Collateral Booms and Information Depletion

Vladimir Asriyan, Luc Laeven, Alberto Martin*

October 5, 2018

Abstract

We develop a new theory of boom-bust cycles driven by information production during credit booms. In our model, entrepreneurs need credit to undertake investment projects, some of which enable them to divert resources towards private consumption. Lenders can protect themselves from such diversion in two ways: through collateralization and through costly screening, which generates durable information about projects. In equilibrium, the collateralization-screening mix depends on the value of aggregate collateral. High collateral values raise investment and economic activity, but they also raise collateralization at the expense of screening. This has important dynamic implications. During credit booms driven by high collateral values, the economy accumulates physical capital but depletes information about investment projects. Because of this, collateral-driven booms end in deep crises and slow recoveries: when booms end, investment is constrained both by the lack of collateral and by the lack of information on existing investment projects, which takes time to rebuild. We provide new empirical evidence using US firm-level data in support of the model's main mechanism.

JEL: E32, E44, G01, D80.

Keywords: Credit Booms, Collateral, Information Production, Screening, Crises.

*Asriyan: vasriyan@crei.cat. Laeven: Luc.Laeven@ecb.europa.eu, Martin: amartin@crei.cat. Asriyan and Martin: CREI, Universitat Pompeu Fabra and Barcelona GSE, Ramon Trias Fargas 25-27, 08005-Barcelona, Spain. Laeven: European Central Bank, Sonnemannstrasse 20, Frankfurt, Germany. We thank seminar and conference participants at CREi-UPF, University of Cambridge, Università Bocconi, the Federal Reserve Bank of Minneapolis, the Federal Reserve Bank of Philadelphia, the Workshop on Bubbles in Macroeconomics in Barcelona, Barcelona GSE Summer Forum, and the Society for Economic Dynamics (SED) meetings in Edinburgh for helpful suggestions and comments. We thank Ilja Kantorovitch for excellent research assistance.

1 Introduction

Credit booms, defined as periods of rapid credit growth, are common phenomena in both advanced and emerging economies.[1] They are generally accompanied by a strong macroeconomic performance, including high asset prices and high rates of investment and GDP growth.[2] Yet, the conventional wisdom is to view them with suspicion. First, credit booms are often perceived to fuel resource misallocation: high asset prices and a positive economic outlook may lead to the relaxation of lending standards and, consequently, to the funding of relatively inefficient activities.[3] Second, credit booms often end in crises that are followed by protracted periods of low growth.[4]

This conventional wisdom raises important questions. What determines the allocation of credit during booms? How does this allocation shape the macroeconomic effects of credit booms, and of their demise? And finally, are all credit booms alike? In this paper, we develop a new theory of information production during credit booms to address these questions and exploit US data to provide new empirical evidence of the theory's main predictions.

We study an economy that is populated by borrowers (entrepreneurs) and lenders. Entrepreneurs have access to long-lived investment projects but need external funding to undertake them; lenders, instead, have resources but they lack the ability to run investment projects. Absent any friction, this would not be a problem, as lenders could simply provide credit to entrepreneurs with productive investment opportunities. We introduce a friction, however, by assuming that some projects enable entrepreneurs to divert resources for private consumption (i.e., they yield non-contractable private benefits).

If they are to break even, lenders need to protect themselves against such diversion by entrepreneurs. They have two ways of doing so. The first is *collateralization*. Entrepreneurs are endowed with assets (e.g. trees), and lenders can ask them to retain "skin in the game" by posting these assets as collateral. The second is costly *screening*. Lenders may engage in costly information production to ensure that the projects undertaken by entrepreneurs do not permit resource diversion. We make two assumptions regarding screening. First, the cost of screening an individual project in any given period is increasing in the economy's aggregate amount of screening in that period. This assumption captures the intuitive notion that there

[1]See Mendoza and Terrones (2008) and Bakker et al. (2012) for a brief discussion on the formal definition and empirical identification of credit booms. Claessens et al. (2011) use a different approach and study "credit cycles," but they also find them to be common among advanced economies.

[2] Mendoza and Terrones (2008) study empirically the macroeconomic conditions during credit booms.

[3]See, for example, García-Santana et al. (2016) and Gopinath et al. (2017).

[4]See Schularick and Taylor (2012) and Krishnamurthy and Muir (2017).

is an increasing cost of producing information in any given period due, for instance, to some fixed underlying factor.[5] Second, the information generated through screening is long-lived, and it accompanies the project throughout its life.

The key insight of the model is that, in equilibrium, the relative intensity of collateralization vs. screening depends on the scarcity of entrepreneurial collateral, i.e. on the price of trees. When the price of trees is low, lenders rely largely on screening. Only few investment projects can be funded via collateralization and, as a result, the return to undertaking additional projects – and thus to screening them – is high. This raises equilibrium screening and thus the amount of information on existing projects. When the price of trees is instead high, the equilibrium mix of screening to collateralization is low. In this case, many investment projects can be funded via collateralization and, as a result, the return to screening them is low. This reduces equilibrium screening and thus the amount of information on existing projects.

This insight has powerful implications for the effects of collateral-driven credit booms. When the economy enters a collateral boom, the price of trees rises and credit, investment and output all expand together. But, for the reasons outlined above, lenders rely more on collateralization and less on screening. Even as the economy booms, therefore, the amount of information on existing projects falls: in this sense, the boom is accompanied by a 'depletion' of information. When the boom ends and the price of trees falls, credit, investment, and output fall as well, but for two reasons: (i) all else equal, the scarcity of collateral means that lenders must increase their reliance on costly screening, and; (ii) this reliance is especially stark because information has been 'depleted' during the boom. For these reasons, the end of a collateral boom is accompanied by a large crash and a slow recovery, i.e., a transitory "undershooting" of economic activity relative to its new long-run level.

Besides this general insight, the model speaks to two recent debates in macroeconomics. First, it shows that not all credit booms are alike. Gorton and Ordoñez (2016) have recently referred to "good" and "bad" booms, depending on whether they end in crises or not. Through the lens of our model, the defining feature of booms lies in the shock that originates them. In particular, unlike collateral-driven booms, productivity-driven booms do not generate information depletion: by raising the return to investment, an increase in productivity actually raises equilibrium screening and information production. Thus, the end of productivity-driven booms does not exhibit a deep crisis with an undershooting of economic activity. Second, our model also speaks to the recent literature on asset price bubbles (e.g. Martin and Ventura (2018)). In essence, one can interpret collateral-driven booms as the result of bubbles, which

[5] Screening borrowers, for instance, may require trained loan officers, information gathering and processing infrastructure, which are difficult to change in the short run.

raise the price of trees but do not affect economic fundamentals. Under this interpretation, our model highlights a hitherto unexplored cost of bubbles that surfaces when they burst: while they last, they deplete information on existing projects.

Finally, we study the normative properties of our economy. Intuitively, it may seem that because information depletion leads to large crises, the information generated during credit booms in a laissez-faire equilibrium is suboptimally low. We show, however, that this intuition is incorrect (if anything, actually too much information is being generated!). The reason is that private agents are rational and they correctly anticipate the value of information in future states of nature: thus, even in the midst of a collateral boom, they understand that – when the bust comes – screened projects will be very valuable and they will be able to appropriate this value. For information generation to be suboptimally low, there must be an additional distortion that prevents agents from internalizing its social value. We explore two such distortions: external economies in the screening technology and frictions in the market for projects.

We test three central predictions of the theory on US firm-level data from COMPUSTAT. First, as is standard in the presence of financial frictions, the theory predicts that a rise in collateral values should coincide with an increase in investment and output. Second, and more central to the theory, an increase in collateral values should lead to information depletion, i.e., to a decline in screened investment. Finally, the theory predicts that a decline in collateral values should reduce investment and output, the more so the lower is the amount of information on existing projects, i.e., the share of past investment that has been screened.

Testing the empirical relevance of the model's main predictions is nontrivial for at least two reasons. First, all three predictions refer to the effect of collateral values on the amount and composition of investment. Assessing this in the data requires identifying changes in collateral values that are orthogonal to other economic conditions, such as productivity, which may affect investment on their own. We deal with this by following Chaney et al. (2012) and estimating the impact of real estate prices on corporate investment. Second, the main prediction of the model is that an increase in net worth or collateral reduces the economy's reliance on screening, so that there is less information on existing projects. Assessing this in the data requires a measure of screening intensity or, analogously, of the availability of information on existing projects. Given the lack of a generally accepted measure of such information, we adopt an indirect approach and use three alternative measures of information at the firm level: the bid-ask spread on the firm's stock, the number of financial analysts that follow the firm, and the ratio of intangible assets to tangible fixed assets of the sector in which the firm operates.

Our empirical results are consistent with the main predictions of the model. First, a firm's investment is increasing in the value of its real estate. Second, this effect is stronger for firms on which there is less information, as measured through the bid-ask spread, the number of analysts covering the firm or the ratio of intangible to tangible assets of the sector in which the firm operates. Moreover, information on a given firm – as measured through the bid-ask spread – is decreasing in the value of the real estate that it owns. Finally, to assess how the distribution of investment during the boom affects the severity of the subsequent bust, we analyze evidence at the state level during the recent housing boom and bust in the United States. We find that, at the state level, investment during the bust years (2007-2012) is negatively correlated with the share of investment that was undertaken by high-spread firms during the boom (2001-2006).

Existing stylized evidence also supports our theory. First, there is ample evidence showing that investment is positively correlated with collateral values (Peek and Rosengren (2000), Gan (2007), Chaney et al. (2012)). Second, there is also evidence that lending standards, and in particular lenders' information on borrowers, deteriorates during booms (Asea and Blomberg (1998), Keys et al. (2010), and Becker et al. (2016)). Finally, and focusing more specifically on collateral booms, Doerr (2018) finds that the US housing boom of the 2000s led to a reallocation of capital and labor to less productive firms. All of these findings are consistent with the model's main predictions.

On the theoretical front, we are of course not the first to consider the link between information production and economic booms and busts (see, for instance, Ordonez (2013), Gorton and Ordonez (2014); Gorton and Ordoñez (2016), and Fajgelbaum et al. (2017)). Within this work, the closest to us are the papers by Gorton and Ordoñez. Like them, we focus on the interaction between information generation in the credit market and credit booms. Also like them, we predict that booms are characterized by a deterioration of information. There are two key differences between our framework and theirs, however. In their framework, information refers to the quality of collateral, whereas in our model it refers to the quality of investment itself. In their framework, moreover, it is the generation of information that triggers a crisis: once lenders realize that some collateral is of low quality, there is a fall in lending and investment. In our framework, instead, information always helps sustain investment. Because of this, it is the crisis that triggers information generation, as the lack of collateral makes it worthwhile for market participants to ramp up screening.

Our paper also speaks to the growing literature on the cost of credit booms and busts.

On the one hand, we have already mentioned the evidence suggesting that credit booms raise misallocation (see, for instance, García-Santana et al. (2016) and Gopinath et al. (2017)). Our model provides one possible cause of such misallocation: information depletion. In a related vein, our model contributes to the literature on rational bubbles (see Martin and Ventura (2018) for a recent survey) by identifying a hitherto unexplored cost of asset bubbles. By providing collateral, bubbles reduce incentives to generate information and this makes their collapse especially costly.

Conceptually, our model is related to papers exploring how the optimal choice of technology is shaped by financial frictions. In our model, the equilibrium mix of screened and unscreened investment depends on the availability of collateral. This is reminiscent of Matsuyama (2007), where the lack of borrower net worth may induce a shift towards less productive but more pledgeable technologies. More recently, Diamond et al. (2017) also develop a model in which low asset prices prompt firms to adopt more pledgeable technologies, because they rely on enhanced pledgeability to sustain borrowing and investment.

Finally, our paper is also related to the banking literature studying the determinants of lending standards and their evolution during the business cycle (see, for instance, Manove et al. (2001), Ruckes (2004), Dell'Ariccia and Marquez (2006), and Petriconi (2015)). Of these, the work closest to ours is Manove et al. (2001), which studies the relationship between collateral and screening in loan contracts. Their focus is on the contracting problem itself, however, and not on the macroeconomic implications of information generation. Ruckes (2004), Gorton and He (2008) and Petriconi (2015) also study the evolution of screening over the cycle, but they stress the effect of cross-bank competition on the equilibrium choice of screening.

The paper is organized as follows. In Section 2, we describe the model. In Section 3, we characterize the equilibrium and present our main results. In Section 4, we consider several extensions of our baseline model. In Section 5, we study the normative properties of our economy. In Section 6, we conduct our empirical analysis. Finally, we conclude in Section 7.

2 The Model

Time is infinite and discrete, $t = 0, 1, ...$ The economy is populated by overlapping generations of young and old. The objective of individual i of generation t is to maximize her utility

$$U_{i,t} = E_t\{C_{i,t+1}\},$$

where $C_{i,t+1}$ is her old age consumption and $E_t\{\cdot\}$ is the expectations operator at time t.

Each generation consists of two types of individuals, entrepreneurs and savers, measure ε and $1-\varepsilon$ respectively. Savers work during youth and save their labor income to finance old age consumption. Entrepreneurs borrow during youth to finance investment, and they produce during old age. There is a risk-neutral international financial market willing to borrow from and lend to domestic agents at a (gross) expected return of ρ. Thus, we think of our economy as being small and open, and refer to ρ as the interest rate.

Savers are endowed (in aggregate) with one unit of labor during youth. Given their preferences, they save their entire labor income. Their only choice is whether to save in the international financial market at rate ρ or to lend to the entrepreneurs in the domestic credit market at an expected rate $E_t R_{t+1}$. Of course, it must hold in equilibrium that $E_t R_{t+1} = \rho$.

Entrepreneurs engage in two types of productive activities. First, young entrepreneurs run investment technologies (or projects) that we specify shortly, which transform consumption goods in period t into capital in period $t+1$. Capital depreciates at rate δ and is reversible. Second, old entrepreneurs combine capital with labor to produce the economy's consumption good. In particular, entrepreneurs produce according to Cobb-Douglas technology: $F_t(l_{i,t}, k_{i,t}) = A_t \cdot k_{i,t}^{\alpha} \cdot l_{i,t}^{1-\alpha}$, where $k_{i,t}$ is the capital stock of entrepreneur i, $l_{i,t}$ is the labor hired by entrepreneur i, A_t reflects aggregate productivity, and $\alpha \in (0,1)$.

Entrepreneurs are endowed with "trees" whose market value in period t is denoted by q_t. Since entrepreneurs can borrow against this market value, we refer to trees indistinctly as the net worth or collateral of entrepreneurs. In the main analysis, we take the collateral value q_t as exogenously given, but we endogenize it in Section 4.1. We think of these trees as an asset distinct from capital, e.g. real estate or land, whose valuation affects entrepreneurs' net worth but is orthogonal to their investment opportunities. Both q_t and A_t are potentially random and are the only sources of aggregate uncertainty in our economy.

The investment technology operated by entrepreneurs to produce capital is as follows. Each unit of investment at time t produces a unit of capital at time $t+1$. Each unit of capital, however, is of uncertain quality: with probability μ, this capital is of type $\theta = H$; with probability $1-\mu$, it is of type $\theta = L$. The quality of each unit of capital is independent of the rest and, once produced, persists throughout the unit's lifetime. We initially assume that both types of capital are equally productive.[6] The L-type capital, however, suffers from an "agency" problem in that it allows the entrepreneur to abscond with all the resources generated by it. Thus, the key difference between the two types is that effectively the income generated by H-type capital can be pledged to outside creditors, whereas that of L-type cannot.[7]

[6]We incorporate heterogeneity in productivities in Section 4.3.

[7]This stark assumption is convenient but inessential. Our main results are unchanged as long as H-type

The central feature of our environment is that, prior to investing in a given technology, young entrepreneurs can reduce their investment uncertainty through screening. In particular, before investing in a given unit of capital, a young entrepreneur can pay a screening cost ψ_t to produce a public signal about the unit's type: for simplicity, we assume throughout that this signal is perfect. Upon having observed the signal, the entrepreneur can choose whether or not to invest in this unit. Any signal generated through screening is public information throughout the unit's lifetime, although the history or past performance of the unit is not. Entrepreneurs may therefore own both, units of "screened capital" whose types are known, and units of "unscreened capital" whose types are unknown.

We use k_t^θ ($k_{i,t}^\theta$) to denote the economy's (entrepreneur i's) stock of screened capital of type θ, and k_t^μ ($k_{i,t}$) to denote the economy's (entrepreneur i's) stock of unscreened capital. Since all units are equally productive, only the total capital stock is relevant for the economy's (entrepreneur's) production and it is given by $k_t = k_t^H + k_t^L + k_t^\mu$ ($k_{i,t} = k_{i,t}^H + k_{i,t}^L + k_{i,t}^\mu$).

2.1 Labor, asset and credit markets

Old entrepreneurs interact with young savers in a competitive labor market. At the beginning of period t, given his capital stock $k_{i,t}$, maximization by entrepreneur i implies

$$l_{i,t} = \left[\frac{A_t \cdot (1-\alpha)}{w_t}\right]^{\frac{1}{\alpha}} \cdot k_{i,t}, \tag{1}$$

where w_t is the wage rate per unit of labor. Equation (1) is the labor demand of entrepreneur i, which results from hiring labor until its marginal product equals the wage. Since the aggregate supply of labor is one, market clearing implies that:

$$w_t = A_t \cdot (1-\alpha) \cdot k_t^\alpha. \tag{2}$$

Thus, equation (2) says that the wage equals the marginal product of labor evaluated at the aggregate capital-labor ratio.[8] We use

$$r_t = A_t \cdot \alpha \cdot k_t^{\alpha-1} \tag{3}$$

to denote the marginal product of capital. The equations (1)-(3) are standard, so we will impose them throughout our analysis.

capital is more pledgeable (see Appendix A.4).

[8]Since all entrepreneurs use the same capital-labor ratio, this must also be the aggregate one.

Entrepreneurs can buy and sell capital in a competitive market. We use p_t^{θ} and p_t^{μ} to denote the market prices of a unit of screened capital of type-θ and of unscreened capital, respectively. After producing in period t, old entrepreneur i is left with $(1-\delta)\cdot k_{i,t}^{j}$ units of capital of "type" $j \in \{H, L, \mu\}$. His only choice at this point is whether to sell his units of capital in the market or to reverse and consume them. It follows immediately that he will strictly prefer to sell all units of capital whose price exceeds one, be indifferent between selling and consuming those units whose price is exactly one, and will strictly prefer to consume any units whose price is lower than one. The key observation here is that old entrepreneurs can obtain $\max\left\{p_t^{j}, 1\right\}$ for each unit of type-j capital.

To finance investment and purchases of capital, young entrepreneurs use their endowment plus the financing that they obtain in the credit market. Credit is supplied by competitive banks that are run by savers. This implies that they are willing to lend to entrepreneurs any amount at the expected return ρ. Banks also run the screening technology used to identify the quality of investment. We make two assumptions regarding this technology, which we interpret in Appendix A.1 as the result of competition in the banking sector that provides screening services by hiring experts who are heterogeneous in their screening costs. First, the cost of screening depends on the aggregate units of investment that are screened s_t, i.e., $\psi_t = \psi(s_t) \geq 0$. Second, there are limits to the information that can be produced in any given period, which we capture by assuming that $\psi(0) = 0$ and $\psi'(\cdot) > 0$. For simplicity, we assume that old entrepreneurs cannot screen capital, but we relax this assumption in Appendix A.5.

Entrepreneurs demand credit from banks, but the existence of L-type capital gives rise to a borrowing limit. If we let $f_{i,t}$ be the credit extended to entrepreneur i and R_{t+1} denote the (state-contingent) interest rate on this contract, then the maximum repayment that she can credibly promise to make to creditors in each state is:

$$R_{t+1}\cdot f_{i,t} \leq r_{t+1}\cdot\left(k_{i,t+1}^{H}+\mu\cdot k_{i,t+1}^{\mu}\right)+\max\left\{p_{t+1}^{H},1\right\}\cdot k_{i,t+1}^{H}+\max\left\{p_{t+1}^{\mu},1\right\}\cdot\mu\cdot k_{i,t+1}^{\mu}, \quad (4)$$

Note that, by the law of large numbers, a fraction μ of the entrepreneur's unscreened capital is of H-type and is thus fully pledgeable.

We do not impose any restrictions on the state-contingency of contracts so that, together with the fact that in any equilibrium $E_t R_{t+1} = \rho$, equation (4) implies:

$$\rho\cdot f_{i,t} \leq E_t\left\{r_{t+1}\cdot\left(k_{i,t+1}^{H}+\mu\cdot k_{i,t+1}^{\mu}\right)+\max\left\{p_{t+1}^{H},1\right\}\cdot k_{i,t+1}^{H}+\max\left\{p_{t+1}^{\mu},1\right\}\cdot\mu\cdot k_{i,t+1}^{\mu}\right\}. \quad (5)$$

Equation (5) states that entrepreneurs can only borrow against the discounted value of expected income generated by the units of capital that have been screened and are known to be good, and by the share of the unscreened units of capital that are expected to be good.

2.2 Entrepreneurs' problem

We now turn to the problem of a young entrepreneur i, who in period t must decide how much to invest and how many units of capital to purchase in the market for capital. Let $x_{i,t}^j$ and $z_{i,t}^j$ respectively denote the entrepreneur's investment in, and purchases of, units of type-$j \in \{H, L, \mu\}$ capital.

Taking factor prices and the screening cost as given, entrepreneur i chooses his units of capital $\{k_{i,t+1}^j\}_j$, its production and purchases $\{x_{i,t}^j\}_j$ and $\{z_{i,t}^j\}_j$, and screening $s_{i,t}$ to maximize expected old age consumption,

$$E_t \left\{ r_{t+1} \cdot k_{i,t+1} + (1-\delta) \cdot \sum_{j=H,L,\mu} \max\{p_{t+1}^j, 1\} \cdot k_{i,t+1}^j \right\} - \rho \cdot f_{i,t}, \tag{6}$$

subject to:

$$\begin{aligned}
q_t + f_{i,t} &= \sum_{j=H,L,\mu} \left(x_{i,t}^j + p_t^j \cdot z_{i,t}^j \right) + \psi_t \cdot s_{i,t}, \\
\rho \cdot f_{i,t} &\leq E_t \left\{ r_{t+1} \cdot \left(k_{i,t+1}^H + \mu \cdot k_{i,t+1}^\mu \right) + (1-\delta) \cdot \left(\max\{p_{t+1}^H, 1\} \cdot k_{i,t+1}^H + \max\{p_{t+1}^\mu, 1\} \cdot \mu \cdot k_{i,t+1}^\mu \right) \right\}, \\
x_{i,t}^H &\leq \mu \cdot s_{i,t}, \\
x_{i,t}^L &\leq (1-\mu) \cdot s_{i,t}, \\
k_{i,t+1}^j &= x_{i,t}^j + z_{i,t}^j, \\
s_{i,t} &\geq 0, \\
k_{i,t+1}^j &\geq 0, \quad \text{for} \quad j \in \{H, L, \mu\}.
\end{aligned}$$

The entrepreneur's old age consumption equals the expected capital income minus interest payments: note that Equation (6) already takes into account that capital will be sold in the market only if its price exceeds one. This consumption is optimized subject to a set of constraints. The first one is the budget constraint, and it says that total spending on investment, capital purchases and screening must equal the value of entrepreneurial endowment plus borrowing. The second constraint is the borrowing limit, and it says that payments to creditors cannot exceed the pledgeable part of capital income. The third and fourth constraints say that the entrepreneur's ability to produce capital of a given quality with certainty is limited by her screening. The final set of constraints states that the entrepreneur's stock of each type of capital is given by its purchases and production, and that both screening and holdings of capital must be non-negative.

To solve the problem of the individual entrepreneur, we begin with a conjecture that the equilibrium prices of capital are as follows:

$$p_t^H = 1 + \frac{\psi(s_t)}{\mu}; \quad p_t^\mu = p_t^L = 1. \tag{7}$$

We will verify shortly that these prices are indeed part of an equilibrium of our economy. Given this conjecture, we solve for the entrepreneurial problem to obtain the capital stocks $k_{i,t+1}^H$, $k_{i,t+1}^L$, and $k_{i,t+1}^\mu$. The solution has the following implications.

First, entrepreneurs never choose to hold L-type capital, i.e. $k_{i,t+1}^L = 0$. The reason for this is simple. Suppose that entrepreneur i pays the screening cost and discovers that the corresponding unit of investment is of type L: she can always do better by not exercising this option and investing in an unscreened unit of capital instead, which is just as productive (and expensive) but more valuable as collateral.

Second, entrepreneur chooses to hold H-type capital if and only if it is profitable to do so, i.e.,

$$k_{i,t+1}^H \begin{cases} = 0 & \text{if } \; E_t R_{t+1}^H < 1 + \frac{\psi_t}{\mu} \\ \in [0, \infty) & \text{if } \; E_t R_{t+1}^H = 1 + \frac{\psi_t}{\mu} \\ = \infty & \text{if } \; E_t R_{t+1}^H > 1 + \frac{\psi_t}{\mu} \end{cases}, \tag{8}$$

where

$$E_t R_{t+1}^H \equiv \frac{E_t \left\{ r_{t+1} + (1-\delta) \cdot \left(1 + \frac{\psi_{t+1}}{\mu}\right) \right\}}{\rho},$$

denotes the expected return of a unit of H-type capital, i.e., the present value of the expected rental plus the resale value. Equation (8) states that as long as this expected return exceeds the cost of producing (or purchasing) a unit of H-type capital, i.e., the sum of investment plus screening costs, the entrepreneur is willing to hold it.[9] Note that this condition implies that the entrepreneur is never constrained in her choice of H-type capital, which is natural because the income that these units generate is fully pledgeable.

[9] At the conjectured prices, young entrepreneurs are indifferent between producing an H-type unit of capital or purchasing it on the market.

Finally, holdings of unscreened units of capital are given by,

$$k_{i,t+1}^{\mu} = \begin{cases} = 0 & \text{if } E_t R_{t+1}^{\mu} < 1 \\ \in \left[0, \dfrac{\rho}{\rho - \mu \cdot E_t \{r_{t+1} + 1 - \delta\}} \cdot q_t\right] & \text{if } E_t R_{t+1}^{\mu} = 1 \\ = \dfrac{\rho}{\rho - \mu \cdot E_t \{r_{t+1} + 1 - \delta\}} \cdot q_t & \text{if } E_t R_{t+1}^{\mu} \in \left(1, \frac{1}{\mu}\right) \\ = \infty & \text{if } E_t R_{t+1}^{\mu} \geq \frac{1}{\mu} \end{cases}, \tag{9}$$

where

$$E_t R_{t+1}^{\mu} \equiv \frac{E_t \{r_{t+1} + 1 - \delta\}}{\rho}$$

denotes the expected return of a unit of unscreened capital. Equation (9) states that the entrepreneur is willing to hold such a unit as long as its expected return exceeds the cost of producing (or purchasing) it. Differently from the case of H-type capital, an entrepreneur's holdings of unscreened capital may be constrained by the borrowing limit because the income generated by these units cannot be fully pledged to creditors.

2.3 Equilibrium

To determine the equilibrium of the economy, we aggregate the behavior of individual entrepreneurs.

From Equation (9), any equilibrium must entail $\rho > \mu \cdot E_t \{r_{t+1} + 1 - \delta\}$, since otherwise entrepreneurs' investment in unscreened capital would be unbounded. This implies that the aggregate stock of unscreened capital is given by:

$$k_{t+1}^{\mu} = \min\left\{\frac{\rho}{\rho - \mu \cdot E_t \{r_{t+1} + 1 - \delta\}} \cdot q_t, k_{t+1}^{*}\right\}, \tag{10}$$

where k_{t+1}^{*} is the unscreened capital consistent with $E_t r_{t+1} = \rho + \delta - 1$.[10] Equation (10) states that entrepreneurs use all of their collateral to finance unscreened investment, unless the collateral is so large that they become unconstrained.

As for L-type capital, we must have,

$$k_{t+1}^{L} = 0, \tag{11}$$

[10] Formally, using the definition of r_{t+1} in Equation (3), k_{t+1}^{*} satisfies,

$$E_t \left\{\alpha \cdot A_{t+1} \cdot \left(k_{t+1}^{H} + k_{t+1}^{L} + k_{t+1}^{*}\right)^{\alpha - 1}\right\} = \rho + \delta - 1.$$

since no entrepreneur wants to hold it. Finally, Equation (8) implies that in equilibrium the return to H-type capital must equal its marginal cost of production,

$$\frac{E_t\left\{r_{t+1}+(1-\delta)\cdot\left(1+\frac{\psi(s_{t+1})}{\mu}\right)\right\}}{\rho}=1+\frac{\psi\left(s_t\right)}{\mu}, \tag{12}$$

where

$$s_t=\max\left\{0,\frac{k_{t+1}^H-(1-\delta)\cdot k_t^H}{\mu}\right\}. \tag{13}$$

Equation (13) says that screening takes place only if there is aggregate investment in H-type capital. If instead the stock of H-type capital is falling, there is no need to screen since all units can be purchased from old entrepreneurs.

These conditions were derived under our conjecture in (7) about equilibrium prices. We now verify these prices are indeed consistent with equilibrium. For H-type capital, young entrepreneurs are indifferent between purchasing units from old entrepreneurs and producing them; old entrepreneurs, in turn, strictly prefer to sell them as long as $s_t > 0$ and are indifferent otherwise. Thus, at the conjectured price p_t^H, the market for H-type capital clears. For μ-type capital, young entrepreneurs are again indifferent between purchasing units from old entrepreneurs and producing them; old entrepreneurs, in turn, are also indifferent between selling their units and consuming them. Thus, at the conjectured price p_t^μ, the market for μ-type capital clears. Finally, L-type capital is weakly dominated by μ-type capital, so the young do not purchase it. At the conjectured price p_t^L, old entrepreneurs are indifferent between selling their capital and consuming it, so the market for L-type capital clears as well.

The equilibrium of our economy is computed as follows. Given an initial condition k_0^H, k_0^L, and k_0^μ, which are the capital units held by the initial generation of old entrepreneurs, and given a stochastic process for the economy's shocks $\{q_t, A_t\}_{t\geq 0}$, the equations (3) and (10)-(13) characterize the evolution of the equilibrium capital stocks and screening $\left\{k_t^H, k_t^L, k_t^\mu, s_t\right\}_{t>0}$.

3 Collateral-driven booms and busts

We are now ready to characterize the dynamic behavior of the economy. Our main objective is to analyze how the economy behaves during a collateral-driven boom-bust cycle, i.e., an economic cycle driven by fluctuations in entrepreneurial collateral q_t. We want to think of these as fluctuations in entrepreneurial net worth that are orthogonal to investment opportunities, e.g. fluctuations in real-estate values. To clarify the role of collateral, we will compare these boom-bust cycles with those driven by fluctuations in productivity, as captured by A_t.

To simplify the exposition, the build-up to the full dynamic analysis of the model gradually. We begin by assuming that $\delta = 1$, so that capital depreciates fully in production. By making capital units short-lived, this assumption means that the economy is essentially static, as it eliminates the forward-looking nature of screening. We then set $\delta < 1$ and analyze the behavior of the economy in response to unanticipated shocks: this enables us to characterize the dynamic interaction between information production through screening, on the one hand, and the volume and composition of investment, on the other, through a simple phase diagram analysis. Finally, we allow for shocks to be anticipated and analyze the behavior of the economy in response to fluctuations in q_t (and A_t).

3.1 Building intuitions: the static model

When $\delta = 1$, capital depreciates fully after production and thus $s_t = \frac{k^H_{t+1}}{\mu}$, i.e. the economy must produce its stock of H-type capital every period. In this case, the economy's equilibrium is characterized by

$$k^{\mu}_{t+1} = \max\left\{\frac{\rho}{\rho - \mu \cdot E_t r_{t+1}} \cdot q_t, k^*_{t+1}\right\}, \tag{14}$$

and

$$\frac{E_t r_{t+1}}{\rho} = 1 + \frac{\psi\left(\max\{\mu^{-1} \cdot k^H_{t+1}, 0\}\right)}{\mu}, \tag{15}$$

where r_{t+1} is defined in Equation (3) and k^*_{t+1} is the unscreened capital consistent with $E_t r_{t+1} = \rho$. Note that the equations (14) and (15) are the equivalents of the equations (10) and (13), when δ is set to equal 1. This economy has no state variables and hence no relevant dynamics. Albeit boring, it is nonetheless useful to illustrate the key role played by entrepreneurial collateral.

Figure 1 illustrates the economy's behavior through a comparative statics exercise. For a given value of productivity A, it depicts the equilibrium capital stock, its composition between H-type and unscreened capital, and the price of both types of capital, as a function of q. The left panel shows that the aggregate capital stock initially increases with q but is constant after a critical value. The middle panel shows why this is the case: an increase in q induces a shift in investment, raising unscreened capital at the expense of H-type capital. Higher values of q relax the borrowing constraints of entrepreneurs, enabling them to expand unscreened investment; this expansion reduces the return to capital, however, and thus the benefits of

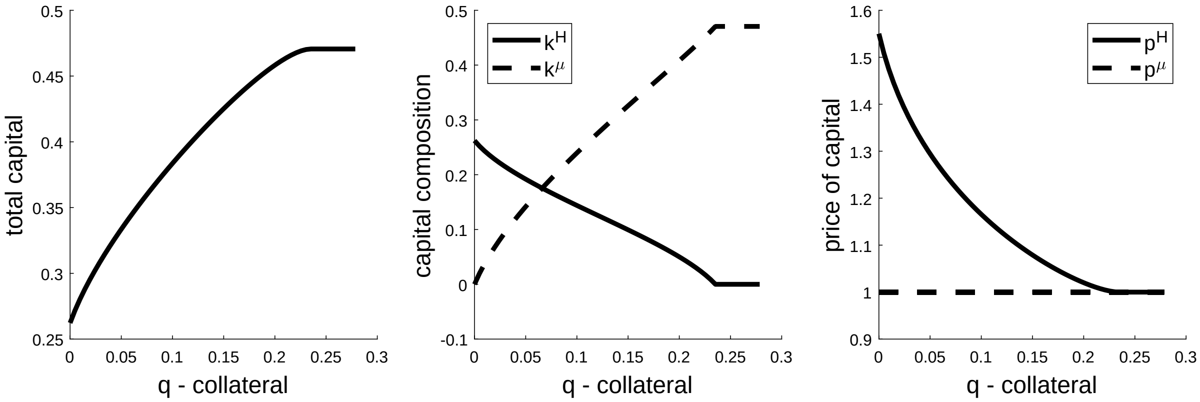

Figure 1: **Effects of collateral with** $\delta = 1$. The figure depicts the equilibrium capital stock, its composition and capital prices, as a function of collateral value q, in the economy with full depreciation..

screened investment. At some point, entrepreneurial collateral is high enough to sustain the unconstrained level of unscreened investment and, beyond this critical level, q no longer affects equilibrium investment. Finally, the right panel shows that the price of H-type capital – which captures the equilibrium value of information – is decreasing in entrepreneurial collateral. This reflects the fact that the value of information embedded in a unit of H-type capital is low when entrepreneurial collateral is abundant and unscreened investment is high.

Figure 1 summarizes the basic insight of our mechanism. There are two ways of investing in the economy: one is information-intensive, in the sense that it relies on screening to select units of H-type capital; the other one is not, in the sense that it relies on collateral and yields unscreened units of capital. In equilibrium, the two means of investment are substitutes. An increase in collateral shifts the composition away from screened investment and, by doing so, enables the economy to save on screening costs.

Before concluding, it is useful to contrast the effects of changes in entrepreneurial collateral with those of changes in aggregate productivity. To this effect, Figure 2 depicts (for a given value of q) the equilibrium capital stock, its composition between H-type and unscreened capital, and the price of both types of capital, as a function of A. The left panel shows that, as expected, increases in aggregate productivity raise the equilibrium capital stock. The middle panel shows that this follows from an increase in both screened and unscreened capital. The reason is that higher productivity raises the expected return to capital, raising both entrepreneurs' willingness to invest in screened capital and their ability to invest in unscreened capital. Finally, the right panel shows that the price of H-type capital is monotonically increasing in productivity. This reflects the fact that the value of the information embedded

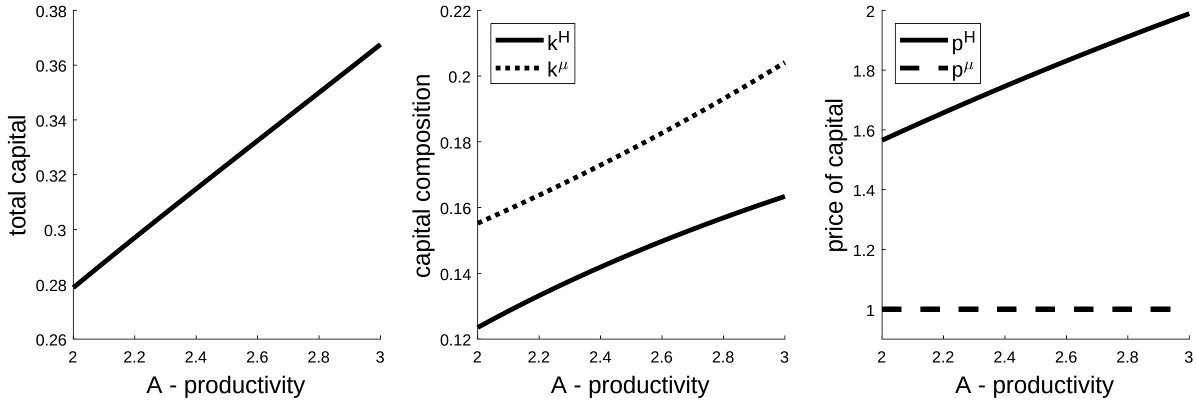

Figure 2: **Effects of productivity with** $\delta = 1$. The figure depicts the equilibrium capital stock, its composition and capital prices, as a function of aggregate productivity A, in the economy with full depreciation.

in such a unit of capital increases in its return, which in turn increases in productivity.

This section has characterized the effects of entrepreneurial collateral on investment in a static environment. To understand how changes in collateral values affect the dynamic trajectory of investment and its composition, we next consider the case of $\delta < 1$.

3.2 The dynamic model

Let us return to the case of $\delta < 1$ and allow for shocks to entrepreneurial collateral and aggregate productivity, i.e., $q_t \in \left\{\underline{q}, \overline{q}\right\}$ and $A_t \in \left\{\underline{A}, \overline{A}\right\}$. If we focus on equilibria in which unscreened investment is always constrained by entrepreneurial net worth, then the dynamics of the economy are fully characterized by the following system of equations:

$$k^{\mu}_{t+1} = \frac{\rho}{\rho - \mu \cdot E_t \left\{\alpha \cdot A \cdot \left(k^H_{t+1} + k^{\mu}_{t+1}\right)^{\alpha-1} + 1 - \delta\right\}} \cdot q_t, \tag{16}$$

$$\frac{E_t \left\{r_{t+1} + (1-\delta) \cdot \left(1 + \frac{\psi(s_{t+1})}{\mu}\right)\right\}}{\rho} = 1 + \frac{\psi\left(s_t\right)}{\mu}, \tag{17}$$

and

$$s_t = \max\left\{0, \frac{k^H_{t+1} - (1-\delta) \cdot k^H_t}{\mu}\right\}, \tag{18}$$

where r_{t+1} is defined in Equation (3). The key difference with the static model is that the stock of screened capital k^H_t is now a state variable. To see why, note that for a given expected future value of screened capital, k^H_{t+1} is increasing in k^H_t: high values of k^H_t reduce the need for screening, as some of the information that is necessary to produce H-type capital is already embedded in the pre-existing units. In this sense, we can think of k_t^H as the economy's stock of informational capital.

But what is the dynamic behavior of this informational capital? To understand this, we next by study the dynamic properties of a deterministic economy and its response to unanticipated shocks. We then analyze the general system given by Equations (3) and (16)-(18), in which shocks are anticipated, and use it to study the properties of boom-bust cycles.

3.2.1 Deterministic economy

Let us suppose that the economy does not experience shocks, i.e. $q_t = q$ and $A_t = A$ for all t. We can characterize both the steady state and the dynamic behavior of the economy with the help of a simple phase diagram in k_t^H and s_t, as shown in Figure 3. The figure depicts the following steady-state relationships:

$$k^H = s \cdot \frac{\mu}{\delta}, \tag{19}$$

and

$$\alpha \cdot A \cdot \left(k^H + k^\mu(k^H, q, A)\right)^{\alpha-1} = (\rho + \delta - 1) \cdot \left(1 + \frac{\psi(s)}{\mu}\right), \tag{20}$$

where $k^\mu(k^H, q, A)$ is implicitly defined by Equation (16), and it is thus increasing in q but decreasing in k^H (though less than one for one). Equation (19) represents the rate of per-period screening s that is necessary to maintain k^H units of H-type capital in steady state. Clearly, k^H is increasing in s. Equation (20) instead represents the profit-maximizing level of H-type capital that, for a given level of screening s, is consistent with equilibrium. Here, k^H is decreasing in s because high levels of screening raise the cost of investing in H-type capital.

The left panel of Figure 3 depicts both loci in the $\left(k^H, s\right)$ space. Their intersection represents the steady state of the deterministic economy, which we denote by $\left(\bar{k}^H, \bar{s}\right)$. This system can be shown to be saddle-path stable, and its saddle path is also depicted in the figure. Given an initial value $k_0^H < \bar{k}^H$, the equilibrium entails a high level of screening ($s_0 > \bar{s}$) as the economy must build up its informational capital: along the transition, k_t^H rises monotonically towards $\bar{k}^H$ and s_t falls monotonically towards $\bar{s}$. On the other hand, given an initial value $k_0^H > \bar{k}^H$, the equilibrium entails a low level of screening ($s_0 < \bar{s}$) as the economy must run down its informational capital: along the transition, k_t^H falls monotonically towards $\bar{k}^H$ and s_t rises monotonically towards $\bar{s}$.

The right panel of Figure 3 depicts the response of the economy to a permanent and unexpected increase in q. Whereas the loci given by Equation (19) is unaffected by this change, the

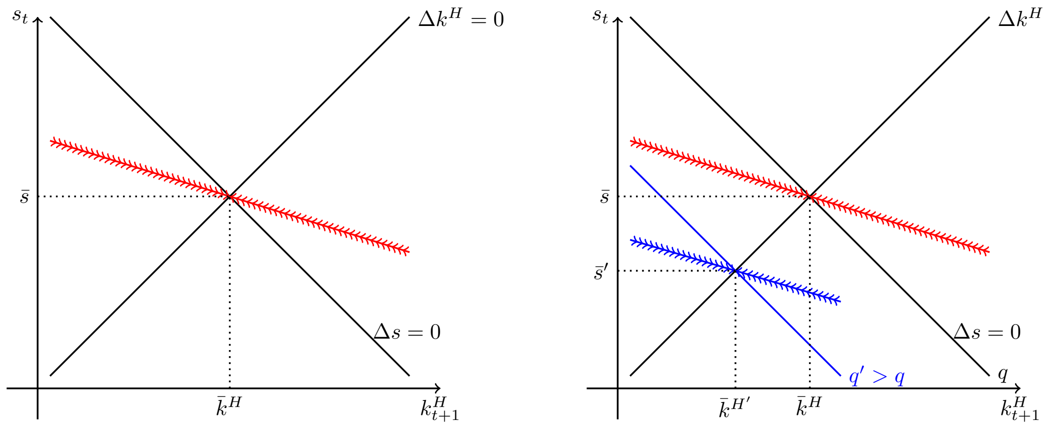

Figure 3: **Information dynamics**. The figure depicts a phase diagram for the joint evolution of per period screening and the stock of H-type capital. In the left panel, the saddle path of the system is depicted in red. In the right panel, the saddle path is depicted in red prior to the unexpected shock to q, and in blue after.

loci given by Equation (20) is affected, since an increase in q raises unscreened capital and thus reduces the return to investing in H-type capital. As a result, on impact, screening collapses as the economy jumps to the new saddle path: at the new, higher level of entrepreneurial collateral, it is simply not worth maintaining the existing stock of H-type capital. From this new saddle path, the economy converges monotonically towards the new steady state, which – relative to the original equilibrium – has lower k^H and s.

Thus, the basic intuitions of the static model carry over to the dynamic setting; that is, the economy responds to an increase in q by reducing its investment in information. In the dynamic economy, however, the depletion of information occurs gradually, as screening first undershoots its new steady state value and then gradually increases to the new steady state. Instead, it is straightforward to show that an increase in aggregate productivity as measured by A would have the opposite effect, i.e., shifting the loci defined by Equation (20) to the right, thereby raising steady-state screening and k^H. In this sense, entrepreneurial collateral "crowds out" investment in information, whereas aggregate productivity "crowds it in".

Equipped with these intuitions, we are now ready to study the behavior of the economy in response to fluctuations in collateral values, taking into account that agents are forward-looking and fully aware of the stochastic nature of the economy.

3.2.2 Boom-bust episodes

Let us suppose that the economy fluctuates between low- and high-collateral states, according to a Markov process with transition probabilities $\varphi = P\left(q_t = \overline{q} | q_{t-1} = \underline{q}\right) \in \left(0, \frac{1}{2}\right)$ and $\varphi = P\left(q_t = \underline{q} | q_{t-1} = \overline{q}\right) \in \left(0, \frac{1}{2}\right)$ We assume that $\overline{q}$ is low enough so that entrepreneurs are

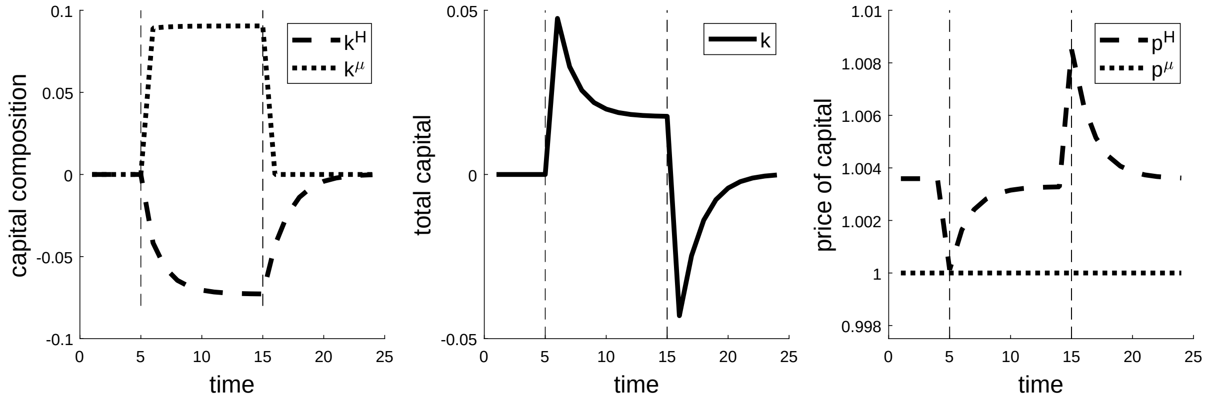

Figure 4: **Collateral boom-bust episode**. The figure depicts the equilibrium evolution of the capital stock, its composition and capital prices throughout a collateral boom-bust episode. Collateral values are $q_t = \underline{q}$ before period 5 and after period 15, and $q_t = \bar{q} > \underline{q}$ between periods 5 and 15.

constrained in both states. Although we provide an interpretation of the source of such fluctuations in the next section, it suffices for now to say that the economy experiences boom-bust episodes driven by exogenous shocks to collateral values.

Figure 4 illustrates the behavior of an economy, which is initially in the low-collateral state but then transitions to the high-collateral state. On impact, the economy experiences an investment boom and a change in the composition of investment: unscreened investment rises at the expense of screened investment. As the high-collateral state persists, the economy gradually converges to a new steady state with a higher total capital stock but with a lower stock of screened capital. In other words, during the high-collateral state, the economy gradually depletes its stock of informational capital. We summarize these findings below.

Result 1 (Collateral booms and information depletion) *Assume that the economy fluctuates between a low- and high-collateral states, and that entrepreneurs are constrained in both states. As the high-collateral state persists, the total capital stock and output increase, but the stock of screened capital decreases over time.*

What happens when the boom ends and the economy returns to the low-collateral state? At this point, the entrepreneurs find that there is neither collateral to sustain the stock of unscreened capital that was built during the boom nor is there informational capital, as it was depleted during the boom. Thus, there is a severe need for screening, which translates into a sharp increase in the cost of screening and thus in the value of screened capital. As it takes time for the economy to rebuild its stock of unscreened capital, output undershoots its new steady-state value at the end of the boom. In other words, the lack of screened capital amplifies the

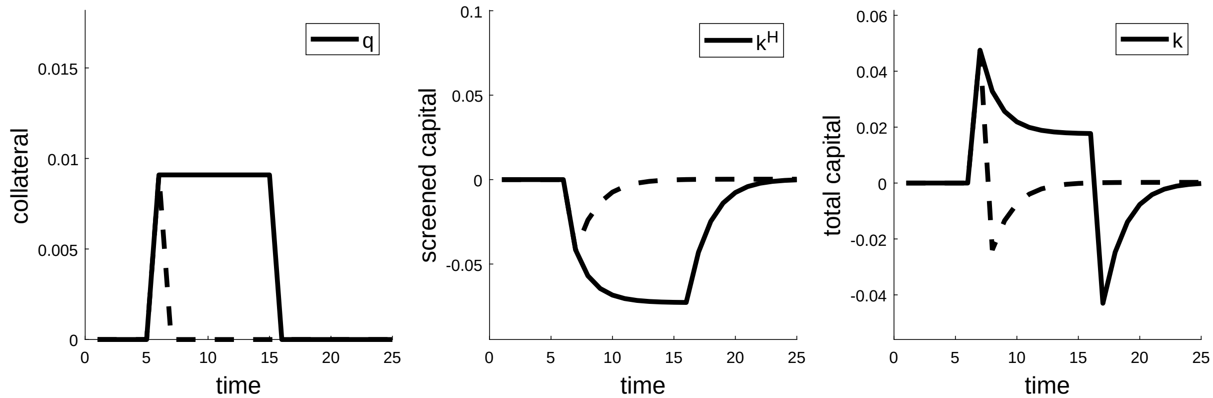

Figure 5: **Longer booms, larger busts**. The figure depicts the equilibrium evolution of the total capital and H-type capital throughout collateral boom-bust episodes of two different durations: one lasts from period 5 to period 6, whereas the other lasts from period 5 to period 7.

fall in output when the economy transitions to the low collateral state. Furthermore, Figure 5 shows that longer booms lead to more information depletion and, therefore, they end in larger busts or "crises." We summarize these findings below.

Result 2 (Collateral busts and under-shooting) *Assume that the economy fluctuates between low- and high-collateral states, and that entrepreneurs are constrained in both states. The longer the economy stays in the high-collateral state, the lower the total capital and output in the period of the bust. Furthermore, if the boom is long enough, the capital stock and output undershoot their long-run low-collateral steady state.*

The results 1 and 2 summarize the key characteristics of collateral-driven booms. As long as they last, collateral booms raise the economy's capital stock and output, but they deplete its informational capital. When the booms end, both the capital stock and output fall, and more so the longer the economy has been in the boom phase, thereby having depleted more information.

It is again instructive to contrast the booms-bust episodes driven by collateral values with those driven by productivity shocks. To this effect, Figure 7 depicts the evolution of an economy that, for given value of q, transitions between low- and high-productivity states. In this case, both types of capital increase when the economy is in the high-productivity state. As a result, when the boom ends and the economy transitions into the low-productivity state, the stock of unscreened capital – and thus output – are higher than in the low productivity steady-state. Although the economy is less productive when the boom ends, it inherits a larger stock of screened capital, which "cushions" its transition to the new steady state.

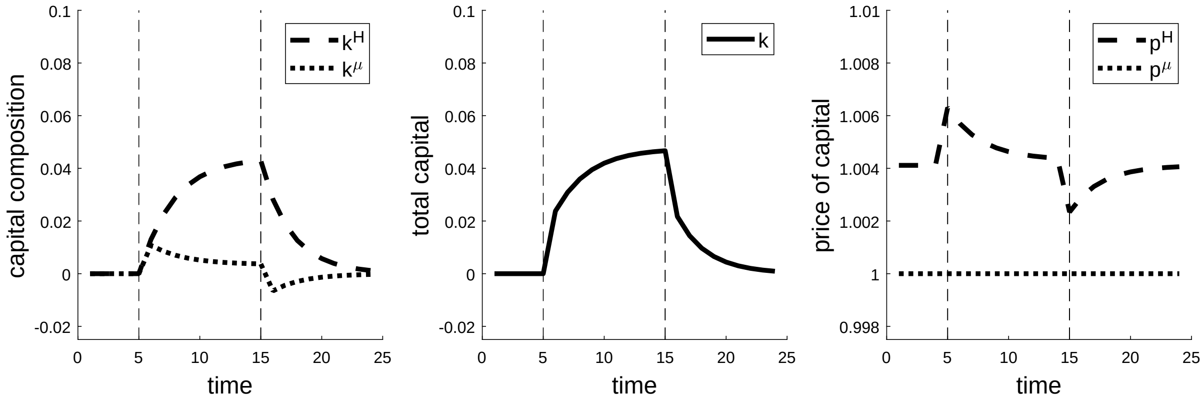

Figure 6: **Collateral boom-bust episode**. The figure depicts the equilibrium evolution of the capital stock, its composition and capital prices throughout a productivity boom-bust episode. Aggregate TFP is $A_t = \underline{A}$ before period 5 and after period 15, and $A_t = \bar{A} > \underline{A}$ between periods 5 and 15.

3.2.3 Discussion

The results 1 and 2 provide three key predictions regarding the interaction of entrepreneurial collateral or net worth, investment, and information generation:

- Prediction 1: investment is increasing in entrepreneurial collateral. This prediction, which is common to many models with financial frictions, follows directly in our model whenever the borrowing limit binds.
- Prediction 2: the share of investment in unscreened capital is increasing in entrepreneurial collateral.
- Prediction 3: falls in entrepreneurial collateral are accompanied by a reduction in investment, and the magnitude of this reduction is increasing in the economy's share of unscreened capital.

In Section 6, we test these predictions on US firm-level data. Before doing so, however, we explore some extensions of the baseline model and analyze its normative implications. Less patient readers may skip these sections and go straight to the empirical results.

4 Additional considerations

This section discusses some economic interpretations and extensions of our baseline model. Specifically, we provide an interpretation of collateral shocks and explore two simple extensions of our baseline model. The first extension introduces fire sales into the model, while the second allows for differences in productivity between H- and L-type capital, thereby generating dispersion in observed productivity.

4.1 Interpreting collateral shocks

Up to now, we have treated fluctuations in the value of collateral q_t as fully exogenous, without specifying their origin. From an economic standpoint, these fluctuations reflect changes in the net worth of entrepreneurs that are orthogonal to their investment and production opportunities. In this section, we provide two interpretations/micro-foundations for such fluctuations, one that is driven by fundamentals and the other that results from over-valuations or asset price bubbles.

In the first and simplest interpretation, each tree is a unit of land or some other "natural resource" that produces a stochastic fruit n_t in period t. The young entrepreneurs of generation t are endowed with land that they can sell to savers at a price:

$$q_t = E_t \left\{ \sum_{s>t} \frac{n_s}{\rho^{s-t}} \right\},$$

where we assume that $\rho > 1$ and impose the "no-bubbles" condition to focus on fundamental equilibria. Note that the savers' rate of discount is the international interest rate ρ, as they can always purchase land by borrowing from the international capital market at this interest rate. Thus, fluctuations in q_t can be interpreted as natural resource shocks, which affect the net worth of entrepreneurs but not the productivity of investment or production.

In the second, subtler interpretation, q_t reflects the existence of asset bubbles. We relegate a more in-depth discussion of this interpretation to Appendix A.2.1, and provide a brief discussion here to show how it works. Consider a slightly modified version of our economy in which production is organized in firms. Firms contain units capital and they can be created by young entrepreneurs at zero cost.

This modified economy admits two types of equilibria. Fundamental equilibria, in which the price of a firm equals the cost of replacing its capital stock, and bubbly equilibria, in which the price of a firm exceeds the cost of replacing its capital stock. Formally, if we use J_t to denote the set of firms that are active in period t, we can write the market price of firm $j \in J_t$

$$\nu_{jt} = (1-\delta) \cdot \left(p_t^{\mu} \cdot k_{jt}^{\mu} + p_t^{H} \cdot k_{jt}^{H} \right) + b_{jt}, \tag{21}$$

where k_{jt}^{μ} and k_{jt}^{H} respectively denote the capital stock owned by firm j in period t, and b_{jt}

denotes the value of the bubble attached to firm j.

In a fundamental equilibrium, $b_{jt} = 0$ for all $j \in J_t$ and a firm's price is exactly equal to the value of the capital stock that it contains. In a bubbly equilibrium, instead, $b_{jt} > 0$ for some $j \in J_t$, and the price of some firms exceeds the value of the capital stock that they contain. Given the international interest rate ρ and firm prices in Equation (21), $b_{jt} > 0$ in equilibrium if and only if:

$$\rho = \frac{E_t b_{jt+1}}{b_{jt}}. \tag{22}$$

Equation (22) says that the expected growth rate of bubbles must equal the interest rate. If this condition was not satisfied with equality, the demand for firms by young entrepreneurs would be either excessive or insufficient. In any bubbly equilibrium, the evolution of b_{jt} is driven by market psychology or investor sentiment.

It is relatively straightforward to show that, together with a process of b_{jt} that satisfies Equation (22), Equations (16)-(18) can be interpreted as a bubbly equilibrium in which q_t reflects the bubbles attached to newly created firms at time t. According to this interpretation, fluctuations in q_t reflect changes in the market psychology that drives these bubbles, which in turn affect entrepreneurial net worth. When this component grows, the market is more willing to lend against the value of new firms and entrepreneurs can use this additional borrowing to expand investment. When this component shrinks (or disappears!), the market is less willing to lend against the bubbly component of new firms and entrepreneurial borrowing and investment falls. Our main result can thus be interpreted as an additional, and so far unexplored, effect of bubbles: they raise investment but, by providing collateral, also shift its composition away from screened capital.[11] This means that bubbly episodes are characterized by a depletion of screened capital and, according to Result 2, the bursting of bubbles is accompanied by an undershooting of the capital stock and output.

4.2 Irreversibilities and fire-sales

Our baseline model assumes that capital is perfectly reversible. Although convenient, this assumption has a very stark (and counterfactual!) implication. When a collateral boom ends, young entrepreneurs can no longer borrow to finance unscreened investment: unable to find buyers for their stock of unscreened capital, old entrepreneurs simply consume part of it. As a result, the bust is fully absorbed by the quantity of unscreened capital and not by its price, which cannot fall below one. And, since the price of screened capital rises alongside screening

[11] See Martin and Ventura (2018) for a survey of the macroeconomic literature on rational bubbles.

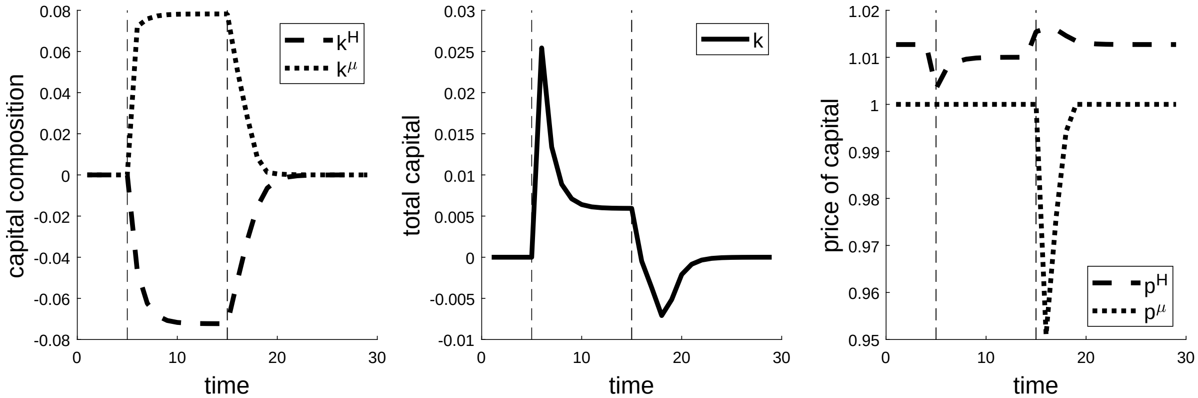

Figure 7: **Collateral boom-bust episode with $\chi < 1$.** The figure depicts the equilibrium evolution of the capital stock, its composition and capital prices throughout a collateral boom-bust episode. Collateral values are $q_t = \underline{q}$ before period 5 and after period 15, and $q_t = \bar{q} > \underline{q}$ between periods 5 and 15.

activity, a collateral bust is actually accompanied by an increase in the average price of capital!

This conclusion of our baseline model may strike the reader as problematic. Crises are typically characterized by falling asset prices, although some assets – especially those perceived as safe – may see their prices rise as agents "fly to quality". This counterfactual implication of our model for the behavior of asset prices can be addressed through a slight modification of the framework, however, which captures irreversibilities in capital formation.

Suppose that, at any point in time, a unit of capital can be liquidated and converted into $\chi \in (0, 1)$ units of consumption. This means that it is costly to reverse capital, since a fraction $1 - \chi$ of each unit is lost in the process. A broader interpretation of this assumption is that there are other agents in the economy that can use capital, albeit less productively than entrepreneurs. Under this interpretation, the magnitude of $1 - \chi$ captures the inefficiencies associated with "fire-sales" of capital during periods of systemic distress (Shleifer and Vishny, 2011). For simplicity, our baseline model has focused on the case of $\chi = 1$.

This assumption has a key implication for our model: whenever the economy liquidates screened or unscreened capital, i.e., $k^j_{t+1} \leq (1 - \delta) \cdot k^j_t$ for $j \in \{H, \mu\}$, the corresponding price will be depressed, i.e., $p^j_t \in [\chi, 1]$. Except for this modification to capital prices, the characterization of equilibrium is basically as before. Equations (45)-(50) in the Appendix provide a formal description of the equilibrium.

Figure 7 illustrates the workings of this modified model by simulating the same collateral boom-bust episode as in Figure 4. We use the same parameterization as in the baseline model, except that we now set $\chi = 0.9$ (instead of $\chi = 1$) therefore allowing for a maximum fall of ten percent in capital prices. The evolution of the total capital stock, as well as its composition between screened and unscreened capital, is qualitatively similar to that of our baseline model. The main difference is that, during the bust, the fall in unscreened capital is moderated: the reason is that the bust is partially absorbed by a fall in the price of capital. As in the baseline model, the fall in collateral values means that young entrepreneurs are unable to maintain the stock of unscreened capital. But this now leads to a fire-sale of capital and to a fall in the price of unscreened capital, which relaxes the borrowing constraint of entrepreneurs and ameliorates the impact of the shock on the capital stock.

Note also that, while the price of unscreened capital falls, the price of screened capital rises. The reason is that the information attached to screened units of capital is particularly valuable during the bust. Thus, the simulation shows that one of the main insights of the baseline model is robust to the inclusion of irreversibilities: the value of information is countercyclical with respect to collateral values, and the relative value of screened assets is highest during collateral busts, when collateral is most scarce.

4.3 Collateral booms and "misallocation"

There has been substantial debate recently regarding the effects of credit booms on the allocation of resources. In particular, there is a growing view that credit booms are associated to an increase in "misallocation" of resources. Following Hsieh and Klenow (2009), misallocation is typically measured as the dispersion of TFP (more precisely, revenue TFP) – normalized by average productivity – across plants or firms in a given industry. In an ideal world, resources would flow from less to more productive firms/plants to eliminate any such dispersion. If this is not the case, the logic goes, there must be frictions that prevent the efficient allocation of resources. Recently, García-Santana et al. (2016) and Gopinath et al. (2017) have documented a significant increase in misallocation during the Spanish credit boom of the early 2000's, which has been broadly interpreted as an indication that the allocation of resources is somehow distorted during episodes of rapid credit growth.

Our model offers an alternative interpretation of this evidence. To see this, it is best to focus on the static version of the model (i.e., $\delta = 1$) and modify it along one key dimension: besides their different pledgeability to outside creditors, units of high-quality capital are also more productive than low-quality capital. In particular, we assume that – for productive purposes – each unit of low-quality capital is equivalent to $\lambda < 1$ units of high-quality capital. With these modifications, the equilibrium of the static model is essentially unchanged relative to Equations (14) and (15).

$$k_{t+1}^{\mu} = \min\left\{\frac{\rho}{\rho - \mu \cdot E_t r_{t+1}} \cdot q_t, \max\left\{0, \left(\frac{A \cdot \alpha \cdot \lambda}{\rho}\right)^{\frac{1}{1-\alpha}} - k_{t+1}^{H}\right\}\right\}, \tag{23}$$

which reflects the fact that unscreened investment is now less productive, whereas the evolution of k_t^H is still governed by (15).

What does the variance of TFP (i.e., "misallocation") look like in this extended model, and how does it evolve during a collateral-driven credit boom? Answering this question requires taking a stance on what the unit of observation is. Since firms are a veil in our constant-returns-to-scale environment, we can consider the case in which each unit of capital is operated separately as an independent plant or business unit. In such a case, misallocation can be expressed as follows:

$$VAR_{TFP} = \frac{k^S + k^{\mu} \cdot \mu}{k^S + k^{\mu}} \cdot \left(\frac{A}{\overline{A}} - 1\right)^2 + \frac{(1-\mu) \cdot k^{\mu}}{k^S + k^{\mu}} \cdot \left(\frac{\lambda^{\alpha} \cdot A}{\overline{A}} - 1\right)^2, \tag{24}$$

where $\overline{A}$ denotes the average of measured TFP. This expression has a very natural interpretation. Of all the units of capital in the economy, $k^S + \mu \cdot k^{\mu}$ are of high quality and for these units measured TFP equals $A > \overline{A}$. The remaining $(1-\mu) \cdot k^{\mu}$ units are of low quality and for these units measured TFP equals $\lambda^{\alpha} \cdot A < \overline{A}$.

Although we relegate the derivation to Appendix A.2.3, misallocation in this economy depends only on the ratio of screened to unscreened capital, k^S/k^{μ}. Specifically, misallocation is decreasing in this ratio if and only if

$$\frac{k^S}{k^{\mu}} > \lambda^{\alpha} \cdot (1-\mu) - \mu. \tag{25}$$

This condition has a natural economic interpretation, which can be phrased as follows: an increase in k^S/k^{μ} reduces misallocation if and only if the stock of high-quality capital in the economy exceeds the (productivity weighted) stock of low-quality capital. This always holds if $\mu > \lambda^{\alpha}/(1+\lambda^{\alpha})$, and it requires k^S/k^{μ} to exceed a certain threshold otherwise.

Figure 8 illustrates, for our baseline parametrization, the evolution of measured misallocation as a function of q. When $q = 0$, all investment is screened and there is no misallocation: ultimately, the economy has only high-quality capital. As q increases and the composition of the capital stock shifts towards unscreened capital (i.e., k^S/k^{μ} grows), misallocation rises. Simply put, agents reduce their screening before investing and this leads to higher investment in low-quality capital. In our baseline parametrization, moreover, the rise in misallocation is monotonic because $\mu > \lambda^{\alpha}/(1+\lambda^{\alpha})$. More generally, though, misallocation would increase

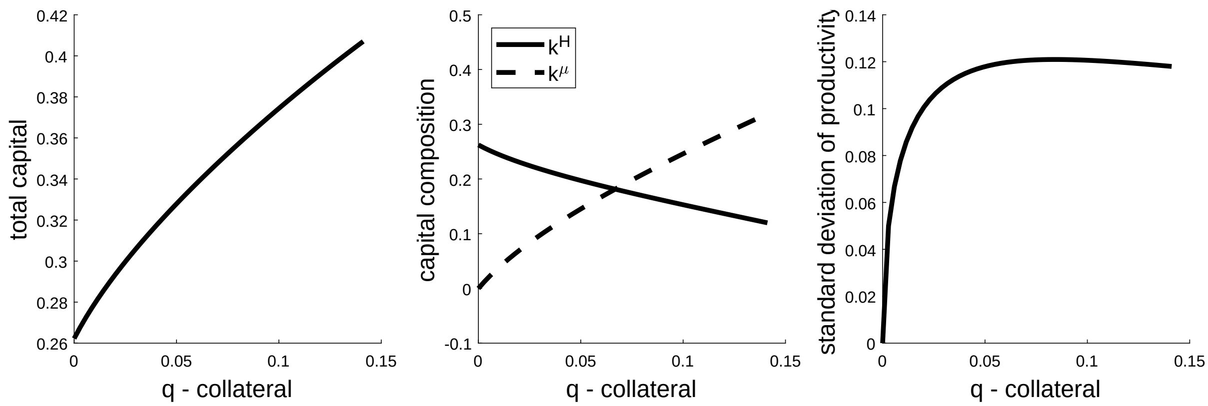

Figure 8: **Collateral values and misallocation**. The figure depicts the equilibrium capital stock and its composition, as well as the standard deviation of productivity (right panel), as a function of collateral q, in the economy with full depreciation.

with q as long as Equation (25) is satisfied.

We can easily extend this static example to the fully dynamic economy to show how collateral-driven booms can be accompanied by rising misallocation. In this way, the model is consistent with the empirical evidence outlined above. It is also consistent, moreover, with the narrative that is commonly used to rationalize this evidence: during booms, credit ends up being allocated to low-quality projects. In our model, however, this is not necessarily inefficient. It is true that agents reduce their screening of investment and therefore make their credit allocation decisions with less information. But generating this information is costly! In other words, the availability of collateral enables the economy to switch to a cheaper investment technology, albeit one that leads to more disperse outcomes.

5 Is there too little information?

One of the main insights of Section 3 was that, during collateral-driven boom-bust cycles, the effects of the bust are magnified due to the depletion of information that takes place during the boom. It may be tempting to conclude that this depletion of information is inefficient, in the sense that the amount of information produced in the laissez-faire equilibrium is inefficiently low. In this section, we show that such a conclusion is unwarranted in our baseline model. Since the market for capital is undistorted and agents are forward-looking, market prices accurately reflect the value of information: thus, even at the peak of a collateral-driven boom, agents effectively anticipate the benefits of owning screened capital in the event that the bust materializes. If anything, due to a pecuniary externality that arises because borrowing constraints are affected by the rental rate of capital, the information produced in the laissez-faire equilibrium is inefficiently high!

To show this, we consider the problem of a social planner whose objective is to maximize the present value of aggregate consumption net of screening costs, discounted at the interest rate ρ. Since agents' preferences are linear, this is equivalent to the maximization of social welfare, where the welfare of future generations is discounted at rate ρ.[12] We make a set of assumptions on what the planner can do in order to not to give her undue advantage over the market. First, we assume that $\rho > 1$: this implies that the economy is dynamically efficient and eliminates gains from inter-generational transfers. Second, we assume that the planner is subject to the same borrowing constraints as private agents: thus, the planner can only finance unscreened investment by posting trees and the returns to H-type capital as collateral. Finally, we focus on parameter values for which borrowing constraints bind for all t at the planner's solution: as in the competitive equilibrium, this requires q_t be low enough for all t.

Under these assumptions, the planner's problem reduces to choosing a sequence of screening policies, $\{s_t\}$, which determine the evolution of H-type capital and – through the borrowing constraints – also the evolution of unscreened capital.[13] This problem can be expressed recursively as follows:

$$\begin{aligned} V\left(k_t^H, q_t, A_t\right) = \max_{s_t, k_{t+1}^{\mu}, k_{t+1}^H} \; & A_t \cdot k_t^{\alpha} + (1-\delta) \cdot k_t - k_{t+1} - \int_0^{s_t} \psi(x)\, dx \\ & + \rho^{-1} \cdot E_t V\left(k_{t+1}^H, q_{t+1}, A_{t+1}\right) \end{aligned} \tag{26}$$

subject to the following set of constraints:

$$k_{t+1} = k_{t+1}^{\mu} + k_{t+1}^H, \tag{27}$$

$$s_t = \mu^{-1} \cdot \max\left\{0, k_{t+1}^H - (1-\delta)\, k_t^H\right\}, \tag{28}$$

$$k_{t+1}^{\mu} = \frac{\rho}{\rho - \mu \cdot E_t\left\{\alpha A_{t+1}\left(k_{t+1}^{\mu} + k_{t+1}^H\right)^{\alpha-1} + 1 - \delta\right\}} \cdot q_t, \tag{29}$$

where V is the planner's value function, which depends on the economy's state variables, i.e., the stock of H-type capital, the price of trees, and aggregate productivity. The planner's per period return is simply the total output of the economy net of investment in physical capital and net of the screening costs of the experts (see derivation in Appendix A.3). Constraints

[12] For simplicity, we abstract from distributional effects within a given a generation.

[13] Just as the entrepreneurs, the planner will never find it optimal to invest in a unit of capital if it is screened and found out to be L-type.

(27)-(29) respectively state that the aggregate capital stock is equal to the sum of H-type and unscreened capital; that the evolution of H-type capital must be consistent with screening activity, and; that investment in unscreened capital must satisfy the borrowing constraint.

The borrowing constraint of Equation 29 plays a key role. It implicitly defines a the stock of unscreened capital stock as a decreasing function of the stock of H-type capital, i.e. $k^{\mu}_{t+1} = k^{\mu}\left(k^{H}_{t+1}, q_t, A_t\right)$, with the property that $\partial k^{\mu}\left(k^{H}_{t+1}, q_t, A_t\right)/\partial k^{H}_{t+1} < 0$. This reflects the fact that an additional unit of screened investment reduces the marginal product of capital, thereby tightening borrowing constraints and crowding out unscreened investment. In the laissez-faire equilibrium, entrepreneurs do not internalize this relationship because they take the marginal product as given. But the planner does, and the first-order conditions to its problem yield:

$$1 + \frac{\psi\left(s_t\right)}{\mu} \geq \frac{E_t\left\{\alpha A_{t+1} k^{\alpha-1}_{t+1} + (1-\delta)\cdot\left(1+\frac{\psi(s_{t+1})}{\mu}\right)\right\}}{\rho} + \left(\frac{E_t\left\{\alpha A_{t+1} k^{\alpha-1}_{t+1} + 1 - \delta\right\}}{\rho} - 1\right)\cdot\frac{\partial k^{\mu}\left(k^{H}_{t+1}, q_t, A_t\right)}{\partial k^{H}_{t+1}}, \tag{30}$$

with equality if $s_t > 0$. Together with the constraints (27)-(29), Equation (30) characterizes the solution to the planner's problem.

Equation (30) clearly illustrates the key difference between the planner's solution and the competitive equilibrium. At the competitive allocation, market clearing and optimization require that the market value of a unit of screened capital, i.e., $1 + \frac{\psi(s_t)}{\mu}$, equal the expected discounted return to that unit. In contrast, the planner's optimality condition has an additional negative term, because it understands that each unit of screened investment crowds out unscreened capital. And, insofar as borrowing constraints bind, this crowding out leads to a first-order welfare loss because the expected return of unscreened investment, $E_t\left\{\alpha A_{t+1} k^{\alpha-1}_{t+1} + 1 - \delta\right\}$, exceeds the interest rate, ρ. This pecuniary externality is akin to those identified in the macro-finance literature (e.g. Caballero and Krishnamurthy (2003), Lorenzoni (2008), Dávila and Korinek (2017), but it arises here because investment in one technology (screened) excessively restricts investment in the other one (unscreened).

Finally, note that the planner's solution can be implemented as a competitive equilibrium through a sequence of Pigouvian taxes $\{\tau_t\}$ on each unit of screened investment, with revenues rebated in a lump sum fashion to the savers. Let $\left\{s^{*}_{t}, k^{*}_{t+1}, k^{H*}_{t+1}\right\}$ denote the planner's allocations, then the sequence of taxes that implements these can be shown to satisfy:

$$\tau_t = -\left(\frac{E_t\left\{\alpha A_{t+1}k_{t+1}^{*\alpha-1}+1-\delta\right\}}{\rho}-1\right)\cdot\frac{\partial k^{\mu}\left(k_{t+1}^{H*},q_t,A_t\right)}{\partial k_{t+1}^{H}}+\frac{1-\delta}{\rho}\cdot E_t\tau_{t+1}. \tag{31}$$

The first term on the right-hand side of Equation (31) reflects the pecuniary externality the planner wants to correct. The second term reflects instead an intertemporal relationship between the planner's interventions at different points in time. In particular, the expected tax in period $t+1$ raises the price of screened capital in that period and, thus, the expected capital gains of screened investment in period t. In order to neutralize these gains, the planner must raise the tax τ_t beyond what would be warranted by the pecuniary externality alone.

Frictional markets and Learning-by-doing

In our baseline model, entrepreneurs fully appropriate the benefits of screened investment. This is the reason for which there is no shortage of information in the laissez-faire equilibrium. Naturally, things would change in the presence of distortions that prevented such appropriation. We briefly explore two natural sources of such distortions here.

A first set of distortions are those that directly affect the market for screened capital. In particular, assume that – instead of being perfectly competitive – trading in this market is attained by matching: every time an old entrepreneur goes to the market, she is matched with a young buyer and they bargain over the price of the sale. The surplus from the transaction is $\frac{\psi(s_t)}{\mu}$, and let us assume that the buyer manages to extract a fraction β of this surplus.

Under this assumption, the zero-profit condition for screened investment becomes,

$$1+\frac{\psi(s_t)}{\mu}=\frac{E_t\left\{\alpha A_{t+1}k_{t+1}^{\alpha-1}+(1-\delta)\cdot\left(1+\frac{\psi(s_{t+1})}{\mu}\right)\right\}}{\rho} - \beta\cdot\frac{1-\delta}{\rho}\cdot E_t\frac{\psi(s_{t+1})}{\mu}, \tag{32}$$

whereas the planner's solution, which depends only on total consumption regardless of its distribution, remains as in the baseline model. Because it prevents entrepreneurs from fully capturing the value of screening upon resale, the matching friction reduces screened investment in the laissez-faire equilibrium. And given that the planner solution is unaffected, it is now possible for screened investment to be inefficiently low in equilibrium.

A second set of distortions are those that directly affect the technology for screening, such as the presence of dynamic economies of scale. Namely, assume that $\psi_t = \psi(s_t, k_t^H)$ with

$\psi_1 > 0 > \psi_2$ and $\psi_1 + \frac{\mu}{\delta}\psi_2 > 0$: relative to our baseline model, the assumption that $\psi_2 < 0$ can be interpreted as the presence of economy-wide "learning-by-doing", so that the cost of screening falls with the cumulative amount of past screening.

Under this assumption, it is the zero-profit condition of individual entrepreneurs that remains unchanged, whereas the planner's optimality condition becomes:

$$
\begin{aligned}
1 + \frac{\psi\left(s_t^*, k_t^{H*}\right)}{\mu} = & \frac{E_t\left\{\alpha A_{t+1} k_{t+1}^{*\alpha-1} + (1-\delta)\cdot\left(1 + \frac{\psi\left(s_{t+1}^*, k_{t+1}^{H*}\right)}{\mu}\right)\right\}}{\rho} \\
& + \left(\frac{E_t\left\{\alpha A_{t+1} k_{t+1}^{*\alpha-1} + 1 - \delta\right\}}{\rho} - 1\right)\cdot\frac{\partial k^\mu\left(k_{t+1}^{H*}, q_t, A_t\right)}{\partial k_{t+1}^H}, \\
& + \frac{E_t \int_0^{s_{t+1}^*} \psi_2(x, k_{t+1}^{H*})dx}{\rho}.
\end{aligned}
\tag{33}
$$

The atomistic entrepreneurs do not internalize the learning-by-doing externality, but the planner does. This is reflected in the last term of Equation (33): the planner understands that, by raising screened investment today, she reduces the expected cost of screening in period $t+1$. Once again, it is possible for screened investment to be inefficiently low in equilibrium.

6 Testing the mechanism

We now test the model's main predictions as outlined in Section 3.2.3. Doing so is non-trivial for at least two reasons.

First, all three predictions refer to the effect of collateral on the amount and composition of investment. Assessing this in the data requires identifying changes in collateral that are orthogonal to other economic conditions, such as productivity, which may affect investment on their own. The literature has dealt with this problem by (i) identifying exogenous shocks to the value of assets, e.g. real estate, and (ii) by tracing out the effects of these shocks on firm-level outcomes. We will follow the same approach here, although we will complement it with regional-level evidence as well. In particular, we build on Chaney et al. (2012) by extending the period to include the post-2007 housing bust.[14] We use their framework to estimate the impact of real estate prices on corporate investment. Specifically, we use local variations in real estate prices as shocks to the collateral value of firms that own real estate to measure the impact of real estate prices on corporate investment.

[14] Our sample covers the period 1993-2012, while their sample covers the period 1993-2007.

Second, the main prediction of the model is that an increase in collateral shifts the composition of investment away from screened investment (i.e., with high information content) towards unscreened investment (i.e., with low information content). Assessing this in the data requires producing a measure of the informational content of investment. Since there is no generally accepted measure of this content, we proceed in a roundabout way by using three alternative measures of firm-level information from the economics and finance literatures.

Our first measure of information is a firm's bid-ask spread on its stock, expressed in percentages. Research has shown that such spreads and other liquidity measures are associated with information asymmetry in trading activities (Amihud and Mendelson, 1986; Huang and Stoll, 1997; Kelly and Ljungqvist, 2012). We therefore interpret a firm's bid-ask spread as an indicator of the lack of information on the firm by market participants. Concretely, we use the measure of bid-ask spread developed by Corwin and Schultz (2012), which is constructed from daily high and low stock prices as a function of high–low ratios over 1-day and 2-day intervals.[15] They show that this measure of bid-ask spreads dominates other commonly used measures, including the Roll (1984) covariance spread estimator, both in capturing the cross-section of bid-ask spreads and month-to-month changes in spreads. In what follows we refer to the bid-ask spread of firm i during year t as $Spread_{it}$, and assume that it is decreasing in the amount of information on the firm.

As alternative measure of information at the firm level, we use the number of financial analysts that follow a particular firm. Financial analysts produce and disseminate information by aggregating and consolidating it in a way that is more easily digestible for less sophisticated

[15] Specifically, the Corwin-Schultz bid-ask spread estimator, S, is computed as follows, where H and L denote the observed high and low stock prices, respectively, β denotes the square of the log high–low price ratios on 2 consecutive single days, and γ denotes the square of the log high–low ratio over a 2-day period:

$$S = \frac{2(e^{\alpha} - 1)}{1 + e^{\alpha}}. \tag{34}$$

$$\alpha = \frac{\sqrt{2\beta} - \sqrt{\beta}}{3 - 2\sqrt{2}} - \sqrt{\frac{\gamma}{3 - 2\sqrt{2}}}. \tag{35}$$

$$\beta = E\left\{ \sum_{j=0}^{1} \left[\ln\left(\frac{H^{o}_{t+j}}{L^{o}_{t+j}} \right) \right]^2 \right\}. \tag{36}$$

$$\gamma = \left[\ln\left(\frac{H^{o}_{t,t+1}}{L^{o}_{t,t+1}} \right) \right]^2. \tag{37}$$

The Corwin-Schultz bid-ask spread estimator is based on two assumptions. First, the daily high prices are typically buyer initiated and low prices are seller initiated, and therefore the ratio of high-to-low prices for a day reflects both the fundamental volatility of stock and its bid-ask spread. Second, the volatility component of the high-to-low price ratio increases proportionately with the length of trading interval whereas the component due to bid-ask spreads does not.

investors (Huang and Stoll (1997)). We follow Chang et al. (2006) and define $Analysts_{it}$ as the maximum number of analysts who make annual earnings forecasts for firm i in any month during year t, computed using data from the I/B/E/S Historical Summary Files. Contrary to the bid-ask spread, $Analysts_{it}$ is increasing in the amount of information on firm i.

Finally, as third measure of information we use the ratio of intangible assets to tangible fixed assets of the sector in which the firm operates. Intangible assets are more difficult to measure than tangible fixed assets (McGrattan and Prescott, 2010; Eisfeldt and Papanikolaou, 2014). This is the main reason intangible investment is largely excluded from the calculation of gross domestic product. As a result, firms operating in sectors that rely more heavily on intangible assets are more difficult to value by investors, i.e., it is relatively difficult to produce hard information about the investment of firms in these sectors. We follow Claessens and Laeven (2003) and use the ratio of intangible assets to tangible fixed assets at the two-digit SIC sectorial level as proxy for information. This measure, which we denote $Intangibility_{it}$ and compute at the sectorial level to reduce reverse causality, is decreasing in the amount of information on firm i.

Our baseline results use $Spread_{it}$ as measure of information. However we show that all our main results are robust to using the two alternative measures of information.

6.1 Empirical specifications

Taking the previous points into account, we perform the following empirical exercises. To test for prediction 1, we estimate – for firm i, at date t, with headquarters in location k (state or MSA) – the following investment equation,

$$I_{it} = \alpha_i + \delta_t + \beta \cdot RE_{it} + \gamma \cdot P_{kt} + controls_{it} + \varepsilon_{it}, \tag{38}$$

where I is the ratio of investment (CAPEX) to lagged properties, plant and equipment (PPE), RE_{it} is the ratio of the market value of real estate assets in year t to lagged PPE, and P_{kt} controls for the level of (residential) real estate prices in location k (at state or MSA level) in year t. The inclusion of P_{kt} should allow us to disentangle the collateral effect of a firm's real estate from the general effect of house prices on the local economy, including their effect on banking conditions. Prediction 1 is that $\beta > 0$ and significant.

There are two potential sources of endogeneity in the estimation of equation (38): (i) real estate prices could be correlated with investment opportunities, and; (ii) the firm's decision to own real estate could be correlated with its investment opportunities. To address the first, we run as a first stage – for MSA k, at date t – the following equation predicting real estate prices P_{kt},

$$P_{kt} = \alpha_k + \delta_t + \gamma \cdot Elasticity_k \times R_t + \upsilon_{kt}, \tag{39}$$

where $Elasticity_k$ measures constraints on land supply at the MSA level (taken from Saiz (2010)), R_t is the nationwide real interest rate at which banks refinance their home loans, α_k is an MSA fixed effect, and δ_t captures macroeconomic fluctuations in real estate prices. Low values of local housing supply elasticity correspond to MSAs with relatively constrained land supply. We expect the coefficient γ to be positive, indicating that the positive effect of declining interest rates on prices is stronger in MSAs with less elastic supply. To address the second source of endogeneity we follow Chaney et al. (2012) and control for initial characteristics of firm i, denoted by X_i, interacted with real estate prices P_{kt}. Vector X_i includes controls that are likely to influence the ownership decision: in particular, it includes five quintiles of age, assets, and return on assets, two-digit industry dummies, and state dummies.

To test prediction 2, we run different specifications. First, we extend equation (38) as follows,

$$I_{it} = \alpha_i + \delta_t + \beta_1 \cdot RE_{it} + \beta_2 \cdot Spread_{it} + \beta_3 \cdot RE_{it} \cdot Spread_{it} + \gamma \cdot P_{kt} + controls_{it} + \varepsilon_{it}, \tag{40}$$

where the coefficient of interest is β_3, which we expect to be positive and significant. In other words, increases in the value of collateral increase investment, but especially for those firms on which available information – as captured by a high value of $Spread_{it}$ – is lowest.[16]

Being estimated at the firm level, one may wonder whether the firm-level effects that we find in specification (40) carry over to the aggregate level. To address this, we run the following regression at the state level,

$$\left(\frac{I_{HS}}{I}\right)_{kt} = \alpha_k + \delta_t + \beta \cdot RE_{kt} + \gamma \cdot P_{kt} + \upsilon_{kt}, \tag{41}$$

where $\left(\frac{I_{HS}}{I}\right)_{kt}$ is the investment rate of high spread firms relative to the investment rate of all firms in state k in year t, computed by aggregating investment and lagged PPE at the state level separately for high- and low-spread firms, and RE_{kt} is the ratio of the market value of real estate assets normalized by lagged PPE, aggregated at the state level. High-spread firms

[16] In testing (1) and (3), we have to make the following decision: Do we estimate the above equations for a panel using annual data over the period 1993-2006 as in Chaney et al. (2012) or we contrast the boom period 2000-2006 with the bust period 2007-2012? The advantage of the former is that the data on real estate assets is only available in 1993 and we can compare with the results in Chaney et al. (2012).

are defined as firms with spreads above the median. This regression is run at the state and not at the MSA level so that we can cover all firms that are active in the state, and not just the subset of those located in an MSA. Moreover, we run it both for the full sample period and for the boom period between 2001 and 2006, which witnessed the largest increase in house prices thereby making it more likely that increases in collateral are driven by the housing boom as opposed to other factors. The regression includes year- and state-level fixed effects. The coefficient of interest is β, which we expect to be positive and significant: an increase in the value of real estate assets implies that a larger proportion of investment goes to high-spread firms.

Finally, to test prediction 3, we would like to show that a prolonged period of information-insensitive investment make the ensuing downturn more severe. To test this, we run the following specification,

$$I_{kt} = \alpha_k + \delta_t + \beta_1 \cdot RE_{kt} + \beta_2 \cdot RE_{kt} \cdot \left(\Delta \frac{I_{HS}}{I}\right)_k^{boom} + \gamma \cdot P_{kt} + \upsilon_{kt}. \tag{42}$$

The dependent variable is the aggregate investment rate at the state level, RE_{kt} is the ratio of the market value of real estate assets normalized by lagged PPE, aggregated at the state level, and $\left(\Delta \frac{I_{HS}}{I}\right)_k^{boom}$ is the change in the share of state-level investment undertaken by high-spread firms during the boom years between 2001 and 2006. The underlying idea is that this share captures the increase of uninformed investment at the state level. We estimate this regression during the bust period between 2007 and 2012, when national housing prices collapsed. The regression includes state- and year-fixed effects.[17] The coefficient of interest is β_2, which we expect to be positive and significant: the larger is the proportion of investment that is undertaken by high-spread firms during the boom, the larger is the drop in investment that is associated to the fall in collateral values during the bust.

6.2 Data

Our analysis uses accounting data from COMPUSTAT on US listed firms, merged with real estate prices at the state and Metropolitan Statistical Area (MSA) level, daily stock return and high/low price data from CRSP, and analyst coverage data from the I/B/E/S Historical Summary Files. The construction of the dataset closely follows that of Chaney et al. (2012), but we also include measures of information and we expand the sample to 2012 in order to cover the post-2007 housing bust. Because the accumulated depreciation on buildings is no

[17]Equation (42) does not separately include $\left(\Delta \frac{I_{HS}}{I}\right)_k^{boom}$ because it is absorbed by state fixed effects.

longer available in COMPUSTAT after 1993, our sample is restricted to firms active in 1993 with non-missing total assets (COMPUSTAT item No. 6). We keep firms whose headquarters are located in the United States and exclude from the sample firms operating in the finance, insurance, real estate, construction, and mining industries. We require firms to have available data every consecutive year they appear in the sample, and keep only firms that appear at least three consecutive years in the sample. This leaves a sample of 2,855 firms and 35,430 firm-year observations for the period 1993 to 2012.

Market value of real estate assets. Real estate assets include buildings, land and improvement, and construction in progress. These assets are not marked-to-market but valued at historical cost. To recover their market value, we follow the procedure in Chaney et al. (2012) which calculates the average age of those assets and uses historical prices to compute their current market value. The ratio of the accumulated depreciation of buildings (COMPUSTAT item No. 253) to the historic cost of buildings (COMPUSTAT item No. 263) measures the proportion of the original value of a building that has been depreciated. Based on a depreciable life of 40 years, we compute the average age of buildings for each firm. We infer the market value of a firm's real estate assets for each year in the sample period (1993–2012) by inflating their historical cost with state-level residential real estate inflation after 1975, and CPI inflation before 1975. We use the headquarter location (COMPUSTAT variables STATE and COUNTY) as a proxy for the location of real estate.

Investment. We compute investment rate as the ratio of capital expenditures (COMPUSTAT item No. 128) to the lagged value of Property Plant and Equipment (COMPUSTAT item No. 8).

Control variables. We compute the Market-to-Book ratio as the total market value of equity divided by the book value of assets (COMPUSTAT item No. 6), and we use the one year lagged value of this ratio in the investment regression. We compute the market value of equity as the number of common stocks (COMPUSTAT item No. 25) times end-of-year close price of common shares (COMPUSTAT item No. 24) plus the book value of debt and quasi equity, computed as book value of assets (COMPUSTAT item No. 6) minus common equity (item No. 60) minus deferred taxes (COMPUSTAT item No. 74). The cash ratio is the ratio of cash flows (COMPUSTAT item No. 18 plus item No. 14) to the lagged value of PPE (COMPUSTAT item No. 8). In most of the regression analysis, we use initial characteristics of firms to control for the potential firm heterogeneity. These controls, measured in 1993, are Return on Assets (operating income before depreciation (COMPUSTAT item No. 13) minus depreciation (COMPUSTAT item No. 14) divided by Assets (COMPUSTAT item No. 6)), Size measured as the natural logarithm of Assets, Age measured as number of years since IPO, two-digit SIC codes and state of headquarters' location. All variables defined as ratios are winsorized using as thresholds the median plus/minus five times the interquartile range.

Real estate price data. We use data on residential real estate prices, both at the state and at the MSA level. Residential real estate prices come from the Office of Federal Housing Enterprise Oversight (OFHEO). The OFHEO Home Price Index (HPI) is a broad measure of single-family home prices in the United States. We match the state level HPI with our accounting data using the state identifier from COMPUSTAT. To match the MSA level HPI, we aggregate Federal Information Processing Standards codes from COMPUSTAT into MSA identifiers using a correspondence table available from the OFHEO website.

Land supply. Controlling for the potential endogeneity of local real estate prices in an investment regression is an important step in our analysis. Following Chaney et al. (2012), we instrument local real estate prices using the interaction of long-term interest rates and local housing supply elasticity. Local housing supply elasticities are provided by Saiz (2010) and are available for 95 MSAs. These elasticities capture the amount of developable land in each metro area and are estimated by processing satellite-generated data on elevation and presence of water bodies. As a measure of long-term interest rates, we use the "contract rate on 30-year, fixed rate conventional home mortgage commitments" from the Federal Reserve's FRED database.

Information. We obtain monthly high-low spread estimates directly from Corwin and Schultz (2012), based on the closed-form solutions for the high-low spread estimator presented in equations (14) and (18) of their paper. Estimates are obtained for all securities available in CRSP and for all months with at least 12 daily observations. These estimates based on CRSP data are then merged to our main dataset of firms included in Compustat using a COMPUSTAT/CRSP concordance table. We use the December values for the bid-ask spread, expressed in percentages, of the firm's stock. In the investment regression, we use the one year lagged value of this spread to mitigate concerns about reverse causality.[18]

We construct the analyst coverage variable using data on the number of analysts who make annual earnings forecasts for a firm in a given month using data from the I/B/E/S Historical Summary Files. The intangibility variable is computed as the ratio of intangible assets (item No. 33) to tangible fixed assets (PPE; item No. 8) at the sectorial level for the two-digit SIC code sector in which the firm is operating, constructed annually using data from COMPUSTAT.

[18]We are grateful to Shane Corwin for sharing his data on bid-ask spreads.

Table 1 shows that real estate is a sizable fraction of the tangible assets that corporations hold on their balance sheet. For the median firm in the entire sample, the market value of real estate represents 26 percent of the book value of Property, Plants and Equipment. The information measures indicate that there is much variation in proxies for information across firms in our sample. The median bid-ask spread is 1.27%, with an interquartile range of 1.87%. The median number of analysts covering a firm is 5 with an interquartile range of 9, and the median ratio of intangible assets is 0.35 with an interquartile range of 0.48.

6.3 Empirical Results

6.3.1 Firm-level results

We start our empirical analysis by replicating the results of Chaney et al. (2012) for our extended sample. Table 2 presents the first-stage regression estimates of Equation (39) and Table 3 presents estimates of various specifications of Equation (38). The first-stage regression results confirm the findings of Chaney et al. (2012), even though the impact of local housing supply elasticity on housing prices is somewhat reduced in the extended sample period. As expected, we find that the positive effect of declining interest rates on real estate prices is stronger in MSAs with less elastic supply. Take the estimates in column 2, for example: they imply that, given a 100-basis-point decline in the interest rate, the increase in real estate prices is 2.3 percentage points higher in cities with high local constraints on land supply (bottom quartile of housing supply elasticity) than in cities with low local constraints (top quartile of housing supply elasticity).

The results in Table 3 broadly confirm those of Chaney et al. (2012). Column 1 shows results with the specification without any additional controls, and with real estate prices measured at the state level. The baseline coefficient is 0.062, implying that each additional \$1 of real estate collateral increases firm investment by \$0.062. The effect is economically substantial: it implies that a one-standard deviation increase in real estate collateral raises investment by 24 percent of its standard deviation. Column 2 includes the initial controls interacted with real estate prices to account for observed heterogeneity in decisions to own property, and for its potential impact on the sensitivity of investment to real estate prices. The results are qualitatively unaltered and remain statistically significant at the 1 percent confidence level. Column 3 includes Cash and Market/Book variables. The estimated effect of real estate collateral is somewhat smaller but remains statistically significant at the 1 percent level. Column 4 uses residential prices measured at the MSA level instead of at the state level. The results remain qualitatively similar.

Column 5 shows results of the IV regression in which real estate prices are instrumented using the interaction of interest rates and local housing supply elasticity. More specifically, predicted prices from the estimation of Equation (39) are used as an explanatory variable in Equation (38). We report bootstrapped standard errors, as in Chaney et al. (2012), because these predicted prices are derived from a different sample. The IV estimate of the coefficient on real estate collateral is very close to the OLS estimate and statistically significant at the 1 percent level.

Having confirmed that Prediction 1 holds in our sample, we incorporate measures of information to estimate Equation (40). The results are presented in Table 4. The regressions mimic those in Table 3 with the exception that they include both the one year lagged *Spread* variable and its interaction with $REValue$ to capture the differential effect of firm-level information on the effect of real estate collateral on investment. To interpret the regression coefficients, it should be remembered that *Spread* is decreasing in the degree of firm-level information.

As expected, we find that the positive effect of real estate collateral on investment is more pronounced for firms on which there is less information, as captured through a high bid-ask spread. The estimated effect is economically substantial. Based on the estimates reported in column 1, where we do not include additional controls, a one-standard deviation increase in real estate collateral increases the investment of high-spread firms (i.e., *Spread* in 75th percentile) by 4.5 percentage points more than the investment of low-spread firms (i.e., *Spread* in 25th percentile). This is a large effect compared to the interquartile range in the investment rate of 27 percentage points. The remaining specifications in Table 4 show that this result is robust to the inclusion of additional initial controls interacted with real estate prices (column 2), the inclusion of Cash and Market/Book variables (column 3), the use of residential prices at the MSA level (column 4), and the instrumenting of real estate prices with local housing supply elasticities (column 5).

Table 5 shows that the main results of Table 4 are robust to using alternative measures of information, be it the number of financial analysts who follow a particular firm, or the ratio of intangible assets to tangible fixed assets of the sector in which the firm is operating. The variable *Analysts* is increasing in information intensity, while the variable $Intangibility$ is decreasing in information intensity. Using either measure of information, we find qualitatively similar results for the expected differential impact of information on the effect of real estate collateral on investment. If anything, the estimated effects tend to be larger using this alternative proxy for information. Based on the IV estimates in column 3, for instance, a one-standard deviation increase in real estate collateral increases the investment of firms with low analyst coverage (i.e., 25th percentile of *Analysts*) by 12.3 percentage points more than the investment of firms with high analyst coverage (i.e., 75th percentile of *Analysts*).

Taken together, these results suggest that the firm-level evidence from the US is consistent with predictions 1-3 of Section 3.2.3.

6.3.2 State-level results

We now turn to the state-level results. These are admittedly less tightly identified than our firm-level regressions, and thus more prone to endogeneity concerns. Despite this caveat, they are useful to see verify whether our firm-level results on information, collateral values and investment, carry over to aggregate data.

Table 6 reports estimates of Equation (41), which relates the value of real estate collateral to the share of total investment undertaken by low-information firms at the state level. The estimates in column 1 are based on the full sample while the estimates reported in column 2 are based on the boom period between 2001 and 2006, during which the increase in nationwide house prices – according to the OFHEO real estate price index – exceeded the 75th percentile of such increases. As expected, both specifications point to a positive and significant relationship between increases in the value of firms' real estate collateral and the share of investment undertaken by low-information firms. Moreover, the effect is stronger during boom years, which is when increases in collateral values are more likely to be driven primarily by increases in house prices rather than other factors.

Table 7 reports estimates of Equation (42), which analyzes the relationship between the severity of the fall in investment during downturns and the composition of investment during the boom. In particular, and by focusing on a period of declining collateral values, we test whether the declines in investment during downturns are increasing in the share of investment undertaken by low-information firms during the preceding boom. The sample period is restricted to the bust period between 2007 and 2012: during each of these years national house price increases, as measured by the OFHEO real estate price index, was below its 25th percentile. As in Table 7, the regression is run at the state level. As expected, we find that the drop in investment during the bust period is more pronounced in states that allocated a larger share of investment to low-information firms during the boom.

7 Conclusions

This paper has developed a new theory of the role of information during credit booms. The main insight of the theory is that collateral-driven credit booms are likely to end in deep recessions. The reason is that the abundance of collateral reduces incentives to produce information on investment projects, which proves costly when collateral values fall. The theory is consistent with existing stylized evidence regarding the relaxation of lending standards during credit booms, as well as the increase and reallocation of investment during real estate booms. We have also shown that the theory's main implications are consistent with firm-level evidence from the United States.

The theory developed here also implies that not all credit booms are alike: in particular, booms that are driven by high collateral values are more likely to end in deep recessions than those driven by productivity. And it suggests that, in order to understand the macroeconomic effects of credit booms, it is crucial to understand their effects on information production. We have taken a first step in this direction by analyzing a host of firm-level variables. But much more remains to be done. Constructing a reliable macroeconomic measure of information production, or – equivalently – of screening intensity, should be instrumental in understanding the nature of different credit booms and their effects. This is a promising and exciting line of research going forward.

References

Amihud, Yakov and Haim Mendelson, "Asset pricing and the bid-ask spread," *Journal of financial Economics*, 1986, *17* (2), 223–249.

Asea, Patrick K and Brock Blomberg, "Lending cycles," *Journal of Econometrics*, 1998, *83* (1-2), 89–128.

Bakker, Mr Bas B, Mr Giovanni Dell'Ariccia, Mr Luc Laeven, Jérôme Vandenbussche, Deniz Igan, and Hui Tong, *Policies for macrofinancial stability: How to deal with credit booms*, International Monetary Fund, 2012.

Becker, Bo, Marieke Bos, and Kasper Roszbach, "Bad times, good credit," 2016.

Caballero, Ricardo J and Arvind Krishnamurthy, "Excessive dollar debt: Financial development and underinsurance," *The Journal of Finance*, 2003, *58* (2), 867–893.

Chaney, Thomas, David Sraer, and David Thesmar, "The collateral channel: How real estate shocks affect corporate investment," *American Economic Review*, 2012, *102* (6), 2381–2409.

Chang, Xin, Sudipto Dasgupta, and Gilles Hilary, "Analyst coverage and financing decisions," *The Journal of Finance*, 2006, *61* (6), 3009–3048.

Claessens, Stijn and Luc Laeven, "Financial development, property rights, and growth," *The Journal of Finance*, 2003, *58* (6), 2401–2436.

_ , M Ayhan Kose, and Marco E Terrones, "Financial cycles: what? how? when?," in "International Seminar on Macroeconomics," Vol. 7 JSTOR 2011, pp. 303–344.

Corwin, Shane A and Paul Schultz, "A simple way to estimate bid-ask spreads from daily high and low prices," *The Journal of Finance*, 2012, *67* (2), 719–760.

Dávila, Eduardo and Anton Korinek, "Pecuniary externalities in economies with financial frictions," *The Review of Economic Studies*, 2017, *85* (1), 352–395.

Dell'Ariccia, Giovanni and Robert Marquez, "Lending booms and lending standards," *The Journal of Finance*, 2006, *61* (5), 2511–2546.

Diamond, Douglas W, Yunzhi Hu, and Raghuram G Rajan, "Pledgeability, industry liquidity, and financing cycles," Technical Report, National Bureau of Economic Research 2017.

Doerr, Sebastian, "Collateral, Reallocation, and Aggregate Productivity: Evidence from the US Housing Boom," 2018.

Eisfeldt, Andrea L and Dimitris Papanikolaou, "The value and ownership of intangible capital," *American Economic Review*, 2014, *104* (5), 189–94.

Fajgelbaum, Pablo D, Edouard Schaal, and Mathieu Taschereau-Dumouchel, "Uncertainty traps," *The Quarterly Journal of Economics*, 2017, *132* (4), 1641–1692.

Gan, Jie, "The real effects of asset market bubbles: Loan-and firm-level evidence of a lending channel," *The Review of Financial Studies*, 2007, *20* (6), 1941–1973.

García-Santana, Manuel, Enrique Moral-Benito, Josep Pijoan-Mas, and Roberto Ramos, "Growing like Spain: 1995-2007," 2016.

Gopinath, Gita, Şebnem Kalemli-Özcan, Loukas Karabarbounis, and Carolina Villegas-Sanchez, "Capital allocation and productivity in South Europe," *The Quarterly Journal of Economics*, 2017, *132* (4), 1915–1967.

Gorton, Gary and Guillermo Ordonez, "Collateral crises," *American Economic Review*, 2014, *104* (2), 343–78.

_ **and Guillermo Ordoñez**, "Good booms, bad booms," Technical Report, National Bureau of Economic Research 2016.

Gorton, Gary B and Ping He, "Bank credit cycles," *The Review of Economic Studies*, 2008, *75* (4), 1181–1214.

Hsieh, Chang-Tai and Peter J Klenow, "Misallocation and manufacturing TFP in China and India," *The Quarterly journal of economics*, 2009, *124* (4), 1403–1448.

Huang, Roger D and Hans R Stoll, "The components of the bid-ask spread: A general approach," *The Review of Financial Studies*, 1997, *10* (4), 995–1034.

Kelly, Bryan and Alexander Ljungqvist, "Testing asymmetric-information asset pricing models," *The Review of Financial Studies*, 2012, *25* (5), 1366–1413.

Keys, Benjamin J, Tanmoy Mukherjee, Amit Seru, and Vikrant Vig, "Did securitization lead to lax screening? Evidence from subprime loans," *The Quarterly journal of economics*, 2010, *125* (1), 307–362.

Krishnamurthy, Arvind and Tyler Muir, "How credit cycles across a financial crisis," Technical Report, National Bureau of Economic Research 2017.

Lorenzoni, Guido, "Inefficient credit booms," *The Review of Economic Studies*, 2008, *75* (3), 809–833.

Manove, Michael, A Jorge Padilla, and Marco Pagano, "Collateral versus project screening: A model of lazy banks," *Rand journal of economics*, 2001, pp. 726–744.

Martin, Alberto and Jaume Ventura, "The macroeconomics of rational bubbles: a user's guide," *Annual Review of Economics*, 2018, (0).

Matsuyama, Kiminori, "Credit traps and credit cycles," *American Economic Review*, 2007, *97* (1), 503–516.

McGrattan, Ellen R and Edward C Prescott, "Unmeasured Investment and the Puzzling US Boom in the 1990s," *American Economic Journal: Macroeconomics*, 2010, *2* (4), 88–123.

Mendoza, Enrique G and Marco E Terrones, "An anatomy of credit booms: evidence from macro aggregates and micro data," Technical Report, National Bureau of Economic Research 2008.

Ordonez, Guillermo, "The asymmetric effects of financial frictions," *Journal of Political Economy*, 2013, *121* (5), 844–895.

Peek, Joe and Eric S Rosengren, "Collateral damage: Effects of the Japanese bank crisis on real activity in the United States," *American Economic Review*, 2000, *90* (1), 30–45.

Petriconi, Silvio, "Bank competition, information choice and inefficient lending booms," 2015.

Roll, Richard, "A simple implicit measure of the effective bid-ask spread in an efficient market," *The Journal of finance*, 1984, *39* (4), 1127–1139.

Ruckes, Martin, "Bank competition and credit standards," *Review of Financial Studies*, 2004, *17* (4), 1073–1102.

Saiz, Albert, "The geographic determinants of housing supply," *The Quarterly Journal of Economics*, 2010, *125* (3), 1253–1296.

Schularick, Moritz and Alan M Taylor, "Credit booms gone bust: Monetary policy, leverage cycles, and financial crises, 1870-2008," *American Economic Review*, 2012, *102* (2), 1029–61.

Shleifer, Andrei and Robert Vishny, "Fire sales in finance and macroeconomics," *Journal of Economic Perspectives*, 2011, *25* (1), 29–48.

A Appendix

A.1 Screening by competitive intermediaries

In this appendix, we microfound the screening technology and the contracts specified in Section 2 as an outcome of an equilibrium in a competitive intermediary sector.

The intermediaries or banks are symmetric in every respect, and their job is to raise funds from the savers, and provide loans and screening services to the entrepreneurs. Banks simultaneously offer entrepreneurs a menu of contracts, and then each entrepreneur decides which contract to apply to. We impose the standard assumption that the intermediary contracts are exclusive. There can be two types of contracts, one that provides screening services and another that does not. In what follows, to conserve on notation, we drop the time subscripts for from all the variables.

If a contract provides no screening, then it specifies investment I^{μ} that the entrepreneur is required to make, loan L^{μ} that the bank provides to the entrepreneur, and (possibly state-contingent) repayment $R^{\mu} \cdot L^{\mu}$ that the entrepreneur must make to the bank.

If a contract provides screening, then the terms of the contract can depend on the type of project/capital being financed, i.e. investment I^{θ}, loan L^{θ} and repayment $R^{\theta} \cdot L^{\theta}$ can depend on $\theta \in \{L, H\}$. Note that if a bank offers a screening contract with terms I^H and I^L, it effectively commits to screen $\max\{\mu^{-1} \cdot I^H, (1-\mu)^{-1} \cdot I^L\}$ projects, if this contract is accepted by an entrepreneur. We assume that the screening provided by the banks is verifiable and the result of screening is public information.

The banks must hire experts to provide screening services to the entrepreneurs. There is a unit mass of such experts,[19] and each expert has the ability to screen at most $n < \infty$ projects. We assume that the experts have heterogeneous effort costs c of screening, which are distributed in the population according to cdf $F(c)$ with full support on $[0, \infty)$. The market for experts is competitive. Given the expert wage ψ, the banks demand expert services (e.g. how many projects to screen) and the experts supply these services; the expert market clears when the demand and supply for expert services is equalized.

Let s denote the equilibrium screening services demanded by the banks. Then, for the expert market to clear, the wage ψ must be such that $s = n \cdot F(\psi)$, i.e. the set of experts who provide screening services are those with effort cost below ψ. This implies an equilibrium screening cost $\psi(s)$ satisfying $\psi(0) = 0$ and $\psi'(\cdot) > 0$, as specified in the text. It is then straightforward to verify that in equilibrium the contracts posted by banks satisfy the following: (i) contracts

[19]Our results do not depend on whether the experts are the savers or some other agents in the economy.

that provide screening satisfy:

$$L^L = I^L = R^L = 0,$$
$$L^H = I^H = \mu^{-1} \cdot s;\ R^H = R^{K,H};\ \mu \cdot \left(\frac{E\{R^{K,H}\}}{\rho} - 1 \right) = \psi,$$

whereas (ii) contracts that do not provide screening satisfy:

$$I^\mu = \omega + L^\mu = \frac{\rho}{\rho - \mu \cdot E\{R^{K,\mu}\}} \cdot \omega;\ E\{R^\mu\} = \rho.$$

After some relabelling, it is easy to verify that these are the contracts specified in Section 2.

A.2 Derivations for Extensions

In this appendix, we provide formal derivations for the extensions of our baseline model.

A.2.1 Interpreting collateral shocks

To interpret fluctuations in collateral as fluctuations in asset bubbles, we follow Martin and Ventura (2011) and consider a slight variation of out model in which production is organized in firms. Firms contain units of capital and, in any given period, old entrepreneurs sell their firms in the market after production takes place. Young entrepreneurs, in turn, can choose whether to purchase pre-existing firms or to create new ones at zero cost.

This modified economy admits two types of equilibria. Fundamental equilibria, in which the price of a firm equals the cost of replacing its capital stock, and bubbly equilibria, in which the price of a firm exceeds the cost of replacing its capital stock. Formally, if we use J_t to denote the set of firms that are active in period t, we can write the market price of firm $j \in J_t$

$$\nu_{jt} = (1 - \delta) \cdot \left(p_t^\mu \cdot k_{jt}^\mu + p_t^H \cdot k_{jt}^H \right) + b_{jt}, \tag{43}$$

where k_{jt}^μ and k_{jt}^H respectively denote the capital stock owned by firm j in period t, and b_{jt} denotes the value of the bubble attached to firm j.

In a fundamental equilibrium, $b_{jt} = 0$ for all $j \in J_t$ and a firm's price is exactly equal to the value of the capital stock that it contains. In a bubbly equilibrium, instead, $b_{jt} > 0$ for some $j \in J_t$, and the price of some firms exceeds the value of the capital stock that they contain. But to determine whether bubbles can indeed be part of an equilibrium, we must ask whether entrepreneurs are willing to purchase overvalued firms. The answer is positive, as long as the stochastic process b_{jt} is such that it yields an attractive return. Given the international interest rate ρ and firm prices in Equation (43), young entrepreneurs are indifferent between establishing new firms and purchasing old firms (overvalued or not) if and only if:

$$\rho = \frac{E_t b_{jt+1}}{b_{jt}}. \tag{44}$$

Equation (44) says that the expected growth rate of bubbles must equal the interest rate. If the growth rate of the bubble were less than the interest rate, owning firms with a bubble would not be attractive. This cannot be an equilibrium. If the growth rate of the bubble exceeded the interest rate, entrepreneurs would want to borrow an infinite amount to purchase bubbly firms. This cannot be an equilibrium either. The requirement that all bubbles have the same expected growth rate does not mean that all bubbles must be correlated though.

It is relatively straightforward to show that, together with a process of b_{jt} that satisfies Equation condition (44) in all periods, Equations (16)-(18) can be interpreted as a bubbly equilibrium in which q_t reflects the bubbles attached to newly created firms at time t. According to this interpretation, fluctuations in q_t reflect movements in the bubble component of new firms, which in turn affect entrepreneurial net worth. When this component grows, the market is more willing to lend against the value of new firms and entrepreneurs can use this additional borrowing to expand investment. When this component shrinks (or disappears!), the market is less willing to lend against the bubbly component of new firms and entrepreneurial borrowing and investment falls.

A.2.2 Collateral busts and fire-sales

Consider an entrepreneur with net worth q_t who is borrowing in order to invest in unscreened capital at time t. The entrepreneur expects to be able to either liquidate the produced capital for fraction χ per unit or sell the produced capital at some price p^{μ}_{t+1}.

Let the price of capital at time t is p^{μ}_t, then because the cost of producing a unit is one, if the entrepreneur is credit constrained we must have that:

$$\min\left\{p^{\mu}_t, 1\right\} \cdot k^{\mu}_{t+1} = q_t + f_t$$

and

$$\mu \cdot E_t \left\{r_{t+1} + \max\left\{p^{\mu}_{t+1}, \chi\right\} \cdot (1-\delta)\right\} \cdot k^{\mu}_{t+1} = \rho \cdot f_t,$$

which imply that:

$$k^{\mu}_{t+1} = \frac{\rho \cdot q_t}{\rho \cdot \min\left\{p^{\mu}_t, 1\right\} - \mu \cdot E_t\left\{r_{t+1} + \max\left\{p^{\mu}_{t+1}, \chi\right\}(1-\delta)\right\}}. \tag{45}$$

On the other hand, if the entrepreneur is unconstrained, we must have:

$$\min\left\{p^{\mu}_t, 1\right\} = \frac{E_t\left\{r_{t+1} + \max\left\{p^{\mu}_{t+1}, \chi\right\} \cdot (1-\delta)\right\}}{\rho}. \tag{46}$$

Since the cost of production of a unit of unscreened capital is one, market clearing for unscreened capital implies that:

$$p^{\mu}_t \begin{cases} = 1 & \text{if } k^{\mu}_{t+1} > (1-\delta)\, k^{\mu}_t \\ \in [\chi, 1] & \text{if } k^{\mu}_{t+1} = (1-\delta)\, k^{\mu}_t \\ = \chi & \text{if } k^{\mu}_{t+1} < (1-\delta)\, k^{\mu}_t \end{cases}, \tag{47}$$

for all t. As for screened investment, we know that entrepreneurs are always unconstrained, so:

$$p^{H}_t = \frac{E_t\left\{r_{t+1} + p^{H}_{t+1} \cdot (1-\delta)\right\}}{\rho}, \tag{48}$$

where screening is given by:

$$s_t = \max\left\{0, k^{H}_{t+1} - (1-\delta)\, k^{H}_t\right\}. \tag{49}$$

The market clearing price of screened capital must therefore be given by:

$$p^{H}_t = \begin{cases} = 1 + \frac{\psi(s_t)}{\mu} & \text{if } k^{H}_{t+1} > (1-\delta)\, k^{H}_t \\ \in [\chi, 1] & \text{if } k^{H}_{t+1} = (1-\delta)\, k^{H}_t \\ = \chi & \text{if } k^{H}_{t+1} < (1-\delta)\, k^{H}_t \end{cases}. \tag{50}$$

Together with the no-bubble condition on the prices of capital, the equations (45)-(50) fully characterize the equilibrium of this economy.

A.2.3 Collateral booms and misallocation

To analyze the impact of booms on misallocation, consider the economy where – for production purposes – each unit of low-quality capital is equivalent to $\lambda < 1$ units of high-quality capital.

Consider that each unit of capital is operated separately as an independent plant or business unit. Then, to an outside observer, the output produced by an high-quality unit of capital (be it screened or unscreened) will be given by

$$A \cdot l_{i,t}^{1-\alpha},$$

and its measured TFP will equal A. The output produced by a low-quality unit of capital will instead be given by

$$A \cdot \lambda^{\alpha} \cdot l_{i,t}^{1-\alpha},$$

and its measured TFP will equal $A \cdot \lambda^{\alpha}$.

Taking this into account, we can compute the variance of TFP relative to the average:

$$VAR_{TFP} = \frac{k^S + k^{\mu} \cdot \mu}{k^S + k^{\mu}} \cdot \left(\frac{A}{\overline{A}} - 1 \right)^2 + \frac{(1-\mu) \cdot k^{\mu}}{k^S + k^{\mu}} \cdot \left(\frac{\lambda^{\alpha} \cdot A}{\overline{A}} - 1 \right)^2, \tag{51}$$

where $\mu \cdot k^{\mu}$ denotes the number of low-quality units of capital in this economy and $\overline{A}$ denotes the average productivity of the economy,

$$\overline{A} = \frac{k^S + k^{\mu} \cdot [\mu + (1-\mu) \cdot \lambda^{\alpha}]}{k^S + k^{\mu}} \cdot A.$$

Noting that

$$\frac{A}{\overline{A}} - 1 = \frac{k^{\mu} \cdot (1-\mu) \cdot (1-\lambda^{\alpha})}{k^S + k^{\mu} \cdot [\mu + (1-\mu) \cdot \lambda^{\alpha}]}$$

and

$$\frac{\lambda^{\alpha} \cdot A}{\overline{A}} - 1 = \frac{k^s + k^{\mu} \cdot \mu}{k^S + k^{\mu} \cdot [\mu + (1-\mu) \cdot \lambda^{\alpha}]} \cdot (\lambda^{\alpha} - 1)$$

we can write Equation (51) as,

$$VAR_{TFP} = \frac{\mu + \kappa^S}{(\kappa^S + \mu + (1-\mu) \cdot \lambda^{\alpha})^2} \cdot \Lambda,$$

where $\Lambda = (1-\mu) \cdot (\lambda^{\alpha} - 1)^2$ is a constant and $\kappa^S = \frac{k^S}{k^{\mu}}$.

The variance of productivity depends only on the ratio of screened to unscreened capital κ^S. Formally,

$$\frac{\partial VAR}{\partial \kappa^S} < 0 \Leftrightarrow \mu + \kappa^S > \lambda^{\alpha} \cdot (1-\mu),$$

which justifies Equation (25). Thus, an increase in κ^S reduces misallocation if and only if the productivity weighted stock of high-quality capital (i.e., $\mu \cdot k^{\mu} + k^S$) is greater than the productivity weighted stock of low-quality capital (i.e., $\lambda^\alpha \cdot (1-\mu) \cdot k^\mu$). In this case, an increase in k^S (or, equivalently, a reduction in k^μ) adds (eliminates) a productivity-weighted unit of capital that is similar to (different from) the average and, in so doing, it reduces dispersion in productivity.

A.3 The planner's problem

The planner's objective is to maximize the expected present discounted value of aggregate consumption net of screening costs, $E_0 \sum_{t=0}^{\infty} \rho^{-t} C_t$.

Consider the consumption goods available to the planner at time t. First, there is the total output, given by $A\left(k_t^H + k_t^\mu\right)^\alpha$. Second, there is the disinvestment in physical capital $(1-\delta)\left(k_t^H + k_t^\mu\right) - k_{t+1}^H - k_{t+1}^\mu$. Third, the planner must us $\int_0^{s_t} \psi(x)dx$ for screening if she is to screen s_t units of capital, i.e. screening costs of all the experts who have lower screening cost than the marginal expert (see Appendix A.1). Finally, the planner can borrow f_t consumption goods from the international market, and she must repay $R_t f_{t-1}$ if she has borrowed f_{t-1} at time $t-1$, which has the property that $E_{t-1} R_t = \rho$, i.e. the international financial market breaks even. Therefore, the aggregate consumption at time t is:

$$c_t = A\left(k_t^H + k_t^\mu\right) + (1-\delta)\left(k_t^H + k_t^\mu\right) - k_{t+1}^H - k_{t+1}^\mu - \int_0^{s_t} \psi(x)dx + f_t - R_t f_{t-1}. \qquad (52)$$

We suppose that the transversality condition holds, i.e. $\lim_{t\to\infty} \rho^{-t} f_t = 0$, and that $f_0 = 0$. This immediately implies that:

$$E_0 \sum_{t=0}^{\infty} \rho^{-t} C_t = E_0 \sum_{t=0}^{\infty} \rho^{-t} \cdot \left(A_t k_t^\alpha + (1-\delta) k_t - k_{t+1} - \int_0^{s_t} \psi(x) dx \right). \qquad (53)$$

The recursive formulation in the text is then obtained by simply defining the planner's value at time t to be $V_t \equiv E_t \sum_{\tau=t}^{\infty} \rho^{-(\tau-t)} \cdot \left(A_t k_t^\alpha + (1-\delta) k_t - k_{t+1} - \int_0^{s_\tau} \psi(x) dx \right)$.

The first-order conditions to the planner's problem of maximizing (53) subject to the constraints (27)-(29) yield:

$$-\mu \cdot \left(1 + \frac{\partial k^\mu\left(k_{t+1}^H, q_t, A_t\right)}{\partial k_{t+1}^H} \right) - \psi(s_t) + \mu \cdot \frac{E_t \frac{\partial V\left(k_{t+1}^H, q_{t+1}, A_{t+1}\right)}{\partial k_{t+1}^H}}{\rho} \leq 0,$$

where the inequality holds with equality when $s_t > 0$ and

$$\frac{\partial V\left(k_t^H, q_t, A_t\right)}{\partial k_t^H} = \left(\alpha A_t k_t^{\alpha-1} + 1 - \delta\right) \cdot \left(1 + \frac{\partial k^\mu\left(k_t^H, q_{t-1}, A_{t-1}\right)}{\partial k_t^H}\right) + (1-\delta) \cdot \mu^{-1} \cdot \psi\left(s_t\right).$$

Combining these, we get Equation (30) in the main body of the paper, which together with (27)-(29) and the transversality condition, $\lim_{t\to\infty} \rho^{-t}\psi(s_t) = 0$, characterizes the solution to the planner's problem.

A.4 Generalized pledgeability

In this section, we extend our analysis to the more general setting in which the pledgeability of θ-type capital is ϕ_θ with $\phi_H > \phi_L$. The key difference from our baseline setting is that now entrepreneurs will earn profits also from operating H-type capital.

The Static Benchmark ($\delta = 1$)

We begin with the static benchmark, that is, the economy with $\delta = 1$. Let q^μ denote the collateral that entrepreneurs put for unscreened investment. Then in equilibrium, if collateral constraints bind, unscreened investment must be given by:

$$k^\mu = \frac{1}{\rho - \left(\mu \cdot \phi_H + (1-\mu) \cdot \phi_L\right) \cdot r} \cdot \rho \cdot q^\mu, \tag{54}$$

whereas screened investment is given by:

$$k^H = \frac{1}{\rho + \rho \cdot \frac{\psi}{\mu} - \phi_H \cdot r} \cdot \rho \cdot \left(q - q^\mu\right), \tag{55}$$

where $q - q^\mu$ is the collateral put up for screened investment.

The entrepreneurs' profits associated with each type of investment are:

$$\Pi^\mu = \left(1 - \mu \cdot \phi_H - (1-\mu) \cdot \phi_L\right) \cdot r \cdot k^\mu \tag{56}$$

$$\Pi^H = \left(1 - \phi_H\right) \cdot r \cdot k^H. \tag{57}$$

In equilibrium, it must be that the entrepreneur is indifferent whether to allocate an additional unit of collateral to unscreened investment:

$$\frac{\partial \Pi^\mu}{\partial q^\mu} + \frac{\partial \Pi^H}{\partial q^\mu} = 0.$$

Using the equations (54)-(56), we have:

$$1 + \frac{\psi}{\mu} = \frac{1 - \phi_H}{1 - \mu \cdot \phi_H - (1 - \mu) \cdot \phi_L} + \frac{(1 - \mu) \cdot (\phi_H - \phi_L)}{1 - \mu \cdot \phi_H - (1 - \mu) \cdot \phi_L} \cdot \frac{r}{\rho}. \tag{58}$$

Therefore, as in our benchmark economy, an increase in q leads to an increase in k^{μ}, a decrease in r, and thus a decrease in screening. Intuitively, in equilibrium the H-type projects yield the same return but are more levered as they are more pledgeable. Hence, their profits (per unit of collateral) are more sensitive to changes in r, i.e. decrease by more when r increases. Thus, in equilibrium the cost of screening must decline to keep entrepreneurs indifferent between screened and unscreened projects.

Intuitively, the reason why in our economy the agents utilize screening is because collateral is scarce (q is small) and screening allows to identify projects that can be funded without it. Therefore, it should not be surprising that the equilibrium of an economy with scarce collateral has more screening than when collateral is abundant. What is rather specific to the static benchmark is that the effect is monotonic. As we show next, in the dynamic economy, the effect of collateral on screening can be non-monotonic.

The Dynamic Economy ($\delta < 1$)

We now extend the analysis to the dynamic economy, that is the economy with $\delta < 1$.

By the same reasoning as before, the stock of unscreened capital is given by:

$$k^{\mu}_{t+1} = \frac{1}{\rho - (\mu \cdot \phi_H + (1 - \mu) \cdot \phi_L) \cdot (E_t r_{t+1} + 1 - \delta)} \cdot \rho \cdot q^{\mu}_t, \tag{59}$$

whereas the screened capital is given by:

$$k^{H}_{t+1} = \frac{1}{\rho + \rho \cdot \frac{\psi_t}{\mu} - \phi_H \cdot E_t \left\{ r_{t+1} + \left(1 + \frac{\psi_{t+1}}{\mu}\right) \cdot (1 - \delta) \right\}} \cdot \rho \cdot (q - q^{\mu}). \tag{60}$$

The entrepreneurs' expected profits are now given by:

$$\Pi^{\mu}_t = (1 - \mu \cdot \phi_H - (1 - \mu) \cdot \phi_L) \cdot E_t \left\{ r_{t+1} + 1 - \delta \right\} \cdot k^{\mu}_{t+1} \tag{61}$$

and

$$\Pi^{H}_t = (1 - \phi_H) \cdot E_t \left\{ r_{t+1} + \left(1 + \frac{\psi_{t+1}}{\mu}\right) \cdot (1 - \delta) \right\} \cdot k^{H}_{t+1}. \tag{62}$$

Note that, in contrast to the static benchmark, the return to screened capital is higher than the return to unscreened.

As before, in equilibrium, it must again be the case that the entrepreneur is indifferent whether to allocate an additional unit of collateral to unscreened investment:

$$\frac{\partial \Pi_t^\mu}{\partial q_t^\mu} + \frac{\partial \Pi_t^H}{\partial q_t^\mu} = 0$$

Using the equations (59)-(62), we have that:

$$1 + \frac{\psi_t}{\mu} = \frac{1 - \phi_H + (1-\mu) \cdot (\phi_H - \phi_L) \cdot \frac{E_t\{r_{t+1}+1-\delta\}}{\rho}}{(1 - \mu \cdot \phi_H - (1-\mu) \cdot \phi_L) \cdot \frac{E_t\{r_{t+1}+1-\delta\}}{\rho}} \cdot \frac{E_t\left\{r_{t+1} + \left(1 + \frac{\psi_{t+1}}{\mu}\right) \cdot (1-\delta)\right\}}{\rho}. \quad (63)$$

Thus, for a given expected screening cost $E_t\psi_{t+1}$, we see that while the second term is increasing in $E_t r_{t+1}$ (which is increasing in collateral value q_t), the second term is decreasing in $E_t r_{t+1}$. Since the screening cost in the future is endogenous to collateral values, in order to determine when each force dominates, consider the steady state of the economy to which the economy converges if $q_t = q$ for sufficiently long. Then, the steady state screening cost is given by:

$$1 + \frac{\psi}{\mu} = \frac{\Phi(r)}{1 - \Phi(r) \cdot \frac{1-\delta}{\rho}} \cdot \frac{r}{\rho}, \quad (64)$$

where

$$\Phi(r) = \frac{1 - \phi_H}{(1 - \mu \cdot \phi_H - (1-\mu) \cdot \phi_L) \cdot \frac{r+1-\delta}{\rho}} + \frac{(1-\mu) \cdot (\phi_H - \phi_L)}{1 - \mu \cdot \phi_H - (1-\mu) \cdot \phi_L},$$

and where r is the steady state marginal product of capital (which is decreasing in q). We now show that ψ is monotonically increasing in r provided collateral constraints are not too tight.

Differentiating ψ in equation (64) w.r.t. r, we have:

$$\frac{\partial\left(1 + \frac{\psi}{\mu}\right)}{\partial r} = \left(1 + \frac{\psi}{\mu}\right) \cdot \left(\frac{1}{r} + \frac{\Phi'(r)}{\Phi(r) \cdot \left(1 - \Phi(r) \cdot \frac{1-\delta}{\rho}\right)}\right),$$

which is positive if and only if:

$$\frac{(1-\mu) \cdot (\phi_H - \phi_L)}{1 - \mu \cdot \phi_H - (1-\mu) \cdot \phi_L} > (1 - \phi_H) \cdot \frac{\left(\frac{r+1-\delta}{\rho} - 1\right) \cdot (1-\mu) \cdot (\phi_H - \phi_L) \cdot \frac{1-\delta}{\rho}}{(1-\phi_H) \cdot \frac{r}{\rho} + (1-\mu) \cdot (\phi_H - \phi_L) \cdot \frac{r+1-\delta}{\rho} \cdot \left(1 - \frac{1-\delta}{\rho}\right)}. \quad (65)$$

Note that this inequality is satisfied when $\frac{r+1-\delta}{\rho} \approx 1$. Furthermore, because the RHS is increasing in r, there is an upper bound $\bar{r}$ such that the inequality (65) is satisfied for $r < \bar{r}$. Furthermore, the upper bound $\bar{r}$ increases to ∞ as ϕ_H goes to 1. This puts a lower bound on the steady state capital stock, which is lowest when $q_t = \underline{q}$. Therefore, a sufficient condition for screening to be declining in collateral values (in steady state) is that $\underline{q}$ is not too low.

When (65) is not satisfied for some values of q, then screening can be non-monotonic in collateral values. Even in this case, however, screening unambiguously decreases with collateral values if we consider an economy in which, when collateral values increase, entrepreneurs transition from being constrained to being sufficiently close to unconstrained; this is because the agents in our economy engage in costly screening precisely in order to increase collateralization.

A.5 Screening pre-existing projects

In our main analysis, we had assumed that the entrepreneurs can only screen projects (or units of capital) that are new. But note that if an entrepreneur undertakes unscreened investment, then when old she will know its type, depending on whether she is able to abscond with the resources of the project or not. We now consider the possibility that this entrepreneur is able to screen her pre-existing projects *after* she finds out their types.

Because the equilibrium price of L-type capital will still be weakly below that of unscreened, entrepreneurs will never pay to screen a project that they know is an L-type. Therefore, we only need to consider whether it is worthwhile for an old entrepreneur to screen a project once she finds out that it is H-type. If only new projects were screened in equilibrium, then the price of a unit of H-type capital would equal $1 + \frac{\psi_t}{\mu}$ as before. But then an old entrepreneur who has an H-type project can deviate and screen it at cost ψ (by paying out of pocket) and sell it in the market for a net profit of $\left(\frac{1}{\mu} - 1\right) \cdot \psi_t > 0$. Hence, it must be that at least some pre-existing projects are screened as well.

If in equilibrium new projects are screened, pre-existing H-types must also be screened. This implies that at any time t, the equilibrium may feature one of the following three possibilities. First, an equilibrium may feature screening of all H-type pre-existing projects (old and new), and the new projects are screened until they earn zero expected profits. Second, the equilibrium may feature screening some pre-existing H-type projects which yields zero profits, and no new projects because they earn negative expected profits. Finally, the equilibrium may feature screening of all H-type pre-existing projects but no screening of new projects because expected profits on those are negative.

In the first case, the equilibrium is as before described by equations (10)-(12), together with the equilibrium screening that is now given by:

$$s_t = \max\left\{0, \frac{k_{t+1}^H - (1-\delta)\cdot k_t^H}{\mu} + \mu\cdot(1-\delta)\cdot k_t^\mu\right\}. \tag{66}$$

A sufficient condition for this to be an equilibrium is that $k_{t+1}^H \geq (1-\delta)\cdot k_t^H$. Notice also that we have assumed that the profits from screening pre-existing H-type projects are non-pledgeable, which can be microfounded by supposing that entrepreneur can always threaten not to screen ex-post (which yields zero profits) and renegotiate creditors down to zero payments from her screening profits. Furthermore, since k_t^μ is increasing in collateral q_t, the equilibrium dynamics are in this region if collateral is scarce enough. Importantly, the qualitative behavior of this economy would be the same as that of our baseline economy, with the exception that the screening of some new projects would be replaced by the screening of pre-existing projects.

In the second case, only a fraction $\sigma_t \in (0,1)$ of pre-existing H -type projects are screened and new projects are not. The equilibrium dynamics are given by (10), together with

$$s_t = \sigma_t \cdot \mu \cdot k_t^\mu,$$

and where:

$$k_{t+1}^H = s_t + (1-\delta)\cdot k_t^H.$$

A sufficient condition for this to be an equilibrium is that:

$$1 + \psi(s_t) = p_t^H = \frac{E_t\{r_{t+1} + (1-\delta)\cdot p_{t+1}^H\}}{\rho} < 1 + \frac{\psi(s_t)}{\mu},$$

i.e. old entrepreneurs are indifferent to whether to screen pre-existing projects or not. Again, in this region, the qualitative behavior of the economy would be the same as that of our baseline economy, with the exception that now the marginal screened projects are the pre-existing ones. Thus, when collateral values increase, it is the screening of these projects that is crowded out.

Finally, in the third case, the equilibrium dynamics are given by equation (10), together with the equilibrium screening that is now given by:

$$s_t = \mu\cdot(1-\delta)\cdot k_t^\mu,$$

and where:

$$k_{t+1}^H = s_t + (1-\delta)\cdot k_t^H.$$

A sufficient condition for this to be an equilibrium is that:

$$1 + \psi(s_t) \leq p_t^H = \frac{E_t\{r_{t+1} + (1-\delta) \cdot p_{t+1}^H\}}{\rho} < 1 + \frac{\psi(s_t)}{\mu}.$$

i.e. it is worthwhile to screen all the pre-existing unscreened projects but not any new ones. In this region, screening at time t does not respond to changes in collateral values, but an increase in collateral values will increase the stock of unscreened projects and, thus, mechanically the screening in the next period. Thus, here, collateral values and screening become complements.

B Tables for Section 6

	Mean	Median	SD	25th percentile	75th percentile	Obs.
Firm-level data						
Investment	0.33	0.20	0.38	0.11	0.38	34,986
Cash	0.04	0.26	1.78	-0.09	0.63	35,204
Market / Book	2.16	1.52	1.76	1.10	2.42	32,512
Spread	2.24	1.27	3.38	0.68	2.55	26,975
Analysts	7.93	5.00	7.46	2.00	11.00	19,921
Intangibility	0.51	0.35	0.62	0.16	0.64	31,167
RE Value (State Prices)	0.89	0.26	1.44	0.00	1.14	35,430
RE Value (MSA Prices)	0.88	0.26	1.42	0.00	1.13	34,892
State Prices	0.29	0.24	0.12	0.20	0.33	35,430
MSA Prices	0.14	0.12	0.05	0.10	0.17	34,907
Housing Supply Elasticity	1.17	0.90	0.67	0.65	1.42	30,753
Initial firm level data (1993)						
Age	8.09	8.00	4.66	3.00	13.00	2,855
ROA	-0.01	0.07	0.25	-0.04	0.12	2,844
Log(Asset)	4.05	3.96	2.19	2.58	5.46	2,852

Notes: Investment is defined as capital expenditure (item No. 128) normalized by the lagged book value of properties, plant and equipment (PPE; item No. 8). Cash is defined as income before extraordinary items + depreciation and amortization (item No. 14 + item No. 18) normalized by lagged PPE (item No. 8). Market / Book is defined as the market value of assets (item No. 6 + (item No. 60 x item No. 24) – item No. 60 – item No. 74) normalized by their book value (item No. 6). Spread is the December value of the bid-ask spread, expressed in percentages, of the firm's stock, from Corwin and Schultz (2011). Analysts is the maximum number of analysts who make annual earnings forecasts in any month over a 12-month period, computed following Chang, Dasgupta and Hilary (2006) using data from the I/B/E/S Historical Summary File. Intangibility is the ratio of intangible assets (item No. 33) to tangible fixed assets (PPE; item No. 8) at the sectoral level for the two-digit SIC code sector in which the firm is operating. RE Value is the ratio of the market value of real estate assets normalized by lagged PPE, computed as in Chaney, Sraer and Thesmar (2012). ROA is defined as operating income before depreciation minus depreciation and amortization normalized by total assets ((item No. 13 – item No. 14) /item No. 6). Age is the number of years since IPO. MSA / State Prices is the level of the MSA / State OFHEO real estate price index, normalized to 1 in 2006. Housing Supply Elasticity comes from Saiz (2010). Sample period covers 1993-2012.

Table 1: **Summary statistics**

VARIABLES	(1) MSA Prices	(2) MSA Prices
Housing supply elasticity	0.00990***	
	(0.00274)	
First quartile of elasticity		-0.0225***
		(0.00682)
Second quartile of elasticity		-0.00548
		(0.00751)
Third quartile of elasticity		0.00141
		(0.00744)
Year FE	Yes	Yes
MSA FE	Yes	Yes
Observations	2,232	2,232
R-squared	0.892	0.893

Notes: This table investigates how local housing supply elasticity, as defined by Saiz (2009), affects real estate prices, following Chaney, Sraer and Thesmar (Table 3, 2012). The dependent variable is the residential real estate price index, defined at the MSA level. Column 1 uses the local housing supply elasticity, while column 2 uses quartiles of the elasticity. All regressions control for year as well as MSA fixed effects and cluster observations at the MSA level. T-stats in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table 2: **First-stage regression: The impact of local housing supply elasticity on housing prices**

VARIABLES	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) IV
RE Value (State Prices)	0.0622***	0.0563***	0.0478***		
	(0.00345)	(0.00361)	(0.00349)		
State Prices	-0.0999*	-0.367	-0.142		
	(0.0529)	(0.305)	(0.347)		
Cash			0.0253***	0.0262***	0.0269***
			(0.00241)	(0.00276)	(0.00293)
Market/Book			0.0577***	0.0604***	0.0605***
			(0.00282)	(0.00295)	(0.00318)
RE Value (MSA Prices)				0.0461***	0.0506***
				(0.00395)	(0.00752)
MSA Prices				-0.465	0.447
				(1.061)	(0.375)
Initial Controls x State Prices	No	Yes	Yes	No	No
Initial Controls x MSA Prices	No	No	No	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes
Observations	34,986	34,746	31,351	26,596	22,901
Adjusted R-squared	0.270	0.281	0.311	0.320	0.322

Notes: The table reports the empirical link between the value of real estate assets and investment, following Chaney, Sraer and Thesmar (Table 5, 2012). The dependent variable is capital expenditure, normalized by the lagged book value of properties, plant and equipment. Columns 1, 2, and 3 use the state-level residential price index. Columns 4 and 5 use MSA-level residential prices. Except for column 1, all regressions control for firm-level initial characteristics (five quintiles of age, asset, and ROA, as well as two-digit industry and state of location) interactions with Real Estate Prices. All regressions, except columns 1 and 2, control for Cash and previous year Market/Book. Column 5 presents IV estimates where MSA residential prices are instrumented using the interaction of real mortgage rate interacted with the local elasticity of land supply taken from Saiz (2010) (see column 1 in Table 2 for the first-stage regressions). All specifications use year and firm fixed effects and cluster observations at the state-year or MSA-year level. In the IV specification in column 5, standard errors are bootstrapped within MSA-year clusters. T-stats are in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table 3: **Investment and collateral**

VARIABLES	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) IV
RE Value (State Prices)	0.0547***	0.0442***	0.0394***		
	(0.00355)	(0.00378)	(0.00383)		
Spread	-0.0159***	-0.0172***	-0.0105***	-0.0104***	-0.00993***
	(0.00163)	(0.00165)	(0.00145)	(0.00171)	(0.00184)
RE Value (State Prices) x Spread	0.00168***	0.00229***	0.00143***		
	(0.000648)	(0.000570)	(0.000443)		
State Prices	-0.158***	-0.725	-0.654		
	(0.0602)	(0.488)	(0.468)		
Cash			0.0266***	0.0275***	0.0281***
			(0.00280)	(0.00320)	(0.00338)
Market/Book			0.0619***	0.0638***	0.0638***
			(0.00290)	(0.00311)	(0.00338)
RE Value (MSA Prices)				0.0378***	0.0430***
				(0.00404)	(0.00485)
RE Value (MSA Prices) x Spread				0.00139**	0.00134*
				(0.000685)	(0.000779)
MSA Prices				0.366	0.644*
				(1.225)	(0.370)
Initial Controls x State Prices	No	Yes	Yes	No	No
Initial Controls x MSA Prices	No	No	No	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes
Observations	26,674	26,566	25,417	21,604	18,601
Adjusted R-squared	0.314	0.326	0.374	0.383	0.381

Notes: The table reports the empirical link between the value of real estate assets, asymmetric information, and investment. The dependent variable is capital expenditure, normalized by the lagged book value of properties, plant and equipment. Spread is the one-year lagged December value of the bid-ask spread, expressed in percentages, of the firm's stock, from Corwin and Schultz (2011). Columns 1, 2, and 3 use the state-level residential price index. Columns 4 and 5 use MSA-level residential prices. Except for column 1, all regressions control for firm-level initial characteristics (five quintiles of age, asset, and ROA, as well as two-digit industry and state of location) interactions with Real Estate Prices. All regressions, except columns 1 and 2, control for Cash and previous year Market/Book. Column 5 presents IV estimates where MSA residential prices are instrumented using the interaction of real mortgage rate interacted with the local elasticity of land supply taken from Saiz (2010) (see column 1 in Table 2 for the first-stage regressions). All specifications use year and firm fixed effects and cluster observations at the state-year or MSA-year level. In the IV specification in column 5, standard errors are bootstrapped within MSA-year clusters. T-stats are in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table 4: **Investment, collateral and information**

VARIABLES	(1) OLS	(2) OLS	(3) IV	(4) OLS	(5) OLS	(6) IV
RE Value (State Prices)	0.0526***			0.0365***		
	(0.00779)			(0.00432)		
RE Value (MSA Prices)		0.0510***	0.0598***		0.0346***	0.0400***
		(0.00835)	(0.00982)		(0.00480)	(0.00569)
Analysts	0.0238***	0.0294***	0.0300***			
	(0.00818)	(0.00846)	(0.00941)			
RE Value (State Prices) x Analysts	-0.00704**					
	(0.00349)					
RE Value (MSA Prices) x Analysts		-0.00721**	-0.00949**			
		(0.00364)	(0.00396)			
Intangibility				-0.00359	-0.00419	-0.00604
				(0.00491)	(0.00531)	(0.00551)
RE Value (State Prices) x Intangibility				0.00546**		
				(0.00249)		
RE Value (MSA Prices) x Intangibility					0.00609**	0.00673**
					(0.00263)	(0.00280)
State Prices	-2.071***			-1.075		
	(0.785)			(0.983)		
MSA Prices		-2.573	0.410		-0.648	0.854
		(2.359)	(0.532)		(2.646)	(0.541)
Cash	0.0313***	0.0308***	0.0303***	0.0277***	0.0287***	0.0296***
	(0.00442)	(0.00486)	(0.00521)	(0.00304)	(0.00337)	(0.00355)
Market/Book	0.0649***	0.0666***	0.0665***	0.0621***	0.0644***	0.0644***
	(0.00388)	(0.00395)	(0.00426)	(0.00311)	(0.00325)	(0.00351)
Initial Controls x State Prices	Yes	No	No	Yes	No	No
Initial Controls x MSA Prices	No	Yes	Yes	No	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	17,051	14,517	12,432	22,436	19,134	16,510
Adjusted R-squared	0.452	0.469	0.471	0.371	0.379	0.380

Notes: The table reports the empirical link between the value of real estate assets, asymmetric information, and investment. The dependent variable is capital expenditure, normalized by the lagged book value of properties, plant and equipment. Analysts is ln(1+A), where A is the maximum number of analysts who make annual earnings forecasts in any month over a 12-month period, computed following Chang, Dasgupta and Hilary (2006) using data from the I/B/E/S Historical Summary File. Intangibility is the ratio of intangible assets to tangible fixed assets at the sectoral level for the two-digit SIC code sector in which the firm is operating. Columns 1 and 4 use state-level residential prices, while Columns 2, 3, 5, and 6 use MSA-level residential prices. All regressions control for firm-level initial characteristics (five quintiles of age, asset, and ROA, as well as two-digit industry and state of location) interactions with Real Estate Prices. All regressions control for Cash and previous year Market/Book. Columns 3 and 6 present IV estimates where MSA residential prices are instrumented using the interaction of real mortgage rate interacted with the local elasticity of land supply taken from Saiz (2010) (see column 1 in Table 2 for the first-stage regressions). All specifications use year and firm fixed effects and cluster observations at the state-year or MSA-year level. In the IV specifications in columns 3 and 6, standard errors are bootstrapped within MSA-year clusters. T-stats are in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table 5: **Investment, collateral and information: alternative proxies**

VARIABLES	(1) Aggregate	(2) Boom years (2001-2006)
RE Value (State Prices) at State Level	0.0280**	0.0647**
	(0.0135)	(0.0302)
State Prices	-3.812	-7.149*
	(2.804)	(3.694)
Year FE	Yes	Yes
State FE	Yes	Yes
Observations	905	190
Adjusted R-squared	0.026	0.013

Notes: The table reports the empirical link between the value of real estate assets and the proportion of investment going to information-intensive firms at the state level. The dependent variable is the investment rate of high spread firms relative to the investment rate of all firms, computed at the state level. High spread firms are defined as firms with above median levels of spread. Investment rates are computed as capital expenditure, normalized by the lagged book value of properties, plant and equipment. Spread is the one-year lagged December value of the bid-ask spread, expressed in percentages, of the firm's stock, from Corwin and Schultz (2011). RE Value (State Prices) at State Level is the ratio of the market value of real estate assets normalized by lagged PPE, computed as in Chaney, Sraer and Thesmar (2012) but aggregated at the state level. State Prices is the level of the state-level OFHEO real estate price index, normalized to 1 in 2006. All specifications include year and state-level fixed effects. The regression in Column 2 limits the sample to the boom period 2001 to 2006, where boom years are defined as years during which national house price growth, according to the OFHEO real estate price index, is above its 75th percentile. T-stats are in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table 6: **Investment, collateral and information: aggregate results**

VARIABLES	(1) Bust years (2007-2012)
Δ Investment Ratio during Boom at State Level × RE Value (State Prices) at State Level	0.300***
	(0.0964)
RE Value (State Prices) at State Level	0.0665***
	(0.0223)
State Prices	-0.0204
	(0.0970)
Year FE	Yes
State FE	Yes
Observations	905
Adjusted R-squared	0.026

Notes: The table reports the empirical link between the value of real estate assets and investment rates at the state level during bust years, conditional on the proportion of investment going to information-insensitive firms during the boom years. The dependent variable is the aggregate investment rate at the state level during the bust period, with investment rates are computed as capital expenditure, normalized by the lagged book value of properties, plant and equipment. The bust period is 2007 to 2012, where bust years are defined as years during which national house price growth, according to the OFHEO real estate price index, is below its 25th percentile. Δ Investment Ratio during Boom at State Level is the increase in the proportion of state-level investment made by high spread firms during the boom period. The boom period is 2001 to 2006, where boom years are defined as years during which national house price growth, according to the OFHEO real estate price index, is above its 75th percentile. High spread firms are defined as firms with above median levels of spread. Spread is the one-year lagged December value of the bid-ask spread, expressed in percentages, of the firm's stock, from Corwin and Schultz (2011). RE Value (State Prices) at State Level is the ratio of the market value of real estate assets normalized by lagged PPE, computed as in Chaney, Sraer and Thesmar (2012) but aggregated at the state level. State Prices is the level of the state-level OFHEO real estate price index, normalized to 1 in 2006. All specifications include year and state-level fixed effects. The regression in Column 2 limits the sample to the boom period 2001 to 2006, where boom years are defined as years during which national house price growth, according to the OFHEO real estate price index, is above its 75th percentile. T-stats are in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table 7: **Investment, collateral and information: aggregate results during busts**