Collateral Crises*

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Abstract

Short-term collateralized debt, private money, is efficient if agents are willing to lend without producing costly information about the collateral backing the debt. When the economy relies on such informationally-insensitive debt, firms with low quality collateral can borrow, generating a credit boom and an increase in output. Financial fragility is endogenous; it builds up over time as information about counterparties decays. A crisis occurs when a (possibly small) shock causes agents to suddenly have incentives to produce information, leading to a decline in output. A social planner would produce more information than private agents, but would not always want to eliminate fragility.

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1 Introduction

Financial crises are hard to explain without resorting to large shocks. But, the recent crisis, for example, was not the result of a large shock. The Financial Crisis Inquiry Commission (FCIC) Report (2011) noted that with respect to subprime mortgages: "Overall, for 2005 to 2007 vintage tranches of mortgage-backed securities originally rated triple-A, despite the mass downgrades, only about 10% of Alt-A and 4% of subprime securities had been 'materially impaired'-meaning that losses were imminent or had already been suffered-by the end of 2009" (p. 228-29). Park (2011) calculates the realized principal losses on the \$1.9 trillion of AAA/Aaa-rated subprime bonds issued between 2004 and 2007 to be 17 basis points as of February 2011.[1] Though house prices fell significantly, the effects on mortgage-backed securities, the relevant shock for the financial sector, were not large. But, the crisis was large: the FCIC report goes on to quote Ben Bernanke's testimony that of "13 of the most important financial institutions in the United States, 12 were at risk of failure within a period of a week or two" (p. 354). A small shock led to a systemic crisis. The challenge is to explain how a small shock can sometimes have a very large, sudden, effect, while at other times the effect of the same size shock is small or nonexistent.

One link between small shocks and large crises is leverage. Financial crises are typically preceded by credit booms, and credit growth is the best predictor of the likelihood of a financial crisis.[2] This suggests that a theory of crises should also explain credit booms. But, since leverage per se is not enough for small shocks to have large effects, it also remains to address what gives leverage its potential to magnify shocks. We develop a theory of financial crises, based on the dynamics of the production and evolution of information in short-term debt markets, that is private money such as (uninsured) demand deposits and money market instruments. As we explain below, we have in mind sale and repurchase agreements (repo) that were at the center of

[1]Park (2011) examined the trustee reports from February 2011 for 88.6% of the notional amount of AAA subprime bonds issued between 2004 and 2007. The final realized losses on subprime mortgages will not be known for some years. Mortgage securitizations originated in 2006 show the worst losses, but even these are low. Subprime MBS originated in 2006 show realized losses of 1.02% through December 2011 and prime MBS originated in 2006 had higher losses, 4.01%. See Xie (2012). The Lehman shock was endogenous to the crisis; see Gorton, Metrick, and Xie (2012).

[2]See, for example, Claessens, Kose, and Terrones (2011), Schularick and Taylor (2009), Reinhart and Rogoff (2009), Borio and Drehmann (2009), Mendoza and Terrones (2008) and Collyns and Senhadji (2002). Jorda, Schularick, and Taylor (2011) (p. 1) study 14 developed countries over 140 years (1870-2008): "Our overall result is that credit growth emerges as the best single predictor of financial instability."

the recent financial crisis. We explain how credit booms arise, leading to financial fragility where a small shock can sometimes have large consequences. In short, ”tail risk” is endogenous.

Gorton and Pennacchi (1990) and Dang, Gorton, and Holmström (2011) argue that short-term debt, in the form of bank liabilities or money market instruments, is designed to provide transactions services by allowing trade between agents without fear of adverse selection (due to possible endogenous private information production). In their terminology, this is accomplished by designing debt to be ”information-insensitive”, that is, such that it is not profitable for any agent to produce private information about the assets backing the debt, the collateral. Adverse selection is avoided in trade. But, in a financial crisis there is a sudden loss of confidence in short-term debt in response to a shock. A ”loss of confidence” has the precise meaning that the debt becomes information-sensitive; agents may produce information, and determine whether the backing collateral is good or not.

We build on these micro foundations to investigate the role of such information-insensitive debt in the macro economy. We do not explicitly model the trading motive for short-term information-insensitive debt. Nor do we explicitly include financial intermediaries. We assume that households have a demand for such debt and we assume that the short-term debt is issued directly by firms to households to obtain funds and finance efficient projects. Information production about the backing collateral is costly to produce, and agents do not find it optimal to produce (costly) information at every date, which leads to a depreciation of information over time in the economy. We isolate and investigate the macro dynamics of this lack of information production and the possible sudden threat of information production in response to a (possibly small) shock.

The key dynamic in the model concerns how the perceived quality of collateral evolves if (costly) information is not produced. Collateral is subject to idiosyncratic shocks so that over time, without information production, the perceived value of all collateral tends to be the same because of mean reversion towards a ”perceived average quality”, such that some collateral is known to be bad, but it is not known which specific collateral is bad. Agents endogenously select what to use as collateral. Desirable characteristics of collateral include a high perceived quality and a high cost of information production. In other words, optimal collateral would resemble a complicated, structured, claim on housing or land, e.g., a mortgage-backed security.

When information is not produced and the perceived quality of collateral is high enough, firms with good collateral can borrow, but in addition some firms with bad collateral can borrow. In fact, consumption is highest if there is never information production, because then all firms can borrow, regardless of their true collateral quality. The resulting credit boom increases consumption because more and more firms receive financing and produce output. In our setting opacity can dominate transparency and the economy can enjoy a blissful ignorance. If there has been information-insensitive lending for a long time, that is, information has not been produced for a long time, there is a significant decay of information in the economy - all is grey, there is no black and white - and only a small fraction of true collateral is of known quality.

In this setting we introduce aggregate shocks that may decrease the perceived value of collateral in the economy. Think of the collateral as mortgage-backed securities, for example, being used as collateral for repo, where the households are lending to the firms and receive the collateral. After a credit boom, in which more and more firms borrow with debt backed by collateral of unknown type (but with high perceived quality), a negative aggregate shock affects a larger fraction of collateral than the same aggregate shock would affect when the credit boom was shorter or if the value of collateral was known. Hence, the origin of a crisis is exogenous, but not its size, which depends on how long debt has been information-insensitive in the past and hence how large the corresponding boom has been.

A negative aggregate shock may or may not trigger information production. There may be no effect. It depends on the length of the credit boom. If the shock comes after a long enough credit boom, households have an incentive to learn the true quality of the collateral. Then firms may prefer to cut back on the amount borrowed (a credit crunch) to avoid costly information production, a credit constraint. Or, information may be produced, in which case only firms with good collateral can borrow. In either case, output declines when the economy moves from a regime without fear of asymmetric information to a regime where asymmetric information is a real possibility.

In our theory, there is nothing irrational about the credit boom. It is not optimal to produce information every period, and the credit boom increases output and consumption. There is a problem, however, because private agents, using short-term debt, do not care about the future, which is increasingly fragile. A social planner arrives at a different solution because his cost of producing information is effectively lower. For the planner, acquiring information today has benefits tomorrow, which are not taken into account by private agents. When choosing an optimal policy to manage the fragile economy, the planner weights the costs and benefits of fragility. Fragility is an inherent outcome of using the short-term collateralized debt, and so the planner chooses an optimal level of fragility. This is often popularly discussed in terms of whether the planner should "take the punch bowl away" at the (credit boom) party. Here, the optimal policy may be interpreted as reducing the amount of punch in the bowl, but not taking it away.

Our model is intended to capture the central features of the recent financial crisis, which was preceded by a credit boom and centered on short-term bank debt, in particular sale and repurchase agreements (repo) (see Gorton (2010) and Gorton and Metrick (2012a)). In a repo transaction a lender lends money at interest, usually overnight, and receives collateral in the form of a bond from the borrower. Because repo transactions are very short-term there is no due diligence about the value of the collateral received by the lenders. The collateral is accepted by both parties as recognizably information-insensitive, i.e., no information is produced. Indeed, as in our model much of the collateral was very opaque (i.e., had high information production costs) and was linked to land and housing (subprime bonds). Opacity was the intention of these structures.

In a repo transaction the loan may be overcollateralized, for example the lender lends \$90 but requests collateral with a market value of \$100. This is known as a "haircut", ten percent in this example. Note that if the loan yesterday was for \$100, backed by \$100 of collateral, then today there was a withdrawal of \$10 from the bank, which must now finance the extra \$10 some other way. The financial crisis essentially was this type of bank run; \$1.2 trillion was withdrawn in a short period of time (see Gorton and Metrick (2012b)). Much of the collateral (we don't know how much) was privately produced securitized bonds. The subprime shock caused haircuts to rise as lenders questioned the value of the collateral.

Prior to the recent crisis there was a credit boom, particularly in housing. The mortgages were typically securitized into bonds that were used as collateral in repo. The decline in house prices led lenders to question the value of the collateral in mortgage-backed bonds, as well as other securitizations. In our model short-term collateralized debt is backed by "land", and the dynamics are the same. There is a lending boom and then a shock can cause the value of the backing collateral to be questioned. The crisis corresponds to the case where information is produced and only good collateral can be used once it has been identified. During the financial crisis, some repo collateral was not as affected; it appeared to be ”good” collateral. For example, the haircuts on corporate bond collateral were zero (for high-quality dealer banks) before and during the crisis until after the Lehman bankruptcy when they rose slightly (see Gorton and Metrick (2010)). The collateralized loan obligation market was also able differentiate itself.[3] And, of course, U.S. Treasury bonds continued as collateral during the crisis.

The repo market was not solely an inter-bank market; see Gorton and Metrick (2012b). In our model we abstract from financial intermediaries and model households lending directly to firms. As in the financial crisis, non-financial firms were dramatically affected as financial intermediaries hoarded cash and refused to lend.[4] In our model we examine this direct impact from the shock to collateral values.

Literature Review

We are certainly not the first to explain crises based on a fragility mechanism. Allen and Gale (2004) define fragility as the degree to which ”...small shocks have disproportionately large effects.” Some literature shows how small shocks may have large effects and some literature shows how the same shock may sometimes have large effects and sometimes small effects. Our work tackles both aspects of fragility.

Among papers that highlight magnification, Kiyotaki and Moore (1997) show that leverage can have a large amplification effect. This amplification mechanism relies on feedback effects to collateral value over time, while our mechanism is about a sudden informational regime switch. In their paper every shock is amplified, which seems unrealistic. In our setting, the effect of the shock only occurs if the credit boom has gone on long enough; the same-sized shock is not always amplified.

Papers that focus on potential different effects of the same shock are based on equilibrium multiplicity. Diamond and Dybvig (1983), for example, show that banks are vulnerable to random external events (sunspots) when beliefs about the solvency of banks are self-fulfilling.[5] Our work departs from this literature because fragility

[3]This is a form of securitization where the bonds are backed by bank loans to nonfinancial firms.

[4]This is documented by, for example, by Ivashina and Scharfstein (2010) and Campello, Graham, and Campbell (2010).

[5]Other examples include Lagunoff and Schreft (1999), Allen and Gale (2004) and Ordonez (2011).

evolves endogenously over time and it is not based on equilibria multiplicity but by switches between uniquely determined information regimes.

Our paper is also related to the literature on leverage cycles developed by Geanakoplos (1997, 2010) and Geanakoplos and Zame (2010), but highlights the role of information production in fueling those cycles. Furthermore, in our model leverage is not captured by more borrowing from a single unit of collateral, but from more units of collateral in the economy.

There are a number of papers in which agents choose not to produce information ex ante and then may regret this ex post. Examples are the work of Hanson and Sunderam (2010), Pagano and Volpin (2010), Andolfatto (2010) and Andolfatto, Berensten, and Waller (2011). Like us these models have endogenous information production, but our work describes the endogenous dynamics and real effects of such information.

Two other recent related papers are those of Chari, Shourideh, and Zetlin-Jones (2012) and Guerrieri and Shimer (2012), who discuss adverse selection and asymmetric information as key elements to understanding the recent crisis. In contrast our paper goes one step further and studies the incentives that may induce asymmetric information in the first place.

There is also a recent literature that stresses the role of a rise in firm-level idiosyncratic risk as a contributor of the crisis (e.g., Bigio (2012) and Christiano, Motto, and Rostagno (2012)). In our model there are two ways to accommodate a mean preserving increase in cross-sectional dispersion. First, an exogenous increase in the dispersion of *perceived* values of collateral, which is endogenous object in our model, has the same effect of a sudden information acquisition, reducing output. Second, an exogenous increase in the dispersion of *real* values of collateral also reduces output, but its effect is smaller when less information about collateral is available. Even when our model generates a relation between dispersion and output in line with previous work, the effect of perceived values dispersion is endogenous while the effect of real values dispersion depends on the phase of the credit boom.

Finally, it is worth noting the differences between our model and a recent literature in which credit constraints or other frictions generate ”over-borrowing.” In some of these settings private agents do not internalize the effects of their own leverage in depressing collateral prices in the case of shocks that trigger fire sales. Since a shock is an exogenous unlucky event, the policy implications are clear: there should be less borrowing. Examples of this literature include Lorenzoni (2008) and Bianchi (2011). In contrast to these settings, there is nothing necessarily bad about leverage in our model, compared to these models. First, leverage manifests itself, not as more borrowing based on each unit of collateral, but as more units of collateral that sustain borrowing. Second, leverage always relaxes endogenous credit constraints. Finally, fire sales are not an issue. In our setting the efficient outcome may be fragility.

In sum, our model produces a "Minsky moment" in which there is an endogenous regime switch causing a crisis, although the mechanism that produces it here is very different from what Minsky had in mind, which was more behavioral (see, e.g., Minsky (1986)). From our point of view, a Minsky moment is the idea that emphasizes that a financial crisis is a special event, not just an amplification of a shock. Our mechanism does not rely on a "large" shock.

In the next section we present a single period setting and study the information properties of debt. In section 3 we study the aggregate and dynamic implications of information. We consider policy implications in section 4. In section 5, we conclude.

2 A Single Period Model

In this section we lay out the basic model in a single period setting. In the next section the model is extended to many periods.

2.1 Setting

There are two types of agents in the economy, each with mass 1 – firms and households – and two types of goods – *numeraire* and *"land"*. Agents are risk neutral and derive utility from consuming numeraire at the end of the period. While numeraire is productive and reproducible – it can be used to produce more numeraire – land is not. Since numeraire is also used as *"capital"* we denote it by K.

Only firms have access to an inelastic fixed supply of non-transferrable managerial skills, which we denote by L^*. These skills can be combined with numeraire in a stochastic Leontief technology to produce more numeraire, K'.

$$K' = \begin{cases} A\min\{K, L^*\} & \texttt{with prob. } q \\ 0 & \texttt{with prob. } (1-q) \end{cases}$$

We assume production is efficient, $qA > 1$. Then, the optimal scale of numeraire in production is simply $K^* = L^*$.

Households and firms not only differ in their managerial skills, but also in their initial endowments. On the one hand, households are born with an endowment of numeraire $\bar{K} > K^*$, enough to sustain optimal production in the economy. On the other hand, firms are born with land (one unit of land per firm), but no numeraire.[6]

Even though land is non-productive, it potentially has an intrinsic value. If land is *"good"*, it delivers C units of numeraire at the end of the period. If land is *"bad"*, it does not deliver any numeraire at the end of the period. We assume a fraction $\hat{p}$ of land is good. At the beginning of the period, the units of land can potentially be heterogeneous in their prior probability of being good. We denote these priors p_i per unit of land i and assume they are common to all agents in the economy. Determining the quality of land with certainty costs γ units of numeraire.

To fix ideas it is useful to think of an example. Assume oil is the intrinsic value of land. Land is good if it has oil underground, which can be exchanged for C units of numeraire at the end of the period. Land is bad if it does not have any oil underground. Oil is non-observable at first sight, but there is a common perception about the probability each unit of land has oil underground. It is possible to confirm this perception by drilling the land at a cost γ units of numeraire.

In this simple setting, resources are in the wrong hands. Households only have numeraire while firms only have managerial skills, but production requires that both inputs be in the same hands. Since production is efficient, if output were verifiable it would be possible for firms to borrow the optimal amount of numeraire K^* by issuing state contingent claims. In contrast, if output were non-verifiable, firms would never repay and households would never be willing to lend.

We focus on this latter case in which firms can hide numeraire but cannot hide land, what renders land useful as *collateral*. Firms can commit to transfer a fraction of land

[6]This is just a normalization. We can alternatively assume firms have an endowment of numeraire $\bar{K}_{firms}$, but not enough to finance optimal production $\bar{K}_{firms} < K^* < \bar{K} + \bar{K}_{firms}$.

to households if they do not repay the promised numeraire, which relaxes the financial constraint imposed by the non-verifiability of output.

The perception about the quality of collateral then becomes critical in facilitating credit. We assume that $C > K^*$, which implies that land that is known to be good can sustain the optimal loan size, K^*. In contrast, land that is known to be bad cannot sustain any loan.[7] But, how much can a firm with a piece of land that is good with probability p borrow? Is information about the true value of land produced or not?

2.2 Optimal loan for a single firm

In this section we study the optimal short-term collateralized debt for a single firm, considering the possibility that households may want to produce information about the land posted as collateral. In this paper we study a single-sided information problem, since the firm does not have resources in terms of numeraire to learn about the collateral. In a companion paper, Gorton and Ordonez (2012) extend the model to allow both borrowers and lenders to be able to acquire information about collateral.

We impose two assumptions. First, lenders' acquisition of information and the information itself only become public at the end of the period, unless lenders decide to disclose it earlier. This implies that asymmetric information can potentially exist during the period. Second, each firm is randomly matched with a household and the firm has the negotiation power in determining the loan conditions. In the Appendix we show that explicitly modeling competition across lenders complicates the exposition, and only strengthen our results.

Firms optimally choose between debt that triggers information acquisition about the collateral (*information-sensitive debt*) or not (*information-insensitive debt*). Triggering information acquisition is costly because it raises the cost of borrowing to compensate for the monitoring cost γ. However, not triggering information acquisition may also

[7] Since we assume $C > K^*$, the issue arises of whether a firm with an excess of good collateral can sell land to another firm with bad collateral to finance optimal borrowing in the economy. We rule this out, implicitly assuming that the firm with good land has to hold the whole unit of land to maintain its value, which renders collateral ownership effectively indivisible. Empirically, for example, if the originator, sponsor, and servicer of a mortgage-backed security is the same firm, the collateral has a higher value compared to the situation in which these roles are separated in different firms. See Demiroglu and James (2012).

be costly because it may imply less borrowing to discourage households from producing information. This trade-off determines the information-sensitiveness of the debt and, ultimately the volume and dynamics of information in the economy.

2.2.1 Information-Sensitive Debt

Under this contract, lenders learn the true value of the borrower's land by paying an amount γ of numeraire, and loan conditions are conditional on the resulting information. Since by assumption lenders are risk neutral and break even,

$$p(qR_{IS} + (1-q)x_{IS}C - K) = \gamma, \tag{1}$$

where K is the size of the loan, R_{IS} is the face value of the debt and x_{IS} is the fraction of land posted by the firm as collateral.

The firm should pay the same in case of success or failure. If $R_{IS} > x_{IS}C$, the firm would always default, handing over the collateral rather than repaying the debt. In contrast, if $R_{IS} < x_{IS}C$ the firm would always sell the collateral directly at a price C and repay lenders R_{IS}. In this setting, then, debt is risk-free, which renders the results under risk neutrality to hold without loss of generality. This condition pins down the fraction of collateral that a firm posts as a function of p,

$$R_{IS} = x_{IS}C \qquad \Rightarrow \qquad x_{IS} = \frac{pK+\gamma}{pC} \leq 1.$$

It is feasible for firms to borrow the optimal scale K^* only if $\frac{pK^*+\gamma}{pC} \leq 1$, or if $p \geq \frac{\gamma}{C-K^*}$. If this is not the case, firms can only borrow $K = \frac{pC-\gamma}{p} < K^*$ when posting the whole unit of good land as collateral. Finally, it is not feasible to borrow at all if $pC < \gamma$.

Expected profits net of the land value pC from information-sensitive debt are:

$$E(\pi|p, IS) = p(qAK - x_{IS}C),$$

and using x_{IS} from above,

$$E(\pi|p, IS) = pK^*(qA-1) - \gamma. \tag{2}$$

Intuitively, with probability p collateral is good and sustains expected production of $K^*(qA-1)$ of numeraire and with probability $(1-p)$ collateral is bad and does not sustain any loan or production. However, the firm always has to compensate in expectation for the monitoring costs, γ.

It is profitable for firms to borrow the optimal scale inducing information as long as $pK^*(qA-1) \geq \gamma$, or $p \geq \frac{\gamma}{K^*(qA-1)}$. Combining the profitability and feasibility conditions, if $\frac{\gamma}{K^*(qA-1)} > \frac{\gamma}{C-K^*}$ (or $qA < C/K^*$), whenever the firm wants to borrow, it is feasible to borrow the optimal scale K^* if the land is found to be good. Simply to minimize the kinks in the firm's profit function, we assume this condition holds

$$E(\pi|p, IS) = \begin{cases} pK^*(qA-1) - \gamma & \texttt{if } p \geq \frac{\gamma}{K^*(qA-1)} \\ 0 & \texttt{if } p < \frac{\gamma}{K^*(qA-1)}. \end{cases}$$

2.2.2 Information-Insensitive Debt

Another possibility is for firms to borrow without triggering information acquisition. Again, since by assumption lenders are risk neutral and break even:

$$qR_{II} + (1-q)px_{II}C = K, \tag{3}$$

subject to debt being risk-free, $R_{II} = x_{II}pC$ for the same reasons as above. Then

$$x_{II} = \frac{K}{pC} \leq 1.$$

For this contract to be information-insensitive, borrowers should be confident that lenders do not have incentives to deviate, secretly checking the value of collateral and lending only if the collateral is good, pretending that they do not know the collateral value. Lenders do not want to deviate if the expected gains from acquiring information, evaluated at x_{II} and R_{II}, are less than its costs, γ. Formally,

$$p(qR_{II} + (1-q)x_{II}C - K) < \gamma \qquad \Rightarrow \qquad (1-p)(1-q)K < \gamma.$$

Intuitively, by acquiring information the lender only lends if the collateral is good, which happens with probability p. If there is default, which occurs with probability $(1-q)$, the lender can sell at $x_{II}C$ of collateral that was effectively purchased at $K = px_{II}C$, making a net gain of $(1-p)x_{II}C = (1-p)\frac{K}{p}$.

It is clear from the previous condition that the firm can discourage information acquisition by reducing borrowing. If the condition does not bind when evaluated at $K = K^*$, there are no incentives for lenders to produce information. In contrast, if the condition binds, the firm will borrow as much as possible given the restriction of not triggering information acquisition:

$$K = \frac{\gamma}{(1-p)(1-q)}.$$

Even though the technology is linear, the constraint on borrowing has p in the denominator, which induces convexity in expected profits.

Information-insensitive borrowing is characterized by the following debt size:

$$K(p|II) = \min\left\{K^*, \frac{\gamma}{(1-p)(1-q)}, pC\right\}. \tag{4}$$

That is, borrowing is either constrained technologically (there are no credit constraints but firms do not need to borrow more than K^*), informationally (there are credit constraints and firms cannot borrow more than $\frac{\gamma}{(1-p)(1-q)}$ without triggering information production) or by low collateral value (the unit of land is not worth more than pC).

Expected profits net of the land value pC for information-insensitive debt are:

$$E(\pi|p, II) = qAK - x_{II}pC,$$

and using x_{II}

$$E(\pi|p, II) = K(p|II)(qA - 1). \tag{5}$$

Considering the kinks explicitly, these profits are:

$$E(\pi|p, II) = \begin{cases} K^*(qA-1) & \texttt{if } K^* \leq \frac{\gamma}{(1-p)(1-q)} \quad \texttt{(no credit constraint)} \\ \frac{\gamma}{(1-p)(1-q)}(qA-1) & \texttt{if } K^* > \frac{\gamma}{(1-p)(1-q)} \quad \texttt{(credit constraint)} \\ pC(qA-1) & \texttt{if } pC < \frac{\gamma}{(1-p)(1-q)} \quad \texttt{(low collateral value).} \end{cases}$$

The first kink is generated by the point at which the constraint to avoid information production is binding when evaluated at the optimal loan size K^*; this occurs when financial constraints start binding more than technological constraints. The second kink is generated by the constraint $x_{II} \leq 1$, under which the firm is not constrained by the threat of information acquisition, but it is directly constrained by the low expected value of the collateral, pC.

2.2.3 Induce Information Acquisition or Not?

Depending on the belief p about its collateral, a firm compares equations (2) and (5) to choose between issuing information-insensitive debt (II) or information-sensitive debt (IS). The proof of the next proposition is trivial. The proofs of all other propositions are in the Appendix.

Proposition 1 *Firms borrow inducing information acquisition if*

$$\frac{\gamma}{qA-1} < pK^* - K(p|II), \tag{6}$$

and without inducing information acquisition otherwise.

Figure 1 shows the ex-ante expected profits, net of the expected value of land, under the two information regimes, for each possible p.

The cutoffs highlighted in Figure 1 are determined in the following way:

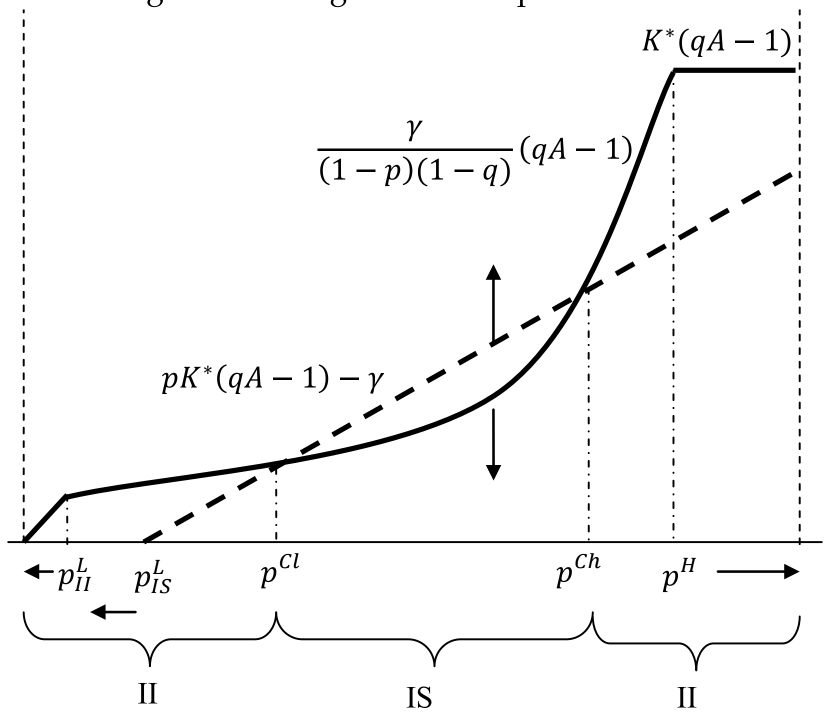
1. The cutoff p^H is the belief that generates the first kink of information-insensitive profits, below which firms have to reduce borrowing to prevent information acquisition:
$$p^H = 1 - \frac{\gamma}{K^*(1-q)}. \tag{7}$$

2. The cutoff p^L_{II} comes from the second kink of information-insensitive profits:[8]
$$p^L_{II} = \frac{1}{2} - \sqrt{\frac{1}{4} - \frac{\gamma}{C(1-q)}}. \tag{8}$$

3. The cutoff p^L_{IS} comes from the kink of information-sensitive profits:
$$p^L_{IS} = \frac{\gamma}{K^*(qA-1)}. \tag{9}$$

[8]The positive root for the solution of $pC = \gamma/(1-p)(1-q)$ is irrelevant since it is greater than p^H, and then firms are not credit, but technologically constrained, just borrowing K^*.

Figure 1: A Single Period Expected Profits



4. Cutoffs p^{Ch} and p^{Cl} are obtained from equalizing the profit functions under information-sensitive and insensitive debt, and solving the quadratic equation:

$$\gamma = \left[pK^* - \frac{\gamma}{(1-p)(1-q)}\right](qA-1). \tag{10}$$

Information-insensitive loans are chosen for collateral with high and low beliefs p. Information-sensitive loans are chosen for collateral with intermediate values of p. The first regime generates symmetric ignorance about the value of collateral. The second regime generates symmetric information about the value of collateral.

How these regions depend on information costs? The five arrows in Figure 1 show how the cutoffs and functions move as we reduce γ. If information is free ($\gamma = 0$), all collateral is information-sensitive (i.e., the IS region is $p \in [0,1]$). As γ increases, the two cutoffs p^{Ch} and p^{Cl} converge and the IS region shrinks until it disappears when γ is large enough (i.e., the II region is $p \in [0,1]$ when $\gamma > \frac{K^*}{C}(C-K^*)$).

Then, conditional on γ, the feasible borrowing for each belief p follows the schedule,

$$K(p) = \begin{cases} K^* & \texttt{if } p^H < p \\ \frac{\gamma}{(1-p)(1-q)} & \texttt{if } p^{Ch} < p < p^H \\ pK^* - \frac{\gamma}{(qA-1)} & \texttt{if } p^{Cl} < p < p^{Ch} \\ \frac{\gamma}{(1-p)(1-q)} & \texttt{if } p^L_{II} < p < p^{Cl} \\ pC & \texttt{if } \quad p < p^L_{II}. \end{cases} \tag{11}$$

2.3 The Choice of Collateral

In this section, in addition to heterogeneous beliefs, p, about land value, we assume land is also heterogenous in terms of the cost γ of acquiring information. What is the combination of p and γ that allows for the largest loans? The next Proposition summarizes the answer.

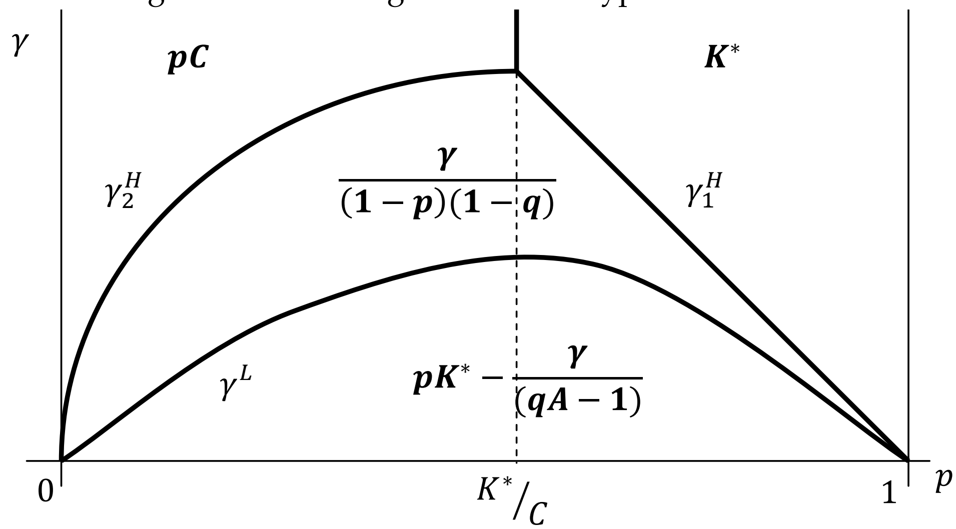
Proposition 2 *Effects of p and γ on borrowing.*

Consider collateral characterized by the pair (p, γ). The reaction of borrowers to these variables depends on financial constraints and information sensitiveness.

1. *Fix γ.*
   - *(a) No financial constraint: Borrowing is independent of p.*
   - *(b) Information-sensitive regime: Borrowing is increasing in p.*
   - *(c) Information-insensitive regime: Borrowing is increasing in p.*
2. *Fix p.*
   - *(a) No financial constraint: Borrowing is independent of γ.*
   - *(b) Information-sensitive regime: Borrowing is decreasing in γ.*
   - *(c) Information-insensitive regime: Borrowing is increasing in γ if higher than pC and independent of γ if pC.*

Figure 2 shows the borrowing possibilities for all combinations (p, γ) and the regions described in Proposition 2 (K^* is the loan without financial constraints, $pK^* - \frac{\gamma}{(qA-1)}$ is the loan in the IS regime, while $\frac{\gamma}{(1-p)(1-q)}$ and pC are the loans in the II regime).

Figure 2: Borrowing for different types of collateral



If it were possible for borrowers to choose the lenders' difficulty in monitoring collateral with belief p, then they would set $\gamma > \gamma_1^H(p)$ for that p, such that $p > p^H(\gamma)$ and the borrowing is K^*, without information acquisition.

This analysis suggests that, endogenously, an economy would be biased towards using collateral with relatively high p and relatively high γ. Agents in an economy will first use collateral that is perceived to be of high quality. As the needs for collateral increase, agents start relying on collateral of worse and worse quality. To accommodate this collateral of poorer expected quality, agents may need to increase γ, making information acquisition difficult and expensive. While outside the scope of our paper, this framework can shed light on security design and the complexity of modern financial instruments.

2.4 Aggregation

Consider a match between a household and a firm with land that is good with probability p. The expected consumption of a household is $\overline{K} - K(p) + E(repay|p)$ and the expected consumption of a firm is $E(K'|p) - E(repay|p)$. Aggregate consumption is the sum of the consumption of all households and firms. Since $E(K'|p) = qAK(p)$,

$$W_t = \overline{K} + \int_0^1 K(p)(qA-1)f(p)dp,$$

where $f(p)$ is the distribution of beliefs about collateral types in the economy and $K(p)$ is monotonically increasing in p (equation 11).

In the unconstrained first best (the case of verifiable output, for example) all firms borrow K^* and operate at the optimal scale, regardless of beliefs p about the collateral. This implies that the unconstrained first best aggregate consumption is:

$$W^* = \overline{K} + K^*(qA - 1).$$

Since collateral with relatively low p is not able to sustain loans of K^*, the deviation of consumption from the unconstrained first best critically depends on the distribution of beliefs p in the economy. When this distribution is biased towards low perceptions about collateral values, financial constraints hinder total production. The distribution of beliefs introduces heterogeneity in production, purely given by heterogeneity in collateral and financial constraints, not by heterogeneity in technological possibilities.

In the next section we study how this distribution of p endogenously evolves over time, and how that affects the dynamics of aggregate production and consumption.

3 Dynamics

In this section we nest the previous analysis for a single period in an overlapping generations economy. The purpose is to study the evolution of the distribution of collateral beliefs that determines the level of production in the economy in each period.

We assume that each unit of land changes quality over time, mean reverting towards the average quality of land in the economy, and we study how endogenous information acquisition shapes the distribution of beliefs over time. First, we study the case without aggregate shocks to land, in which the average quality of collateral in the economy does not change, and discuss the effects of endogenous information production on the dynamics of credit. Then, we introduce aggregate shocks that reduce the average quality of land in the economy, and study the effects of endogenous information acquisition on the size of crises and the speed of recoveries.

3.1 Extended Setting

We assume an overlapping generations structure. Every period is populated by two cohorts of individuals who are risk neutral and live for two periods. These individuals are born as households (when *"young"*), with a numeraire endowment of $\bar{K}$ but no managerial skills, and then become firms when *"old"*, with managerial skills L^*, but no numeraire to use in production. We assume the numeraire is non-storable and land is storable until the moment its intrinsic value (either C or 0) is extracted, after which the land disappears. This implies that as long as land is transferred, its potential value as collateral remains.

As in the single period model, we still assume there is random matching between a firm and a household in every period. The timing is as follows:

- At the beginning of the period land that is good with probability p_{-1} may suffer idiosyncratic or aggregate shocks that move this probability to p.
- After the shocks, each member of the "young" generation (households) is matched with a member of the "old" generation (firms) with land that is good with probability p. The household determines the conditions of a loan (pairs (R_{II};x_{II}) and (R_{IS};x_{IS})) that make him indifferent between lending or not (conditions 1 and 3). The firm then chooses a lending contract that maximizes profits selecting the maximum between $E(\pi|p, IS)$ and $E(\pi|p, II)$ (equations 2 and 5) and begins production. Depending on whether there is information acquisition or not beliefs are updated to 0 (bad land) or 1 (good land) or remains at p respectively.
- At the end of the period, the firm can choose to sell its unit of land (or the remaining land after default) to the household at a price $Q(p)$ or to extract and consume its intrinsic value.

The optimal loan contract follows the characterization described in the single period model above. The market for land is new. Land can be transferred across generations, and agents want to buy land when young to use it as collateral to borrow productive numeraire when old. This is reminiscent of the role of fiat money in overlapping generations, with the critical differences that land is intrinsically valuable and is subject to imperfect information about its quality. Still, as in those models, we have multiple equilibria based on multiple paths of rational expectations about land prices that incorporate the use of land as collateral.

However, in this paper we are not interested in credit booms, bubbles or crises arising from transitions across multiple equilibria, which are typical features of those models. So, we impose restrictions to select the equilibrium in which the land price just reflects the expected intrinsic value of land when it can be used as collateral (that is, the price of a unit of land with belief p is just $Q(p) = pC$). Choosing this particular equilibrium has the advantage of isolating the dynamics generated by information acquisition.[9]

The first restriction is that information can only be produced at the beginning of the period, not at the end. This assumption means that firms prefer to post land as collateral rather than sell land with the risk of information production. The second restriction is that buyers (households) make take-it-or-leave-it offers for the land of their matched firm at the end of the period; households have all the bargaining power. This implies that sellers will be indifferent between selling the unit of land at pC or consuming pC in expectation. As we discuss in the Appendix, we can characterize the competitive environment to sustain this assumption.

Under these assumptions, the single period analysis from the previous section just repeats over time. The only changing state variable linking periods is the distribution of beliefs about collateral. We can now define the equilibrium.

Definition 1 *Definition of Equilibrium*

In each period, for each match of a household and a firm of type p an equilibrium is:

- *A pair of debt face values (R_{II} and R_{IS}) and a pair of fractions of land to be collected in case of default (x_{II} and x_{IS}) such that lenders are indifferent; and a profit maximizing choice of information-sensitive debt or information-insensitive debt.*
- *A land price $Q(p)$ is determined by take-it-or-leave-it offer by the household.*
- *Beliefs are updated after information or shocks, using Bayes rule.*

Next we study the interaction between shocks to collateral and information acquisition to study the dynamics of production in the economy. First we imposed a simple

[9] Still, our results are robust since the information dynamics that we focus on remain an important force in the other equilibria we ruled out, as long as the price of land increases with p. In the Appendix, we discuss the multiplicity of land prices.

mean reverting process of idiosyncratic shocks and show that information may vanish over time, generating a credit boom sustained by increased symmetric ignorance in the economy. Then, we allow for an unexpected aggregate shock that may introduce the threat of information acquisition and generate crises.

This is the main advantage of focusing on the equilibrium in which the price of collateral just reflects its intrinsic value, and not the future value of collateral. First, credit booms do not arise from bubbles in the price of each unit of collateral, but from an increase in the volume of land that can be used as collateral. Second, credit crises are not generated by shifting from a good to a bad equilibrium, but by shifting from the information-insensitive to the information-sensitive regime that coexist in a unique equilibrium.

3.2 No Aggregate Shocks

Here we just introduce idiosyncratic shocks to collateral. We impose a specific process of idiosyncratic mean reverting shocks that are useful in characterizing analytically the dynamic effects of information production on aggregate consumption. First, we assume that the idiosyncratic shocks are observable, but their realization is not observable, unless information is produced. Second, we assume that the probability that a unit of land faces an idiosyncratic shock is independent of land type. Finally, we assume that the probability a unit of land becomes good, conditional on having an idiosyncratic shock, is also independent of its type. These assumptions just simplify the exposition, and the main results are robust to different processes, as long as there is mean reversion of collateral in the economy.

Formally, in each period either the true quality of each unit of land remains unchanged with probability λ or there is an idiosyncratic shock that changes its type with probability $(1-\lambda)$. In this last case, land becomes good with a probability $\hat{p}$, independent of its current type. Even when the shock is observable, its realization is not, unless a certain amount of the numeraire good γ is used to learn about it.[10]

In this simple stochastic process for idiosyncratic shocks, and in the absence of aggregate shocks to $\hat{p}$, this distribution has a three-point support: 0, $\hat{p}$ and 1. The next

[10] To guarantee that all land is traded, households should have enough resources to buy good land, $\bar{K} > C$, and they should be willing to pay C for good land even when facing the probability that it may become bad next period, with probability $(1-\lambda)$. Since this fear is the strongest for good land, the sufficient condition is enough persistence of collateral, $\lambda(K^*(qA-1)+C) > C$.

proposition shows that the evolution of aggregate consumption depends on $\hat{p}$, which can be either in the information-sensitive or in the information-insensitive region.

Proposition 3 *Evolution of aggregate consumption in the absence of aggregate shocks.*

Assume there is perfect information about land types in the initial period. If $\hat{p}$ is in the information-sensitive region ($\hat{p} \in [p^{Cl}, p^{Ch}]$), consumption is constant over time and is lower than the unconstrained first best. If $\hat{p}$ is in the information-insensitive region, consumption grows over time if $\hat{p} > \hat{p}_h^*$ or $\hat{p} < \hat{p}_l^*$, where $\hat{p}_l^*$ and $\hat{p}_h^*$ are the solutions to the quadratic equation $\hat{p}^* K^* = \frac{\gamma}{(1-\hat{p}^*)(1-q)}$.

This result is particularly important if the economy has collateral such that $\hat{p} > p^H > \hat{p}_h^*$. In this case consumption grows over time towards the unconstrained first best. When $\hat{p}$ is high enough, the economy has enough good collateral to sustain production at the optimal scale. As information vanishes over time good collateral implicitly subsidizes bad collateral, and after enough periods virtually all firms are able to produce at the optimal scale, not just those firms with good collateral.

3.3 Aggregate Shocks

Now we introduce negative aggregate shocks that transform a fraction $(1 - \eta)$ of good collateral into bad collateral. As with idiosyncratic shocks, the aggregate shock is observable, but which good collateral changes type is not. When the shock hits, there is a downward revision of beliefs about all collateral. That is, after the shock, collateral with belief $p = 1$, gets revised downwards to $p' = \eta$ and collateral with belief $p = \hat{p}$ gets revised downwards to $p' = \eta\hat{p}$.

Based on the discussion about the endogenous choice of collateral, which justifies that collateral would be constructed to maximize borrowing and prevent information acquisition, we focus on the case where, prior to the negative aggregate shock, the average quality of collateral is good enough such that there are no financial constraints (that is, $\hat{p} > p^H$).

In the next proposition we show that the longer the economy does not face a negative aggregate shock, the larger the consumption loss when such a shock does occur.

Proposition 4 *The larger the credit boom and the shock, the larger the crisis.*

Assume $\hat{p} > p^H$ and a negative aggregate shock η hits after t periods of no aggregate shocks. The reduction in consumption $\Delta(t|\eta) \equiv W_t - W_{t|\eta}$ is non-decreasing in the size of the shock η and non-decreasing in the time t elapsed previously without a shock.

The intuition for this proposition is the following. Pooling implies that bad collateral is confused with good collateral. This allows for a credit boom because firms with bad collateral get credit that they would not otherwise obtain. Firms with good collateral effectively subsidize firms with bad collateral since good collateral still gets the optimal leverage, while bad collateral is able to leverage more.

However, pooling also implies that good collateral is confused with bad collateral. This puts good collateral in a weaker position in the event of negative aggregate shocks. Without pooling, a negative shock reduces the belief that collateral is good from $p = 1$ to $p' = \eta$. With pooling, a negative shock reduces the belief that collateral is good from $p = \hat{p}$ to $p' = \eta\hat{p}$. Good collateral gets the same credit regardless of having beliefs $p = 1$ or $p = \hat{p}$. However, credit may be very different when $p = \eta$ and $p = \eta\hat{p}$. In particular, after a negative shock to collateral, credit may decline since either a high amount of the numeraire needs to be used to produce information, or borrowing needs to be excessively constrained to avoid such information production.

If we define *"fragility"* as the probability that aggregate consumption declines more than a certain value, then the next corollary immediately follows from Proposition 4.

Corollary 1 *Given a negative aggregate shock, the* fragility *of an economy* increases *with the number of periods the debt in the economy has been informationally-insensitive, and hence* increases *with the fraction of collateral that is of unknown quality.*

Proposition 3 describes how information deterioration may induce credit booms and Proposition 4 describes how the threat of information acquisition may induce crises. What happens next? How does information production affect the speed of recovery?

Proposition 5 *Information and recoveries.*

Assume $\hat{p} > p^H$ and that a negative aggregate shock η generates a crisis in period t. The recovery from the crisis is faster if information is generated after the shock when $\eta\hat{p} < \overline{\eta\hat{p}} \equiv \frac{1}{2} + \sqrt{\frac{1}{4} - \frac{\gamma}{K^*(1-q)}}$, where $p^{Ch} < \overline{\eta\hat{p}} < p^H$. That is, $W^{IS}_{t+1} > W^{II}_{t+1}$ for all $\eta\hat{p} < \overline{\eta\hat{p}}$ and $W^{IS}_{t+1} \leq W^{II}_{t+1}$ otherwise.

The intuition for this proposition is the following. When information is acquired after a negative shock, not only are a lot of resources being spent in acquiring information but also only a fraction $\eta\hat{p}$ of collateral can sustain the maximum borrowing K^*. When information is not acquired after a negative shock, collateral that remains with belief $\eta\hat{p}$ will restrict credit in the following periods, until mean reversion moves beliefs back to $\hat{p}$. This is equivalent to restricting credit proportional to monitoring costs in subsequent periods. Not producing information causes a kind of "lack of information overhang" going forward. The proposition generates the following Corollary.

Corollary 2 *There exists a range of negative aggregate shocks (η such that $\eta\hat{p} \in [p^{Ch}, \overline{\eta\hat{p}}]$) in which agents do not acquire information, but recovery would be faster if they did.*

Finally, the next Proposition describe the evolution of the standard deviation of beliefs in the economy during credit booms and credit crises.

Proposition 6 *Dispersion of Beliefs During Booms and Crises*

During a credit boom, the standard deviation of beliefs declines. During a credit crisis, if the aggregate shock η triggers information production about collateral with belief $\eta\hat{p}$, the standard deviation of beliefs increases. This increase is larger the longer was the preceding boom.

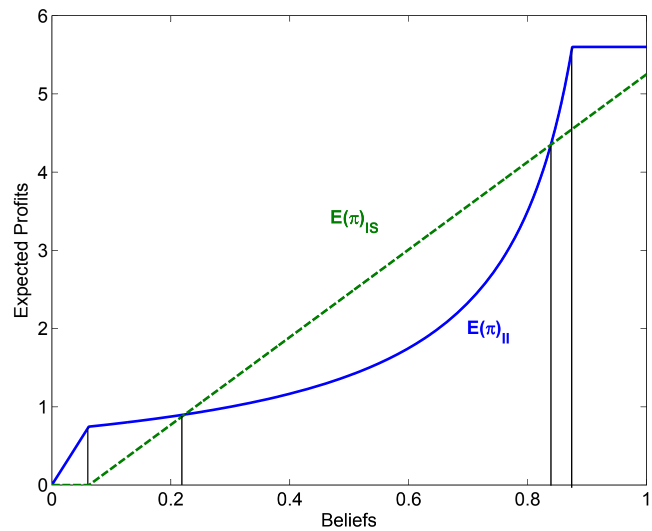
Intuitively, credit booms are generated by vanishing information. Since over that process beliefs accumulate to the average quality $\hat{p}$, the dispersion of the belief distribution declines. If this process developed long enough, an aggregate shock that triggers information reveals the true type of most land, and beliefs return to $p = 0$ and $p = 1$ increasing the dispersion of the belief distribution. This effect is stronger the longer the preceding boom that accumulated collateral with beliefs $\hat{p}$.

3.4 Numerical Illustration

Now we illustrate our dynamic results with a numerical example. We assume idiosyncratic shocks happen with probability $(1 - \lambda) = 0.1$, in which case the collateral becomes good with probability $\hat{p} = 0.92$. Other parameters are $q = 0.6$, $A = 3$ (investment is efficient and generates a return of 80% in expectation), $\bar{K} = 20$, $L^* = K^* = 7$, $C = 15$ (the endowment is large enough to provide a loan for the optimal scale of production and to buy the most expensive unit of land), and $\gamma = 0.35$ (information costs are 5% of the optimal loan).

Given these parameters we can obtain the relevant cutoffs for our analysis. Specifically, $p^H = 0.88$, $p^L_{II} = 0.06$ and the information-sensitive region of beliefs is $p \in [0.22, 0.84]$. Figure 3 plots the ex-ante expected profits with information sensitive (dotted green) and insensitive (solid blue) debt, and the respective cutoffs.

Figure 3: Expected Profits and Cutoffs



Using these cutoffs in each period, we simulate the model for 100 periods. At period 0 we assume perfect information about the true quality of each unit of land in the economy. Unless replenished, information vanishes over time due to idiosyncratic shocks. The dynamics of production mirrors that of the belief distribution.

In periods 5 and 50 we perturb the economy by introducing negative aggregate shocks that transform a fraction $(1 - \eta)$ of good collateral into bad collateral. We consider shocks of different size, ($\eta = 0.97$, $\eta = 0.91$ and $\eta = 0.90$) and compute the dynamic reaction of aggregate production to them. We choose the size of these shocks to guarantee that $\eta\hat{p}$ is above p^H when $\eta = 0.97$, is between p^{Ch} and p^H when $\eta = 0.91$ and is less than p^{Ch} when $\eta = 0.90$.

Figure 4 shows the evolution of the average quality of collateral for the three negative aggregate shocks. Since mean reversion guarantees that average quality converges back to $\hat{p} = 0.92$ after the shocks, their effects are only temporary.

Figure 4: Average Quality of Collateral

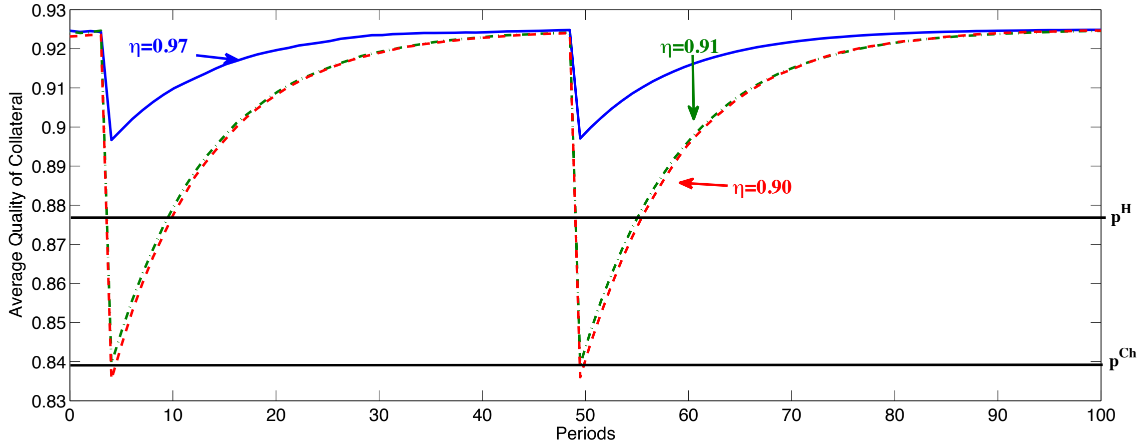
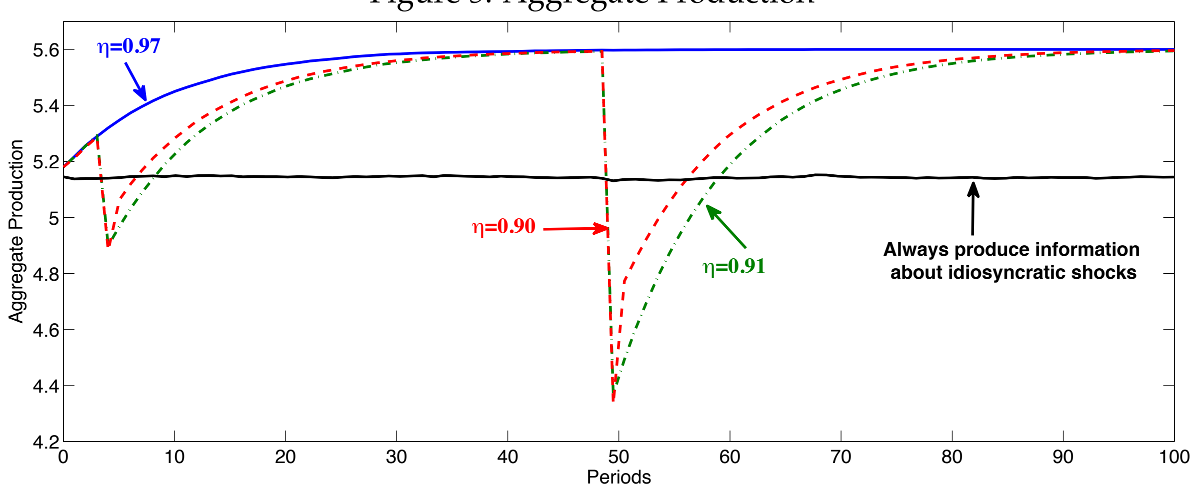


Figure 5 shows the evolution of aggregate production for the three negative aggregate shocks. A couple of features are worth noting. First, if $\eta = 0.97$, the aggregate shock is so small that it never constrains borrowing or modifies the evolution of production. Second, as proved in Proposition 4, if $\eta = 0.91$ or $\eta = 0.90$, aggregate production drops more in period 50, when the credit boom is mature and information is scarce, than in period 5, when there is still a large volume of information about collateral in the economy. Critically, the crisis is larger in period 50, not only because it finishes a large boom, but also because credit drops to a lower level. Indeed aggregate production in period 50 is lower than in period 5 because credit dries up for a larger fraction of collateral when information is scarcer.

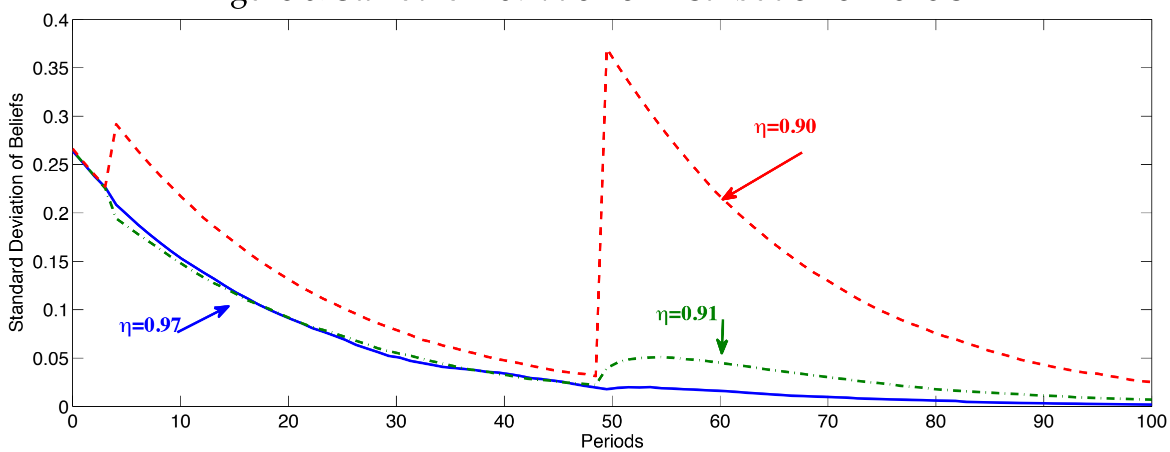
Figure 5: Aggregate Production



As proved in Proposition 5, a shock $\eta = 0.91$ does not trigger information production, but a shock $\eta = 0.90$ does. Even when these two shocks generate production drops of similar magnitude, recovery is faster when the shock is slightly larger and information is replenished.

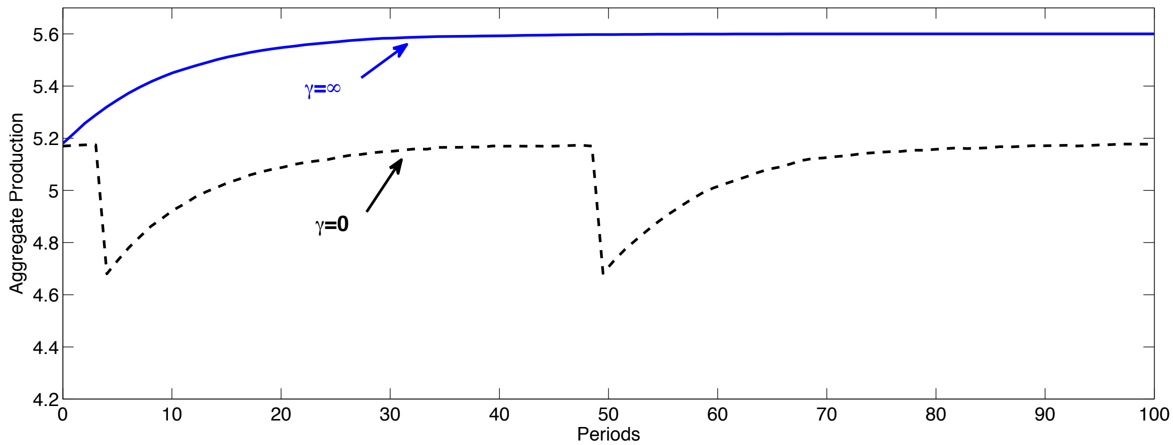
Figure 6 shows the evolution of the beliefs' dispersion, a measure of information availability. As proved in Proposition 6, a credit boom is correlated with a decline in the dispersion of beliefs and, given that after many periods without a shock most collateral looks the same, the information acquisition triggered by a shock $\eta = 0.90$ generates a larger increase in dispersion in period 50.

Figure 6: Standard Deviation of Distribution of Beliefs



Finally, to illustrate the negative side of information, Figure 7 shows the evolution of production under two very extreme cases: information acquisition is free ($\gamma = 0$) and it is impossible ($\gamma = \infty$). Aggregate production is lower and more volatile when information is free. It is lower because only firms with good collateral get loans. It is more volatile because the volume of good collateral is subject to aggregate shocks. When information acquisition is free, the reaction of credit is independent of the length of the preceding boom and only depends on the size of the shock. In contrast, when information acquisition is impossible, over time all land is used as collateral and shocks do not introduce any fear that someone will acquire information and leads to a credit decline.

Figure 7: Extreme Information Costs



4 Policy Implications

In this section we discuss optimal information production when a planner cares about the discounted consumption of all generations and faces the same information restrictions and costs as households and firms. Welfare is measured by

$$U_t = E_t \sum_{\tau=t}^{\infty} \beta^{\tau-t} W_t.$$

First, we study the economy without aggregate shocks, and show that a planner would like to produce information for a wider range of collateral p than short-lived agents. Then, we study the economy with negative aggregate shocks, and show that it may still be optimal for the planner to avoid information production, riding the credit boom even when facing the possibility of collapse.

4.1 No Aggregate Shocks

The next Proposition shows that, when $\beta > 0$, the planner wants to acquire information for a wider range of beliefs p. Lying behind this inefficiency is the myopia of firms, who only consider the potential benefits of information for one period.

Proposition 7 *The planner's optimal range of information-sensitive beliefs is wider than the decentralized range of information-sensitive beliefs from equation (6). Specifically, the planner* *produces information if*

$$(1-\beta\lambda)\frac{\gamma}{qA-1} < pK^* - K(p|II), \tag{12}$$

and does not produce information otherwise.

Comparing this condition with equation (6), it is clear that the cost of information is effectively lower for the planner. The planner's expected loan from acquiring information is pK^* for all future periods until an idiosyncratic shock hits. Decentralized agents, however, do not internalize these future gains when deciding whether to trigger information acquisition or not, since they are myopic and do not weigh the information impact in future generations. This difference widens with the planner discounting (β) and with the probability that the collateral remains unchanged (λ).

The planner can align incentives easily by subsidizing information production by a fraction $\beta\lambda$ of information acquisition, possibly using lump sum taxes on individuals. In this way, after the subsidy, the cost of information production that agents face is effectively $\gamma(1-\beta\lambda)$. Figure 8 illustrates this efficiently wider range of information-sensitive beliefs p.

We denote by $\widetilde{K}(p)$ the net effective loan obtained by the planner at each belief p.

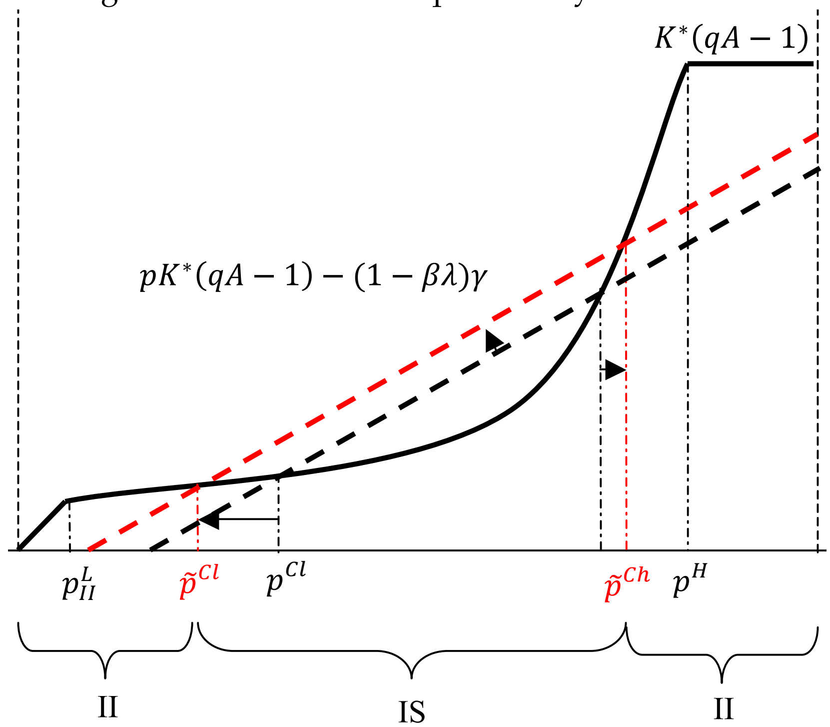
$$\widetilde{K}(p) = \max\left\{K(p|II), pK^* - \frac{\gamma(1-\beta\lambda)}{qA-1}\right\}$$

where $K(p|II)$ is given in equation (4) and the function follows the same schedule as $K(p)$ in equation (11), but using instead the effective information cost $\gamma(1-\beta\lambda)$ and the cutoffs $\widetilde{p}^{Ch}$ and $\widetilde{p}^{Cl}$ depicted in Figure 8.

4.2 Aggregate Shocks

In this section we assume that the planner assigns a probability μ per period that a negative shock η occurs at some point in the future. The next Proposition shows that there are levels of p for which, even in the presence of the potential future shock the planner prefers not to produce information, maintaining a high level of current output rather than avoiding a potential reduction in future output. This insight is consistent with the findings of Ranciere, Tonell, and Westermann (2008) who show

Figure 8: Information Acquisition by the Planner



that *"high growth paths are associated with the undertaking of systemic risk and with the occurrence of occasional crises."*

Proposition 8 *The possibility of a future negative aggregate shock does not necessarily justify acquiring information, reducing current output to avoid potential future crises. In the presence of possible future negative aggregate shocks, the planner produces information if*

$$(1-\beta\lambda)\frac{\gamma}{qA-1} > \frac{(1-\beta\lambda)}{(1-\beta\lambda)+\beta\lambda\mu}[pK^* - K(p|II)] + \frac{\beta\lambda\mu}{(1-\beta\lambda)+\beta\lambda\mu}[p\widetilde{K}(\eta) - \widetilde{K}(\eta p)], \tag{13}$$

and does not produce information otherwise.

The IS range of beliefs widens if $[pK^* - K(p|II)] < [p\widetilde{K}(\eta) - \widetilde{K}(\eta p)]$. Furthermore, the effect of future shocks η on the IS range of beliefs increases with their probability μ.

To build intuition, assume the aggregate shock is not large enough to make $\widetilde{K}(\eta) < K^*$ but is large enough to make $\widetilde{K}(\eta p) < K(p|II)$ (for example, $\eta > p^H$ and $p = p^H$). In this case, the aggregate shock, regardless of its probability, does not affect the expected discounted consumption of acquiring information (since even with the shock, a firm with a unit of good land is able to borrow K^*), but the shock reduces the expected discounted consumption of not acquiring information (since with the shock, the loan size declines from $K(p|II)$ to $\widetilde{K}(\eta p)$). In this example, producing information relaxes the potential borrowing constraint in case of a future negative shock. Hence, when that shock is more likely, there are more incentives to acquire information.

Now assume very large shocks. Take, as an example, the extreme case $\eta = 0$, such that all collateral becomes bad. In this case the condition (13) simply becomes,

$$(1 - \beta\lambda + \beta\lambda\mu)\frac{\gamma}{qA - 1} < pK^* - K(p|II),$$

increasing effective information costs, and hence reducing the incentives to acquire information. In this extreme case the planner wants to acquire less information than in the the absence of shocks (condition 12) but still wants to acquire more information than decentralized agents (condition 6).

5 Conclusions

It has been difficult to explain financial crises and how they are linked to credit booms. "Large shocks" or multiple equilibria do not incorporate credit booms and are not convincing explanations of financial crises. Further, they do not lead to policy recommendations. Explaining a financial crisis requires the modeling discipline of fixing the shock size and showing how that shock can sometimes have no effect and sometimes lead to a crisis. Our explanation is based on the endogenous dynamics of information in the economy which creates fragility as a rational credit boom develops. Confidence is lost when a long-lasting credit boom is tipped by a potentially small shock.

The amount of information in an economy is time-varying. It is not optimal for lenders to produce information every period about the borrowers because it is costly. In that case, the information about the collateral degrades over time, a kind of amnesia sets in. Instead of knowing which borrowers have good collateral and which have bad collateral, all collateral starts to look alike. These dynamics of information result in a credit boom in which firms with bad collateral start to borrow. During the credit boom, output and consumption rise, but the economy becomes increasingly fragile. The economy becomes more susceptible to small shocks. If information production becomes a credible threat, all collateral with depreciated information can borrow less, a credit crunch. Alternatively, if information is effectively produced after such a shock, firms with bad collateral cannot access credit, a financial crisis.

Why did complex securities, such as subprime mortgage-backed securities, play a leading role in the recent financial crisis? Agents choose (and construct) collateral that has a high perceived quality when information is not produced and collateral that has a high cost of producing information. For example, to maximize borrowing firms will tend to use complex securities linked to land, such as mortgage-backed securities. The opacity and complexity of collateral securities is endogenous, as part of the credit boom. This increases fragility over time.

A credit boom results in output and consumption rising, but it also increases systemic fragility. Consequently, a credit boom presents a delicate problem for regulators and the central bank. We show that a social planner would produce more information than private agents, but would not always want to eliminate fragility.

Our model matches the main outline of the recent financial crisis. The crisis followed a credit boom in which increasing amounts of complex mortgages were securitized. Short-term debt in the form of repo and asset-backed commercial paper used a variety of securitized debt as collateral, including subprime mortgage-backed securities. For example, during the credit boom, over 1996-2007, non-agency (i.e. private) residential mortgage-backed security issuance grew by 1,248% while commercial mortgage-backed securities grew by 1,691%. When house prices started to decline these mortgage-backed securities became questionable, leading to the financial crisis, when the short-term debt was not renewed, leading to almost a complete collapse in the volume of collateral. Over 2007-2012, non-agency residential mortgage-backed security fell by 100%, while commercial mortgage-backed securities fell by 91%.[11] This outline of the crisis is more generally a description of historical banking panics, as well, though this is a subject for future research.

We focus on exogenous shocks to the expected value of collateral to trigger crises. However in Gorton and Ordonez (2012) we show not only that crises can be triggered by exogenous shocks to productivity but also that they may even arise endogenously as the credit boom grows, without the need for any exogenous shock.

[11] The source of this information is SIFMA, "U.S. Mortgage-Related Issuance and Outstanding", http://www.sifma.org/research/statistics.aspx

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A Appendix

A.1 Proof of Proposition 2

Point 1 is a direct consequence of $K(p|\gamma)$ being monotonically increasing in p for $p < p^H$ and independent of p for $p > p^H$.

To prove point 2 we derive the function $\widehat{K}(\gamma|p)$, which is the inverse of the $K(p|\gamma)$,and analyze its properties. Consider first the extreme case in which information acquisition is not possible (or $\gamma = \infty$). In this case the limit to financial constraints is the point at which $K^* = pC$; lenders will not acquire information but will not lend more than the expected value of collateral, pC. Then, the function $\widehat{K}(\gamma|p)$ has two parts. One for $p \geq \frac{K^*}{C}$ and the other for $p < \frac{K^*}{C}$.

1. $p \geq \frac{K^*}{C}$:

$$\widehat{K}(\gamma|p) = \begin{cases} K^* & \texttt{if } \gamma_1^H \leq \gamma \\ \frac{\gamma}{(1-p)(1-q)} & \texttt{if } \gamma^L \leq \gamma < \gamma_1^H \\ pK^* - \frac{\gamma}{(qA-1)} & \texttt{if } \gamma < \gamma^L \end{cases}$$

where γ_1^H comes from equation (7). Then

$$\gamma_1^H = K^*(1-p)(1-q) \tag{14}$$

and γ^L comes from equation (10). Then

$$\gamma^L = pK^* \frac{(1-p)(1-q)(qA-1)}{(1-p)(1-q) + (qA-1)} \tag{15}$$

2. $p < \frac{K^*}{C}$:

$$\widehat{K}(\gamma|p) = \begin{cases} pC & \texttt{if } \gamma_2^H \leq \gamma \\ \frac{\gamma}{(1-p)(1-q)} & \texttt{if } \gamma^L \leq \gamma < \gamma_2^H \\ pK^* - \frac{\gamma}{(qA-1)} & \texttt{if } \gamma < \gamma^L \end{cases}$$

where γ_2^H in this region comes from equation (8). Then

$$\gamma_2^H = p(1-p)(1-q)C \tag{16}$$

and γ^L is the same as above.

It is clear from the function $\widehat{K}(\gamma|p)$ that, for a given p, borrowing is independent of γ in the first region, it is increasing in the second region (information-insensitive regime) and it is decreasing in the last region (information-sensitive regime).

A.2 Proof of Proposition 3

1. $\hat{p}$ is information-sensitive ($\hat{p} \in [p^{Cl}, p^{Ch}]$): In this case, information about the fraction $(1-\lambda)$ of collateral that gets an idiosyncratic shock is reacquired every period t. Then $f(1) = \lambda\hat{p}$, $f(\hat{p}) = (1-\lambda)$ and $f(0) = \lambda(1-\hat{p})$. Considering $K(0) = 0$,

$$W_t^{IS} = \bar{K} + [\lambda\hat{p}K(1) + (1-\lambda)K(\hat{p})]\,(qA-1). \tag{17}$$

Aggregate consumption W_t^{IS} does not depend on t; it is constant at the level at which information is reacquired every period.

2. $\hat{p}$ is information-insensitive ($\hat{p} > p^{Ch}$ or $\hat{p} < p^{Cl}$): Information on collateral that suffers an idiosyncratic shock is not reacquired and at period t, $f(1) = \lambda^t\hat{p}$, $f(\hat{p}) = (1-\lambda^t)$ and $f(0) = \lambda^t(1-\hat{p})$. Since $K(0) = 0$,

$$W_t^{II} = \bar{K} + \left[\lambda^t\hat{p}K(1) + (1-\lambda^t)K(\hat{p})\right](qA-1). \tag{18}$$

Since $W_0^{II} = \bar{K} + \hat{p}K(1)(qA-1)$ and $\lim_{t\to\infty} W_t^{II} = \bar{K} + K(\hat{p})(qA-1)$, the evolution of aggregate consumption depends on $\hat{p}$. A credit boom ensues and aggregate consumption grows over time, whenever $K(\hat{p}) > \hat{p}K(1)$, or

$$\frac{\gamma}{(1-\hat{p}^*)(1-q)} > \hat{p}^*K^*.$$

A.3 Proof of Proposition 4

Assume a negative aggregate shock of size η after t periods without an aggregate shock. Aggregate consumption before the shock is given by equation (18) because we assume $\hat{p} > p^H$ and the average collateral does not induce information. In contrast, aggregate consumption after the shock is:

$$W_{t|\eta} = \bar{K} + \left[\lambda^t\hat{p}K(\eta) + (1-\lambda^t)K(\eta\hat{p})\right](qA-1).$$

Defining the reduction in aggregate consumption as $\Delta(t|\eta) = W_t - W_{t|\eta}$

$$\Delta(t|\eta) = [\lambda^t\hat{p}[K(1) - K(\eta)] + (1-\lambda^t)[K(\hat{p}) - K(\eta\hat{p})]](qA-1).$$

That $\Delta(t|\eta)$ is non-decreasing in η is straightforward. That $\Delta(t|\eta)$ is non-decreasing in t follows from

$$\hat{p}[K(1) - K(\eta)] \leq [K(\hat{p}) - K(\eta\hat{p})],$$

which holds because $K(\hat{p}) = K(1)$ (by assumption $\hat{p} > p^H$) and $K(p)$ is monotonically decreasing in p.

A.4 Proof of Proposition 5

If the negative shock happens in period t, the belief distribution is $f(\eta) = \lambda^t \hat{p}$, $f(\eta\hat{p}) = (1-\lambda^t)$ and $f(0) = \lambda^t(1-\hat{p})$.

In period $t+1$, if information is acquired (IS case), after idiosyncratic shocks are realized, the belief distribution is $f_{IS}(1) = \lambda\eta\hat{p}(1-\lambda^t)$, $f_{IS}(\eta) = \lambda^{t+1}\hat{p}$, $f_{IS}(\hat{p}) = (1-\lambda)$, $f_{IS}(0) = \lambda[(1-\lambda^t\hat{p}) - \eta\hat{p}(1-\lambda^t)]$. Hence, aggregate consumption at $t+1$ in the IS scenario is,

$$W_{t+1}^{IS} = \overline{K} + [\lambda\eta\hat{p}(1-\lambda^t)K^* + \lambda^{t+1}\hat{p}K(\eta) + (1-\lambda)K(\hat{p})](qA-1). \tag{19}$$

In period $t+1$, if information is not acquired (II case), after idiosyncratic shocks are realized, the belief distribution is $f_{II}(\eta) = \lambda^{t+1}\hat{p}$, $f_{II}(\hat{p}) = (1-\lambda)$, $f_{II}(\eta\hat{p}) = \lambda(1-\lambda^t)$, $f_{II}(0) = \lambda^{t+1}(1-\hat{p})$. Hence, aggregate consumption at $t+1$ in the II scenario is,

$$W_{t+1}^{II} = \overline{K} + [\lambda^{t+1}\hat{p}K(\eta) + \lambda(1-\lambda^t)K(\eta\hat{p}) + (1-\lambda)K(\hat{p})](qA-1). \tag{20}$$

Taking the difference between aggregate consumption at $t+1$ between the two regimes

$$W_{t+1}^{IS} - W_{t+1}^{II} = \lambda(1-\lambda^t)(qA-1)[\eta\hat{p}K^* - K(\eta\hat{p})]. \tag{21}$$

This expression is non-negative for all $\eta\hat{p}K^* \geq K(\eta\hat{p})$, or alternatively, for all $\eta\hat{p} < \overline{\eta\hat{p}} \equiv \frac{1}{2} + \sqrt{\frac{1}{4} - \frac{\gamma}{K^*(1-q)}}$. From equation (10), $p^{Ch} < \overline{\eta\hat{p}} < p^H$.

A.5 Proof of Proposition 6

Assume at period 0 that the belief distribution is $f(0) = 1-\hat{p}$ and $f(1) = \hat{p}$. The original variance of beliefs is

$$Var_0(p) = \hat{p}^2(1-\hat{p}) + (1-\hat{p})^2\hat{p} = \hat{p}(1-\hat{p}).$$

At period t, during a credit boom, the belief distribution is $f(0) = \lambda^t(1-\hat{p})$, $f(\hat{p}) = 1-\lambda^t$ and $f(1) = \lambda^t\hat{p}$. Then, at period t the variance of beliefs is

$$Var_t(p|II) = \lambda^t[\hat{p}^2(1-\hat{p}) + (1-\hat{p})^2\hat{p}] = \lambda^t\hat{p}(1-\hat{p}),$$

decreasing in the length of the boom t.

Assume a shock η at period t that triggers information acquisition about collateral with belief $\eta\hat{p}$. If the shock is *"small"* ($\eta > p^{Ch}$), there is no information acquisition about collateral *known to be good before the shock*. If the shock is *"large"* ($\eta < p^{Ch}$), there is information acquisition about collateral *known to be good before the shock*. Now we study these two cases when the shock arises after a credit boom of length t.

1. $\eta > p^{Ch}$. The distribution of beliefs in case information is generated is given by $f(0) = \lambda^t(1-\hat{p}) + (1-\lambda^t)(1-\eta\hat{p})$, $f(\eta) = \lambda^t\hat{p}$ and $f(1) = (1-\lambda^t)\eta\hat{p}$. Then, at period t the variance of beliefs with information production is

$$Var_t(p|IS) = \lambda^t\hat{p}(1-\hat{p})\eta^2 + (1-\lambda^t)\eta\hat{p}(1-\eta\hat{p}).$$

Then

$$Var_t(p|IS) - Var_t(p|II) = (1-\lambda^t)\eta\hat{p}(1-\eta\hat{p}) - \lambda^t\hat{p}(1-\hat{p})(1-\eta^2),$$

increasing in the length of the boom t.

2. $\eta < p^{Ch}$. The distribution of beliefs in case information is produced is given by $f(0) = \lambda^t(1-\hat{p}) + (1-\lambda^t(1-\hat{p}))(1-\eta\hat{p})$, and $f(1) = (1-\lambda^t(1-\hat{p}))\eta\hat{p}$. Then, at period t the variance of beliefs with information production is

$$Var_t(p|IS) = \lambda^t\hat{p}(1-\hat{p})\eta^2\hat{p} + (1-\lambda^t(1-\hat{p}))\eta\hat{p}(1-\eta\hat{p}).$$

Then

$$Var_t(p|IS) - Var_t(p|II) = (1-\lambda^t(1-\hat{p}))\eta\hat{p}(1-\eta\hat{p}) - \lambda^t\hat{p}(1-\hat{p})(1-\eta^2\hat{p}),$$

also increasing in the length of the boom t.

The change in the variance of beliefs also depends on the size of the shock. For very large shocks ($\eta \to 0$) the variance can decline. This decline is lower the larger is t.

A.6 Proof of Proposition 7

Denote the expected discounted consumption sustained by a unit of collateral with belief p if producing information as $V^{IS}(p)$ and if not producing information as $V^{II}(p)$. The value function from such unit of land is then $V(p) = \max\{V^{IS}(p), V^{II}(p)\}$.

If acquiring information, expected discounted consumption is

$$V^{IS}(p) = pK^*(qA-1) - \gamma + \beta[\lambda(pV(1) + (1-p)V(0)) + (1-\lambda)V(\hat{p})] + pC.$$

Since we know that for $p = 0$ and $p = 1$ there is no information acquisition, ($V(1) = V^{II}(1)$ and $V(0) = V^{II}(0)$) we can compute

$$V(1) = K^*(qA-1) + \beta[\lambda V(1) + (1-\lambda)V(\hat{p})] + pC,$$

and

$$V(0) = 0 + \beta[\lambda V(0) + (1-\lambda)V(\hat{p})] + pC.$$

Taking expectations

$$pV(1) + (1-p)V(0) = \frac{pK^*(qA-1)}{1-\beta\lambda} + \frac{\beta(1-\lambda)}{1-\beta\lambda}V(\hat{p}) + \frac{pC}{1-\beta\lambda},$$

and solving for $V^{IS}(p)$, we get

$$V^{IS}(p) = \frac{pK^*(qA-1)}{1-\beta\lambda} - \gamma + Z(p,\hat{p}), \tag{22}$$

where

$$Z(p,\hat{p}) = \frac{\beta(1-\lambda)}{1-\beta\lambda}V(\hat{p}) + \frac{pC}{1-\beta\lambda}.$$

If *not* acquiring information, expected discounted consumption is

$$V^{II}(p) = K(p|II)(qA-1) + \beta[\lambda V(p) + (1-\lambda)V(\hat{p})] + pC.$$

Assume $V(p) = V^{II}(p)$, then

$$V^{II}(p) = \frac{K(p|II)(qA-1)}{1-\beta\lambda} + Z(p,\hat{p}), \tag{23}$$

and $V(p)$ is indeed information insensitive if $V^{II}(p) > V^{IS}(p)$

$$(1-\beta\lambda)\frac{\gamma}{qA-1} > pK^* - K(p|II).$$

Similarly, assume $V(p) = V^{IS}(p)$. We denote as $V^{II}(p|Dev)$ the expected discounted consumption from deviating and not producing information only for one period. Then

$$V^{II}(p|Dev) = K(p|II)(qA-1) + \beta[\lambda V^{IS}(p) + (1-\lambda)V(\hat{p})] + pC$$

replaces equation (22),

$$V^{II}(p|Dev) = K(p|II)(qA-1) + \beta[\lambda\left(\frac{pK^*(qA-1)}{1-\beta\lambda} - \gamma + Z(p,\hat{p})\right) + (1-\lambda)V(\hat{p})] + pC,$$

and plugging in $Z(p,\hat{p})$ and rearranging, obtain

$$V^{II}(p|Dev) = \left[K(p|II) + \frac{\beta\lambda pK^*}{1-\beta\lambda}\right](qA-1) - \beta\lambda\gamma + Z(p,\hat{p}).$$

$V(p)$ is indeed information sensitive if $V^{II}(p|Dev) < V^{IS}(p)$, which is again

$$(1-\beta\lambda)\frac{\gamma}{qA-1} < pK^* - K(p|II).$$

This result effectively means that the decision rule for the planner is the same as the decision rule for decentralized agents, but with $\beta > 0$ for the planner and $\beta = 0$ for the agents.

This result allows us to characterize value functions in equilibrium generally as

$$V(p) = \frac{\widetilde{\pi}(p)}{1-\beta\lambda} + Z(p,\hat{p}), \tag{24}$$

where $\widetilde{\pi}(p) = \widetilde{K}(p)(qA-1)$ and $\widetilde{K}(p) = \max\left\{K(p|II), pK^* - \frac{\gamma(1-\beta\lambda)}{qA-1}\right\}$, which is the same as array (11), but with new cutoffs given by lower effective costs of information $\gamma(1-\beta\lambda)$.

A.7 Proof of Proposition 8

Without loss of generality we assume the negative shock η can happen only once. Until the shock occurs, its ex-ante probability is μ per period, turning to 0 after the shock is realized. This assumption just simplifies the analysis because, conditional on a shock, we can impose the results obtained previously without aggregate shocks. Furthermore we do not need to keep track of all the possible paths of shocks and beliefs. Generalizing this result just requires more algebra, but hides the main forces at work behind the results.

Denote by $\widehat{V}(p)$ the expected discounted consumption sustained by a unit of collateral with belief p prior to the realization of the shock. As in Proposition 7, denote by $V(p)$ the expected discounted consumption sustained by a unit of collateral with belief p after the shock realized, hence in the absence of possible future shocks. This is convenient because we can replace value functions after the shock with the results from Proposition 7 and because we do not need to keep track of different paths of beliefs.

The value of producing information (*IS*) in periods preceding potential shocks is,

$$\begin{aligned}\widehat{V}^{IS}(p) \;&=\; pK^*(qA-1) - \gamma + \beta(1-\mu)\lambda[p\widehat{V}(1) + (1-p)\widehat{V}(0)] + \beta(1-\mu)(1-\lambda)\widehat{V}(\hat{p}) \\ &\quad + \beta\mu\lambda[pV(\eta) + (1-p)V(0)] + \beta\mu(1-\lambda)V(\eta\hat{p}) + pC.\end{aligned}$$

Again we know that for $p=0$ and $p=1$ there is no information acquisition, ($\widetilde{V}(1) = \widetilde{V}^{II}(1)$ and $\widetilde{V}(0) = \widetilde{V}^{II}(0)$) and we can compute

$$\begin{aligned}p\widehat{V}(1) + (1-p)\widehat{V}(0) \;&=\; \frac{1}{1-\beta\lambda(1-\mu)}\left[pK^*(qA-1) + \beta(1-\mu)(1-\lambda)\widehat{V}(\hat{p}) + pC\right] \\ &\quad + \frac{1}{1-\beta\lambda(1-\mu)}\left[\beta\mu\lambda(pV(\eta) + (1-p)V(0)) + \beta\mu(1-\lambda)V(\eta\hat{p})\right].\end{aligned}$$

Also, using value functions in the absence of shocks, $V(p)$, from equation (24).

$$pV(\eta) + (1-p)V(0) = \frac{p\widetilde{K}(\eta)(qA-1)}{1-\beta\lambda} + Z(p,\hat{p}).$$

Plugging these results in $\widehat{V}^{IS}(p)$ and rearranging we obtain:

$$\widehat{V}^{IS}(p) = \frac{pK^*(qA-1)}{1-\beta\lambda(1-\mu)} - \gamma + \frac{\beta\lambda\mu}{1-\beta\lambda(1-\mu)}\left[\frac{p\widetilde{K}(\eta)(qA-1)}{1-\beta\lambda} + Z(p,\hat{p})\right] + \widehat{Z}(p,\hat{p},\eta,\mu), \tag{25}$$

where

$$\widehat{Z}(p,\hat{p},\eta,\mu) = \frac{\beta(1-\lambda)[(1-\mu)\widehat{V}(\hat{p}) + \mu\widehat{V}(\eta\hat{p})] + pC}{1-\beta\lambda(1-\mu)}.$$

The value of NOT producing information (*II*) in periods preceding potential shocks,

$$\begin{aligned}\widehat{V}^{II}(p) \;&=\; K(p|II)(qA-1) + \beta(1-\mu)\lambda\widehat{V}(p) + \beta(1-\mu)(1-\lambda)\widehat{V}(\hat{p}) \\ &\quad + \beta\mu\lambda V(\eta p) + \beta\mu(1-\lambda)V(\eta\hat{p}) + pC,\end{aligned}$$

Assuming $\widehat{V}(p) = \widehat{V}^{II}(p)$,

$$\widehat{V}^{II}(p) = \frac{K(p|II)(qA-1)}{1-\beta\lambda(1-\mu)} + \frac{\beta\lambda\mu}{1-\beta\lambda(1-\mu)}\left[\frac{\widetilde{K}(\eta p)(qA-1)}{1-\beta\lambda} + Z(p,\hat{p})\right] + \widehat{Z}(p,\hat{p},\eta,\mu), \tag{26}$$

and $\widehat{V}(p)$ is indeed information insensitive if $\widehat{V}^{II}(p) > \widehat{V}^{IS}(p)$, which happens if

$$\frac{\gamma}{qA-1}(1-\beta\lambda) < \frac{(1-\beta\lambda)}{(1-\beta\lambda+\beta\lambda\mu)}[pK^* - K(p|II)] + \frac{\beta\lambda\mu}{(1-\beta\lambda+\beta\lambda\mu)}[p\widehat{K}(\eta) - \widehat{K}(\eta p)].$$

Assuming $\widehat{V}(p) = \widehat{V}^{IS}(p)$, the question is if the planner gains anything by deviating and not producing information for one period. We denote this possibility as $\widehat{V}(p|Dev)$

$$\begin{aligned}\widehat{V}^{II}(p|Dev) \;&=\; K(p|II)(qA-1) + \beta\lambda(1-\mu)\left[\frac{pK^*(qA-1)}{1-\beta\lambda(1-\mu)} - \gamma\right] + \widehat{Z}(p,\hat{p},\eta,\mu) \\ &\quad + \frac{\beta\lambda\mu}{1-\beta\lambda(1-\mu)}\left[\frac{\widetilde{K}(\eta p)(qA-1)}{1-\beta\lambda} + Z(p,\hat{p}) + \beta\lambda(1-\mu)\frac{\widetilde{K}(\eta p)(qA-1)}{1-\beta\lambda}\right].\end{aligned}$$

$\widehat{V}(p)$ is indeed information-insensitive if $\widehat{V}^{II}(p|Dev) > \widehat{V}^{IS}(p)$, which happens if

$$\frac{\gamma}{qA-1}(1-\beta\lambda) < \frac{(1-\beta\lambda)}{(1-\beta\lambda+\beta\lambda\mu)}[pK^* - K(p|II)] + \frac{\beta\lambda\mu}{(1-\beta\lambda+\beta\lambda\mu)}[p\widehat{K}(\eta) - \widehat{K}(\eta p)]$$

which is the same condition obtained before. Based on this condition, the following Lemmas are self-evident.

Lemma 1 *Incentives to acquire information are larger in the presence of future shocks if $pK^* - K(p|II) < p\widetilde{K}(\eta) - \widetilde{K}(\eta p)$, and smaller otherwise. Hence, whether there are more or less incentives to acquire information in the presence of shocks just depends on their size η, and not on their probability μ.*

Lemma 2 *If in the presence of aggregate shocks there are more incentives to acquire information, these are larger the larger the difference between $pK^* - K(p|II)$ and $p\widetilde{K}(\eta) - \widetilde{K}(\eta p)$ and the larger μ.*

Proof The first part of the Lemma is trivial. The second arises from noting the weight assigned to $p\widetilde{K}(\eta) - \widetilde{K}(\eta p)$ increases with μ. Q.E.D.

These two Lemmas, together with the condition for information acquisition we derived provide a complete characterization of the IS and II ranges of beliefs under the possibility of a future aggregate shock η that occurs with probability μ, and that is summarized in the Proposition.

A.8 Results with Lenders' Competition (Not for Publication)

In the main text we assume random matching between firms and households, and we assign the negotiation power to the firm. This implies both that firms cannot go to another household after the negotiation of a loan and that households, in their role of lenders, break even. These assumptions, however, are made just for expositional purposes. Here we show that the conclusions in the main text remain, and even strengthen, if we endogeneize the borrowers' negotiation power by modeling explicitly competition among lenders.

Households may post loan contracts under which they offer not to produce information about the collateral (information-insensitive debt), and loan contracts under which they offer to produce information (information-sensitive debt). Every firm can approach as many households as it wants anonymously. Once a loan is agreed on, it becomes public knowledge and cannot be renegotiated or refinanced. Given restrictions on the endowment, each household can lend at most to a single firm.

We assume there are more potential lenders (households) than potential borrowers (only a fraction of firms have skills L^*, for example), which implies that households compete a la Bertrand when offering contracts, such that they are indifferent between offering the contract or not. From the analysis in the main text, if the firm can only approach a single household, these contracts are the following:

- Information-sensitive debt (IS): The contract is only offered if $p > \frac{\gamma}{K^*(qA-1)}$. In that case, the household produces information about the land. If the land is bad, there is no loan. If the land is good, the contract specifies the firm has to post a fraction $x_{IS} = \frac{pK^*+\gamma}{pC}$ of land as collateral to receive a loan of $K_{IS} = K^*$.[12]
- Information-insensitive debt (II): The household does not produce information about the land and the contract specifies the firm has to post a fraction $x_{II} = \min\left\{\frac{K}{pC}, 1\right\}$ of land as collateral to receive a loan K_{II}, which is the maximum loan size that avoids information acquisition, as specified in equation (4).

Under a competitive setting, if firms can approach many households, do they still approach only a single household in equilibrium? Are these contracts still offered in equilibrium? Here we show that in a competitive setting, IS contracts are offered under the same conditions. However, there is a range of beliefs p for which information-insensitive contracts *are not offered*. Furthermore, this range includes the range of beliefs p for which information-insensitive contracts *are not chosen* when assuming random matching. When offered, however, II contracts specify the conditions above.

[12] For this loan we still assume $qA < C/K^*$ as in the main text. Relaxing this assumption just introduces more conditions on the contract.

The difference arises because, when both contracts are offered in a competitive environment, firms that ex ante, with random matching, would have preferred to take an II debt, may want to deviate, first approaching an IS contract to learn the type of their land virtually for free. If this deviation is possible, lenders know that any II contract that offers a positive loan in equilibrium only attracts firms with bad collateral, so they decide not to offer any II contract.

Hence, we need to study the incentives for firms to approach a second lender.

1. II debt: A firm that approaches a household who offers an II contract does not improve its information set, not having incentives to approach a second potential lender, otherwise they would have done it before.

2. IS debt: Since we assume lending relations are anonymous, information is non-verifiable before the end of the period and contracts cannot be refinanced, basically there are no free-riding problems. A firm which chooses to approach a lender who offers an IS contract, and learns his land is good, cannot credibly communicate this information to another lender in order to obtain better loan terms. In contrast, a firm who chooses to approach a lender which offers an IS contract, and learns his land is bad, later wants to approach a lender who offers an II contract.

   Given this possibility, when both contracts are offered, the firm wants to first learn its land type approaching an IS offer, and then, if its land is bad, to take an II offer. This is the optimal strategy of firms with land with belief p if

   $$p[K^*(qA-1)-\frac{\gamma}{p}]+(1-p)E(\pi|p,II)>E(\pi|p,II).$$

   The left hand side represents the expected gains for the firm to approach an IS offer first. If the land is good the gains for the firm are $K^*(qA-1)-\frac{\gamma}{p}$. If the land is bad the firm just issues an II debt as long as it provides a positive loan and generates $E(\pi|p,II)>0$. The right hand side represents the expected gains for the firm just to issue II debt directly.

   This condition is summarized by

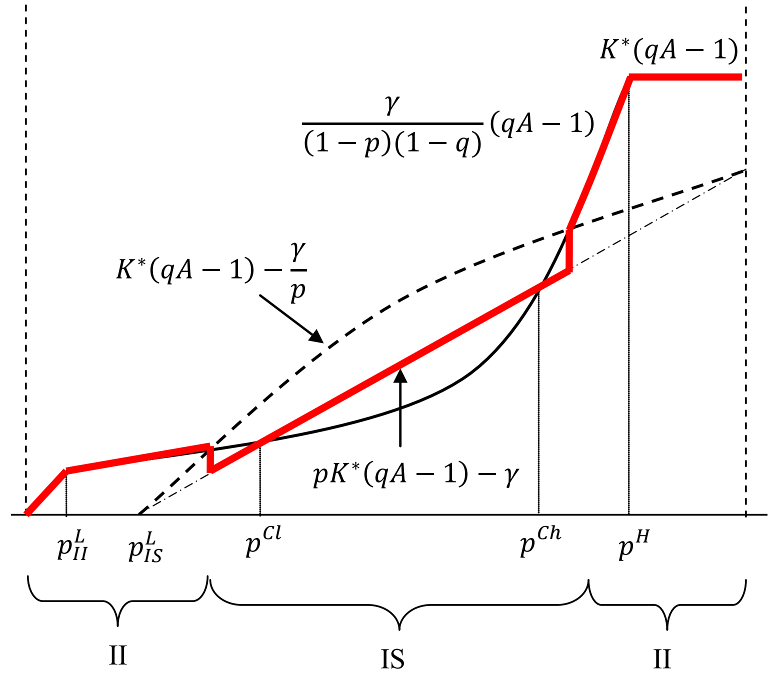
   $$K^*(qA-1)-\frac{\gamma}{p}>E(\pi|p,II).$$

   The left hand side is represented by the dotted black curve in Figure 9 and the right hand side cannot be larger than the solid black curve in Figure 9. If this condition holds (IS range in Figure 9), households know that offering an II contract only attracts firms with bad land, and prefer to offer just IS contracts.

Since

$$K^*(qA-1)-\frac{\gamma}{p}>E(\pi|p,IS)\equiv pK^*(qA-1)-\gamma,$$

Figure 9: Information Sensitiveness with Competitive Lenders



the range of the IS region is larger than the one characterized in the main text. This implies a discontinuity in the size of loans and the expected profits of firms (red solid function in Figure 9), when II debt just becomes not incentive compatible.

Naturally this characterization in a competitive setting just strengthen all the conclusions in the paper. A small shock that moves the system to the IS region generates a sudden and large discontinuous decline in aggregate output because of the sudden unavailability of information-insensitve debt in the economy.

A.9 Land Prices that Include the Value of Land as Collateral (Not for Publication)

In the main text the price of land just reflects its outside option, or fundamental value, since we assumed buyers have all the negotiation power and make take-it or leave-it offers. In this extension we generalize the results assuming Nash bargaining between buyers and sellers, where the sellers' negotiation power $\theta \in [0,1]$ determines how much they can extract from the surplus of buyers (in the main text we assumed $\theta = 0$). To simplify the exposition in the main text we also assumed no discounting (i.e., $\beta = 1$). In this extension we assume a generic discount factor $\beta \in [0,1]$.

First, we assume the case without aggregate shocks and then we discuss how the introduction of aggregate shocks just enter into prices as a an expectation. We denote the price of a unit of land with perceptions p as $Q(p)$.

The surplus of a unit of land for the seller is just its expected intrinsic value

$$J_S(p) = pC.$$

The surplus of land for the buyer is the expected profit from a firm plus the expected price of the land. If p is such that debt is information-sensitive, the surplus is

$$J_B(p|IS) = E(\pi|p, IS) + \lambda[pQ(1) + (1-p)Q(0)] + (1-\lambda)Q(\hat{p}),$$

where $E(\pi|p, IS) = [pK(1) + (1-p)K(0)](qA - 1) - \gamma$.

If p is such that debt is information-insensitive, the surplus is

$$J_B(p|II) = E(\pi|p, II) + \lambda Q(p) + (1-\lambda)Q(\hat{p}),$$

where $E(\pi|p, II) = K(p)(qA - 1)$.

Then

$$Q(p) = \beta[\theta J_B(p) + (1-\theta)J_S(p)] \tag{27}$$

since $Q(p) = J_S(p) + \theta(J_B(p) - J_S(p))$.

1. Borrowing as a function of land price

Firms can compute the possible borrowing with both information-sensitive and insensitive debt and determine which one is higher. In the main text we impose the price of land as the sellers' outside option and we determine the optimal borrowing as a function of that price. Now the price of land also depends on the optimal borrowing, and then they should be determined simultaneously.

In the case of information-sensitive debt, $R_{IS}(1) = x_{IS}(1)Q(1)$ and $R_{IS}(0) = x_{IS}(0)Q(0)$ because debt is risk-free. Lenders break even when,

$$p[x(1)Q(1) - K(1)] + (1-p)[x(0)Q(0) - K(0)] = \gamma$$

where $x(1)Q(1) \geq K(1)$ and $x(0)Q(0) \geq K(0)$.

In the case of information sensitive debt, $R_{II}(p) = x_{II}(p)Q(p)$ because debt is risk-free. Lenders break even when,

$$x(p)Q(p) = K(p).$$

with the constraint that

$$p[x(p)(qQ(p) + (1-q)Q(1)) - K(p)] \leq \gamma$$

or, which is the same as

$$K(p) \leq \frac{\gamma}{(p\frac{Q(1)}{Q(p)} - p)(1-q)}. \tag{28}$$

In the main text, where $\theta = 0$, $Q(1) = C$, $Q(p) = pC$ and then $K(p) \leq \frac{\gamma}{(1-p)(1-q)}$.

2. Solving Borrowing and Land Prices Simultaneously

We now show how to solve simultaneously for optimal borrowing and land prices.

1. *When $\gamma > 0$, firms with collateral $p = 0$ and $p = 1$ prefer to borrow without producing information.*

   This is clear because knowing the type of the collateral (which is the case with $p = 0$ and $p = 1$), it does not make sense for the borrower to pay γ.

2. $K(1) = K^*$

   Since $K(1)$ is not financially constrained in the information-insensitive case.

3. *Determination of $K(\hat{p})$, $Q(\hat{p})$ and $Q(1)$. There are three possible cases.*

   (a) $\hat{p}$ is information-insensitive and $K^* \leq \frac{\gamma}{(\hat{p}\frac{Q(1)}{Q(\hat{p})} - \hat{p})(1-q)}$: This implies $K(\hat{p}) = K^*$ and

   $$Q(\hat{p}) = \frac{\beta(1-\theta)\hat{p}C + \beta\theta K^*(qA-1)}{1-\beta\theta}.$$

   (b) $\hat{p}$ is information-insensitive and $K^* > \frac{\gamma}{(\hat{p}\frac{Q(1)}{Q(\hat{p})} - \hat{p})(1-q)}$: Since $Q(\hat{p})$ and $Q(1)$ just depend on $K(\hat{p})$, it is obtained from equation (28).

(c) $\hat{p}$ is information-sensitive: When information reveals the collateral is bad, and assuming the firm maximizes borrowing $x_{IS}(0) = 1$. The following two equations jointly determine $K(0)$ and $K(\hat{p})$:

$$K(\hat{p}) = \hat{p}K^* + (1-\hat{p})K(0) - \frac{\gamma}{(qA-1)}, \tag{29}$$

$$K(0) = Q(0) = \frac{\beta\theta[K(0)(qA-1) + (1-\lambda)Q(\hat{p})]}{1-\beta\theta\lambda}, \tag{30}$$

where $Q(\hat{p})$ just depends on $K(\hat{p})$.

In these three cases $K(\hat{p})$ is solvable, and the prices

$$Q(\hat{p}) = \frac{\beta(1-\theta)\hat{p}C + \beta\theta K(\hat{p})(qA-1)}{1-\beta\theta}$$

and

$$Q(1) = \frac{\beta(1-\theta)C + \beta\theta[K^*(qA-1) + (1-\lambda)Q(\hat{p})]}{1-\beta\theta\lambda}$$

are well-defined. Similarly, expected profits for $\hat{p}$ in both the cases of information-sensitive and insensitive can be computed such that firms choose the highest possible amount of borrowing.

4. *Determination of $K(0)$ and $Q(0)$.*

These are determined by

$$K(0) = Q(0) = \frac{\beta\theta[K(0)(qA-1) + (1-\lambda)Q(\hat{p})]}{1-\beta\theta\lambda}.$$

5. *Determination of $K(p)$ and $Q(p)$.*

There are two cases, from which the firm chooses the highest possible borrowing:

(a) p is information-insensitive:

$$K(p) = \frac{\gamma}{(p\frac{Q(1)}{Q(p)} - p)(1-q)}.$$

(b) p is information-sensitive:

$$K(p) = pK^* + (1-p)K(0) - \frac{\gamma}{(qA-1)}.$$

where in both cases $Q(p)$ only depends on $K(p)$,

$$Q(p) = \frac{\beta(1-\theta)pC + \beta\theta[K(p)(qA-1) + (1-\lambda)Q(\hat{p})]}{1-\beta\theta\lambda}.$$

The determination of which regions are information-sensitive and insensitive is similar to the case in the main text. Expected profits with information-sensitive debt is linear while expected profits with information-insensitive debt depend on the shape of the land prices.

3. Multiplicity

In the previous steps we show how to solve the optimal borrowing when land prices are endogenous. However these steps do not guarantee uniqueness of the solution (for example under information-insensitiveness, equation (28) does not imply uniqueness). The intuition is the following: If there is no confidence that in the future low quality collateral can be used to sustain borrowing, this will reduce the price of the collateral, reinforcing the fact that it will not be able to sustain such a borrowing. This "complementarity" between the price of collateral and borrowing capabilities is what creates potential multiplicity.

An interesting example is the extreme opposite to the one assumed in the main text, this is $\theta = 1$. In this extreme case, the potential multiplicity takes a very clear form. Assume an equilibrium where all collateral sustain borrowing of K^* without producing information, regardless of the perception p that land is good. If this is the case, the price for all collateral is independent of p,

$$Q(p) = \frac{\beta K^*(qA-1)}{1-\beta}.$$

Given these prices, borrowing without information acquisition is not binding because $Q(1) = Q(p)$ and then $K^* < \frac{\gamma}{(p-p)(1-q)} = \infty$, from equation (28). As conjectured, all collateral can borrow K^* regardless of p. In general, a larger θ allows for the existence of an equilibrium that sustains a lot of credit without information acquisition, but fragile to beliefs about whether land with low p can sustain high credit.