Collateral Booms and Information Depletion

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Abstract

We develop a new theory of 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: collateralization and 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 (e.g., real estate booms), the economy accumulates physical capital but depletes information about investment projects. As a result, 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 empirical support for the mechanism using US firm-level data.

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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] As the old banker maxim goes, "bad loans are made in good times." 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 resources during credit 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 provide supporting new evidence of the theory's key prediction.

We study an economy that is populated by borrowers (entrepreneurs) and lenders, in which output is produced by combining capital and labor. To produce capital, 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-contractible 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., real estate), and lenders can ask them to retain "skin in the game" by posting these assets as collateral. The second is costly *screening*. Lenders may require experts to evaluate or screen the projects undertaken by entrepreneurs and make sure they do not permit resource diversion. We make three assumptions regarding screening. First, screening requires the time and effort of experts, so that it is costly. Second, expertise is scarce, in the sense that experts are heterogeneous in their skills and their time is limited.

[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).

This naturally implies that the cost of screening an individual project in any given period is increasing in the economy's aggregate amount of screening: as aggregate screening increases, it requires the use of less and less skilled experts thereby raising its cost.[5] Third, the information generated through screening is long-lived, and it accompanies the project throughout its life.

In equilibrium, collateralized and screened investment are effectively substitutes. An expansion in collateralized investment, for instance, raises the capital stock and thus labor demand and wages: all else equal, this reduces the return to screened investment. This general mechanism underpins the theory's main insight: the relative intensity of collateralization vs screening depends on the scarcity of entrepreneurial collateral, i.e., on the price of real estate. When the price of real estate is low, only a few investment projects can be funded via collateralization. This raises the return to investment, and thus the equilibrium level of screening and the amount of information on existing projects. Instead, when the price of real estate is high, the equilibrium mix of screening to collateralization is low. In this case, since many investment projects can be funded via collateralization, the marginal return to investment 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, i.e., booms that originate in high asset prices. When the economy enters a collateral boom, the price of real estate rises and credit, investment and output all expand together. But, for the reasons outlined above, lenders rely more on collateralization and less on screening. Therefore, even as the economy booms, 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 real estate falls, credit, investment, and output fall as well, but they do so for two reasons: (i) all else equal, the scarcity of collateral means that lenders must increase their reliance on costly screening, and; (ii) this need for screening is especially strong because information has been 'depleted' during the boom. Hence, 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.

We think of collateral-driven booms as originating in high asset prices as opposed to high productivity. In this regard, the implications of the theory are highly relevant in a world of high and volatile asset values. Over the last three decades, for instance, Japan, the United States, and parts of the Eurozone (e.g. Spain, Ireland) have all exhibited large booms and busts in asset prices, which have had significant implications for economic activity despite

[5] More broadly, this assumption captures the intuitive notion that the production of information is limited by factor scarcity. Screening borrowers, for instance, may require trained loan officers or experts, and information gathering and processing infrastructure, which are difficult to change in the short run. In the banking literature, it is common to assume that the screening cost function is increasing and convex due to capacity constraints (see, for instance, Ruckes (2004)).

having been often unrelated to productivity. Much has been written already on the possible origins of these asset price fluctuations, and we take them here as given. Instead, our main focus is on their transmission and amplification through information depletion.

Taking this into account, the theory sheds light on three key debates regarding credit booms and their macroeconomic effects. First, it shows that not all credit booms are alike. Richter et al. (2017) and 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 drives 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, the model 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 raise asset prices and thus collateral but do not affect economic fundamentals. Under this interpretation, the model highlights a hitherto unexplored cost of bubbles that surfaces when they burst: while they last, bubbles deplete information on existing projects. Third, the model also shows why credit booms can lead to resource or factor misallocation: by reducing information, collateral booms raise dispersion in the productivity of investment. However, there is a positive counterpart to this increase in dispersion, as the economy saves on information costs.

Finally, we study the normative properties of our economy. Intuitively, it may seem that market participants produce too little information during booms: if screening was supported somehow, the busts would be less severe and recoveries faster. We show, however, that this intuition is incorrect. Since agents are rational, they correctly anticipate the value of information in future states of nature. Thus, even in the midst of a collateral boom, agents understand that – when the bust comes – screened projects will be very valuable and they will be able to appropriate this value. If anything, we find that due to pecuniary externalities information production is inefficiently high! We show that a necessary condition for information generation to be inefficiently low is that there be additional distortions that prevent agents from fully internalizing the social return to information production. We explore two such distortions: external economies in the screening technology and frictions in the market for projects.

Our theory is consistent with various strands of stylized evidence. 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; Becker et al., 2016; Lisowsky et al., 2017). Third, 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. Fourth, there is evidence that credit booms that are accompanied by house price booms (Richter et al., 2017) and that are characterized by low productivity growth (Gorton and Ordoñez, 2016) are more likely to end in crises. All of these findings are consistent with the theory's main prediction.

But there is one prediction that is specific to our theory: an increase in collateral values leads to information depletion, i.e., to a decline in the economy's reliance on screening. We test this prediction on US firm-level data from COMPUSTAT. This is nontrivial for at least two reasons. First, assessing this in the data requires identifying changes in collateral values that are orthogonal to other economic conditions, such as productivity, which may affect screening intensity on their own. We deal with this by following Chaney et al. (2012) and estimating the impact of real estate prices on screening intensity using instrumental variables. Second, there is no universally accepted measure of screening intensity or, analogously, of the availability of information on existing projects. We therefore adopt a holistic approach and use two alternative measures of information at the firm level: the duration of the firm's main lending relationship in the syndicated loan market and the number of financial analysts that follow the firm. Our empirical results are consistent with this key prediction of the model. The information generated on a firm, as measured through the duration of its main lending relationship or the number of analysts covering the firm, is decreasing in the value of its real estate.

We are not the first to consider the conceptual link between information production and economic booms and busts (Van Nieuwerburgh and Veldkamp, 2006; Ordoñez, 2013; Gorton and Ordoñez, 2014; Ambrocio, 2015; Gorton and Ordoñez, 2016; Fajgelbaum et al., 2017; Straub and Ulbricht, 2017; Farboodi and Kondor, 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 is a key difference between our framework and theirs, however. In their framework, information is about the quality of entrepreneurs' collateral. Because of this, information production is detrimental for investment in their framework, and – in fact – it is information production that triggers a crisis: once lenders can distinguish between collateral of high and low quality, there is a fall in lending and investment. In our framework, instead, information is about the quality of entrepreneurs' investment. Because of this, information production helps sustain investment. Differently from Gorton and Ordoñez, it is the crisis that triggers information production, 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 (García-Santana et al., 2016; Gopinath et al., 2017; Doerr, 2018). Our model provides a possible cause of such misallocation: information depletion. Relatedly, 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, making their collapse especially costly.

Conceptually, our theory is related to previous work that studies the optimal choice of technology in the presence of 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 the equilibrium choice of technology depends on financial conditions: in particular, high expected asset prices in an industry prompt firms to adopt less pledgeable technologies, because they can obtain credit simply by collateralizing assets. This exacerbates the severity of downturns caused by a decline in asset prices, however, because firms' inability to pledge their cash flow prevents them from obtaining credit and leads to their liquidation.

Finally, our paper is also related to the literature studying the determinants of lending standards and their evolution over the business cycle (Manove et al., 2001; Ruckes, 2004; Martin, 2005; Dell'Ariccia and Marquez, 2006; Favara, 2012; 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 production. Ruckes (2004), Gorton and He (2008) and Petriconi (2015) also study the evolution of screening over the cycle, but they stress the effect of bank competition on the equilibrium choice of screening. Instead, Martin (2005) and Favara (2012) study how the interplay between entrepreneurial net worth and lender incentives can give rise to endogenous lending cycles.

The paper is organized as follows. In Section 2, we present the baseline model. In Sections 3 and 4, we characterize the equilibrium and derive our main results. In Section 5, we consider several extensions, and we provide supporting empirical evidence in Section 6. Finally, we conclude in Section 7.

2 The Model

2.1 Environment: preferences, endowment and technology

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 sets of individuals, entrepreneurs and households. We respectively use I_t^e and I_t^h to denote the set of entrepreneurs and households in generation t. Households work and provide expert services during youth, and they save their 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 lend to and borrow from domestic agents at a (gross) expected return of ρ. Thus, we think of our economy as being small and open, and we refer to ρ as the interest rate.

Households are endowed with one unit of labor during youth, which they supply inelastically in a competitive labor market. They are also endowed with expertise, which enables them to assess or "screen" the quality of entrepreneurial projects. Given preferences, households save their entire income but they decide whether to do so through the international financial market at rate ρ or to lend to domestic entrepreneurs.

Entrepreneurs engage in two types of productive activities. First, young entrepreneurs run investment technologies (or projects), which transform consumption goods in period t into capital in period $t+1$. Capital depreciates (or becomes obsolete) at rate δ and is reversible.[6] Second, old entrepreneurs combine capital with labor to produce the economy's consumption good. In particular, entrepreneurs produce according to a Cobb-Douglas technology: $F_t(l_{it}, k_{it}) = A_t \cdot k_{it}^{\alpha} \cdot l_{it}^{1-\alpha}$, where k_{it} and l_{it} respectively denote the capital owned and the labor hired by entrepreneur $i \in I_{t-1}^e$, A_t reflects aggregate productivity, and $\alpha \in (0, 1)$.

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 H; with probability $1-\mu$, it is of type L. The quality of each unit of capital produced by an entrepreneur 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.[7] The L-type capital, however,

[6] We incorporate capital irreversibilities in Section 5.3, where we study how credit busts affect the prices of productive assets.

[7] We incorporate productivity heterogeneity in Section 5.2, where we study how credit booms affect mea-

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 the income generated by H-type capital can be pledged to outsiders, whereas that of L-type cannot.

Entrepreneurs are also 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 to be exogenous, but we endogenize it in Section 5.1. We think of these trees as an asset distinct from projects or 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.

Thus, at any point in time, entrepreneurs have two sources of collateral that can be pledged to lenders: trees (or *outside* collateral, which is exogenous to production) and the return to H-type capital (or *inside* collateral, which is endogenous to production).

The central feature of our environment is that entrepreneurs can screen their projects before investing. Doing so requires the services of households, however, who have the expertise to screen. Each household $i \in I_t^h$ has the ability to screen up to $n > 0$ units of capital at a unit cost of ψ_i. We assume that this cost is heterogeneous across households, and it is distributed in the population according to cdf $G(\psi_i)$, which is continuous and has full support on $[0, \infty)$. Thus, the "best" experts in the economy can costlessly screen projects while the "worst" face a prohibitive cost of doing so. If an expert screens a unit of capital, she produces a signal about the unit's type: for simplicity, we assume throughout that this signal is perfect. Moreover, any signal generated through screening is public information throughout the unit's lifetime, although the history or past performance of the unit is not.[8] Upon having observed the signal, the entrepreneur can decide whether to invest in the specific unit of capital or not.

Hence, there are potentially three types of capital in any period t: capital that has been screened and is known to be of H quality; capital that has been screened and is known to be of L quality, and; capital that has not been screened, which we denote by U. We use k_t^m (k_{it}^m) to denote the economy's (entrepreneur $i \in I_{t-1}^e$'s) stock of type-$m \in \{H, L, U\}$ 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 $k_t = k_t^H + k_t^L + k_t^U$ $(k_{it} = k_{it}^H + k_{it}^L + k_{it}^U)$.[9]

sured factor misallocation.

[8]Thus, none of our baseline results will rely on information asymmetries, although we discuss their effects in Section 3.3.

[9]The assumption that the type $m \in \{H, L, U\}$ is inherent to a unit of capital is a convenient modeling device, but it should not be interpreted literally. In Appendix A.4, we show that our model is formally equivalent to a setting where entrepreneurs operate projects, which combine both capital and labor to produce consumption goods; expertise is needed to screen the projects (which are of heterogeneous quality), but the capital employed by different projects is homogeneous.

2.2 Markets

Labor Market. Old entrepreneurs interact with young households in a competitive labor market. At the beginning of period t, given her capital stock k_{it}, maximization by entrepreneur $i \in I_{t-1}^e$ implies:

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

where w_t is the wage rate per unit of labor. Equation (1) is the labor demand of entrepreneur $i \in I_{t-1}^e$, 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) indicates that the wage equals the marginal product of labor evaluated at the aggregate capital-labor ratio.[10]

Given the optimal demand for labor, and if we use r_t to denote the marginal product of capital, it follows that:

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

Equations (1)-(3) are standard, so we impose them throughout our analysis.

Capital market. Entrepreneurs can buy and sell capital in a competitive market. We use p_t^m to denote the market price of a unit of type $m \in \{H, L, U\}$ capital. After producing in period t, old entrepreneur $i \in I_{t-1}^e$ is left with $(1-\delta) \cdot k_{it}^m$ units of capital of type m. Her 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 she will strictly prefer to sell all units of capital whose price exceeds one, she will be indifferent between selling and consuming those units whose price is exactly one, and she will strictly prefer to consume any units whose price is lower than one. Thus, old entrepreneurs can obtain $\max\{p_t^m, 1\}$ for each undepreciated unit of type-m capital after production.

Expertise market. To produce screened units of capital, young entrepreneurs need to hire screening services in the market for expertise. This market is perfectly competitive, and both young entrepreneurs and young households – who supply the expertise – act as price takers.

Given competition in the market for expertise and the distribution of expertise among households, it follows immediately that the equilibrium compensation for screening services will equal the effort cost of the marginal expert. In particular, if we use s_{it} to denote the screening services demanded by entrepreneur $i \in I_t^e$, we have that the equilibrium compensa-

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

tion for a unit of screening is given by:

$$\psi_t \equiv \psi(s_t) = G^{-1}\left(\frac{s_t}{n}\right), \tag{4}$$

where $s_t = \int\limits_{i \in I_t^e} s_{it} \cdot di$. Equation (4) is intuitive and says that the cost of screening a unit of investment in period t increases in the aggregate demand for screening services in that period.

Credit market. In order to purchase capital and invest in new units, young entrepreneurs obtain financing in a competitive credit market, where they exchange credit contracts with domestic households or the international financial market.

Entrepreneurs back their borrowing by using both their trees and the income generated by their capital units. Since trees are fully pledgeable, entrepreneurs can borrow an amount q_t against them.[11] Their capital income, however, is not fully pledgeable as the existence of L-type capital gives rise to a borrowing limit. In particular, if we let f_{it} denote the credit extended to entrepreneur i against her projects, and R_{it+1} denote the (possibly state-contingent) interest rate on this credit, then the maximum repayment that she can credibly promise in each state is:

$$R_{it+1} \cdot f_{it} \leq \left(r_{t+1} + (1-\delta) \cdot \max\left\{p_{t+1}^H, 1\right\}\right) \cdot k_{it+1}^H + \left(r_{t+1} + (1-\delta) \cdot \max\left\{p_{t+1}^U, 1\right\}\right) \cdot \mu \cdot k_{it+1}^U. \tag{5}$$

This constraint reflects the fact that, in period $t+1$, the entrepreneur can (and will!) abscond with all the resources generated by L-type units. In other words, entrepreneurs can only pledge the income generated by the units that have been screened and are known to be H-type, and by the share of the unscreened units that are expected to be H-type.

We do not impose any restrictions on the state-contingency of contracts. Aggregating across states, and taking into account that perfect competition among creditors implies that $E_t R_{it+1} = \rho$ in equilibrium, it follows that:

$$\rho \cdot f_{it} \leq E_t \left\{\left(r_{t+1} + (1-\delta) \cdot \max\left\{p_{t+1}^H, 1\right\}\right) \cdot k_{it+1}^H + \left(r_{t+1} + (1-\delta) \cdot \max\left\{p_{t+1}^U, 1\right\}\right) \cdot \mu \cdot k_{it+1}^U\right\}, \tag{6}$$

which characterizes an upper bound to the financing that entrepreneur $i \in I_t^e$ can obtain in the credit market in period t.

2.3 Entrepreneurs' problem

We now turn to the problem of a young entrepreneur $i \in I_t^e$, 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_{it}^m

[11] Equivalently, entrepreneurs can sell a tree in the market for q_t and use this amount to invest.

and z_{it}^m respectively denote the entrepreneur's production and purchases of type-m capital, for $m \in \{H, L, U\}$.

Entrepreneur $i \in I_t^e$ takes factor prices and the screening cost as given, and chooses his units of capital $\{k_{it+1}^m\}_m$, its production and purchases $\{x_{it}^m\}_m$ and $\{z_{it}^m\}_m$, and screening s_{it} to maximize expected old age consumption:

$$E_t \left\{ \sum_{m=H,L,U} \left(r_{t+1} + (1-\delta) \cdot \max\{p_{t+1}^m, 1\} \right) \cdot k_{it+1}^m \right\} - \rho \cdot f_{it}, \tag{7}$$

subject to:

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

The entrepreneur's old age consumption equals the expected capital income minus interest payments: note that Equation (7) already takes into account that capital will be sold in the market only if its price exceeds one, and that $E_t R_{it+1} = \rho$. 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 trees plus any additional borrowing against projects. 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 known quality (H or L) is limited by her screening. The final set of constraints states that the entrepreneur's stock of each type of capital is equal to her production and purchases, and that both holdings of capital and screening 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:

$$p_t^H = 1 + \frac{\psi(s_t)}{\mu}; \quad p_t^U = p_t^L = 1. \tag{8}$$

We will verify shortly that these prices are indeed part of equilibrium of our economy.[12] Given this conjecture, we solve for the entrepreneurial problem to obtain the capital stocks k_{it+1}^H, k_{it+1}^L, and k_{it+1}^U. The solution has the following implications.

First, entrepreneurs never choose to hold L-type capital, i.e., $k_{it+1}^L = 0$. The reason for this is simple. Suppose that entrepreneur $i \in I_t^e$ 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. The same logic implies that the entrepreneur will find it (weakly) sub-optimal to purchase a pre-existing unit of L-type capital.

Second, entrepreneurs hold H-type capital if and only if it is profitable to do so:

$$k_{it+1}^H \begin{cases} = 0 & \text{if } \frac{E_t R_{t+1}^H}{\rho} < 1 + \frac{\psi_t}{\mu} \\ \in [0, \infty) & \text{if } \frac{E_t R_{t+1}^H}{\rho} = 1 + \frac{\psi_t}{\mu} \\ = \infty & \text{if } \frac{E_t R_{t+1}^H}{\rho} > 1 + \frac{\psi_t}{\mu} \end{cases}, \tag{9}$$

where

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

denotes the expected return of a unit of H-type capital, i.e., the present value of its expected marginal product plus its resale value. Equation (9) states that as long as the discounted 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.[13] Note that this condition implies that the entrepreneur is never constrained in her choice of H-type capital, which is natural because the income generated by these units is fully pledgeable.

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

$$k_{it+1}^U = \begin{cases} = 0 & \text{if } \frac{E_t R_{t+1}^U}{\rho} < 1 \\ \in \left[0, \dfrac{\rho}{\rho - \mu \cdot E_t R_{t+1}^U} \cdot q_t \right] & \text{if } \frac{E_t R_{t+1}^U}{\rho} = 1 \\ = \dfrac{\rho}{\rho - \mu \cdot E_t R_{t+1}^U} \cdot q_t & \text{if } \frac{E_t R_{t+1}^U}{\rho} \in \left(1, \frac{1}{\mu}\right) \\ = \infty & \text{if } \frac{E_t R_{t+1}^U}{\rho} \geq \frac{1}{\mu} \end{cases}, \tag{10}$$

where

$$E_t R_{t+1}^U \equiv E_t \left\{ r_{t+1} + 1 - \delta \right\}$$

[12] We abstract throughout from the possibility of bubbles in the prices of capital.

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

denotes the expected return of a unit of unscreened capital. Equation (10) states that the entrepreneur is willing to hold unscreend capital as long as its expected discounted 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. In this case, Equation (10) shows that an entrepreneur's holdings of unscreened capital will be equal to her net worth, captured by q_t, times a financial multiplier that determines the extent to which this net worth can be leveraged in the credit market.

2.4 Equilibrium

To determine the equilibrium, we aggregate the behavior of individual entrepreneurs. From Equation (10), 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:

$$k_{t+1}^U = \min \left\{ \frac{\rho}{\rho - \mu \cdot E_t \{r_{t+1} + 1 - \delta\}} \cdot q_t, \ \tilde{k}_{t+1} \right\}, \tag{11}$$

where $\tilde{k}_{t+1}$ is the stock of unscreened capital consistent with $E_t r_{t+1} = \rho + \delta - 1$.[14] Equation (11) 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:

$$k_{t+1}^L = 0, \tag{12}$$

since no entrepreneur wants to hold it. Finally, Equation (9) implies that in equilibrium the discounted return to H-type capital must equal its cost of production:

$$\frac{E_t \left\{ r_{t+1} + (1-\delta) \cdot \left(1 + \frac{\psi(s_{t+1})}{\mu}\right) \right\}}{\rho} = 1 + \frac{\psi(s_t)}{\mu}, \tag{13}$$

where

$$s_t = \mu^{-1} \cdot \max \left\{ 0, \ k_{t+1}^H - (1-\delta) \cdot k_t^H \right\}. \tag{14}$$

[14] Formally, using the definition of r_{t+1} in Equation (3), $\tilde{k}_{t+1}$ satisfies:

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

Equation (14) 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 conjecture (8) about equilibrium prices. We now verify that these prices are indeed consistent with equilibrium. At the conjectured price $p_t^H = 1 + \frac{\psi(s_t)}{\mu}$, young entrepreneurs are indifferent between purchasing units of H-type capital from old entrepreneurs and producing them; old entrepreneurs, in turn, strictly prefer to sell these units as long as $s_t > 0$ (and thus $p_t^H > 1$) and are indifferent otherwise. Thus, at this price, the market for H-type capital clears. For U-type capital, at the conjectured price $p_t^U = 1$, young entrepreneurs are again indifferent between purchasing these units from old entrepreneurs and producing them; old entrepreneurs, in turn, are also indifferent between selling their units and consuming them. Thus, the market for U-type capital also clears. Finally, L-type capital is weakly dominated by the U-type, so the young do not purchase it. At the conjectured price $p_t^L = 1$, old entrepreneurs are indifferent between selling their capital and consuming it, so the market for L-type capital clears as well.

The equilibrium is computed as follows. Given an initial condition k_0^H, k_0^L, and k_0^U, which are the capital units held by the initial generation of old entrepreneurs, and given a stochastic process for the economy's shocks $\{q_t, A_t\}_{t\geq 0}$, Equations (3) and (11)-(14) jointly characterize the evolution of the equilibrium capital stocks and screening $\left\{k_t^H, k_t^L, k_t^U, s_{t-1}\right\}_{t>0}$.

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. Once again, we think of these as fluctuations in entrepreneurial net worth that are orthogonal to investment opportunities, e.g., fluctuations in land or 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, we gradually build up to the full dynamic analysis of the model. We begin by assuming that $\delta = 1$, so that capital disappears fully after production. By making capital units short-lived, this eliminates the forward-looking nature of screening and essentially makes the economy static. We then set $\delta < 1$ and analyze the behavior of the economy in response to unanticipated shocks. This intermediate step enables us to use a simple phase diagram analysis to illustrate the "slow-moving" nature of information, and its interaction with investment and its composition. Finally, we allow for shocks to be anticipated

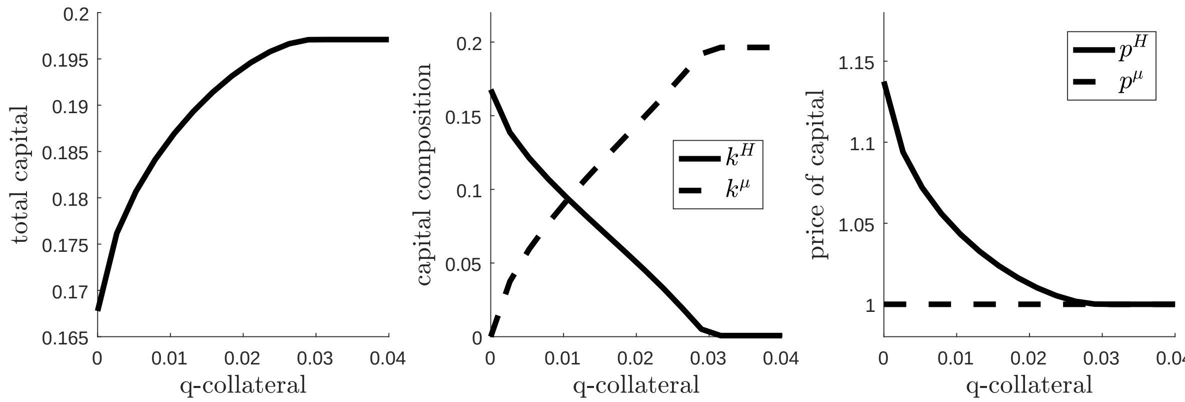

Figure 1: **Effects of collateral when $\delta = 1$.** The figure depicts the equilibrium capital, its composition and capital prices, as a function of collateral value q, in the economy with full depreciation. The parameter values used to produce the figures are provided in Appendix A.6.

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 disappears fully after production and thus $k^H_{t+1} = \mu \cdot s_t$, i.e., the economy must produce its entire stock of H-type capital by screening in every period. In this case, the equilibrium is characterized by:

$$k^U_{t+1} = \min\left\{\frac{\rho}{\rho - \mu \cdot E_t r_{t+1}} \cdot q_t,\ \tilde{k}_{t+1}\right\}, \tag{15}$$

and

$$\frac{E_t r_{t+1}}{\rho} = 1 + \frac{\psi\left(\mu^{-1} \cdot \max\{0, k^H_{t+1}\}\right)}{\mu}, \tag{16}$$

where r_{t+1} is defined in Equation (3) and $\tilde{k}_{t+1}$ is the unscreened capital consistent with $E_t r_{t+1} = \rho$. 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.

To illustrate the behavior of this economy, Figure 1 depicts a comparative statics exercise. For a given value of productivity A, it shows the equilibrium capital stock, its composition between H-type and unscreened capital, and the price of both types of capital, as a function of entrepreneurial collateral 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 relaxes the borrowing constraints of entrepreneurs, enabling them to expand unscreened investment. In equilibrium, this expansion raises labor demand and wages

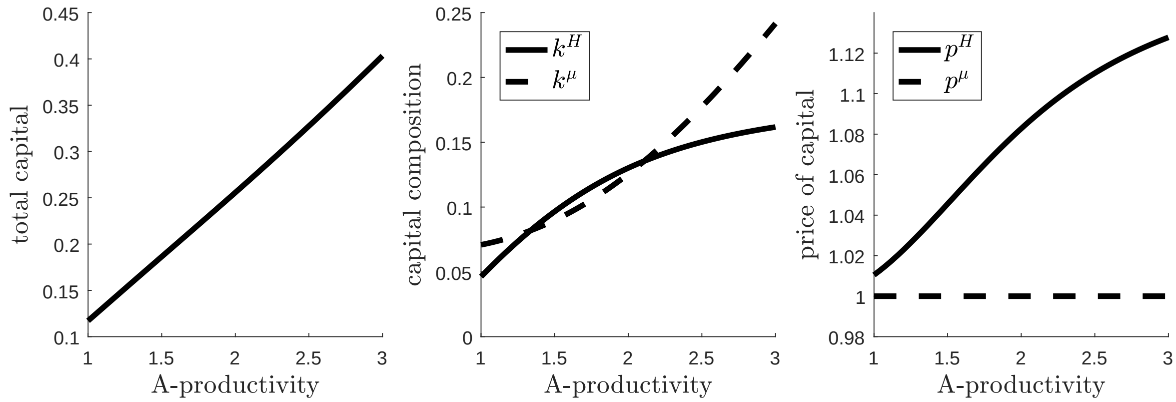

Figure 2: **Effects of productivity when $\delta = 1$.** The figure depicts the equilibrium capital, its composition and capital prices, as a function of aggregate productivity A, in the economy with full depreciation. The parameter values used to produce the figures are provided in Appendix A.6.

(see Equation (2)), thereby reducing the return to capital and thus screened investment. Simply put, an increase in q induces a shift in investment, raising unscreened capital at the expense of H-type capital. 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 the equilibrium capital stock. 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 an increase in entrepreneurial collateral reduces the need for screening and thus the value of information embedded in each unit of H-type capital.

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 costly 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. Due to general equilibrium effects, these two types of investment are substitutes: all else equal, an expansion in unscreened capital raises the demand for labor and thus wages, reducing the return to investment in H-type capital. Through this mechanism, an increase in collateral shifts the composition of investment away from screened investment thereby enabling the economy to save on screening costs. In a nutshell, collateral enables the economy to switch to a cheaper investment technology. But, as we shall see, this has important dynamic implications.

Before concluding, it is useful to contrast the effects of changes in entrepreneurial collateral and 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, an increase in aggregate productivity raises the equilibrium capital stock. The middle panel shows, however, that this is due to an increase in *both* screened *and* unscreened capital. The reason is that higher productivity raises the expected return to all units of capital, increasing 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, by raising the return to screened investment, an increase in productivity raises the equilibrium value of information embedded in each unit of H-type capital.

3.2 The dynamic model

We now set $\delta < 1$ and allow for shocks to entrepreneurial collateral and aggregate productivity, i.e., $q_t \in \{\underline{q}, \overline{q}\}$ and $A_t \in \{\underline{A}, \overline{A}\}$, where $\underline{q} < \overline{q}$ and $\underline{A} < \overline{A}$. Thus, the economy oscillates between "normal times," in which $q_t = \underline{q}$, and collateral booms, in which asset prices are high and $q_t = \overline{q}$. Two comments about this modelling choice are in order. First, it is an admittedly stark representation of collateral booms, as it implies that they are symmetric: booms begin and end with discrete jumps and collapses in q_t. In reality, booms tend to be asymmetric, with asset prices growing gradually during the boom phase and falling sharply during the bust. In adopting this simple representation of collateral booms, we have chosen to forego realism in order to convey the theory's main implications in the most transparent way. Second, our objective is not to explain fluctuations in asset prices, but rather to study their propagation through information depletion. Hence, we take the values $\underline{q}$ and $\overline{q}$ (as well as the transition probabilities specified below) as parametric.

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:

$$k^U = \frac{\rho}{\rho - \mu \cdot E_t \left\{ \alpha \cdot A_{t+1} \cdot \left(k_{t+1}^H + k_{t+1}^U \right)^{\alpha - 1} + 1 - \delta \right\}} \cdot q_t, \tag{17}$$

$$\frac{E_t \left\{ r_{t+1} + (1-\delta) \cdot \left(1 + \frac{\psi(s_{t+1})}{\mu} \right) \right\}}{\rho} = 1 + \frac{\psi\left(s_t\right)}{\mu}, \tag{18}$$

and

$$s_t = \mu^{-1} \cdot \max\left\{ 0,\ k_{t+1}^H - (1-\delta) \cdot k_t^H \right\}, \tag{19}$$

where r_{t+1} is defined in Equation (3). The key difference with the "static" model is that the stock of screened capital k_t^H now becomes a state variable. To see this, observe that – for a given expected value of information in the future,– k_{t+1}^H is increasing in k_t^H. Intuitively, a higher value of k_t^H reduces equilibrium screening, as some of the information that is necessary to produce H-type capital is already embedded in pre-existing units: the ensuing fall in the cost of screening, in turn, raises k_{t+1}^H as well. In this sense, we can think of k_t^H as embodying the economy's stock of information. But what is the dynamic behavior of this information? To understand this, we next study the equilibrium dynamics in response to unanticipated shocks, through the help of a simple phase diagram.

3.2.1 "Slow-moving" information

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

$$k^H = s \cdot \frac{\mu}{\delta}, \tag{20}$$

and

$$\alpha \cdot A \cdot \left(k^H + k^U(k^H, q, A)\right)^{\alpha-1} = (\rho + \delta - 1) \cdot \left(1 + \frac{\psi(s)}{\mu}\right), \tag{21}$$

where $k^U(k^H, q, A)$ is implicitly defined by Equation (17), with k^U increasing in q but decreasing in k^H (though less than one for one). Equation (20) represents the rate of per-period screening s necessary to maintain k^H units of H-type capital in steady state: clearly, s is increasing in k^H. Equation (21) represents the combinations of s and k^H that are consistent with profit maximization by entrepreneurs and market clearing: here, s and k^H are negatively related because high levels of screening reduce the return to investment 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 the dynamics of the system along the saddle path, as indicated by the arrows, depict the slow-moving nature of information. To see this, suppose the economy starts with an initial value $k_0^H < \bar{k}^H$. In this case, the economy needs to build up its stock of information and therefore requires a high level of screening ($s_0 > \bar{s}$): along the transition, k_t^H rises gradually towards $\bar{k}^H$ and s_t falls gradually towards $\bar{s}$. Analogously, given an initial value $k_0^H > \bar{k}^H$, the economy must instead run down its stock of information and it therefore requires a low level of screening ($s_0 < \bar{s}$): along the transition, k_t^H falls towards $\bar{k}^H$ and s_t rises towards $\bar{s}$.

The key takeaway of this dynamic model is that the economy cannot accumulate information instantaneously, as that would be too costly because it would require drawing on inefficient

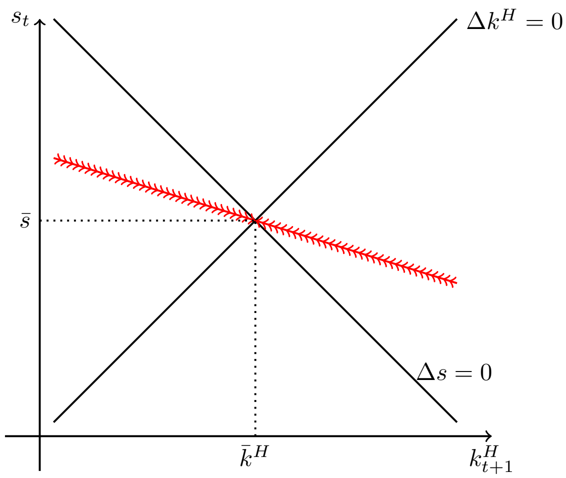

Figure 3: **Information dynamics.** The figure illustrates a phase diagram for the joint evolution of per period screening and of H-type capital. In the left panel, the saddle path of the system is depicted in red. In the right panel, the saddle path is depicted in red prior to the unexpected shock to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

experts. Instead, information is optimally accumulated gradually over time and is in this sense "slow-moving." To further illustrate this adjustment, the right panel of Figure 3 depicts the response of the economy to a permanent and unexpected increase in q. Whereas the locus of Equation (20) is unaffected by this change, the locus of Equation (21) shifts down. The reason is that a higher value of q raises unscreened capital, reducing the return to capital and thus the benefits of screening. As a result, screening collapses on impact as the economy jumps to the new saddle path: at the new, higher level of entrepreneurial collateral, it is simply not worth maintaining the pre-existing stock of H-type capital. Along this new saddle path, the economy gradually transitions towards the new steady state, which has both lower k^H and s relative to the original steady state.

As in the static model, therefore, the dynamic economy responds to an increase in q by reducing its information production. Crucially, however, now the depletion of information (or its accumulation) occurs gradually over time, as screened capital transitions slowly to its new steady state. As we will see shortly, such slow-moving information dynamics have important bearing on the equilibrium dynamics of boom-bust cycles.

Finally, it is worth noting that an increase in aggregate productivity as measured by A would have the opposite effect to that of an increase in q, as it would induce an upward shift of the locus defined by Equation (21), thereby raising the steady-state values of k^H and s. Therefore, just as in the static model, increases in entrepreneurial collateral deplete information production whereas increases in aggregate productivity foster it.

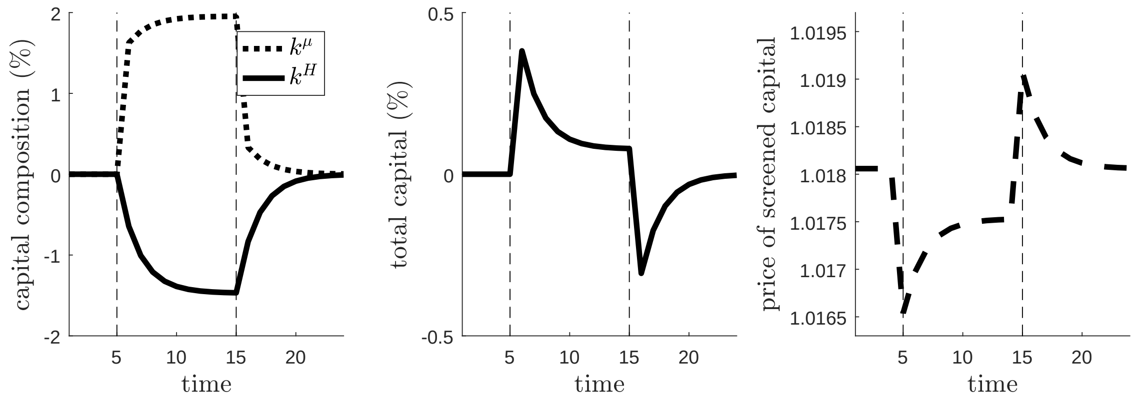

Figure 4: **Collateral boom-bust episode**. The figure depicts the equilibrium evolution of capital, its composition and capital prices throughout a collateral boom-bust episode. Collateral values are $q_t = \underline{q}$ before period 5 and after period 15, and $q_t = \overline{q} > \underline{q}$ between periods 5 and 15. The variables are expressed in percentage deviation from their low-collateral steady state value, except for the price of screened capital. The parameter values used to produce the figures are provided in Appendix A.6.

3.2.2 Boom-bust episodes

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

Figure 4 illustrates the behavior of an economy that 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 shift in the composition of investment: unscreened investment increases 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, and as discussed in the previous section, the economy depletes its stock of information during the high-collateral state.

What happens when the boom ends and the economy returns to the low-collateral state? At this point, young entrepreneurs do not have enough collateral to sustain the stock of unscreened capital that was built during the boom. Thus, they shift their investment towards H-type capital, but its stock was depleted during the boom and there is not enough of it to go around. This scarcity of screened capital translates into both a higher price, which can be interpreted as a "flight to information," and a spike in the cost of screening. The high cost of screening, in turn, limits the economy's ability to expand screened capital quickly. Unable to

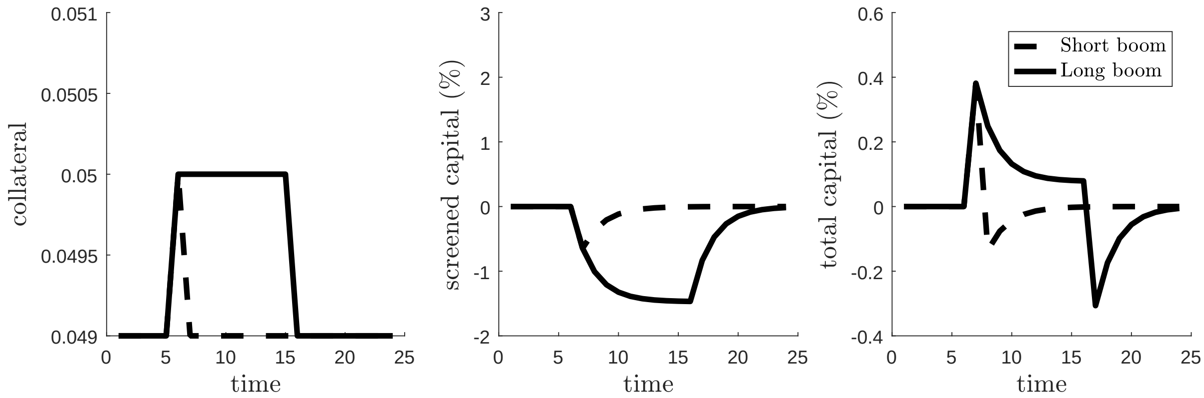

Figure 5: **Longer booms, larger busts**. The figure depicts the equilibrium evolution of the total capital and H-type capital throughout collateral boom-bust episodes of two different durations: one lasts from period 5 to period 7, whereas the other lasts from period 5 to period 15. The variables are expressed in percentage deviation from their low-collateral steady state value, except for collateral. The parameter values used to produce the figures are provided in Appendix A.6.

maintain the stock of unscreened capital or to quickly rebuild the stock of screened capital, the economy temporarily undershoots its new steady-state level of output. Thus, the depletion of information during the boom amplifies the fall in output when the bust comes. Moreover, as Figure 5 shows, because longer booms lead to more information depletion, they also tend to end in deeper busts or “crises” and slower recoveries.

Figures 4 and 5 thus summarize the key properties of collateral-driven booms. As long as they last, collateral booms raise the economy’s capital stock and output, but they deplete its stock of information embedded in screened capital. As a result, when the boom comes to an end, it triggers a decline in economic activity, which is stronger and longer-lasting the more time the economy has spent in the boom.

It is again instructive to contrast the boom-bust episodes driven by collateral values with those driven by productivity shocks. To this effect, Figure 6 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 during the boom. As a result, when the economy transitions back to the low-productivity state, it does so with a relatively high stock of screened capital. Despite the fall in productivity, this relative abundance of screened capital “cushions” the economy’s transition to the new steady state.

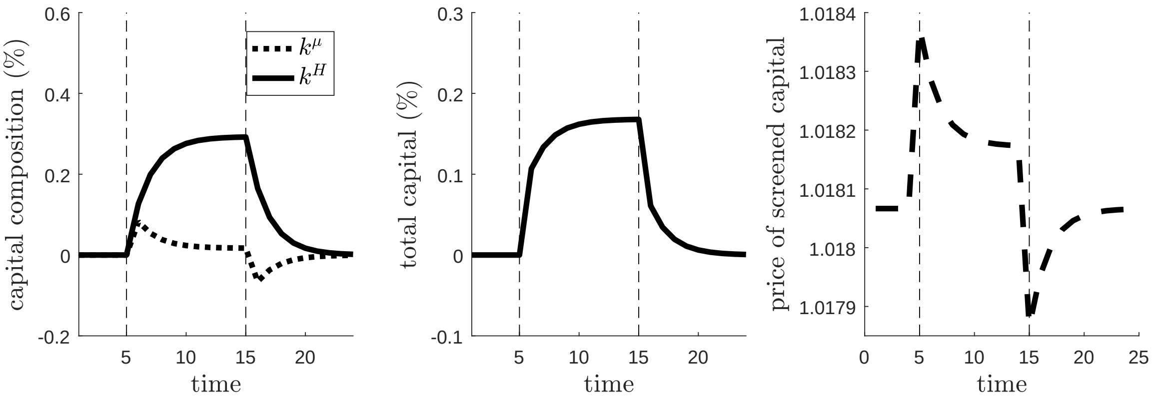

Figure 6: **Productivity boom-bust episode**. The figure depicts the equilibrium evolution of capital, its composition and capital prices throughout a productivity boom-bust episode. Aggregate TFP is $A_t = \underline{A}$ before period 5 and after period 15, and $A_t = \bar{A} > \underline{A}$ between periods 5 and 15. The variables are expressed in percentage deviation from their low-productivity steady state value, except for the price of screened capital. The parameter values used to produce the figures are provided in Appendix A.6.

3.3 Discussion

This section has outlined the key insight of our theory: namely, the equilibrium amount of screening depends on the availability of collateral. During collateral booms, the economy naturally relies less on screening and more on collateralization. But this depletes the stock of information embedded in screened projects. Because information is slow-moving, moreover, the end of a collateral boom is accompanied by a deep bust and a slow recovery.

These results rely on two features of the environment. The first is that the production technology combines capital and labor, but labor is scarce. In our setting, this scarcity is captured starkly through a fixed supply of labor, but nothing substantial would change if we assumed that the labor supply was increasing in the wage. What is key is that the equilibrium wage is increasing in labor demand, as depicted by Equation (2): hence, whenever investment in some projects expands, the ensuing increase in the demand for labor raises wages and reduces the return to all investment projects. In general equilibrium, therefore, different investment projects are effectively substitutes because they compete for a common factor of production – labor.

The second feature of the environment is the scarcity of expertise, which is formally captured by the assumption that experts face a capacity constraint and have heterogeneous abilities to screen projects. These assumptions jointly imply that screening is costly and that screening costs are effectively convex. As a result, it costly for the economy to produce a large amount of information all at once, which implies that it takes time to replenish the depleted stock of information in the wake of a collateral bust. These features of the screening technology are standard in the banking literature (e.g., Ruckes (2004), Freixas and Rochet (2008)) and often motivated by the fact that screening borrowers may require trained loan officers and information gathering/processing infrastructure that are difficult to change in the short run.

Besides these two central features, we have made additional assumptions regarding the screening technology that are convenient but not central for the results. We comment on two of them here. The first assumption is that there is no asymmetric information, so that screening is equally informative for lenders and entrepreneurs. As we show in Appendix A.5, however, our model is essentially equivalent to a setting with asymmetric information in which entrepreneurs can ex-ante choose whether to produce H quality projects, which enable entrepreneurs to pledge the entire stream of revenues, or L quality projects, which enable entrepreneurs to pledge only a fraction of these revenues.

The second assumption is that the information produced through screening is public. In the context of our OLG setting with two-period lifetimes, where only public information can act as a state-variable, it is important that the outcome of screening become public information with positive probability.[15] However, we conjecture that the same relation between collateral and information depletion would arise in a more complex world, where creditors are long-lived (so that private information acts as a state-variable) and where screening produces private information for them that cannot be disclosed to the market. The reason is that, even in such a world, creditors would face a trade-off between producing (costly) private information about their borrowers or lending to them against collateral. Once this trade-off exists, a collateral boom is bound to relax the constraints that restrict unscreened investment and – through the aforementioned effects – lead to information depletion.

4 Is there too little information?

One of the main insights of the previous section is 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 equilibrium is inefficiently low. In this section, we show that such a conclusion is unwarranted in our baseline model. Since the asset market 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, we show that due to pecuniary externalities the information produced in equilibrium is inefficiently high!

[15]This could be either because entrepreneurs are able disclose the outcome of screening to the public, or because entrepreneurs' or lenders' equilibrium behavior partially reveals this outcome.

To see this, 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.[16] We make a set of assumptions on what the planner can do so as to avoid giving 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 at the planner's solution: as in the competitive equilibrium, this requires q_t to 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.[17] This problem can be expressed recursively as follows (see Appendix A.1 for detailed derivations):

$$V\left(k_t^H, k_t^U, q_t, A_t\right) = \max_{\left\{s_t, k_{t+1}^H, k_{t+1}^U\right\}} A_t \cdot k_t^\alpha + (1-\delta) \cdot k_t - k_{t+1} - \int_0^{s_t} \psi(x)dx + q_t + \rho^{-1} \cdot E_t V\left(k_{t+1}^H, k_{t+1}^U, q_{t+1}, A_{t+1}\right) \tag{22}$$

subject to the following set of constraints:

$$k_{t+1} = k_{t+1}^H + k_{t+1}^U, \tag{23}$$

$$s_t = \mu^{-1} \cdot \max\left\{0,\ k_{t+1}^H - (1-\delta) k_t^H\right\}, \tag{24}$$

$$k_{t+1}^U = \frac{\rho}{\rho - \mu \cdot E_t \left\{\alpha A_{t+1} \left(k_{t+1}^H + k_{t+1}^U\right)^{\alpha-1} + 1 - \delta\right\}} \cdot q_t, \tag{25}$$

where V is the planner's value function, which depends on the economy's state variables: the stock of screened and unscreened capital, the value of collateral and aggregate productivity. The planner's per period return is given by the total output of the economy net of investment in physical capital and net of the screening costs of the experts plus the value of collateral. Constraints (23)-(25) 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; and that investment in unscreened capital must satisfy the borrowing constraint.

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

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

The borrowing constraint in Equation (25) plays a key role. It implicitly defines the stock of unscreened capital as a decreasing function of the stock of H-type capital, i.e., $k_{t+1}^{U} = k^{U}\left(k_{t+1}^{H}, q_t, A_t\right)$, with $\partial k^{U}\left(k_{t+1}^{H}, q_t, A_t\right)/\partial k_{t+1}^{H} < 0$. This reflects the fact that each additional unit of screened investment increases the demand for labor and thus the equilibrium wages, which (by depressing the marginal product of capital) reduces the pledgeable output of unscreened investment, thereby crowding it out. In the laissez-faire equilibrium, entrepreneurs do not internalize this relationship because they take the wages as given. But the planner does, and the first-order conditions to her problem yield:

$$1+\frac{\psi\left(s_t\right)}{\mu}=\frac{E_t\left\{\alpha A_{t+1}k_{t+1}^{\alpha-1}+(1-\delta)\cdot\left(1+\frac{\psi(s_{t+1})}{\mu}\right)\right\}}{\rho}$$
$$+\left(\frac{E_t\left\{\alpha A_{t+1}k_{t+1}^{\alpha-1}+1-\delta\right\}}{\rho}-1\right)\cdot\frac{\partial k^{\mu}\left(k_{t+1}^{H}, q_t, A_t\right)}{\partial k_{t+1}^{H}}, \tag{26}$$

which together with Equations (23)-(25) characterize the solution to the planner's problem.

Equation (26) illustrates the key difference between the planner's solution and the competitive equilibrium. At the competitive equilibrium, market clearing and optimization require that the market value of a unit of screened capital, i.e., $1+\frac{\psi(s_t)}{\mu}$, equals its expected discounted return. In contrast, the planner's optimality condition has an additional negative term in the right-hand-side of Equation (26), because she understands that in equilibrium each additional unit of screened investment crowds out unscreened investment. And, insofar as borrowing constraints bind, the expected return to unscreened investment, $E_t\left\{\alpha A_{t+1}k_{t+1}^{\alpha-1}+1-\delta\right\}$, exceeds the interest rate, ρ, and this crowding out leads to a first-order welfare loss. This pecuniary externality is related to, but also different from, those identified in the recent macro-finance literature on excessive borrowing (Caballero and Krishnamurthy, 2003; Lorenzoni, 2008; Dávila and Korinek, 2017). The externalities typically analysed in that literature arise because agents do not internalize the effects of their borrowing decisions on asset prices, which can have first-order welfare effects if asset prices affect borrowing constraints and/or risk-sharing among agents is imperfect. In contrast, the externality in our setting arises because agents do not internalize that some investments (screened) reduce the return to other investments (unscreened) through their effects on labor markets, and this can have first-order welfare effects in the presence of financial constraints.

As for implementation, the planner's allocations can be decentralized as a competitive equilibrium through a sequence of state-contingent Pigouvian taxes $\{\tau_t\}$ on each unit of screened investment, with revenues rebated in lump sum fashion to the households. Letting $\left\{s_t^{*}, k_{t+1}^{H*}, k_{t+1}^{U*}\right\}$ denote the planner's allocation, the sequence of taxes that implements it can be shown to satisfy:

$$\tau_t = -\left(\frac{E_t\left\{\alpha A_{t+1}k_{t+1}^{*\alpha-1}+1-\delta\right\}}{\rho}-1\right)\cdot\frac{\partial k^U\left(k_{t+1}^{H*},q_t,A_t\right)}{\partial k_{t+1}^H}+\frac{1-\delta}{\rho}\cdot E_t\tau_{t+1}, \tag{27}$$

where $k_{t+1}^* = k_{t+1}^{H*} + k_{t+1}^{U*}$. The first term on the right-hand side of Equation (27) reflects the pecuniary externality the planner wants to correct: by taxing screened investment, the planner reduces it relative to the competitive equilibrium. 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.

To conclude, contrary to conventional wisdom, there is no shortage of information in equilibrium. Although this result may appear surprising to most readers, it is quite natural given that the entrepreneurs fully appropriate the social benefits of screened investment. Clearly, things could change in the presence of distortions that prevented such appropriation. We briefly explore two sources of such distortions in the next section.

4.1 Frictional markets and learning-by-doing

A first set of distortions are those that directly affect the market for screened capital. Assume for instance 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 entrepreneur and they bargain over the price. 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. In this setting, the zero-profit condition for screened investment becomes:

$$\begin{aligned}1+\frac{\psi\left(s_t\right)}{\mu} = & \frac{E_t\left\{\alpha A_{t+1}k_{t+1}^{\alpha-1}+(1-\delta)\cdot\left(1+\frac{\psi(s_{t+1})}{\mu}\right)\right\}}{\rho} \\ & -\beta\cdot\frac{1-\delta}{\rho}\cdot\frac{E_t\psi(s_{t+1})}{\mu},\end{aligned} \tag{28}$$

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 decentralized equilibrium. And given that the planner's solution is unaffected, it is now possible (if β is high enough) 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, suppose that $\psi_t = \psi\left(s_t, k_t^H\right)$ 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 capturing economy-wide "learning-by-doing," so that the experts' cost of screening projects falls with the cumulative amount of screening done in the past. In this setting, it is the zero-profit condition of individual entrepreneurs that remains unchanged, whereas the planner's optimality condition becomes:

$$1 + \frac{\psi\left(s_t^*, k_t^{H*}\right)}{\mu} = \frac{E_t\left\{\alpha A_{t+1} k_{t+1}^{*\alpha-1} + (1-\delta)\cdot\left(1 + \frac{\psi\left(s_{t+1}^*, k_{t+1}^{H*}\right)}{\mu}\right)\right\}}{\rho} + \left(\frac{E_t\left\{\alpha A_{t+1} k_{t+1}^{*\alpha-1} + 1 - \delta\right\}}{\rho} - 1\right)\cdot\frac{\partial k^\mu\left(k_{t+1}^{H*}, q_t, A_t\right)}{\partial k_{t+1}^H}, + \frac{E_t \int_0^{s_{t+1}^*}\psi_2(x, k_{t+1}^{H*})dx}{\rho}. \tag{29}$$

Agents in the decentralized economy do not internalize the learning-by-doing externality, but the planner does. As reflected in the last term of Equation (29), the planner understands that, by raising screened investment today, she reduces the expected cost of screening in period $t+1$. Once again, if this effect is strong enough, it is possible for screened investment to be inefficiently low in equilibrium.

5 Bubbles, misallocation and fire-sales

We have developed a theory of information production during collateral booms and have derived its main implications. Now we turn to some lingering questions. What exactly is the origin of collateral booms? And what does the theory say about other phenomena typically associated to credit booms, such as rising factor misallocation during booms and fire-sales of productive assets during busts?

5.1 Bubble-driven credit booms

Up to now, we have analyzed the effects of fluctuations in the value of collateral q_t without specifying the origin of these fluctuations. Strictly speaking, they reflect changes in the net worth or collateral of entrepreneurs that are orthogonal to their investment and production opportunities. One natural interpretation is that q_t reflects the value of natural resources owned by entrepreneurs, such as land, and that fluctuations in q_t reflect fluctuations in the expected dividends or rents generated by these resources.

A second, subtler interpretation is that q_t reflects the existence of asset bubbles. To see this, consider a slightly modified version of our economy in which production and investment must take place within firms that are owned and managed by entrepreneurs. Young entrepreneurs can purchase pre-existing firms in the stock market or they can create new ones at zero cost. In this modified economy, entrepreneurs can obtain credit to purchase their firms and/or to invest in them, but they can hide the output produced by L-type capital from outsiders.

If the equilibrium interest rate is lower than the growth rate of the economy, i.e., $\rho < 1$, it is easy to show that this modified economy admits two types of equilibria: fundamental equilibria, in which the stock market value of all firms is equal to the cost of replacing their capital stock, and bubbly equilibria, in which the stock market value of some firms exceeds the cost of replacing their capital stock.[18] Formally, if we use J_t to denote the set of firms that are active in period t, we can write the stock market value of firm $j \in J_t$ as:

$$\nu_{jt} = (1-\delta) \cdot \left(p_t^U \cdot k_{jt}^U + p_t^H \cdot k_{jt}^H\right) + b_{jt}, \tag{30}$$

where k_{jt}^U and k_{jt}^H respectively denote the units of unscreened and H-type capital 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 stock market value 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 stock market value of some firms exceeds the value of the capital stock that they contain. Given the international interest rate ρ and firm prices in Equation (30), $b_{jt} > 0$ in equilibrium if and only if:

$$\rho = \frac{E_t b_{jt+1}}{b_{jt}}. \tag{31}$$

Equation (31) 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 (31), Equations (17)-(19) can be interpreted as a bubbly equilibrium in which q_t reflects the value of 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 q_t is high, the market is

[18] See Martin and Ventura (2018) for a discussion of these conditions in a closely related framework.

more willing to lend against the value of new firms and entrepreneurs can use this additional borrowing to expand investment. When q_t is low, the market is less willing to lend against the bubbly component of new firms and entrepreneurial borrowing and investment falls.

Under this interpretation, our theory highlights a novel and yet unexplored cost of asset bubbles. Bubbles provide collateral without changing the economy's production possibilities: hence, bubbly episodes are likely to be accompanied by information depletion and, as in Section 3, the bursting of bubbles is likely to be characterized by deep crises and slow recoveries.

5.2 Credit booms and factor misallocation

There is a growing view among economists that credit booms are associated with a less efficient allocation of resources, i.e., with "misallocation." 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 theory 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 assume that aggregate productivity is constant (i.e., $A_t = A$ for all t), and modify it along one key dimension: besides their different pledgeability to outsiders, 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.[19]

With these modifications, the equilibrium of the "static" model is essentially unchanged relative to Equations (15) and (16). While the evolution of k_t^H is still governed by (16), the evolution of k_{t+1}^U is now given by:

$$k_{t+1}^U = \min\left\{\frac{\rho}{\rho - \mu \cdot E_t r_{t+1}} \cdot q_t, \max\left\{0, \left[\left(\frac{A \cdot \alpha \cdot \bar{\lambda}}{\rho}\right)^{\frac{1}{1-\alpha}} - k_{t+1}^H\right] \frac{1}{\bar{\lambda}}\right\}\right\}, \tag{32}$$

where $\bar{\lambda} = \mu + (1 - \mu) \cdot \lambda$ reflects the fact that unscreened investment is now less productive.

What does the variance of TFP (i.e., "misallocation") look like in this extended model,

[19] The arguments that follow require only that there be some correlation (positive or negative!) between productivity and pledgeability of projects.

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:

$$VAR_{TFP,t} = \frac{k_t^H + \mu \cdot k_t^U}{k_t^H + k_t^U} \cdot \left(\frac{A}{\overline{A}_t} - 1 \right)^2 + \frac{(1-\mu) \cdot k_t^U}{k_t^H + k_t^U} \cdot \left(\frac{\lambda^\alpha \cdot A}{\overline{A}_t} - 1 \right)^2, \tag{33}$$

where $\overline{A}_t$ denotes the average of measured TFP. This expression has a very natural interpretation. Of all the units in the economy, $k_t^H + \mu \cdot k_t^U$ are of H-type and for these units measured TFP equals $A > \overline{A}_t$. The remaining $(1-\mu) \cdot k_t^U$ units are of L-type and for these units measured TFP equals $\lambda^\alpha \cdot A < \overline{A}_t$.

As we show in Appendix A.2, misallocation in this economy depends only on the ratio of screened to unscreened capital, $\kappa_t \equiv k_t^H / k_t^U$. Specifically, it is decreasing in this ratio (and thus increasing in q_t) if and only if:

$$\kappa_t > \lambda^\alpha \cdot (1-\mu) - \mu. \tag{34}$$

The economic intuition behind this condition is as follows: an increase in κ_t 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 requires κ_t to exceed a certain threshold, which is negative if $\mu > \lambda^\alpha/(1+\lambda^\alpha)$.

Figure 7 illustrates, for our baseline parametrization, the evolution of measured misallocation as a function of q_t. In this parametrization, condition (34) always holds. When $q_t = 0$, all investment is screened and there is no misallocation: ultimately, the economy has only high-quality capital. As q_t increases and the composition of the capital stock shifts towards unscreened capital (i.e., κ_t falls), misallocation rises. Simply put, agents reduce their screening before investing and this leads to higher investment in low-quality capital. When q_t is large enough, entrepreneurs become unconstrained, and their investment decisions and thus misallocation no longer depends on collateral values.

We could 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

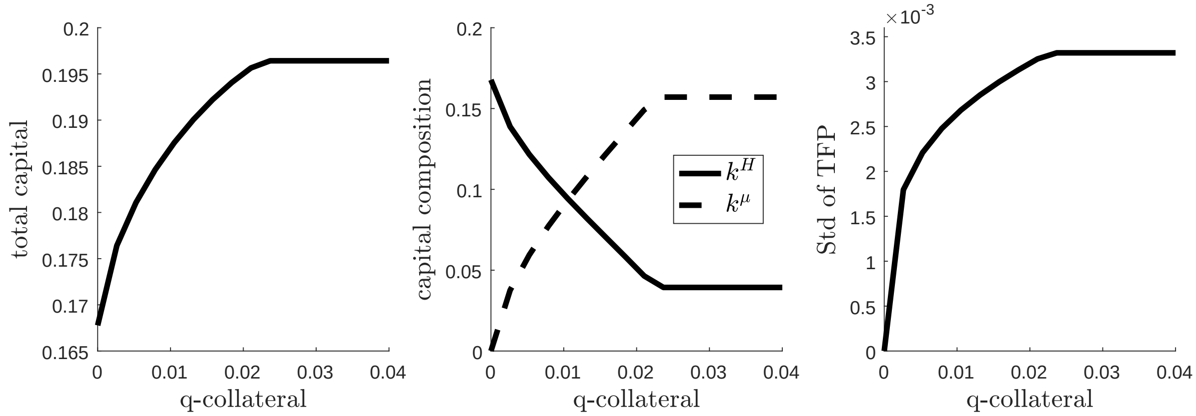

Figure 7: **Collateral values and misallocation**. The figure depicts the equilibrium capital stock and its composition, and the standard deviation of productivity, as a function of collateral q, in the economy with full depreciation. The parameter values used to produce the figures are provided in Appendix A.6.

inefficient. It is true that agents reduce their screening and therefore make their investment decisions in a less informed manner. 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.

5.3 Credit busts and fire-sales

Our baseline model assumes that capital is perfectly reversible. Although convenient, this assumption has a very stark 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 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 a fall in 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

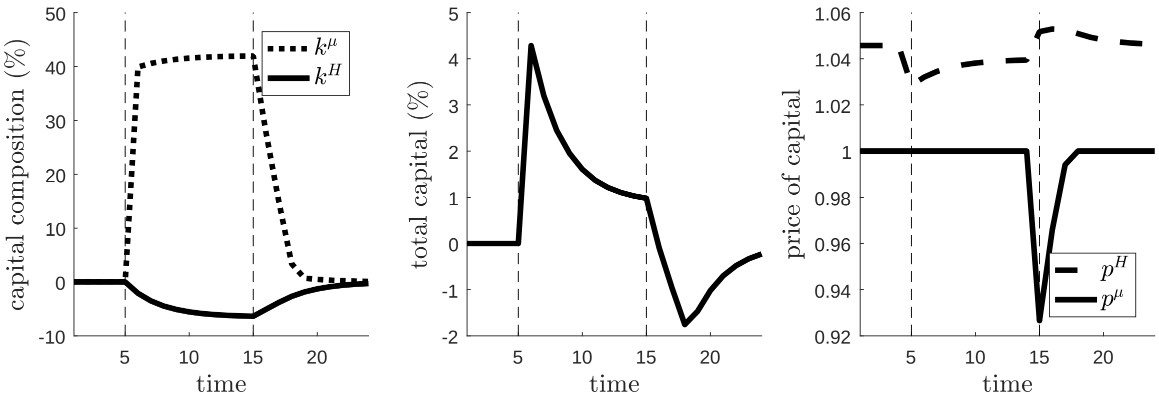

Figure 8: **Collateral boom-bust episode with** $\chi < 1$. The figure depicts the equilibrium evolution of capital, its composition and capital prices throughout a collateral boom-bust episode. Collateral values are $q_t = \underline{q}$ before period 5 and after period 15, and $q_t = \bar{q} > \underline{q}$ between periods 5 and 15. The variables are expressed in percentage deviation from their low-collateral steady state value, except for the price of screened capital. The parameter values used to produce the figures are provided in Appendix A.6.

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 capital, i.e., $k^m_{t+1} \leq (1-\delta) \cdot k^m_t$ for $m \in \{H, U\}$, the corresponding price will be depressed, i.e., $p^m_t \in [\chi, 1]$. Except for this modification, the characterization of equilibrium is basically as before. Equations (49)-(54) in the Appendix provide a formal description of the equilibrium.

Figure 8 illustrates the workings of this modified model by simulating a collateral boom-bust episode. We use the same parametrization 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, and we feed a larger shock to collateral values to ensure that fire-sales are triggered in the low-collateral state. 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 absorbed by a decline in its price. 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 unscreened capital and to a decline in its price, which relaxes the borrowing constraint of entrepreneurs and absorbs 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.

6 Supporting evidence

Our theory is based on a simple premise: some types of investment enable entrepreneurs to divert resources for private consumption. Lenders protect themselves against such diversion either by asking entrepreneurs for collateral or by engaging in costly screening of entrepreneurs' projects. The key insight of the model is that, in equilibrium, the economy's reliance on screening depends on the aggregate availability of collateral. During collateral booms, the economy naturally relies less on screening and more on collateralization. This depletes the stock of information embedded in screened projects, however. Because information is slow-moving, moreover, the end of a collateral boom is accompanied by a deep bust and a slow recovery.

The main implications of the theory are broadly in line with several strands of stylized evidence. First, there is ample evidence that investment is increasing in the value of collateral (e.g., Chaney et al. (2012)). Second, there is also evidence that the quality of lenders' information on borrowers is lower in good times (Becker et al., 2016; Lisowsky et al., 2017), which is consistent with information depletion during booms.[20] At a more aggregate level, the theory is consistent with the empirical finding that not all credit booms are alike: in particular, credit booms that are accompanied by house price booms (Richter et al., 2017) and that are characterized by low productivity growth (Gorton and Ordoñez, 2016) are more likely to end in crises.

But we want to go beyond this stylized evidence and focus on the prediction that is at the core of our theory: namely, increases in collateral values lead to a decline in the economy's reliance on screening (i.e., to less information). We test this prediction on US firm-level data. Doing so is non-trivial for at least two reasons.

First, we need to identify changes in collateral that are orthogonal to other economic conditions, such as productivity, which may affect screening intensity on their own. Previous research has dealt with this problem (i) by 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. In particular, we build on the work of Chaney et al. (2012)

[20]Using Swedish data, for instance, Becker et al. (2016) find that banks are less able to predict the credit quality of borrowers in good times. Lisowsky et al. (2017), in turn, show that banks significantly reduced their collection of audited financial statements from construction firms during the US housing boom before 2008.

and use the value of US firms' real estate holdings as a proxy for their collateral. We can then interpret local variations in real estate prices as shocks to the collateral value of firms that own real estate and use this variation to measure the impact of real estate prices on screening intensity (i.e., information generation). Relative to the original paper of Chaney et al. (2012), we extend the sample period to include the post-2007 housing bust and – crucially – we focus on the effect of real estate prices on firm-level measures of screening intensity (as opposed to their effect on investment).

Second, there is no generally agreed upon measure of screening or information generation. We proceed by focusing on two alternative firm-level measures of information generation that have previously been used in the literature. The first measure is the duration of a firm's main lending relationship in the syndicated loan market. The banking literature has shown that close relationships between banks and firms facilitate monitoring and screening, generating information about borrowers. Such information is gathered over time through multiple interactions (Slovin et al., 1993; Petersen and Rajan, 1995; Berger and Udell, 1995). Under this interpretation, the theory would imply that the strength of a firm's relationship with its banks (as proxied by length) should be negatively affected by firm's collateral. A second measure of information is the number of financial analysts that follow a particular firm. Similar to screening in our model, financial analysts produce and disseminate information by aggregating and consolidating it in a way that is more easily digestible for less sophisticated investors (Huang and Stoll, 1997; Chang et al., 2006). Through the lens of our theory, we should therefore expect the number of analysts that follow a firm to be decreasing in the value of the firm's collateral.

6.1 Empirical specifications

To test the prediction that information decreases when collateral values increase, we estimate – for firm i, at date t, with headquarters in location k (state or MSA) – the following information equation:

$$Info_{it} = \alpha_i + \delta_t + \beta \cdot RE_{it} + \gamma \cdot P_{kt} + controls_{it} + \varepsilon_{it}, \tag{35}$$

where $Info_{it}$ is a firm-level measure of information in year t, RE_{it} is the ratio of the market value of real estate assets in year t to lagged property, plant and equipment, 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. Our prediction is that $\beta < 0$ and significant. In other words, increases in the value of collateral decreases information generation.

There are two potential sources of endogeneity in the estimation of Equation (35): (i) real estate prices could be correlated with information generation, and; (ii) the firm's decision to own real estate could be correlated with its information generation. 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}:

$$P_{kt} = \alpha_k + \delta_t + \gamma \cdot Elasticity_k \times R_t + v_{kt}, \tag{36}$$

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), who use the same setup to study firm investment 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 decision to own real estate: five quintiles of age, assets, return on assets, two-digit industry dummies, and state dummies.

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, bank relationship information from LPC Dealscan, and analyst coverage data from the I/B/E/S Historical Summary Files. The sample period is 1993 to 2016. For a detailed description of the construction of the dataset and definitions of the control variables, see Appendix B.1.

Our first measure of information is the duration of the firm's main lending relationship, expressed in years. We construct this measure of the duration of the firm's lending relationship with its main bank using data from the syndicated loans market. We obtain data on the characteristics of syndicated loan deals, the lead arranger and the participant lender from LPC's Dealscan.[21] Our relationship measure is volume-weighted by loan amount across all main bank relationships of the firm. In what follows we refer to the volume-weighted duration of the main banking relationship of firm i during year t as $Relationship_{it}$, and assume that it is increasing in the amount of information on the firm.

As alternative measure of firm-level information, we use the number of financial analysts

[21] This dataset on syndicated loans has been widely used in the academic literature; see, for example, Sufi (2007), Ivashina (2009) and Ivashina and Scharfstein (2010).

that follow a particular firm. 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. Like the relationship measure, $Analysts_{it}$ is increasing in the amount of information on firm i.

Because the distributions of the $Relationship_{it}$ and $Analysts_{it}$ variables are skewed, we use $ln(1 + Relationship_{it})$ and $ln(Analysts_{it})$ as dependent variables in our empirical analysis. Figure 9 shows the evolution of our two proxies for firm-level information over our sample period. We observe that both measures are increasing over the first part of the sample period and then taper off over the post-crisis period.

Table 3 presents the descriptive statistics of our regression variables. In our sample, real estate is a sizable fraction of the tangible assets that corporations hold on their balance sheet. For the median firm in the 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 main bank relationship is 3.6 years, with an interquartile range of 7.4 years, and the median number of analysts covering a firm is 5 with an interquartile range of 9.

6.3 Empirical results

Table 1 presents estimates of various specifications of Equation (35), using the alternative measures of information as dependent variables. The regression results support our central prediction that collateral price increases are associated with a decline in information generation at the firm level.

Columns 1-3 depict the results when the dependent variable is the volume-weighted duration of the firm's main banking relationship. The baseline coefficient, which corresponds to the case in which real estate prices are measured at the state level, is reported in column 1 and equals -0.069. This implies that each additional 1 percentage point increase in real estate collateral (relative to PPE) decreases the length of the firm's main banking relationship by 0.069 years, or 0.83 months. The effect is economically substantial: it suggests that a one-standard deviation increase in real estate collateral lowers the average duration of the banking relationship by 10.1 percent of its standard deviation.[22] Column 2 uses residential prices measured at the MSA level instead of at the state level. The results remain qualitatively similar. Column 3 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

[22]The sample standard deviation of RE_{it} is 1.44 and the sample standard deviation of $ln(1+Relationship_{it})$ is 0.98.

Table 1: **Information and collateral**

VARIABLES	(1) Relationship OLS	(2) Relationship OLS	(3) Relationship IV	(4) Analysts OLS	(5) Analysts OLS	(6) Analysts IV
RE Value (State Prices)	-0.0691***			-0.136***		
	(0.00869)			(0.00771)		
RE Value (MSA Prices)		-0.0429***	-0.0486***		-0.142***	-0.154***
		(0.00920)	(0.0101)		(0.00838)	(0.00919)
State Prices	-3.127***			-4.992***		
	(1.209)			(1.415)		
MSA Prices		-0.597	-3.378***		-14.33***	-1.294
		(3.624)	(1.008)		(4.792)	(0.865)
Cash	-0.00141	-0.00360	-0.00349	0.0176***	0.0198***	0.0177***
	(0.00409)	(0.00445)	(0.00454)	(0.00376)	(0.00415)	(0.00434)
Market/Book	-0.0315***	-0.0311***	-0.0294***	0.0646***	0.0657***	0.0684***
	(0.00414)	(0.00513)	(0.00541)	(0.00375)	(0.00410)	(0.00426)
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	23 153	19 841	17 031	17 135	14 572	12 529
Adjusted R-squared	0.671	0.668	0.665	0.809	0.810	0.816

Notes: The table reports the empirical link between the value of real estate assets and information at the firm level. The dependent variable in Columns 1 to 3 is ln(1+R), where R is the volume-weighted duration of the firm's main bank relationship, expressed in number of years, computed using data from LPC Dealscan. The dependent variable in Columns 4 to 6 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 et al. (2006) using data from the I/B/E/S Historical Summary File. RE Value is the ratio of the market value of real estate assets normalized by the lagged value of PPE. 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 Cash, previous year Market/Book, and firm-level initial characteristics (five quintiles of age, asset, and ROA, as well as two-digit industry and state of location) interacted with Real Estate Prices. 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 4 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. Sample period is 1993 to 2016. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

prices from the estimation of Equation (36) are used as an explanatory variable in Equation (35). The IV estimate of the coefficient on real estate collateral is close to the OLS estimate and statistically significant at the 1 percent level. The first-stage regression estimates of Equation (36) are presented in Table 4 and confirm the findings of Chaney et al. (2012), even though the impact of local housing supply elasticity on housing prices is somewhat reduced in our 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.

In columns 4 to 6 of Table 1, we show that our results are robust to measuring information through the number of financial analysts that follow the firm. The estimated economic effects tend to be somewhat larger than they are under the relationship-based measure of information. Based on the IV estimates in column 6, for instance, a one-standard deviation increase in real estate collateral decreases analyst coverage by 27.6 percent of its standard deviation.[23] Taken together, these results suggest that the firm-level evidence from the US is consistent with the central prediction of the theory: increases in collateral prices reduce information.

7 Conclusions

This paper has developed a new theory of information production 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, which proves costly when collateral values fall. The theory is consistent with existing stylized evidence on the relaxation of lending standards during credit booms, and on the increase and reallocation of investment during real estate booms. We have also provided supporting evidence for the theory's core mechanism using US firm-level data.

Crucially, the theory developed here 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 assess their effects on information production. We have taken a first step in this direction by analyzing different proxies for information at the firm level. 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.

[23] The sample standard deviation of $ln(Analysts_{it})$ is 0.80.

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A Appendix: Derivations for Sections 2-5

A.1 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 total output, given by $A \cdot \left(k_t^H + k_t^U\right)^{\alpha}$. Second, there is the disinvestment in physical capital $(1-\delta) \cdot \left(k_t^H + k_t^U\right) - k_{t+1}^H - k_{t+1}^U$. Third, the planner must devote $\int_0^{s_t} \psi(x)dx$ resources 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. Finally, the planner can borrow f_t consumption goods from the international market, and she must repay $R_t \cdot f_{t-1}$ 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:

$$C_t = A\left(k_t^H + k_t^U\right)^{\alpha} + (1-\delta)\left(k_t^H + k_t^U\right) - k_{t+1}^H - k_{t+1}^U - \int_0^{s_t} \psi(x)dx + f_t - R_t \cdot f_{t-1} + q_t. \quad (37)$$

We impose the transversality condition, $\lim_{t\to\infty} \rho^{-t} f_{t-1} = 0$, and suppose that $f_{-1} = 0$. This immediately implies that:

$$E_0 \sum_{t=0}^{\infty} \rho^{-t} C_t = E_0 \sum_{t=0}^{\infty} \rho^{-t} \cdot \left(A_t k_t^{\alpha} + (1-\delta) k_t - k_{t+1} - \int_0^{s_t} \psi(x)\, dx + q_t\right). \quad (38)$$

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

The first-order conditions to the planner's problem of maximizing (38) subject to the constraints (23)-(25) yield:

$$-\mu \cdot \left(1 + \frac{\partial k^U\left(k_{t+1}^H, q_t, A_t\right)}{\partial k_{t+1}^H}\right) - \psi(s_t) + \mu \cdot \frac{E_t \frac{dV\left(k_{t+1}^H, k_{t+1}^U, q_{t+1}, A_{t+1}\right)}{dk_{t+1}^H}}{\rho} = 0, \quad (39)$$

and

$$\frac{dV\left(k_t^H, k_t^U, q_t, A_t\right)}{dk_t^H} = \left(\alpha A_t k_t^{\alpha-1} + 1 - \delta\right) \cdot \left(1 + \frac{\partial k^U\left(k_t^H, q_{t-1}, A_{t-1}\right)}{\partial k_t^H}\right) + (1-\delta) \cdot \mu^{-1} \cdot \psi(s_t). \quad (40)$$

Combining these, we get Equation (26) in the main body of the paper, which together with (23)-(25) and the transversality condition, $\lim_{t\to\infty} \rho^{-t} \psi(s_t) = 0$, characterizes the solution to the planner's problem.

A.2 Credit booms and factor 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:

$$VAR_{TFP,t} = \frac{k_t^H + \mu \cdot k_t^U}{k_t^H + k_t^U} \cdot \left(\frac{A}{\overline{A}_t} - 1 \right)^2 + \frac{(1-\mu) \cdot k_t^U}{k_t^H + k_t^U} \cdot \left(\frac{\lambda^{\alpha} \cdot A}{\overline{A}_t} - 1 \right)^2, \tag{41}$$

where $(1-\mu) \cdot k_t^U$ denotes the number of low-quality units of capital in this economy and $\overline{A}_t$ denotes the average productivity of the economy,

$$\overline{A}_t = \frac{k_t^H + k_t^U \cdot [\mu + (1-\mu) \cdot \lambda^{\alpha}]}{k_t^H + k_t^U} \cdot A. \tag{42}$$

Noting that

$$\frac{A}{\overline{A}_t} - 1 = \frac{(1-\mu) \cdot k_t^U}{k_t^H + k_t^U \cdot [\mu + (1-\mu) \cdot \lambda^{\alpha}]} \cdot (1 - \lambda^{\alpha}) \tag{43}$$

and

$$\frac{\lambda^{\alpha} \cdot A}{\overline{A}_t} - 1 = \frac{k_t^H + \mu \cdot k_t^U}{k_t^H + k_t^U \cdot [\mu + (1-\mu) \cdot \lambda^{\alpha}]} \cdot (\lambda^{\alpha} - 1) \tag{44}$$

we can write Equation (41) as,

$$VAR_{TFP,t} = \frac{\kappa_t + \mu}{(\kappa_t + \mu + (1-\mu) \cdot \lambda^{\alpha})^2} \cdot \Lambda, \tag{45}$$

where $\Lambda \equiv (1-\mu) \cdot (\lambda^{\alpha} - 1)^2$ is a constant and $\kappa_t \equiv \frac{k_t^H}{k_t^U}$.

The variance of productivity depends only on the ratio of screened to unscreened capital κ.

Formally,

$$\frac{\partial VAR_{TFP,t}}{\partial \kappa_t} < 0 \iff \mu + \kappa_t > \lambda^\alpha \cdot (1 - \mu), \tag{46}$$

which justifies Equation (34). Thus, an increase in κ_t reduces misallocation if and only if the productivity weighted stock of high-quality capital (i.e., $\mu \cdot k_t^U + k_t^H$) is greater than the productivity weighted stock of low-quality capital (i.e., $\lambda^\alpha \cdot (1-\mu) \cdot k_t^U$). In this case, an increase in k_t^H (or, a reduction in k_t^U) 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 Credit 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_{t+1}^U.

Let p_t^U denote the price of unscreened capital at time t. Given that the cost of producing a unit equals one, if the entrepreneur is credit constrained it must hold that:

$$\min\left\{p_t^U, 1\right\} \cdot k_{t+1}^U = q_t + f_t, \tag{47}$$

whereas, given that old entrepreneurs can liquidate old units and obtain χ,

$$\mu \cdot E_t \left\{r_{t+1} + \max\left\{p_{t+1}^U, \chi\right\} \cdot (1 - \delta)\right\} \cdot k_{t+1}^U = \rho \cdot f_t. \tag{48}$$

Jointly considered, both expression imply that,

$$k_{t+1}^U = \frac{\rho \cdot q_t}{\rho \cdot \min\{p_t^U, 1\} - \mu \cdot E_t\left\{r_{t+1} + \max\left\{p_{t+1}^U, \chi\right\}(1 - \delta)\right\}}. \tag{49}$$

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

$$\min\left\{p_t^U, 1\right\} = \frac{E_t\left\{r_{t+1} + \max\left\{p_{t+1}^U, \chi\right\} \cdot (1 - \delta)\right\}}{\rho}. \tag{50}$$

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

$$p_t^U \begin{cases} = 1 & \text{if } k_{t+1}^U > (1 - \delta)\, k_t^U \\ \in [\chi, 1] & \text{if } k_{t+1}^U = (1 - \delta)\, k_t^U \\ = \chi & \text{if } k_{t+1}^U < (1 - \delta)\, k_t^U \end{cases}, \tag{51}$$

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

$$p_t^H = \frac{E_t \left\{ r_{t+1} + p_{t+1}^H \cdot (1-\delta) \right\}}{\rho}, \tag{52}$$

where screening is given by:

$$s_t = \mu^{-1} \cdot \max \left\{ 0, k_{t+1}^H - (1-\delta)\, k_t^H \right\}. \tag{53}$$

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

$$p_t^H = \begin{cases} = 1 + \frac{\psi(s_t)}{\mu} & \text{if } k_{t+1}^H > (1-\delta)\, k_t^H \\ \in [\chi, 1] & \text{if } k_{t+1}^H = (1-\delta)\, k_t^H \\ = \chi & \text{if } k_{t+1}^H < (1-\delta)\, k_t^H \end{cases}. \tag{54}$$

Equations (49)-(54) fully characterize the equilibrium of this economy.

A.4 Heterogeneous projects, homogeneous capital

We consider a variation of our baseline economy in which production is organized in projects. In particular, the economy contains an infinite sequence of generations of projects, indexed by $j \in J_t$. The set J_t contains all projects that produce in period t. Projects produce output with a Cobb-Douglas technology:

$$F_t(l_{jt}, k_{jt}) = A_t \cdot k_{jt}^{\alpha} \cdot l_{jt}^{1-\alpha}, \ \text{ for } k_{jt} \leq \bar{k},$$

where k_{jt} is the capital stock employed in project j, l_{jt} is the labor employed in project j, A_t reflects aggregate productivity, and $\alpha \in (0,1)$. Note that there is a maximum "scale" of each project, i.e., a maximum amount of capital $\bar{k}$ that any one project can employ. We can think of projects as different plants or production processes that are used for production.

Investment takes place within projects, with a technology that uses one unit of output in period t to produce one unit of capital in period $t+1$. Entrepreneurs can also expand the capital stock of a given project by purchasing pre-existing units of capital in the capital market. The capital stock of project j thus evolves as follows:

$$k_{jt+1} = \frac{z_{jt}}{p_{kt}} + (1-\delta) \cdot k_{jt}, \tag{55}$$

where z_{jt} is the total investment in project j, p_{kt} is the price of capital in period t, and $\delta \in [0,1]$ is the rate of capital depreciation. As in the baseline model, capital is reversible and can be turned into consumption goods one-to-one.

There is no limit to the amount of projects that an entrepreneur can create or operate, and we make two assumptions about the life cycle of projects. First, each project $j \in J_t$ becomes obsolete with probability γ after production takes place. In the event of obsolescence, a project can no longer be used to produce, but its capital can be sold or transformed back to consumption goods. Second, new projects can be created at zero cost by young entrepreneurs. Each new project, however, is of uncertain quality: with probability μ, the project is of type H; with probability $1-\mu$, it is of type L. The quality of each project created by an entrepreneur is independent of the other projects created by the same entrepreneur and, once produced, it persists throughout the project's lifetime. The distinctive feature of L-type projects is that they suffer from an "agency" problem in that they allow the entrepreneur who operates them to abscond with all the resources that they generate. The income generated by H-type projects, however, can be fully pledged to creditors.

All other features of the baseline model remain the same, with the natural innovations that come from considering projects separately from capital. Namely, screening still requires the services of experts, but it refers to a project and not to a unit of capital. Moreover, capital and projects can be traded separately in their respective markets. Entrepreneurs, at any point in time, must choose how many projects of type $m \in \{H, L, U\}$ to purchase and initiate, and how much to invest in each of the projects that they manage.

In this environment, it is relatively straightforward to show that entrepreneurs find it (weakly) optimal to operate projects at the maximum feasible scale, i.e., setting $k_{jt} = \bar{k}$ for all $j \in J_t$. In the case of unscreened and L-type projects, this follows from the fact that they can be costlessly produced: hence, their market price is zero and entrepreneurs are indifferent between running many projects of scale $k < \bar{k}$ or running fewer projects of scale $k = \bar{k}$. In the case of screened projects, entrepreneurs strictly benefit by operating them at maximum scale: since the cost of screening applies to the project as a whole, it is efficient to minimize total screening costs by operating projects that are as large as possible.

It follows that the equilibrium conditions of this modified economy are exactly as in the baseline model, with the exception that the cost of screening is normalized by the scale of projects $\bar{k}$. Formally, let k_t^m denote the stock of capital employed in period t within all projects of type $m \in \{H, L, U\}$, then the laws of motion of k_t^U and k_t^L are still given by Equations (11) and (12), while the law of motion of k_t^H is now given by:

$$\frac{E_t \left\{ r_{t+1} + 1 - \delta + (1-\gamma) \cdot \frac{\psi(s_{t+1})}{\bar{k} \cdot \mu} \right\}}{\rho} = 1 + \frac{\psi(s_t)}{\bar{k} \cdot \mu}, \tag{56}$$

where

$$s_t = \left(\bar{k} \cdot \mu\right)^{-1} \cdot \max\left\{0,\ k_{t+1}^H - (1-\gamma) \cdot k_t^H\right\}. \tag{57}$$

Equations (56) and (57) differ from their counterparts of the baseline model (see Equations (13) and (14)) in two respects. First, both the cost and amount of screening per unit of capital are now divided by $\bar{k}$. Second, since projects can become obsolete, the information embedded in screened projects now depreciates at the rate of obsolescence γ. Clearly, our baseline model corresponds to the case in which $\bar{k} = 1$ and $\gamma = \delta$.

A.5 Privately informed entrepreneurs

We now show our main qualitative results remain robust to the presence of asymmetric information between entrepreneurs and lenders. We modify our baseline setup along two dimensions. First, we assume that before investing entrepreneur knows the quality θ of each of her projects; thus, entrepreneurs effectively choose what type of project to produce. Second, we assume that L-type project allows an entrepreneurs to divert a fraction $1-\omega$ of its resources for private consumption; as before H-type projects do not permit diversion. Given the above modifications, the following equilibrium properties are straightforward to derive.

Entrepreneurs only produce and screen H-type units, and there must be zero profits on these units:

$$1 + \psi(s_t) = \frac{E_t\left\{r_{t+1} + (1-\delta) \cdot (1 + \psi(s_{t+1}))\right\}}{\rho}, \tag{58}$$

with

$$s_t = \max\left\{0,\ k_{t+1}^H - (1-\delta)\, k_t^H\right\}. \tag{59}$$

Comparing with Equations (13)-(14), we note the first difference from our baseline model. Because entrepreneurs know the quality of each unit ex-ante, in order to produce a unit of H-type capital, they only need to screen one unit (rather than μ^{-1} units). As a result, the price or the production cost of each unit of H-type capital is now $1 + \psi_t$ (rather than $1 + \frac{\psi_t}{\mu}$).

Entrepreneurs finance unscreened units with collateralized loans, and lenders will (correctly) infer that all such units are of L-type:

$$k_{t+1}^U = \min\left\{\frac{\rho}{\rho - \omega \cdot E_t\left\{r_{t+1} + 1 - \delta\right\}} \cdot q_t,\ \tilde{k}_{t+1}\right\}, \tag{60}$$

where $\tilde{k}_{t+1}$ is such that $E_t\left\{r_{t+1} + 1 - \delta\right\} = \rho$. Comparing with Equation (11), we note the second difference our baseline model. Because entrepreneurs know the quality of each unit ex-ante, they will never produce L-type capital and screen it. The lenders will (correctly) anticipate that all unscreened units are of L-type; if they thought otherwise, entrepreneurs

Table 2: **Parameter values**

Baseline model		
α	0.2	Capital share
δ	0.15	Depreciation rate
μ	0.85	Probability of H-type investment
ρ	1.1	International interest rate
λ	0.95	Productivity of L-type capital
a	3	Parameter of the screening cost function
b	2	Parameter of the screening cost function
$\underline{q}$	0.049	Low collateral state
$\overline{q}$	0.05	High collateral state
$\underline{A}$	1	Low productivity state
$\overline{A}$	1.0015	High productivity state
π^s	0.01	Probability for a boom to start
π^e	0.01	Probability for a boom to end
Credit busts and fire-sales		
χ	0.9	Conversion factor
$\underline{q}$	0.035	Low collateral state
δ	0.1	Depreciation rate
μ	0.75	Probability of H-type investment

would have an incentive to produce only L-types to increase resource diversion, implying that lenders would make losses. Thus, the lenders fund unscreened units with the anticipation that only a fraction ω of their revenues is pledgeable.

As before, total capital is $k_{t+1} = k^H_{t+1} + k^U_{t+1}$, and $r_{t+1} = \alpha A_{t+1} \left(k^H_{t+1} + k^U_{t+1}\right)^{\alpha-1}$. Despite the above differences, it should be clear that the qualitative behavior of this modified model is the same as that of our baseline.

A.6 Parameter values used for illustrations in Figures 1 to 8

In Table 2, we report the parameter values used to produce all the figures. The functional form for the cost of screening is as follows: $\psi(s_t) = a \cdot s_t^b$. The parameter λ is only used to produce Figure 7, when we allow for heterogeneous productivities. Figure 8 uses the same parameter values as the other figures, except for $\underline{q}$, δ and μ. These adjustments are ensure that large fire-sales are triggered in the low-collateral state.

B Appendix: Data, Variables, and Empirical Analysis

B.1 Data and variable definitions

This section describes the dataset and definitions of the variables used in the empirical analysis in Section 6. The dataset is the same as in Chaney et al. (2012) with two exceptions: we add measures of information and we expand the sample to 2016 in order to cover the post-2007 housing bust. As in Chaney et al. (2012), we start the sample in 1993 because the accumulated depreciation on buildings is not available in COMPUSTAT after 1993. We include firms headquartered in the United States and exclude firms operating in the construction, finance, insurance, real estate, and mining sectors. We keep only firms that appear at least three consecutive years in the sample. This leaves a sample of 3,126 firms and 35,346 firm-year observations for the period 1993 to 2016.

Information. We compute the volume-weighted average length of the firm's main bank relationship, expressed in years, at the monthly level using data from LPC Dealscan. Because we need information on the history of loan transactions to construct a measure of lending relationships over our sample period, we use Dealscan data starting in 1985 which is the first year with adequate coverage in the Dealscan dataset. We restrict the sample to US borrowers and syndicated loans issued in US dollars with a defined facility amount and maturity. Following Sufi (2007), we define a lender as lead lender if the variable "Lead Arranger Credit" takes on the value of "Yes," and if the lender is the only bank specified in the loan deal.

As syndicated loan contracts often consist of multiple tranches, each with at least one lead lender, it is common for multiple banks to be registered as lead banks on the same deal. In such cases, we select the "main" lead bank in two steps. First, we filter for the lead banks whose contracts offer the longest loan maturity. Second, we choose among these banks the ones with the largest amount pledged. In those cases where this algorithm leads to multiple 'lead bank-borrower pairs', we treat those as distinct syndicated loans.

As 'lead bank-borrower pairs' interact repeatedly with each other, it is necessary to evaluate information production over the pairs' entire relationship history. We compute the duration of the lending relationship as the difference between the pairs' latest loan contract expiration date and the earliest loan contract signing date, expressed in years. For borrowers that switch lead banks, we set this variable to zero. Moreover, this variable drops to zero whenever the last loan contract in our sample expires and there are no new lending relationships. To smooth this transition, in such cases we set this variable equal to its last positive observation for up to three more years. Our results are however not affected by this adjustment.

To aggregate this lending relationship measure into an information measure at the firm level, the relationship measure is volume-weighted by the respective amount pledged for each

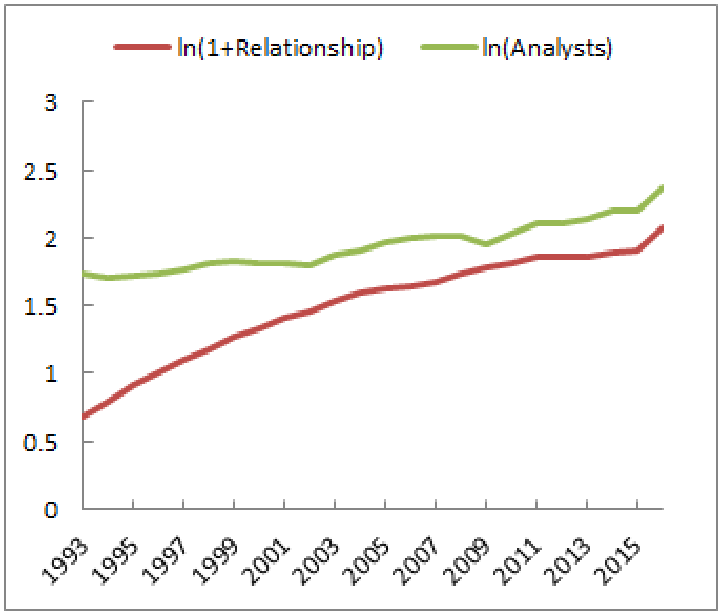

Figure 9: **Firm-level information**

'lead bank-borrower pair' relative to the total loan amount received by each borrower. Loan amounts are expressed in real terms using the US GDP deflator obtained from the US Bureau of Economic Analysis. We follow Chava and Roberts (2008) to merge our relationship measure to COMPUSTAT.

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. We define the Analyst variable as the maximum number of analysts who make annual earnings forecasts for a given firm in any month during the year.

Figure 9 depicts the evolution of the two proxies for information at the firm level, averaged across all firms in the sample, over the sample period 1993 to 2016.

Market value of real estate assets. RE Value is the ratio of the market value of real estate assets normalized by the lagged value of Property, Plant and Equipment (PPE) (COMPUSTAT item No. 8). Real estate assets include buildings, land and improvement, and construction in progress. These assets are valued at historical cost. To impute their market value, we follow the procedure in Chaney et al. (2012), which calculates the average age of these 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 fraction of the initial value of a building that has been depreciated. We impute the average age of real estate assets by assuming that these assets depreciate over 40 years, and we infer the market value of these real estate assets 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.

Real estate prices and land supply. 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 to our main dataset using the state identifier from COMPUSTAT. To match the MSA level HPI, we link Federal Information Processing Standards codes from COMPUSTAT to MSA identifiers using a correspondence table obtained from OFHEO.

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 for a total of 95 MSAs are obtained from Saiz (2010). These elasticities capture the amount of local land that can be developed and are estimated using satellite-generated images of the terrain. We measure long-term interest rates using the 30-year conventional mortgage rate from the Federal Reserve's FRED database.

Control variables. We compute cash holdings as the ratio of cash flows (COMPUSTAT item No. 18 plus item No. 14) to lagged PPE. Market-to-Book ratio is the total market value of equity divided by the book value of assets (COMPUSTAT item No. 6). The market value of equity is calculated by multiplying the number of common stocks (COMPUSTAT item No. 25) by the year-end closing price of common shares (COMPUSTAT item No. 24) plus the book value of debt and quasi equity, computed as book value of assets minus common equity (item No. 60) minus deferred taxes (COMPUSTAT item No. 74). We use the one year lagged value of the market-to-book ratio in the regression. Following Chaney et al. (2012), we include initial firm characteristics to control for 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 the book value of assets, Size measured as the natural logarithm of the book value of assets, Age measured as number of years since initial public offering (IPO), two-digit SIC codes and state of headquarters' location. All variables defined in terms of ratios are winsorized at five times the interquartile range from the median.

B.2 Tables for the empirical analysis in Section 6

Table 3 reports the descriptive statistics and Table 4 reports the first-stage regression results.

Table 3: **Summary statistics**

	Mean	Median	SD	25th percentile	75th percentile	Obs.
Firm-level data						
Relationship	4.74	3.58	4.91	0.00	7.42	25 717
Analysts	7.93	5.00	7.46	2.00	11.00	19 921
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
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
Regional data						
State Prices	0.29	0.26	0.11	0.21	0.35	1 031
MSA Prices	0.14	0.14	0.04	0.11	0.17	3 641
Housing Supply Elasticity	1.66	1.45	0.87	1.01	2.10	1 632
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: Relationship is the volume-weighted average length of the firm's relationship with its main bank, expressed in number of years, computed using data from LPC Dealscan. Analysts is the maximum number of analysts who make annual earnings forecasts in any month over the year, computed following Chang, Dasgupta and Hilary (2006) using data from the I/B/E/S Historical Summary File. 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). 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 is 1993 to 2016.

Table 4: **First-stage regression: the impact of local housing supply elasticity on housing prices**

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. Sample period is 1993 to 2016. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.