141	0.0189	0.0185	0.0180
	(0.32)	(0.36)	(0.33)	(0.41)	(0.40)	(0.39)
*priv credit*shock* $_t$	-0.0087	-0.0079	-0.0069	-0.0350	-0.0521	-0.0594
	(-2.08)**	(-1.89)*	(-2.39)**	(-2.14)**	(-2.45)**	(-2.16)**
*priv credit*shock* $_{t-1}$	0.0024	0.0033	0.0039	-0.0422	-0.0517	-0.0627
	(0.96)	(1.78)*	(1.53)	(-2.00)*	(-2.11)**	(-1.85)*
*priv credit*shock* $_{t-2}$	0.0004	-0.0025	-0.0011	-0.0465	-0.0807	-0.1214
	(0.15)	(-0.90)	(-0.33)	(-1.71)	(-2.32)**	(-2.39)**
*comm share*shock* $_t$			-0.0001			0.0001
			(-1.28)			(0.09)
*comm share*shock* $_{t-1}$			-0.0001			0.0000
			(-1.82)*			(-0.04)
*comm share*shock* $_{t-2}$			-0.0001			-0.0036
			(-1.19)			(-2.00)*
Controls:						
shocks, income	yes	yes	yes	yes	yes	yes
country & year FE	yes	yes	yes	yes	yes	yes
income & rulelaw interactions	no	yes	yes	no	yes	yes
abs(shock)<=1	no	no	no	yes	yes	yes
R-squared	0.788	0.790	0.791	0.784	0.786	0.787
# countries	21	21	21	21	21	21
N	728	728	728	603	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-weighted commodity price shocks. Private credit and income are measured as moving lagged averages over (t-1, t-5). Columns 4-6 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, control for the main effects of all three shocks, and cluster errors at the country level. t-statistics in parenthesis. ***,**,* significant at 1%, 5%, and 10%.*

If countries that are big natural resource producers tend to have lower levels of financial development, our findings may reflect their higher sensitivity to commodity shocks and not a credit constraints channel. This concern, however, does not appear to be a problem for our analysis for three reasons. First, in the full cross-section of 128 countries with available data, the correlation between the share of commodities in a country's net exports and its 1960-2000 average private credit is small in magnitude and slightly negative at -0.07. This correlation is, however, low and slightly positive, 0.07, in the sample of 21 countries with data on structural investment which we use in our main regressions.

Second, the country-year specific commodity-price shocks we construct take into account countries' export characteristics. In particular, for a given change in world commodity prices, we assign a higher shock to large net commodity exporters. The interaction terms in (16) are thus identified from the combined variation in financial development and exposure to commodity price shocks across countries and over time. In other words, our results indicate that two countries with the same export profile but different levels of financial development will react differently to the same commodity price shock.

Finally, our findings are robust to explicitly controlling for the interaction of commodity price shocks with a country's share of commodities in net exports, $\sum_c \frac{NX_{ic}}{NX_i}$. As column 3 in Table 2 shows, financial development mitigates the effect of concurrent shocks on the share of structural investment even when we include these controls.

Columns 4-6 confirm that our results also hold in the sample of country-year observations for which the commodity-price shock does not exceed 100% in absolute value.[18] 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 for 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 ($0.05\% = 0.26 \cdot (0.052 + 0.052 + 0.081)$). These results are once again not driven by overall development or the broad institutional environment, as proxied by GDP per capita and rule of law respectively. They are also robust to controlling for countries' share of commodities in net exports.[19]

[18] The commodity-price shock may exceed 100% either because of extremely large inflation in commodity prices, or because a country has enormous exposure to commodity shocks. Restricting the sample to [-100%, 100%] shocks thus also partly addresses the concern about large resource producers being financially underdeveloped.

[19] 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 concurrent shocks. This result is robust to controlling for overall development or the rule of law, and obtains in both the entire

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)
fin devt				-0.054	-0.053	-0.003	-0.002
				(-0.93)	(-0.91)	(-0.05)	(-0.04)
*fin devt*shock$_t$*	-0.012	-0.044	-0.066	-0.058	-0.089	-0.019	-0.027
	(-2.89)***	(-2.39)**	(-2.27)**	(-3.43)***	(-3.11)***	(-0.55)	(-0.77)
*fin devt*shock$_{t-1}$*	0.003	-0.052	-0.052	-0.062	-0.073	-0.043	-0.055
	(1.26)	(-1.76)*	(-1.58)	(-3.10)***	(-2.90)***	(-1.48)	(-1.43)
*fin devt*shock$_{t-2}$*	0.000	-0.087	-0.113	-0.054	-0.095	-0.053	-0.066
	(-0.10)	(-4.79)***	(-4.89)***	(-1.56)	(-2.61)**	(-1.25)	(-1.25)
Controls:							
shocks, income	yes	yes	yes	yes	yes	yes	yes
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	0.782	0.776	0.777	0.752	0.756	0.783	0.786
# 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-weighted commodity price shocks. All regressions include a constant term, country and year fixed effects, control for the main effects of all three shocks, 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 there is time-series variation in financial development and using this lagged value mitigates potential endogeneity and reverse causality concerns, some bias may remain if shocks trigger slow changes in the level of private credit. The empirical evidence, however, rejects this possibility. The simple correlations between private credit and concurrent, once- and twice-lagged shocks are statistically insignificant at -0.021, -0.018 and -0.017, respectively. As Appendix Table 3 demonstrates, when we regress the moving average of private credit on the three shocks, we always obtain insignificant coefficients. This is true in the full sample of country-year observations with data on private credit and shocks, as well as in the restricted sample with data on structural investment (columns 1 and 5). Moreover, the same result obtains when we control for country and year fixed effects (columns 2 and 6), when we exploit only shocks below 100% (columns 3 and 7), and when we cluster the error term by country (columns 4 and 8). We thus believe that our measure of private credit does not endogenously respond to movements in commodity prices.

In columns 1-3 of Table 3, we nevertheless confirm the robustness of our findings to a measure of financial development that varies only in the cross-section: the country average of private credit over the entire period in the sample (1960-2000). Once again, the interaction of private credit with the

sample and the sub-sample with shocks smaller than 100%.

concurrent shock is always negative and significant, as is the interaction with twice-lagged shocks in the sample with non-extreme shocks.[20] In the rest of Table 3, we then explore the robustness of our results to two alternative indicators of financial development: the volume of liquid liabilities and total stock market capitalization as a share of GDP. We find negative and significant point estimates on the interaction of liquid liabilities with all three shocks, but imprecisely estimated negative coefficients when we use market capitalization.[21][22]

Our model 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 investment rate. 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 magnified if we find no effect on the aggregate investment rate.

In Table 4, we document that lower levels of financial development do not predict a stronger impact of commodity-price shocks on the share of investment in total GDP. If anything, tighter credit dampens, rather than amplifies, the reaction of total investment to shocks. This result is robust to allowing the effect of shocks to vary with countries' GDP per capita, rule of law or commodity share of net exports (columns 3 and 4); to using the 1960-2000 average value of private credit (column 5); and to restricting the sample to shocks within the [-100%, 100%] range (columns 2-5). These findings directly contradict models that focus on how financial frictions amplify the impact of shocks on aggregate investment, and strengthen our position that other channels, such as the composition of investment and endogenous productivity, are 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 6-10 of Table 4 show, our main findings continue to hold: financial development mitigates the impact of shocks on long-run investment even holding the overall level of investment fixed.

Remark. The preceding empirical analysis proxied long-term investment with the share of structural investment. In a previous version of this paper and other unreported results, we have also considered the share of R&D spending. We obtained qualitatively similar results, although point estimates were sometimes imprecisely estimated. This is probably because of data limitations: most countries report almost zero R&D spending, indicating that reported R&D spending is a very poor empirical measure for our purposes. See, however, Aghion et al. (2008) for complementary evidence using R&D data from panel of French firms.

[20] We obtain similar results when we use an initial value of private credit (results available upon request).

[21] 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 averages or unrestricted shocks.

[22] Since data on liquid liabilities and market capitalization is available for fewer country-years than private credit, columns 4-7 in table 4 have fewer observations.

Table 4. Total investment vs. the composition of investment

Dependent variable:	Total investment / GDP					Structural inv / Total inv				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
investment / GDP						0.000	0.001	0.001	0.001	0.002
						(0.10)	(0.44)	(0.50)	(0.52)	(0.61)
priv credit	3.43	2.42	2.49	2.52		0.013	0.016	0.015	0.014	
	(1.76)*	(1.05)	(1.13)	(1.13)		(0.32)	(0.36)	(0.34)	(0.33)	
*priv credit*shock* $_t$	-0.18	1.61	2.53	1.72	-0.02	-0.009	-0.037	-0.056	-0.062	-0.055
	(-0.60)	(1.10)	(1.52)	(1.21)	(-0.01)	(-2.13)**	(-2.22)**	(-2.42)**	(-2.18)**	(-3.41)***
*priv credit*shock* $_{t-1}$	0.41	2.54	3.26	1.82	2.43	0.002	-0.045	-0.056	-0.065	-0.055
	(3.57)***	(1.90)*	(2.45)**	(1.46)	(1.56)	(1.03)	(-2.20)**	(-2.14)**	(-1.92)*	(-2.05)*
*priv credit*shock* $_{t-2}$	-0.61	0.10	3.00	3.22	1.21	0.001	-0.047	-0.085	-0.126	-0.102
	(-2.31)**	(0.05)	(1.61)	(1.54)	(0.60)	(0.18)	(-1.76)*	(-2.41)**	(-2.46)**	(-4.17)***
*comm share*shock* $_t$				-0.12					0.000	
				(-0.72)					(0.20)	
*comm share*shock* $_{t-1}$				-0.20					0.000	
				(-3.92)***					(0.17)	
*comm share*shock* $_{t-2}$				0.08					-0.004	
				(0.86)					(-2.02)*	
Controls:										
shocks; income; country & year FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
income & rulelaw interactions	no	no	yes	yes	yes	no	no	yes	yes	yes
abs(shock)<=1	no	yes	yes	yes	yes	no	yes	yes	yes	yes
R-squared	0.732	0.739	0.746	0.748	0.729	0.788	0.786	0.787	0.789	0.786
# countries	21	21	21	21	21	21	21	21	21	21
N	728	603	603	603	630	728	603	603	603	603

Note: Annual 1960-2000 data, except where lost due to lags. The dependent variable in the first 5 columns is the share of investment in GDP for the sample with structural investment data. The dependent variable in columns 6-10 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-weighted commodity price shocks. Private credit and income are calculated as a moving lagged average over (t-1, t-5) in all columns except for columns 5 and 10 where private credit is the 1960-2000 average. Columns 2-5 and 7-10 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, control for the main effects of all three shocks, and cluster errors at the country level. t-statistics in parenthesis. ***,**,* significant at 1%, 5%, and 10%.*

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. This section shows that financial frictions also reinforce the effect of shocks on income and productivity growth.

We first examine the sensitivity of growth to commodity-price shocks in an annual panel between 1960 and 2000. We estimate the following specification:

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

Here, Δy_{it} denotes annual growth for country i in time t. 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 include country and year fixed effects, condition on twice-lagged GDP per capita, and cluster errors at the country level.

The left half of Table 5 presents our baseline results. In line with our model's predictions, we find that once-lagged commodity-price shocks boost growth today, but financial development mitigates this effect. This result obtains in the sample with shocks under 100% in absolute value (column 2), and is robust to allowing growth to respond differentially across countries at varying levels of commodity exposure in net exports (column 3). Our findings are also unchanged when we identify the effects of financial development purely from the cross-sectional variation in average private credit over the 1960-2000 period (column 4).

The right half of Table 5 establishes that none of these effects are channeled through the level of aggregate investment. More specifically, we control for the concurrent, once- and twice-lagged values of total investment as a share of GDP, and find our results unchanged. This test serves an additional purpose as well. In the absence of a direct TFP measure, conditioning on aggregate investment and GDP per capita is akin to controlling for total capital, and hence to 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.[23]

Since credit constraints amplify the business cycle in our theoretical framework, an additional implication of our model is that growth should be less persistent at lower levels of financial development. We find evidence consistent with this prediction in Table 6, where we examine the cross-sectional correlation between countries' average private credit and the autocorrelation of their GDP per capita growth over the 1960-2000 period. As expected, we establish a positive and statistically

[23] All of 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 of structural investment tends to predict higher growth. Results available upon request.

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)	(7)	(8)
priv credit	-0.004	-0.008	-0.008		-0.005	-0.009	-0.009	
	(-0.45)	(-0.75)	(-0.75)		(-0.55)	(-0.92)	(-0.93)	
*priv credit*shock* $_t$	0.000	0.006	0.008	0.024	-0.001	0.006	0.009	0.023
	(-0.13)	(0.39)	(0.49)	(1.49)	(-0.59)	(0.46)	(0.59)	(1.38)
*priv credit*shock* $_{t-1}$	-0.005	-0.030	-0.031	-0.035	-0.004	-0.027	-0.030	-0.033
	(-4.63)***	(-2.38)**	(-2.16)**	(-2.90)***	(-3.22)***	(-2.19)**	(-2.12)**	(-3.00)***
*priv credit*shock* $_{t-2}$	-0.003	-0.005	0.001	-0.015	-0.002	-0.002	0.004	-0.010
	(-1.56)	(-0.59)	(0.11)	(-1.60)	(-1.28)	(-0.25)	(0.41)	(-0.92)
Controls:								
income $_{t-2}$	yes	yes	yes	yes	yes	yes	yes	yes
abs(shock)<=1	no	yes	yes	yes	no	yes	yes	yes
comm share interactions	no	no	yes	no	no	no	yes	no
R-squared	0.410	0.456	0.457	0.455	0.425	0.468	0.469	0.466
# countries	21	21	21	21	21	21	21	21
N	727	602	602	629	727	602	602	629

Note: Annual 1960-2000 data, except where lost due to lags, for the sample of observations with data on structural investment. shock $_t$*, shock* $_{t-1}$*, shock* $_{t-2}$ *refer to the contemporaneous, 1-year and 2-year lagged net-exports-weighted commodity price shocks. Private credit is measured as a moving lagged average over (t-1, t-5) in all columns except for columns 4 and 8 where it is the 1960-2000 average. Columns 2-4 and 6-8 restrict the sample to observations with the absolute value of contemporaneous and lagged shocks less than 100%. Columns 3 and 7 control for the interaction of countries' commodity share in net exports with all three shocks. Columns 5-8 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, control for income and time t-2, and cluster errors at the country level. t-statistics in parenthesis. ***,**,* significant at 1%, 5%, and 10%.*

significant correlation, which is robust to controlling for cross-country differences in rule of law and economic development (1960-2000 average income) (column 2). Our findings are also not driven by the volatility of output growth (column 3) or the volatility and autocorrelation of commodity shocks (column 4). These results indicate that financially underdeveloped countries experience less persistent growth rates, and foreshadow our observations for growth volatility in the next section.

6.4 On the cross-country correlation between volatility and growth

Having tested the core predictions of our theory, we now return to the negative cross-country correlation between volatility and growth, which was part of the motivating background. We already discussed how our model provides a simple spurious interpretation of this correlation. But we also indicated that, when idiosyncratic liquidity risk increases with aggregate volatility, the causal effect of volatility on growth is expected to be more negative the tighter the credit constraints. While this possibility is not as central to our theory as the predictions we have already tested, it is of special interest because of its implications for welfare and policy: it suggests that the cost of business cycles may be higher in countries with lower financial development, as well as that stabilization policies can have more favorable growth effects in such countries.

We thus close the empirical part of the paper by taking a first look at whether such a regularity is present in the data. In Table 6, we repeat the Ramey and Ramey (1995) 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 at lower levels of financial development. This effect is economically important. For example, in the specification of column 1, a one-standard-deviation improvement in private credit would reduce the negative growth impact of a 1% rise in volatility by -0.14%. 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). The main and interaction effects of private credit are, however, always jointly statistically significant. We conclude that the negative relation between growth and volatility appears to stronger in countries with tighter credit, in accordance with the aforementioned theoretical prediction.

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.

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	-0.003	-0.010	-0.011	-0.006	-0.009	-0.010
	(-1.51)	(-3.79)***	(-4.37)***	(-3.78)***	(-3.97)***	(4.42)***
growth volatility	-0.161	-0.257	-0.137	-0.172	-0.218	-0.134
	(-2.35)**	(-2.46)**	(-1.27)	(-3.15)***	(-2.37)**	(-1.40)
private credit	0.014	-0.005	0.064	-0.004	-0.015	0.036
	(1.20)	(-0.35)	(2.37)**	(-0.43)	(-1.33)	(1.43)
*volatility*private credit*	0.520	0.757	0.458	0.441	0.575	0.375
	(2.23)**	(2.50)**	(1.50)	(2.36)**	(2.14)**	(1.37)
investment/GDP				0.001	0.001	0.001
				(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)	0.046	0.027	0.309	0.008	0.047	0.322
F-test (credit terms)	0.000	0.002	0.000	0.003	0.102	0.011
R-squared	0.356	0.529	0.584	0.591	0.644	0.673
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%.*

Needless to say, both the theoretical and the empirical lessons of this paper have their limitations. Also, any careful quantitative assessment would require that our mechanism be embedded within a more standard business-cycle model—an exercise that we leave for future research. We nevertheless hope that our findings may draw more attention to the important interaction between credit constraints and the composition of investment, and the implications of this interaction for short-run fluctuations and long-run growth.

Largely motivated by our findings, Aghion, Bacchetta, Ranciere and Rogoff (2006) proceed to investigate the relationship between growth and exchange-rate volatility, while Aghion, Hemous, and Kharroubi (2009) look at the relationship between growth and the cyclicality of fiscal policy. The former paper finds that exchange-rate volatility has a stronger negative effect on growth in countries with tighter credit, while the latter paper finds that countercyclical fiscal policy has a stronger positive effect on growth in industries with higher financial dependence within countries with tighter credit. Finally, using a panel of French firms, Aghion et al. (2008) find that the share of R&D investment—another natural measure of long-term investments—is more procyclical in firms that face tighter credit constraints. Combined, this subsequent work complements the contribution of our paper and further highlights the value of investigating the joint determination of the composition of investment, short-run volatility, and long-run growth.

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Table A1. Private credit in the sample

This table summarizes the variation in financial development in the data. Columns 1 and 2 report the time-series mean and standard deviation of private credit as a share of GDP for each country in the sample, over the 1960-2000 period. The bottom rows show summary statistics for the cross-section of means and for the entire panel, 1960-2000.

Country	Average	St Dev
Australia	0.383	0.218
Austria	0.650	0.221
Canada	0.556	0.226
Denmark	0.416	0.088
Finland	0.514	0.163
France	0.757	0.174
Germany	0.806	0.197
Greece	0.306	0.124
Ireland	0.490	0.188
Italy	0.599	0.089
Japan	1.200	0.372
Mexico	0.213	0.073
Netherlands	0.901	0.381
New Zealand	0.401	0.343
Norway	0.735	0.141
Republic of Korea	0.721	0.332
Spain	0.783	0.066
Sweden	0.910	0.228
Switzerland	1.251	0.293
United Kingdom	0.549	0.407
United States	0.811	0.207
	Average in the panel:	0.660
	Standard deviation in the panel:	0.359
	Average in the cross-section:	0.664
	Standard deviation in the cross-section:	0.269

Table A2. Commodity price shocks in the sample

This table summarizes the variation in commodity price shocks in the data. Columns 1 and 2 report the time-series mean and standard deviation of net-exports weighted shocks for each country in the sample, over the 1960-2000 period. The bottom rows show summary statistics for the cross-section of country averages and for the entire panel.

Country	Average	St Dev
Australia	-0.751	2.808
Austria	0.023	0.103
Canada	0.069	0.228
Denmark	0.081	0.658
Finland	-0.065	0.412
France	0.082	0.366
Germany	-0.021	0.092
Greece	0.019	0.074
Ireland	-0.022	0.239
Italy	0.027	0.127
Japan	-0.030	0.116
Mexico	0.144	0.602
Netherlands	-0.020	0.093
New Zealand	0.218	1.510
Norway	-0.827	4.055
Republic of Korea	-0.036	0.156
Spain	0.056	0.225
Sweden	-0.029	0.182
Switzerland	0.050	0.191
United Kingdom	0.063	0.299
United States	0.017	0.080
	Average in the panel:	-0.045
	Standard deviation in the panel:	1.171
	Average in the cross-section:	-0.045
	Standard deviation in the cross-section:	0.256