THE OPPORTUNITY COST OF COLLATERAL*

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Abstract

We develop a dynamic model of borrowing and lending in the interbank market, in which banks fund investments through short-term collateralized debt, like repos. This debt is not a perfect substitute for cash: lending banks may not be able to convert their loans to cash to fund their own investments. Hence, lending comes with an opportunity cost that generates positive spreads even absent any credit risk. The opportunity cost channel gives a new explanation for why credit is tight in crises and loose beforehand. Through banks' collateral constraints, the opportunity cost also determines asset demand and prices, creating a feedback loop that can result in multiple, welfare-ranked equilibria. High-leverage equilibria are inefficient in booms; hence, countercyclical capital regulation can improve welfare.

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1 Introduction

Banks borrow from one another with short-term collateralized debt, using the $12 trillion repo market to fund investments in everything from prop trades to commercial loans (CGFS (2017); Gorton and Metrick (2012)). These investment opportunities are especially attractive in financial crises, when assets are cheap and returns are high (e.g., Muir (2017))). But credit is tight in crises (e.g., Krishnamurthy and Muir (2017)); indeed, the repo market dried up in the 2008 crisis (e.g., Gorton and Metrick (2010)).[1] Hence, it is hard for banks to get credit when they can use it to fund high-expected-return investments. Why is credit tight in crises, exactly when the high expected returns available make it most valuable? And why is it loose in the build-up to crises, even though returns to borrowing are low? Is such procyclical credit efficient? If not, what can a regulator do about it?

To give a new perspective on these questions, we develop a dynamic model of interbank borrowing and lending based on the limited moneyness of collateralized debts. Lending banks may not be able to convert their loans to cash to undertake their own investments. Hence, lending comes with an opportunity cost that generates positive spreads even absent any credit risk. The high returns available in a crisis increase the opportunity cost of lending, and hence lead to high spreads and tight credit. In contrast, the anticipation of high future returns before a crisis decreases the opportunity cost of lending, and hence leads to low spreads and loose credit. This opportunity-cost channel also affects asset demand and prices through banks' collateral constraints, and thereby creates a feedback loop that can result in multiple, welfare-ranked equilibria. We find that credit can be too loose in booms, when moneyness is high, supporting the idea of countercyclical bank capital regulation.

Model preview. A continuum of ex ante identical banks exist in continuous time. At each time, some banks get investment opportunities, and borrow from the other banks to fund them. The model is based on two key assumptions. First, the pledgeability of cash flows is limited as in, e.g., Holmstrom and Tirole (1997): if a bank gets an investment opportunity, it needs to post collateral to borrow and fund it. Second, the moneyness of loans is limited as in, e.g., Kiyotaki and Moore (2000)[2]: if a bank makes a loan, it cannot frictionlessly convert it to cash to fund its own investments.

Results preview. Our first main result is a characterization of how much investing banks borrow and at what spread. The spread is positive even though, given loans are fully collateralized in the optimal lending contract, there is no credit risk. Thus, the spread is not

[1] Note, however, that Krishnamurthy, Nagel, and Orlov (2014) find that the dry-ups were not market wide, but confined to a subset of repos.

[2] See also Donaldson and Micheler (2018) and Kiyotaki and Moore (2001a, 2001b, 2005, 2012).

a risk premium. Rather, it a result of limited moneyness: it is purely compensation for the forgone investment opportunities that lending banks cannot undertake if they are unable to convert their loans to cash. Hence, the spread is an increasing function of the ratio of the value of the investments they must forgo to the value of the cash they get as interest. This spread determines how much banks have to repay against their collateral ex post, and hence how much they can borrow ex ante. This opportunity-cost channel determines the volume of credit, which leads to our next two results.

Our second main result is that if the return on banks' investments increases, the spread increases and leverage decreases—in line with our motivating facts, we find that credit is tight when returns are high (i.e. in crises, when prices are depressed). The reason is that the better investment opportunities are, the more compensation lending banks need for forgoing them. Hence, the higher is the spread. This high spread leads to tight credit, because banks have to promise higher repayments against the same collateral.

Our third main result is that if the expected return on banks' future investments increases, the spread decreases and leverage increases today—in line with our motivating facts, credit is loose when future returns are high (i.e. before crises, when banks anticipate low prices in the future). The reason is that the better future investment opportunities are, the more valuable cash is today, since you can save it to invest profitably. Thus, each dollar of interest is worth more today, and lending banks require less total interest as compensation for forgone investment opportunities—it is not the absolute value of forgone investments that matters; it is their value relative to cash. Hence, if cash becomes more valuable, the spread goes down. This low spread leads to loose credit, because banks have to promise lower repayments against the same collateral.

For our fourth main result, we include a market for capital assets to model endogenous asset prices, which we abstracted from so far to keep things as simple as possible. Now, there is a two-way interaction between asset prices and the opportunity-cost channel: tight credit depresses demand, leading to low prices and high returns; these high returns feed back to tighten credit further, via our opportunity cost channel. This feedback loop is powerful enough to generate multiple equilibria due to self-fulfilling beliefs. There is a high-leverage equilibrium and a low-leverage equilibrium: if banks believe returns are high, credit is tight, demand is low, and returns are indeed high, and vice versa. We show that these equilibria are welfare ranked, and hence there is a case for regulation that can rule out the inefficient equilibrium.

For our fifth main result, we characterize which equilibrium is efficient as a function of frictions in the lending market. We find that welfare is higher in the high-leverage equilibrium if frictions are low—e.g., loans are easy to sell—and higher in the low-leverage equilibrium otherwise. Thus, when frictions are low, bank capital regulation is a good idea—a regulator can improve welfare by capping bank leverage, and thereby forcing the market into the "good" equilibrium—but a bad idea if they are high—a regulator could inhibit banks from taking on debt when they need to. Since frictions seem to be high in crises and low in booms, this result provides a new rationale for the idea that capital regulation "measures have to be counter-cyclical, i.e. tough during a credit boom and more relaxed during a crisis" (Brunnermeier, Crockett, Goodhart, Persaud, and Shin (2009), p. 31).

Repos and rehypothecation. In our model, as in practice, money-like debt is debt that can be converted to cash easily, either by selling it in the market or, in the case of repos, rehypothecating collateral, a transaction that resembles "spending a repo."[3] Still, it is not as frictionless as spending cash. In fact, in the 2008 financial crisis, the amount of collateral available for rehypothecation dropped by half (Singh and Aitken (2009, 2010)). This "immobility of collateral" led repo spreads, which had been loose in the build up to the crisis, to shoot up, even though high haircuts kept default risk at a minimum (Gorton and Muir (2015))—in line with our opportunity-cost channel, spreads are not compensation for risk.

Related literature. Our credit cycles, based on the opportunity cost of collateral, complement those in the literature, based on assets being used as collateral. In Kiyotaki and Moore (1997) and Brunnermeier and Pedersen (2009), falling asset prices lead collateral constraints to tighten, which depresses asset demand and make asset prices fall further. Credit fluctuates result. Although distinct, our cycles can amplify these, exacerbating financial fragility (Subsection 5).[4] This interaction is specific to markets in which lenders value cash to fund their own investments—i.e. to markets, like the interbank market, in which lenders can also be borrowers. Thus, unlike other theories, our analysis can help explain why credit in the interbank market is especially prone to drying up.

Our finding that the high-leverage equilibrium is inefficient in booms complements papers on constrained inefficient credit booms. Many of these models, such as Bianchi (2016), Gersbach and Rochet (2012), Korinek and Simsek (2016), and Lorenzoni (2008), are based

[3] As Gorton and Metrick (2010) put it,

> [An] important feature of repos is that the...collateral can be "spent"...used as collateral in another, unrelated, transaction.... This...means that there is a money velocity associated with the collateral. In other words, the same collateral can support multiple transactions, just as one dollar of cash can.... The collateral is functioning like cash (p. 510).

[4] Other theories of credit cycle include that of Fostel and Geanakoplos (2008) and Geanakoplos (2010) based on collateral constraints under heterogeneous beliefs, Myerson (2012) on moral hazard, Gu, Mattesini, Monnet, and Wright (2013) on the beliefs about future credit conditions, Gorton and Ordoñez (2014) on the time-varying information sensitivity of debt, and Kurlat (2016) on adverse selection. He and Krishnamurthy (2012, 2013) focus on the role of asset prices in banks' equity constraints.

on pecuniary externalities induced by asset prices in collateral constraints. In our model, both spreads and asset prices enter collateral constraints, and they feed back on each other to generate multiple equilibria. Thus, unlike in these papers, leverage regulation serves as equilibrium selection; Donaldson, Piacentino, and Thakor (2018) propose a similar strategy for the household credit market, arguing it could mitigate labor-search externalities.

Our policy analysis fits into the literature on regulating the leverage cycle. Davydiuk (2018) and Malherbe and Bahaj (2018) argue that countercyclical regulation can mitigate cyclical inefficiencies of bank credit extension in the corporate loan market. We argue, in contrast, that it can mitigate inefficiencies in the interbank market.

Our paper also fits into the literature on the private creation of money-like securities that are imperfect substitutes for cash.[5] With our focus on limited moneyness in the repo market, we relate to the theory literature on repos,[6] especially those that study rehypothecation (e.g., Gottardi, Maurin, and Monnet (2017) and Maurin (2017)). None of the papers in these literatures studies the opportunity cost, which is at the heart of our analysis. Some corporate finance papers, such as Bolton, Chen, and Wang (2011), do; we complement them, focusing on how it is determined in market equilibrium.

2 Model

2.1 Environment, Agents, and Technologies

There is one good, a numeraire called cash. It is storable at the risk-free rate, which we normalize to zero. There is a unit of ex ante identical risk-neutral agents, called banks. Each starts with initial wealth W_0 and discounts the future at rate $\rho > 0$ in continuous time, $t \geq 0$.

At each time t, a bank may get an investment opportunity, which arrive with Poisson intensity α. The investment is (very) short-term, riskless, and constant returns to scale: investing w at time t yields Rw at time $t + \mathrm{d}t$, where $\mathrm{d}t$ is the time differential. After a bank completes its investment, it consumes and dies.

[5] E.g., Gorton and Pennacchi (1990), Dang, Gorton, and Hölmstrom (2015a, 2015b), Dang, Gorton, Hölmstrom, and Ordoñez (2015), and Gorton and Ordoñez (2014) all study how banks should design securities to circulate in secondary markets in the presence of asymmetric information. In contrast He and Milbradt (2014) focus on search frictions in the secondary market, and study how they interact with default decisions in the primary market. Stein (2012) focuses on debt maturity, rather than default, and shows that a premium for moneyness leads to inefficient shortening of maturity. Rather than focus on fixed-maturity debt, Donaldson and Piacentino (2018) examine the option to redeem on demand, and argue that the banks' ability to provide this option creates a rationale for traditional banking. Sunderam (2015) moves the focus to shadow banks, studying how they create near-money substitutes.

[6] E.g., Martin, Skeie, and von Thadden (2014a, 2014b) study coordination-based repo runs.

2.2 Collateral Constraint

A bank with an investment opportunity can invest its own wealth, denoted by w, plus anything it borrows from other banks. We denote a bank's leverage by b, so the amount it borrows is bw. What it can borrow is limited by what it can repay, as described by the collateral constraint that

$$\text{total repayment } \leq \text{capital invested}, \tag{1}$$

i.e. the bank's investment is pledgeable, but its new output is not as in, e.g., Rampini and Viswanathan (2013). Letting σ denote the interest rate spread (over the risk-free rate of zero), this reads

$$(1+\sigma)bw \leq w + bw, \tag{2}$$

or

$$b \leq \frac{1}{\sigma}. \tag{3}$$

Equivalence to the constraint in an A-k model. Before moving on, observe that this constraint is equivalent to the constraint in a two-good model in which a borrower invests k in pledgeable capital and produces Ak in non-pledgeable output. Denoting by p the price of capital, we can combine the budget and borrowing constraints to recover equation (3):

$$\underbrace{pk = w + bw}_{\text{budget constraint}} \quad \& \quad \underbrace{(1+\sigma)bw \leq pk}_{\text{borrowing constraint}} \quad \Longrightarrow \quad b \leq \frac{1}{\sigma} \tag{4}$$

(having written $p \equiv p_t$ and used $p_{t+\mathrm{dt}} \to p_t$ as $\mathrm{dt} \to 0$).

In this set-up, the investment return $R = A/p$. We analyze this environment in detail in Subsection 5 in which we endogenize the price of capital and hence the return on investment.

2.3 Lending Market

A bank without an investment opportunity can choose to hold cash, in which case it gets investment opportunities with intensity α. Alternatively, it can choose to make loans. We assume that there are frictions in the lending market, so if it chooses to lend, a bank does not make a loan immediately, but only with Poisson intensity β; it delivers the (endogenous) spread σ. A bank that chooses to lend may still get investment opportunities, but they do not arrive with the same intensity as they do if it holds cash, but with a lower intensity $\phi\alpha < \alpha$. Thus, choosing to lend comes not only with the benefit of interest, but also with the cost of forgone investment opportunities.

This set-up can be directly interpreted in the search-and-matching framework: a bank can either search for investment opportunities or search for lending opportunities. $\phi < 1$ captures the extent to which searching for lending opportunities instead of investment opportunities decreases their arrival rate. This is literally the opportunity cost of lending.

ϕ can also be interpreted as the moneyness (or resaleability) of loans: a lending bank can undertake an investment opportunity only if it can sell its loan/rehypothecate its collateral, which it can do with probability ϕ. Hence ϕ is the extent to which lending is a substitute for cash, i.e. the moneyness of loans.[7]

2.4 Aggregate State

The exogenous parameters α, β, ϕ, and R can depend on an aggregate state at time t, denoted by s_t.[8] We assume that s_t changes only once, at random time τ that arrives with Poisson intensity π. (The assumption of a single shock allows us to solve the model in closed form, which we think helps it gives a new perspective on the credit cycle despite its stylized aggregate dynamics.)

2.5 Equilibrium Definition

An equilibrium is an allocation of quantities invested, lent, and held in cash and the spread at each time t such that the following hold at each t:

1. Banks optimize: investing banks optimally choose how much to invest and other banks optimally choose how much to hold in cash and how much to lend (with all banks taking σ as given).

2. The lending and cash markets clear.

Markov equilibrium with binding collateral constraints. We focus on Markov equilibria with binding collateral constraints, i.e. in which the state s_t is a sufficient statistic for the entire history and the collateral constraints in equation (3) always bind.

[7] This is not a literal interpretation in our model, because all banks that choose to lend suffer from the decreased ability to undertake their investments—in line with the search interpretation, ϕ affects all banks that choose to lend, not only those that successfully make loans, but also those that do not. In continuous time, this is necessary to ensure that the expected flow payoffs from choosing to lend and choosing to hold cash are both $o(\mathrm{dt})$. But this is a purely technical distinction; it does not affect the economics. In discrete time, these technical considerations do not arise, so we can solve the analogous version of our model with a more literal formulation of moneyness/resaleability. Our baseline model effectively nests that one. Indeed, for appropriately chosen β it gives the exact same expression for the spread. See Appendix B.

[8] We do not index the the discount rate ρ by the state just because we think it is more natural to assume that preference parameters are constant; this does not affect the main results.

Like the parameters α, β, ϕ, and R, the equilibrium leverage b and spread σ are implicitly indexed by s_t. We omit this index when we can, and often use the following shorthand when we cannot: recalling that state changes only once—there is one "shock" at the random time τ—we use the subscript τ for values after the shock. E.g., for v_{s_t}, which denotes the value of cash below, we write

$$v_{s_t} =: \begin{cases} v & \text{if } t < \tau, \\ \\ v_\tau & \text{if } t \geq \tau. \end{cases} \tag{5}$$

3 Equilibrium Characterization

In this section, we characterize the equilibrium. We proceed in three steps: (i) we write down the value functions corresponding to investing, holding cash, and lending; (ii) we find the dynamics of aggregate wealth and its proportions that are invested, lent, and held in cash from market clearing; (iii) we solve for the spread and leverage.

3.1 Value Functions

Value of investing V. We begin with the value of investing, which we denote by V. Taking the spread σ as given, a bank with an investment opportunity and wealth w chooses its leverage b to maximize its final output net of the loan repayment. Thus, it solves the program to

$$\text{maximize } \Big(R(1+b) - (1+\sigma)b\Big)w \tag{6}$$

over $b \geq 0$ subject to its collateral constraint in equation (3), or

$$V(w) := \max\left\{ \Big(R + (R-1-\sigma)b\Big)w \;\middle|\; b \in \left[0\,,\, \frac{1}{\sigma}\right] \right\}. \tag{7}$$

Observe that V is linear in w, so we define $V := V(1)$ and write $V(w) \equiv Vw$.

Since we focus on equilibria in which the collateral constraint in equation (3) binds, it must be that $b = 1/\sigma$ at the optimum, or

$$R \geq 1 + \sigma, \tag{8}$$

which says that the return on investment is sufficiently high to compensate for the cost of borrowing. Since σ is endogenous, we verify this condition after finding the candidate equilibrium (cf. Proposition 4). Assuming it holds for now, we can express V in terms of σ:

Lemma 1. **(Value of investing.)** *The value of investing against w dollars is Vw, where*

$$V = (R-1)\left(1+\frac{1}{\sigma}\right). \tag{9}$$

Value of cash v. Next we turn to the value of holding cash. We use v to denote the value of cash and $\bar{v}$ to denote the expected value of cash a differential amount of time dt in the future, $\bar{v}_{s_t} := \mathbb{E}_t\left[v_{s_{t+\mathrm{dt}}}\right]$. Since v inherits linearity from V,[9] we can write it recursively as

$$v(w) = vw = \frac{1}{1+\rho\,\mathrm{dt}}\left(\alpha\mathrm{dt}Vw + (1-\alpha\mathrm{dt})\,\bar{v}w\right), \tag{10}$$

i.e. with probability αdt the bank gets an investment opportunity worth Vw and with probability $1-\alpha$dt it keeps its cash worth $\bar{v}$; everything is discounted at rate ρ.

Value of lending v^ℓ. Finally, we turn to the value of lending, which we denote by v^ℓ. Again v^ℓ inherits linearity from V, so we can write it recursively as

$$v^\ell w = \frac{1}{1+\rho\,\mathrm{dt}}\left(\phi\alpha\mathrm{dt}Vw + (1-\phi\alpha\mathrm{dt})(1+\beta\sigma\mathrm{dt})\bar{v}w\right), \tag{11}$$

i.e. with probability $\phi\alpha$dt the lending bank gets an investment opportunity worth Vw and with probability $1-\phi\alpha$dt it does not, and gets the expected interest $\beta\sigma$dt in cash worth $\bar{v}$; everything is discounted at rate ρ.

3.2 Market Clearing and Wealth Shares

We now impose market clearing in the lending market and calculate how aggregate wealth is distributed among investing, lending, and holding cash. Because the value functions are linear, it does not matter how wealth is distributed among individual banks, but only how much of it is allocated to each activity.

The total wealth held by all agents at time t, denoted by W_t, constitutes the wealth held by (i) investors/borrowers, denoted by w_t^I, (ii) lending banks, denoted by w_t^ℓ, and (iii) cash holders, denoted by $w_t^\$$. These quantities must satisfy three constraints:

1. **Investment arrivals.** New investments arrive at rate α for cash holders and rate $\phi\alpha$ for lenders:

$$w_t^I = \alpha w_t^\$\mathrm{dt} + \phi\alpha w_t^\ell\mathrm{dt}. \tag{12}$$

[9] You can verify this formally by checking equations (24) and (29) below.

2. **Market clearing.** The amount borrowed equals the amount lent:

$$\beta w_t^\ell \mathrm{dt} = b w_t^I. \tag{13}$$

3. **Adding up.** The wealth of all types of agents is the total wealth:

$$w_t^\$ + w_t^\ell = W_t, \tag{14}$$

   where we have used that the measure of investing banks at any single time is vanishingly small compared to the measures of lenders and cash holders, i.e. $w_t^I = o(\mathrm{dt})$ from equation (12).

Combining these three, we can find the wealth shares (assuming they are positive).

Lemma 2. **(Wealth shares.)**

$$\frac{w_t^I}{W_t} = \frac{\alpha\beta}{\beta + \alpha(1-\phi)b}\mathrm{dt}, \tag{15}$$

$$\frac{w_t^\ell}{W_t} = \frac{\alpha b}{\beta + \alpha(1-\phi)b}, \tag{16}$$

$$\frac{w_t^\$}{W_t} = \frac{\big(\beta - \phi\alpha b\big)}{\beta + \alpha(1-\phi)b}. \tag{17}$$

To ensure the wealth shares are positive, we require that

$$b \leq \frac{\beta}{\phi\alpha} \tag{18}$$

(cf. equation (17)). Since b is endogenous, we verify this condition after finding a candidate equilibrium, as we do with the assumption on σ in equation (8) above (cf. Proposition 4).

Flow of funds. Given the wealth shares, we can calculate the growth rate of the economy via the flow of funds condition: a borrower eats his wealth and dies; a lender gets expected interest $\beta\sigma\mathrm{dt}$; and a cash holder gets nothing. Thus, the change in total wealth is the interest income of all lenders minus the wealth investing banks eat:

$$\mathrm{d}W_t = \beta\sigma w_t^\ell \mathrm{dt} - w_t^I \tag{19}$$

$$= \left(\sigma - \frac{1}{b}\right)\beta w_t^\ell \mathrm{dt}, \tag{20}$$

$$= \left(\sigma - \frac{1}{b}\right)\frac{\alpha\beta b}{\beta + \alpha(1-\phi)b} W_t \mathrm{dt} \tag{21}$$

where we have used the market clearing condition (equation (13)).

Since the collateral constraint in equation (3) binds in equilibrium, $b = 1/\sigma$ and the lenders' interest income is exactly the wealth of investing banks. Thus, the total wealth remains constant:

$$\mathrm{d}W_t = 0. \tag{22}$$

3.3 Equilibrium Spread and Leverage

Given that value functions are linear, non-investing banks must be indifferent between lending and holding cash (in any equilibrium in which $w^{\$}, w^I > 0$); otherwise, they would all prefer to do one thing or the other, and the market could not clear.[10] Equating $v = v^\ell$ from equations (10) and (11) and taking the limit $\mathrm{d}t \to 0$, we can solve for the spread σ.

Proposition 1. **(Spread.)** *The spread σ solves*

$$\sigma = \frac{(1-\phi)\alpha}{\beta}\left(\frac{V}{v} - 1\right). \tag{23}$$

This expression for the spread captures the trade-off at the heart of our model. Expected interest income must compensate lending banks for their forgone investment opportunities: $\beta\sigma$ exactly makes up for lowering the chance of getting the investment value V from α to $\phi\alpha$. Indeed, if $\phi \to 1$, so loans become completely money-like, then spreads go to zero. But for $\phi < 1$, spreads are positive even though there is no credit risk whatsoever.

We can read other implications directly off the expression for σ in equation (23): the spread goes up when forgone investment opportunities are more likely (α is high); when lending frictions are severe (β is low); and when investments are valuable relative to cash (V/v is high). We stress that it is this relative value of investments that matters, not the absolute value V. As a result, the spread can change just because the value of cash changes and, since the value of cash reflects future investment opportunities, the spread can change even if nothing about current investment opportunities changes.

$t \geq \tau$**: Steady state.** We now solve for the value of cash, starting after the shock ($t \geq \tau$) and working backward. Since we are focusing on Markov equilibria, the economy is in steady state after the single shock: the expected value of cash is the value today ($\bar{v} = v$).

Solving equation (10) for v, we find that the value of cash is a discounted value of future

[10]For some parameters, there are equilibria in which all banks choose to lend. In these equilibria, borrowers' collateral constraints do not bind. Hence, they are ruled out by the conditions of Proposition 3 (cf. the equilibrium description in Subsection 2.5).

investments:

$$v_\tau = \frac{\alpha_\tau V_\tau}{\rho + \alpha_\tau}, \tag{24}$$

where we use the τ subscripts introduced in equation (5) to emphasize that the expression holds only after the shock.

To ensure the value of cash is greater than one, and hence a bank would always prefer to save than to consume, we require that

$$V_\tau \geq 1 + \frac{\rho}{\alpha_\tau}. \tag{25}$$

Since V_τ is endogenous, we verify this condition after finding a candidate equilibrium, as we do with the assumptions on σ and b in equations (8) and (18) above (cf. Proposition 4).

From here, we can use the expression for the spread (Proposition 1) to solve for the equilibrium for $t \geq \tau$:

PROPOSITION 2. **(Steady state.)** *In steady state (i.e. if $t \geq \tau$), the spread and leverage are given by*

$$\sigma_\tau = \frac{(1 - \phi_\tau)\rho}{\beta_\tau} \tag{26}$$

and

$$b_\tau = \frac{1}{\sigma_\tau} = \frac{\beta_\tau}{(1 - \phi_\tau)\rho}. \tag{27}$$

Observe that the steady-state spread and leverage do not depend on the investment return R_τ or its arrival rate α_τ. This was unexpected to us, but has a straightforward explanation, based on the fact that what matters is not the absolute value of investment opportunities V, but only their value relative to the value of cash v (cf. equation (23)). Indeed, increasing R_τ or α_τ has the direct effect of increasing the opportunity cost of lending—the investment opportunities forgone by lending are more valuable/more likely. But it also has the indirect effect of increasing the value of cash—future investment opportunities available from holding cash are more valuable/more likely (cf. equation (24) for the value of cash). In steady state, these two effects exactly cancel out.

Rather than being determined by the value of forgone investment opportunities, prices and allocations are determined by frictions: spreads go down and leverage goes up as frictions decrease, whether by increasing the intensity of matching with lenders β_τ or the moneyness of loans ϕ_τ. This last finding that increasing moneyness leads to higher leverage is in line with Gorton and Muir's (2015) empirical finding that keeping collateral mobile helps to keep credit loose.

$t < \tau$**: "Dynamics."** Moving onward (but solving backward), we consider what happens before the shock. In this case, the expected value of cash is the average of the value v today and its value v_τ after the shock:

$$\bar{v} = (1 - \pi \mathrm{dt})v + \pi \mathrm{dt}\, v_\tau. \tag{28}$$

This allows us to use the recursive equation for v (equation (10)) to find v in terms of v_τ: with $\mathrm{dt}^2 = 0$,

$$v = \frac{\alpha V + \pi v_\tau}{\rho + \alpha + \pi}, \tag{29}$$

where v_τ is given by equation (24).

As above, to ensure that the value of cash is greater than one, we require that

$$V \geq 1 + \frac{\rho - \pi\left(v_\tau - 1\right)}{\alpha}. \tag{30}$$

And, as above, we verify this condition after finding the candidate equilibrium, as we do with the assumptions on σ, b, and v_τ in equations (8), (18), and (25) above (cf. Proposition 4).

With the expression for the value of cash (29), we can use our results above on the investing banks' program (7) and the spread (Proposition 1) to express the equilibrium allocation as the solution of a quadratic equation.

LEMMA 3. **(Equilibrium leverage.)** *Before the shock (i.e. if $t < \tau$), the equilibrium leverage b is given by*

$$b = \frac{-a_1 + \sqrt{a_1^2 - 4a_2 a_0}}{2a_2}, \tag{31}$$

where

$$a_2 = (1 - \phi)(\rho + \pi), \tag{32}$$

$$a_1 = (1 - \phi)(\rho + \pi) - \beta - \frac{(1 - \phi)\pi v_\tau}{R - 1}, \tag{33}$$

$$a_0 = -\beta - \frac{\beta \pi v_\tau}{\alpha(R - 1)}. \tag{34}$$

This expression for b is essential for our analysis of the equilibrium below. Among other things, you can already see that the value of cash after the shock v_τ is a sufficient statistic for all variables after the shock. In other words, we will not have to look at the separate effects of different future parameters on equilibrium, but just at how they affect v_τ.

3.4 Equilibrium Characterization

The results so far put us in a position to characterize the equilibrium fully.

Proposition 3. **(Equilibrium characterization.)** *In a Markov equilibrium with binding collateral constraints, leverage b is given by Proposition 2 for $t \geq \tau$ and Lemma 3 for $t < \tau$; the spread is equal to $\sigma = 1/b$; the aggregate wealth is constant and equal to W_0; and the wealth shares are given by Lemma 2.*

Finally, we prove the existence and uniqueness of equilibrium, returning to the assumptions that we made in equations (8), (18), (25), and (30). These assumptions ensure that it is optimal for investing banks to borrow to capacity, it is optimal for lending banks to lend, and the lending market clears.

Proposition 4. **(Existence and uniqueness.)** *There exists a Markov equilibrium with binding collateral constraints if and only if the following conditions hold:*

$$R_\tau - 1 \geq \frac{(1-\phi_\tau)\rho}{\beta_\tau} \geq \frac{\alpha_\tau \rho}{(\alpha_\tau + \rho)\,\beta_\tau}, \tag{35}$$

$$\max\left\{\frac{1}{R-1}, \frac{\rho - \alpha\,(R-2) - \pi\,(v_\tau - 1)}{\alpha\,(R-1)}\right\} \leq b \leq \frac{\beta}{\phi\alpha}, \tag{36}$$

where b is given by (31)*, and*

$$v_\tau = \frac{\alpha_\tau\,(R_\tau - 1)\,(\beta_\tau + (1-\phi_\tau)\rho)}{(\rho + \alpha_\tau)\,(1-\phi_\tau)\rho} \geq 1. \tag{37}$$

If an equilibrium exists, it is unique.

4 Analysis of the Equilibrium

In this section, we explore the implications of our opportunity cost channel for credit and business cycles. The model provides explanations for why credit is loose in booms and tight in crises that contrast with the received theories but resonate with empirical evidence. The model also generates procyclical fluctuations in capital allocation, which can be even more important to aggregate output than productivity shocks, in line with recent evidence on the drivers of business cycles.

4.1 The Credit Cycle

Having characterized the equilibrium, we can revisit our motivating questions. First, we ask what happens when the return R goes up—a state we view as a crisis, in which returns are high, e.g., due to depressed prices (something we endogenize below; see Subsection 4.2 and Subsection 5.1). And, second, we ask what happens when the return R is expected to go up—a state we view as the build up to a crises, in which banks anticipate high expect returns in the future, when the crisis hits.

What happens if there is a crisis today? I.e. if R goes up for $t < \tau$?

Proposition 5. **(Tight credit for high R.)** *Increasing the return on investment R increases the spread σ and decreases the leverage b.*

Intuitively, high R means that investing is valuable. Hence, there is a high opportunity cost of lending. Thus, the spread σ must increase to compensate lenders for this opportunity cost. And increasing the spread tightens the collateral constraint, since what investing banks need to repay goes up, but what they can pledge stays same—the same collateral does not go as far when spreads are high. Thus, high spreads lead credit to tighten when it is needed most.

This result resonates with our motivating facts: crises are associated with high returns, high spreads, and tight credit. To date, the literature has stressed the explanation based on decreased risk-bearing capacity.[11] We point out that limited moneyness delivers the same patterns, even with no change in risk-bearing capacity—with no risk whatsoever, in fact. In our model, the chain of causality runs in the opposite direction of the usual story. Tight financial constraints do not lead to high returns—it is not that demand gets depressed, keeping prices down (and hence returns up). Rather, tight financial constraints result from high returns—it is that opportunity costs go up, driving up the spread (which feeds back into the collateral constraint).

Now, what happens if there is likely to be a crisis in the future? I.e. if R_τ goes up for $t \geq \tau$? Or, more generally, given v_τ is a sufficient statistic for everything after the shock, including R_τ, what happens as v_τ goes up?

Proposition 6. **(Loose credit in boom.)** *Increasing the future value of cash v_τ decreases the spread σ and increases leverage b.*

Intuitively, high v_τ means that investing in the future is valuable, and hence cash is valuable today—i.e. the value v of cash today is high whenever the value v_τ of cash in the future is; cf. equation (24). And valuable cash means valuable interest: for a fixed spread σ, the interest

[11] Think of the literature on intermediary asset pricing (e.g., He and Krishnamurthy (2012, 2013)) and on limits to arbitrage (e.g., Gromb and Vayanos (2002) and Shleifer and Vishny (1997)).

paid (in cash) is worth more when the value of cash v is high: it is the product σv that matters. In other words, when the value of cash goes up, lenders get the same value at a lower spread. Thus, an increase in v_τ leads to a decrease in σ in equilibrium. And decreasing the spread loosens the collateral constraint, since what investing banks need to repay goes down, but what they can pledge stays the same—the same collateral goes further when spreads are low. The pecuniary externality of the spread on the collateral constraint leads credit to loosen. Banks can borrow freely, even though—indeed because—the investments they need to fund have relatively low returns.

This result also resonates with our motivating facts: booms are associated with low returns, low spreads, and loose credit—indeed, as Krishnamurthy and Muir (2017) put it, "spreads fall pre-crisis and appear too low, even as credit grows ahead of a crisis." To date, the literature has stressed the explanation based on how the build-up of leverage in booms can lead to costly deleveraging in recessions.[12] We point out that limited moneyness delivers the same patterns. In our model, the chain of events again runs in the opposite direction of the usual story. Loose credit does not lead to low returns—it is not that demand gets inflated, keeping prices high (and hence returns low). Rather, loose credit results from low returns—it is the anticipation of high returns in the future that increases the value of cash, lowering the equilibrium spread today (which feeds back into the collateral constraint).

4.2 Aggregate Output

So far, we have studied the credit cycle under the interpretation that high-return times are recessions and low-return times are booms. This interpretation captures the idea that asset prices fall in recessions (making returns high) and rise back up in booms (making returns low): as we formalize in Section 5, the return on an investment should be thought of as its output Ak divided by the price of its capital input pk, so $R = A/p$. In our baseline model, however, there is only one good, so $p \equiv 1$ and the investment return R is just the productivity of individual investments A. Thus, by describing low-R times as booms and high-R times as recessions, we are implying that individual productivity is countercyclical. This may seem at odds with the "[r]ecent macroeconomic literature [which] views [the] stylized fact of procyclical [aggregate] productivity as an essential feature of business cycles" (Basu and Fernald (2001), p. 225). But we show here that there is actually no contradiction: an increase in individual productivity can actually undermine aggregate productivity growth, even in our baseline set-up with exogenous R.

[12] Think of the literature on debt-induced fire sales (e.g., Lorenzoni (2008)), on neglected risk (e.g., Gennaioli, Shleifer, and Vishny (2012)), on the financial accelerator (e.g., Bernanke and Gertler (1989) and Bernanke, Gertler, and Gilchrist (1996)), and on balance sheet recessions (e.g., Di Tella (2017)).

Here, we ask what happens to aggregate output in our model when R goes up. Aggregate output, which we denote by Y, is the product of investing banks' total investment (i.e. their wealth times their gross leverage) with their return on investment:

$$Y = (1 + b)w^I R. \tag{38}$$

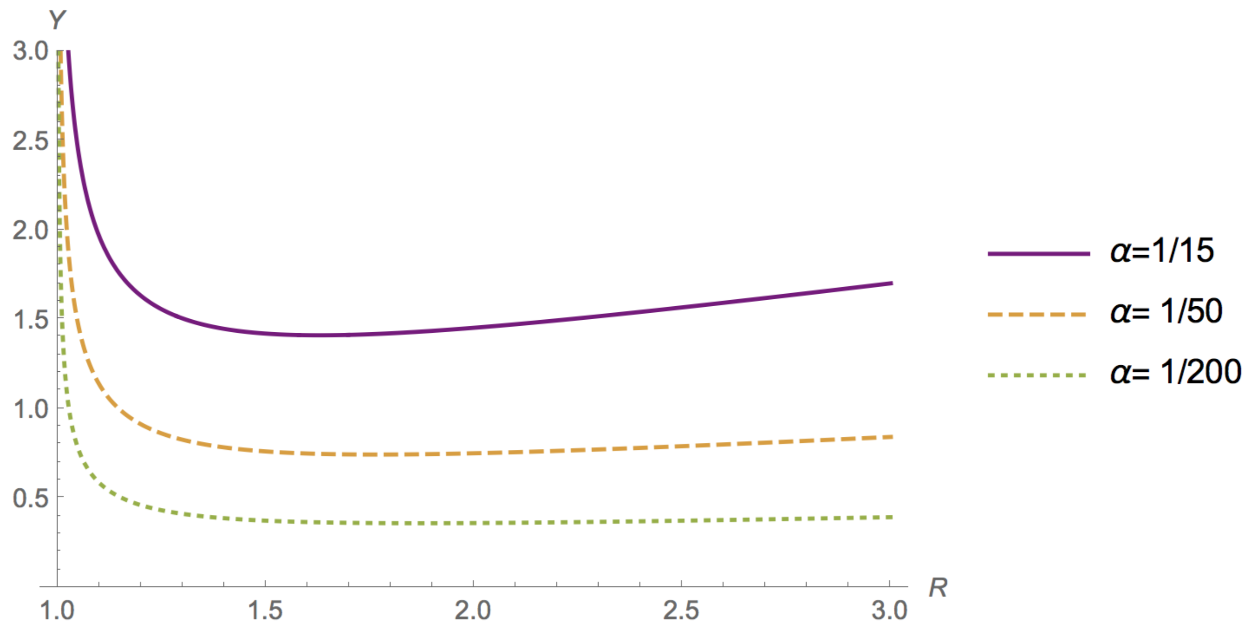
This expression captures the usual effect of increasing R: it increases the output of each dollar invested. However, there is also a new effect of increasing R: it decreases the number of dollars invested since it tightens credit—as described above, increasing R increases the opportunity cost of lending, which drives up the spread and tightens collateral constraints (Proposition 5). When leverage is high (due to low opportunity costs/low α), this new effect can actually overpower the usual one:

PROPOSITION 7. **(Low output for high R.)** *If α is sufficiently small, increasing the return on investment R decreases aggregate output Y.*

This result suggests that capital allocation could be as important as productivity for aggregate output fluctuations. This resonates with evidence in Eisfeldt and Rampini (2006) and Hsieh and Klenow (2009) on the importance of procyclical capital allocation for the business cycle. And it goes a step further. It suggests that individual productivity and aggregate productivity are two sides of the same coin. Since individual productivity shocks drive up the opportunity cost of collateral, they can lead to negative aggregate productivity shocks.

That said, the result only says that this is the case for low α, when investment opportunities arrive rarely, making the opportunity cost of parting with cash small and the spread σ low. Since the leverage b equals $1/\sigma$, low σ makes b sensitive to the opportunity cost. As illustrated in Figure 1, in this case, our new capital-allocation effect of R on output can be more important than its usual direct effect, a finding that points to the potential quantitative importance of our channel (even if this low-α is not necessarily the most empirically relevant one).

Figure 1: Aggregate output is decreasing in R for α sufficiently small. In the plot, $\beta = 3/2$, $\pi = \rho = 1$, $v_\tau = 2$, and $\phi = 3/4$.



4.3 Welfare

Since all agents are risk-neutral and ex ante identical, the total welfare is just the expected value of consumption of all banks. Since they consume only after they invest, the consumption is Vw^I at each time. Integrating up gives the total welfare for each path, which we denote by U^τ:

$$U^\tau \equiv e^{-\rho t} \int_0^\infty V_t w_t^I \tag{39}$$

(note that there is no dt in the integral since it is already inside $w_t^I = o(dt)$). Since we know that τ is exponentially distributed, we can compute expected welfare $U := \mathbb{E}[U^\tau]$ directly:

PROPOSITION 8. **(Welfare characterization.)** *Welfare is given by the value of cash times the initial amount of cash:*

$$U = vW_0. \tag{40}$$

This expression, although somewhat involved to derive, is easy to understand: given time is continuous and investments arrive with Poisson intensity, effectively no one is investing exactly at $t = 0$; everyone is either holding cash or lending. Since banks are indifferent between holding cash, we can calculate welfare as if everyone is holding cash, i.e. as the initial value of cash times the initial amount of cash: vW_0. Moreover, the proof does not depend on the market being in equilibrium, i.e. the expression $U = vW_0$ holds for arbitrary leverage b, not just equilibrium b. Since $V = (R-1)(1+b)$ by Lemma 1, this implies that welfare is increasing in leverage. Since leverage is maximal in equilibrium—the collateral constraints bind—this implies that the equilibrium outcome is constrained efficient:

PROPOSITION 9. **(Constrained efficiency.)** *The equilibrium is constrained efficient in the sense that it achieves the maximum welfare among all levels of leverage b for $t < \tau$ and b_τ for $t \geq \tau$ that satisfy investing banks' collateral constraints (given the spread σ is determined by market clearing).*

5 Asset Prices, Welfare, and Regulation

So far we have taken the return R as an exogenous parameter. This approach allowed us to study our new channel on how R affects credit supply in isolation from the usual channels on how credit supply affects R (through asset prices). In this section, we explore how these channels interact. It turns out that we can endogenize asset prices and R without losing tractability. Again we find closed-form expressions for the spread and leverage. They reveal that the channels amplify each other. They can even generate multiple equilibria. These equilibria are welfare ranked, thus leverage regulation can ensure the economy is in the "good" equilibrium in some circumstances. These circumstances resemble booms, supporting the idea that leverage regulation should be counter-cyclical.

5.1 Asset Prices and Multiple Equilibria

Here, we suppose that investing banks use a capital good k to produce output Ak at $t + \mathrm{d}t$. Hence, the return on their investments is $R = A/p$, where p is the price of the capital good. Now we assume that p is determined by market clearing: banks' total demand for capital must equal its (fixed) supply $K\mathrm{d}t$.[13] After we find p, we can simply replace R with A/p in the analysis above to find the equilibrium.

To find p, we need only to find the aggregate demand. Given the binding budget and collateral constraints (equation (4)), each investing bank's demand for capital assets is

$$k = \frac{(1+b)w}{p}. \tag{41}$$

[13]Since the wealth of investing banks is $o(\mathrm{d}t)$, the supply of capital must also be $o(\mathrm{d}t)$ for their demand to affect prices, which is what we want to focus on now.

Since this is linear in wealth, we can easily aggregate up: just replace the individual bank's wealth with the total wealth of all investing banks w^I form equation (15). The market clearing condition is thus

$$\frac{(1+b)w^I}{p} = K\mathrm{dt}. \tag{42}$$

Substituting in for w^I from equation (15), we get an expression for the price in terms of individual banks' leverage b:

$$p = \frac{(1+b)}{K}\frac{\alpha\beta W}{\beta + \alpha(1-\phi)b}. \tag{43}$$

Observe that, all else equal, p is increasing in b, in line with the standard view that loose credit drives up prices by increasing asset demand. But all else is not equal, and we need to substitute in for the endogenous b from equation (31) to solve for the equilibrium.

Proposition 10. **(Equilibrium characterization with endogenous R.)** *In equilibrium, the leverage b is given by Proposition 2 for $t \geq \tau$ and the solution to the following equation for $t < \tau$:*

$$\hat{a}_2 b^2 + \hat{a}_1 b + \hat{a}_0 = 0 \tag{44}$$

where

$$\hat{a}_2 := \alpha(\pi+\rho)(1-\phi)\Big((1-\phi)AK - \beta W_0\Big), \tag{45}$$

$$\hat{a}_1 := \beta(1-\phi)\big(\pi+\rho-\alpha\big)AK + \alpha\beta\Big(\beta - (1-\phi)\big(\pi+\rho+\pi v_\tau\big)\Big)W_0, \tag{46}$$

$$\hat{a}_0 := \beta^2\Big((\alpha - \pi v_\tau)W_0 - AK\Big). \tag{47}$$

The spread is equal to $\sigma = 1/b$; the aggregate wealth is constant and equal to W_0; and the wealth shares are given by Lemma 2.

Recall that in the steady state ($t \geq \tau$), the equilibrium spread and leverage do not depend on the return R (Proposition 2). Now, since p matters only in so far as $R = A/p$, p does not affect them either. Hence the interaction between credit and asset prices reduces to the standard channel, by which tight credit depresses asset demand, decreasing prices—this is the partial equilibrium effect captured in equation (43).

Away from steady state, however, there is a two-way interaction between this standard channel and our opportunity cost channel. Recall that increasing R tightens credit due to our opportunity cost channel (Proposition 5). This depresses asset demand and lowers prices, as per the standard channel. But now, since $R = A/p$, this feeds back into higher returns, which make our channel kick in again, tightening credit further. This feedback loop between the two channels is powerful enough to generate multiple equilibria:

PROPOSITION 11. **(Multiple equilibria.)** *There can be two equilibria satisfying the description in Proposition 10: a "high-leverage equilibrium" in which b is high for $t < \tau$ and a "low-leverage equilibrium" in which b is lower for $t < \tau$. These equilibria correspond to the two solutions of equation (44), which are both positive whenever β is sufficiently large and α is sufficiently small. These are all Markov equilibria in which the collateral constraint binds.*

As in the equilibrium characterization in the baseline model, we need to check that the requirements we imposed on the allocation hold. Although it is intractable to write these conditions in terms of primitives now that R depends on the solution to a quadratic equation, it is still easy to check whether a candidate allocation satisfies them. Hence, to show existence, we just pick one set of parameters, calculate the two candidate equilibria corresponding to the two solutions of equation (44), and show that they both satisfy our requirements: with $\alpha = 1/20$, $\beta = 3/2$, $\rho = \pi = K = W_0 = 1$, $v_\tau = 2$, and $\phi = 3/4$, there are two equilibria. In both equilibria our requirements in equations (8), (18), (25), and (30) are satisfied. In the high-leverage equilibrium, $b \approx 31.6$ and prices are high, $p \approx 1.3$. In the low-leverage equilibrium, $b \approx 8.7$ and prices are lower, $p \approx 0.5$.

5.2 Welfare Ranking and Capital Regulation

In the baseline model, more leverage always benefits everyone (Proposition 9). Here, in contrast, leverage can have a downside: by increasing asset demand and driving up prices, it decreases the returns on each dollar invested. Thus, we can ask whether banks are necessarily better off in the high-leverage equilibrium here. The answer is no.

PROPOSITION 12. **(Welfare ranking.)** *The equilibria in Proposition 11 are welfare ranked. The high-leverage equilibrium is better if and only if*

$$\frac{1-\phi}{\beta} \geq \frac{W_0}{AK}. \tag{48}$$

The result implies that if a regulator caps leverage, forcing the economy into the low-leverage equilibrium, then welfare is higher if and only if $(1-\phi)/\beta$ is low. $(1-\phi)/\beta$ is a measure of the costs/frictions to lending: it is high when ϕ is low, or if it is hard for lending banks to undertake investment opportunities, and if β is low, or if it is hard for lending banks to find borrowers. Thus, the result says that forcing the economy into the low-leverage equilibrium is good if frictions are low, but bad if they are high.

If we assume that these credit frictions are countercyclical, so $(1-\phi)/\beta$ is high in crises, we can speak to counter-cyclical capital regulation:

COROLLARY 1. **(Counter-cyclical regulation.)** *Under the interpretation that high* $(1-\phi)/\beta$ *is a crisis, capping leverage can help force economy into the good equilibrium in a boom, but prevent it from achieving the good equilibrium in a crisis.*

Thus, our model supports the idea that regulation should be countercyclical, as advocated by, e.g., Brunnermeier, Crockett, Goodhart, Persaud, and Shin (2009) who say "measures have to be counter-cyclical, i.e. tough during a credit boom and more relaxed during a crisis" (p. 31).

6 Conclusion

We present a model of the interbank market based on the limited money of collateralized debt. We find that positive spreads compensate lenders for parting with cash, even absent any credit risk. Thus, the model may be especially useful to understand the repo market, in which collateral makes debt almost risk-less, but spreads are still positive, and went up in the crisis (Hördahl and King (2008) and Gorton and Metrick (2012)). We find that high expected returns cause tight credit today and high expected returns in the future cause loose credit today. This is consistent with our motivating facts that credit is tight in crises when prices are depressed and loose in booms when prices are higher, but future fire sales are anticipated. The chain of causality contrasts with what has been emphasized in the literature. In our model, tight credit does not decrease demand and loose credit does not sew the seeds of a crisis. The next question is how our opportunity-cost-based channel interacts with these important established narratives of credit and crisis.

A Proofs

A.1 Proof of Lemma 1

The result follows from the program in the text; see equation (7). □

A.2 Proof of Lemma 2

The result follows immediately from solving the system of equations (12)–(14). □

A.3 Proof of Proposition 1

Using $\mathrm{dt}^2 = 0$, we can re-write equation (10) for the value of cash v as

$$(1 + \rho \mathrm{dt})v = \alpha \mathrm{dt}(V - \bar{v}) + \bar{v} \tag{49}$$

and equation (11) for the value of lending as

$$(1 + \rho \mathrm{dt})v^{\ell} = \alpha \mathrm{dt}\phi(V - \bar{v}) + \bar{v} + \beta\sigma \mathrm{dt}\bar{v}. \tag{50}$$

Equating the expressions in equations (49), using that $\mathrm{dt}\bar{v} = \mathrm{dt}v$,[14] and (50) and solving for σ gives the expression in the proposition. □

A.4 Proof of Proposition 2

From equation (24) we have that

$$\frac{V_\tau - v_\tau}{v_\tau} = \frac{\rho}{\alpha}. \tag{51}$$

We can substitute this into equation (23) to find the spread:

$$\sigma_\tau = \frac{(1 - \phi_\tau)\rho}{\beta_\tau}, \tag{52}$$

which is the expression in the proposition.

Now, given we are looking for equilibria in which the collateral constraint in equation (3) binds, we have $b_\tau = 1/\sigma_\tau$, or

$$b_\tau = \frac{\beta_\tau}{(1 - \phi_\tau)\rho}, \tag{53}$$

[14]For $t \geq \tau$ this immediate—in that case there is no future shock and $\bar{v} \equiv v$—and for $t < \tau$ if follows from $\mathrm{dt}^2 = 0$—in that case $\bar{v} = \pi \mathrm{dt} v_\tau + (1 - \pi \mathrm{dt})v$, implying $\mathrm{dt}\bar{v} = \mathrm{dt}v$ as desired.

which is the expression in the proposition. $\square$

A.5 Proof of Lemma 3

We can use the value of cash (equation (28)),

$$v = \frac{\alpha V + \pi v_\tau}{\rho + \alpha + \pi}, \tag{54}$$

to write

$$\frac{V - v}{v} = \frac{(\rho + \alpha + \pi)V - \alpha V - \pi v_\tau}{\alpha V + \pi v_\tau} \tag{55}$$

$$= \frac{(\rho + \pi)V - \pi v_\tau}{\alpha V + \pi v_\tau}. \tag{56}$$

Now, substituting this into the expression for the spread in Proposition 1, we find

$$\sigma = \frac{\alpha(1 - \phi)}{\beta} \cdot \frac{(\rho + \pi)V - \pi v_\tau}{\alpha V + \pi v_\tau}. \tag{57}$$

From the binding constraint from in equation (3), we get

$$\sigma = \frac{1}{b}, \tag{58}$$

which we can equate to the spread σ in equation (57) to find

$$\frac{1}{b} = \frac{\alpha(1 - \phi)}{\beta} \cdot \frac{(\rho + \pi)V - \pi v_\tau}{\alpha V + \pi v_\tau}. \tag{59}$$

Rearranging gives

$$\Big(\beta + \alpha(1 - \phi)b\Big)\pi v_\tau = \alpha\Big((1 - \phi)(\rho + \pi)b - \beta\Big)V. \tag{60}$$

Finally, use $V = (R - \theta)(1 + b)$ from Lemma 1 to get

$$\Big(\beta + \alpha(1 - \phi)b\Big)\pi v_\tau = \alpha\Big((1 - \phi)(\rho + \pi)b - \beta\Big)(R - 1)(1 + b). \tag{61}$$

Rearranging gives

$$a_2 b^2 + a_1 b + a_0 = 0, \tag{62}$$

where a_2, a_1 and a_0 are as given in the proposition. This equation has a unique positive solution because $a_0 a_2 < 0$, hence b is given by the expression in the proposition (equation (31)). □

A.6 Proof of Proposition 3

The equilibrium leverage is given by Proposition 2 for $t \geq \tau$ and Lemma 3 for $t < \tau$. The spread $\sigma = 1/b$ because the collateral constraints bind (equation (3)). The wealth shares follow from Lemma 2, where the aggregate wealth is constant since $\mathrm{d}W = 0$ (equation (22)). □

A.7 Proof of Proposition 4

Proposition 3 characterizes a unique candidate equilibrium, so the equilibrium is unique if it exists. For a Markov equilibrium with binding collateral constraints to exist, the candidate equilibrium must satisfy the requirements in equations (8), (18), (25), and (30). Conversely, if the candidate equilibrium satisfies the four assumptions, it is indeed a Markov equilibrium with binding collateral constraints because all banks optimize, markets clear, collateral constraints bind, and it is Markov. Thus, a necessary and sufficient condition for the existence is that the four requirements all hold.

Using that collateral constraints bind, i.e. $b = 1/\sigma$ (equation (3)), we can write equations (8) and (18) as

$$\frac{1}{R-1} \leq b \leq \frac{\beta}{\phi\alpha}. \tag{63}$$

Observe that these must be satisfied both before and after the shock, while equation (25) only applies after the shock and equation (30) only applies before the shock.

We begin with $t < \tau$. Substituting V from Lemma 1 into equation (30) yields

$$b \geq \frac{\rho - \alpha\left(R-2\right) - \pi\left(v_\tau - 1\right)}{\alpha\left(R-1\right)}, \tag{64}$$

where v_τ is given by equation (24). Combining this with (63), we have

$$\max\left\{\frac{1}{R-1}, \frac{\rho - \alpha\left(R-2\right) - \pi\left(v_\tau - 1\right)}{\alpha\left(R-1\right)}\right\} \leq b \leq \frac{\beta}{\phi\alpha}. \tag{65}$$

This is the second condition of the proposition (equation (36)).

Next, we turn to the steady state. Recall that equation (25) is equivalent to $v_\tau \geq 1$. Substituting the V from Lemma 1 and b from Proposition 2 into the expression for v_τ in equation (24), we get that

$$v_\tau = \frac{\alpha_\tau \left(R_\tau - 1\right)\left(\beta_\tau + (1-\phi_\tau)\rho\right)}{\left(\rho + \alpha_\tau\right)\left(1-\phi_\tau\right)\rho} \geq 1, \tag{66}$$

which is the third condition of the proposition (equation (37)).

Lastly, using the steady state equilibrium leverage from Proposition 2, we can write equation (63) as

$$R_\tau - 1 \geq \frac{(1-\phi_\tau)\rho}{\beta_\tau} \geq \frac{\alpha_\tau \rho}{\left(\alpha_\tau + \rho\right)\beta_\tau}, \tag{67}$$

which is the first condition of the proposition (equation (35)). □

A.8 Proofs of Proposition 5 and Proposition 6

The comparative statics results in both propositions can be established by differentiating the expression for b in equation (31). Here, we present an alternative graphical proof to this "brute force" approach instead. To do so, we rewrite the equation for b as follows:

$$\Big(\beta + \alpha(1-\phi)b\Big)\frac{\pi v_\tau}{R-1} = \alpha\Big((1-\phi)(\rho+\pi)b - \beta\Big)(1+b). \tag{68}$$

Observe that the equilibrium leverage b is the point at which the line on the LHS intersects the parabola on the RHS. Then, increases in R and v_τ rotate the line (in opposite directions) without affecting the parabola, delivering the desired comparative statics.

In Figure 2, we start by plotting these two curves, the line on the LHS,

$$\text{LHS} : y = \Big(\beta\theta + \big(\alpha(1-\phi) - \beta(1-\theta)\big)b\Big)\frac{\pi v_\tau}{R-\theta} \tag{69}$$

and the parabola on the RHS,

$$\text{RHS} : y = \alpha\Big(\big((1-\phi)(\rho+\pi) + \beta(1-\theta)\big)b - \beta\theta\Big)(1+b). \tag{70}$$

Comparative statics on equilibrium leverage are comparative statics on the b-coordinate where these curves intersect.

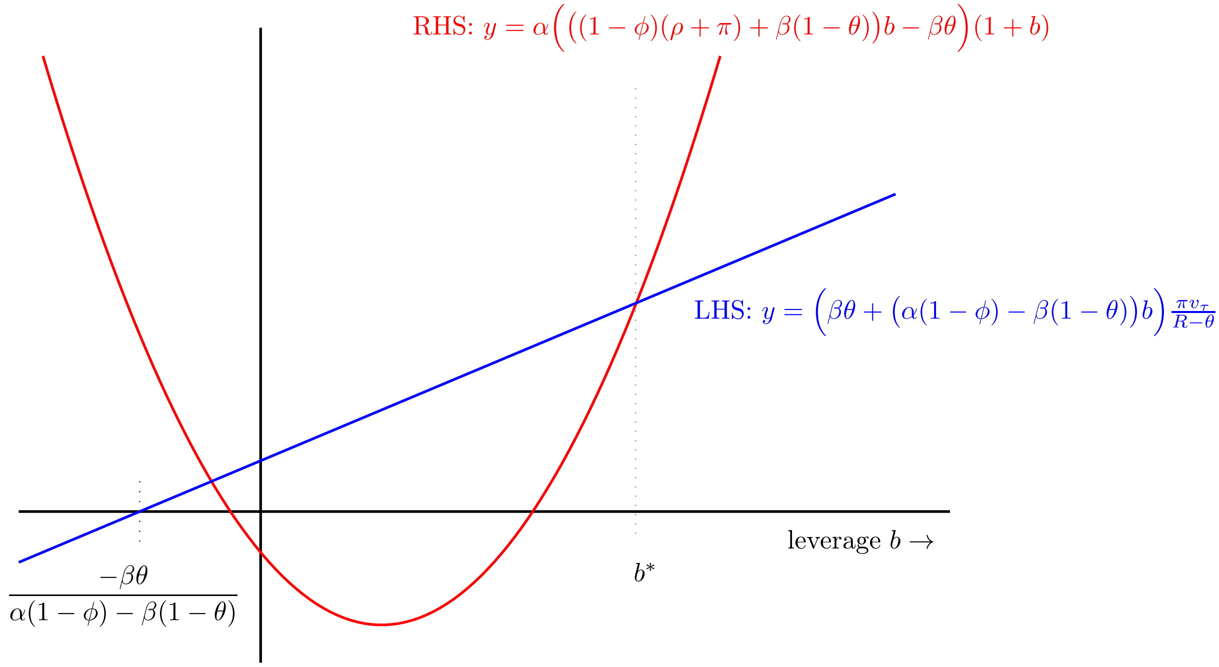


Figure 2: The equilibrium leverage is the b-coordinate of the point at which the line on the LHS and parabola on the RHS intersect.

Observe that the parabola on the RHS is always positive and it is already written in factored form: it has one root at $b = -1 < 0$ and one at $b = \frac{\beta\theta}{(1-\phi)(\rho+\pi)+\beta(1-\theta)} > 0$. The line on the LHS has root $\frac{-\beta\theta}{\alpha(1-\phi)-\beta(1-\theta)}$. This can be positive or negative (we drew the figure with this negative), but it does not matter for the argument. What does matter, is that it does not depend on R or v_τ, and neither does the parabola. Hence, changing R and v_τ just rotates the line, leaving its horizontal intercept and the entire parabola unchanged.

An increase in R or a decrease in v_τ corresponds to a clockwise rotation, which means that the line intersects the parabola sooner—i.e. the equilibrium b is lower—as depicted in Figure 3. In other words, as R increases, b decreases, and as v_τ increases, b increases, as desired.

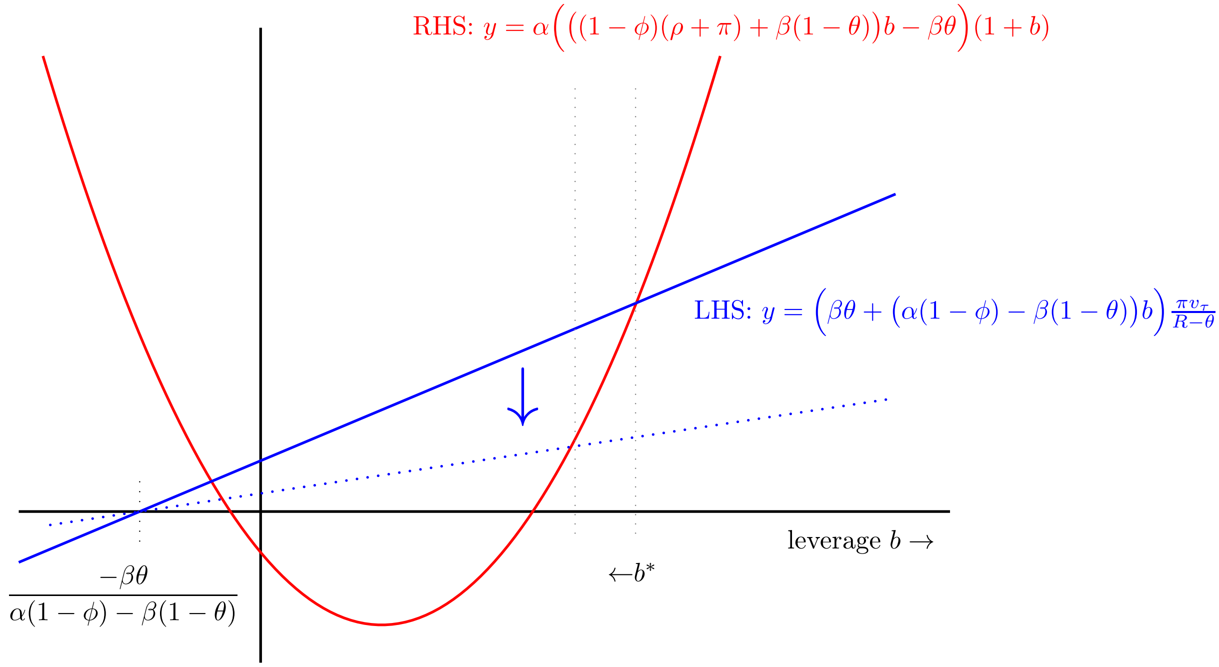


Figure 3: The line on the LHS rotates clockwise as R increases or v_τ decreases. Thus the b-coordinate of intersection with the parabola on the RHS decreases.

A.9 Proof of Proposition 7

Because we have fully characterized the equilibrium in closed form, we can compute the comparative static $\partial Y/\partial R$ directly. There is still a little of work involved only because b is slightly complicated (it is the solution to the quadratic equation (31)) and we have to take the limit $\alpha \to 0$ (since the result is for α small), which requires a little care.

Using the expressions for Y and w^I from equations (38) and (15) and the fact that $W_t \equiv W_0$ from equation 22, we have that

$$Y = (1+b)\frac{\alpha\beta W_0}{\beta + \alpha(1-\phi)b}R, \tag{71}$$

where b is the positive root of the quadratic equation (31). Differentiating we have that

$$\frac{\partial Y}{\partial R} = \frac{\alpha\beta\left(\beta + \Big(\beta+\alpha(1-\phi)\Big)b + \alpha(1-\phi)b^2 + \Big(\beta-\alpha(1-\phi)\Big)R\dfrac{\partial b}{\partial R}\right)}{\Big(\beta+\alpha(1-\phi)b\Big)^2}W_0. \tag{72}$$

Now, from the above we have that $\partial Y/\partial R < 0$ whenever

$$\alpha\left(\beta+\Big(\beta+\alpha(1-\phi)\Big)b+\alpha(1-\phi)b^2+\Big(\beta-\alpha(1-\phi)\Big)R\frac{\partial b}{\partial R}\right)<0. \tag{73}$$

By implicitly differentiating equation (31), we find that

$$\frac{\partial b}{\partial R}=\frac{\pi\big(\beta+\alpha(1-\phi)b\big)v_\tau}{(R-1)^2\left(-\alpha(1-\phi)(\pi+\rho)(1+b)+\alpha\big(\beta-(1-\phi)(\pi+\rho)b\big)+\dfrac{\alpha(1-\phi)\pi v_\tau}{R-1}\right)}. \tag{74}$$

Substituting this into equation (73), we get that $\partial Y/\partial R < 0$ whenever

$$\begin{aligned}&\alpha\beta+\alpha\Big(\beta+\alpha(1-\phi)\Big)b+\alpha^2(1-\phi)b^2+\\&+\frac{\Big(\beta-\alpha(1-\phi)\Big)\Big(\beta+\alpha(1-\phi)b\Big)\pi v_\tau R}{\left(\Big(\beta-(\pi+\rho)(1-\phi)\Big)(R-1)-2(1-\phi)(\pi+\rho)(R-1)b+(1-\phi)\pi v_\tau\right)(R-1)}<0.\end{aligned} \tag{75}$$

We want to know whether this inequality holds in the limit as $\alpha \to 0$, but we cannot yet take the limit mechanically, because b is a function of α. We need to prove the following lemma first:

Lemma 4. *As $\alpha \to 0$, $b \to \infty$ and $\alpha b \to 0$.*

Proof. We start by substituting in for a_0 into the equation for b (equation (31)) to get

$$b=\frac{-a_1+\sqrt{a_1^2+4a_2\left(\beta+\dfrac{\beta\pi v_\tau}{\alpha(R-1)}\right)}}{2a_2}. \tag{76}$$

Importantly, a_2 and a_1 do not depend on α (cf. equations (32) and (33)).

Further, $a_2 > 0$, so it is immediate that $b \to \infty$ as $\alpha \to 0^+$.

To see that $\alpha b \to 0$, multiply by α and carry it under the square root:

$$\alpha b=\frac{-\alpha a_1+\sqrt{\alpha^2a_1^2+4a_2\left(\alpha^2\beta+\dfrac{\alpha\beta\pi v_\tau}{(R-1)}\right)}}{2a_2}. \tag{77}$$

All the terms above go to zero as $\alpha \to 0^+$, hence so does the whole expression.

$\square$

Given this lemma, we can take the limit of equation (75) by simply deleting the α and αb terms. Now, we have the for α sufficiently small, $\partial Y/\partial R < 0$ as long as

$$\frac{\beta^2 \pi v_\tau \pi}{\left(\left(\beta - (\pi+\rho)(1-\phi)\right)(R-1) - 2(1-\phi)(\pi+\rho)(R-1)b + (1-\phi)\pi v_\tau\right)(R-1)} < 0. \tag{78}$$

Observe that the only thing left that depends on α is b in the denominator, which becomes large as α becomes small. Since it has a negative coefficient, the inequality is always satisfied for small α. $\square$

A.10 Proof of Proposition 8

In this proof, we do not suppose banks' leverage b is necessarily the equilibrium leverage b. This makes the proof a bit more computationally cumbersome, but shows the generality of our welfare formulation and also allows us to do welfare analysis of policies that regulate leverage, forcing it away from its equilibrium level.

We start with a lemma that characterizes the welfare for each path. Then we use it to characterize the ex ante welfare as the expectation over all paths. To do this, we use equation (21) to write

$$\mathrm{d}W_t = g_t W_t \mathrm{dt} \tag{79}$$

where the growth rate g_t is

$$g_t := \left(\sigma - \frac{1}{b}\right) \frac{\alpha\beta b}{\beta + \alpha(1-\phi)b}. \tag{80}$$

Lemma 5. **(Welfare of path τ.)**

$$U^\tau = \frac{1 - e^{-(\rho-g)\tau}}{\rho - g} \frac{\alpha\beta V W_0}{\beta + \alpha(1-\phi)b} + \frac{\alpha_\tau \beta_\tau V_\tau W_0}{\beta_\tau + \alpha_\tau(1-\phi_\tau)b_\tau} \frac{e^{(g-\rho)\tau}}{\rho - g_\tau}. \tag{81}$$

Proof. The proof is by direct computation:

$$U^\tau = \int_0^\infty e^{-\rho t} V_{s_t} w_t^I \tag{82}$$

$$= \int_0^\infty e^{-\rho t} V_{s_t} \frac{\alpha_{s_t}\beta_{s_t} W_t}{\beta_{s_t} + \alpha_{s_t}(1-\phi_{s_t}) b_{s_t}} \mathrm{dt} \tag{83}$$

$$= \int_0^\tau e^{-\rho t} \frac{\alpha\beta V W_t}{\beta + \alpha(1-\phi) b} \mathrm{dt} + \int_\tau^\infty e^{-\rho t} \frac{\alpha_\tau \beta_\tau V_\tau W_t}{\beta_\tau + \alpha_\tau(1-\phi_\tau) b_\tau} \mathrm{dt} \tag{84}$$

$$= \frac{\alpha\beta V W_0}{\beta + \alpha(1-\phi) b} \int_0^\tau e^{(g-\rho)t} \mathrm{dt} \; + \; \frac{\alpha_\tau \beta_\tau V_\tau e^{(g-g_\tau)\tau} W_0}{\beta_\tau + \alpha_\tau(1-\phi_\tau) b_\tau} \int_\tau^\infty e^{(g_\tau - \rho)t} \mathrm{dt} \tag{85}$$

$$= \frac{1 - e^{-(\rho-g)\tau}}{\rho - g} \frac{\alpha\beta V W_0}{\beta + \alpha(1-\phi) b} \; + \; \frac{\alpha_\tau \beta_\tau V_\tau W_0}{\beta_\tau + \alpha_\tau(1-\phi_\tau) b_\tau} \frac{e^{(g-\rho)\tau}}{\rho - g_\tau} \tag{86}$$

$\square$

We start by computing the integral under the expectation $U = \mathbb{E}\left[U^\tau\right]$ using the expression in Lemma 5:

$$\mathbb{E}\left[U^\tau\right] = \frac{1 - \mathbb{E}\left[e^{-(\rho-g)\tau}\right]}{\rho - g} \frac{\alpha\beta V W_0}{\beta + \alpha(1-q) b} \; + \; \frac{\alpha_\tau \beta_\tau V_\tau W_0}{\beta_\tau + \alpha_\tau(1-\phi_\tau) b_\tau} \frac{\mathbb{E}\left[e^{(g-\rho)\tau}\right]}{\rho - g_\tau} \tag{87}$$

Now, given that τ is a Poisson variable (it is exponentially distributed), we have that

$$\mathbb{E}\left[e^{-(\rho-g)\tau}\right] = \int_0^\infty e^{-(\rho-g)\tau} \pi e^{-\pi\tau} \mathrm{d}\tau = \frac{\pi}{\rho - g + \pi}. \tag{88}$$

Substituting into the above, computing, and substituting v_τ in from equation (24), we get

$$U = \frac{W_0}{\rho - g + \pi} \left(\frac{\alpha\beta V}{\beta + \alpha(1-\phi) b} + \pi v_\tau \right). \tag{89}$$

Now, substituting in for g from equation (80) we get that

$$U = \frac{\alpha\beta V + \big(\beta + \alpha(1-\phi) b\big) \pi v_\tau}{(\rho + \pi)\big(\beta + \alpha(1-\phi) b\big) - \alpha\beta\big(\sigma b - 1\big)} W_0. \tag{90}$$

Finally, we can substitute for σ from Proposition 1 and use the expression for v (equation (10)) to get the expression in the proposition:

$$U = \frac{\alpha V + \pi v_\tau}{\rho + \alpha + \pi} W_0 \equiv v W_0. \tag{91}$$

$\square$

A.11 Proof of Proposition 9

The result follows almost immediately from the fact that

$$U = \frac{\alpha(R-1)(1+b) + \pi v_\tau}{\rho + \alpha + \pi} \tag{92}$$

where

$$v_\tau = \frac{\alpha_\tau(R_\tau - 1)(1+b_\tau)}{\rho + \alpha_\tau}, \tag{93}$$

by Proposition 8, Lemma 1, and equation (24). This implies that welfare is increasing in b and b_τ: more leverage is always better.

There is just one subtlety to address before we can conclude that making collateral constraints bind is always the best way to max out on leverage: regulating leverage after τ can affect the collateral constraint before τ. I.e. if capping b_τ loosened collateral constraints before τ, allowing you to increase b, it could improve welfare. But this is not the case. Increasing b_τ increases v_τ mechanically. And recall that v_τ is a sufficient statistic for all variables after the shock, and that collateral constraints before the shock actually loosen as v_τ increases by Proposition 6. $\square$

A.12 Proof of Proposition 10

The proposition follows from using the equilibrium price in equation (43) to write R

$$R = R(b) = \frac{AK\big(\beta + \alpha(1-\phi)b\big)}{(1+b)\alpha\beta W}, \tag{94}$$

which we can substitute back into the quadratic equation (62) for b to find the equilibrium allocation.

Specifically, for $t \geq \tau$, the equilibrium spread does not depend on prices, as described in the text. For $t < \tau$, we get the following equation for b:

$$(1+b)\alpha\left(\beta - (1-\phi)(\pi+\rho)b - \frac{\beta\Big(\beta + \alpha(1-\phi)b\Big)\pi v_\tau W}{\alpha\beta(1+b)W - \Big(\beta + \alpha(1-\phi)b\Big)AS}\right) = 0. \tag{95}$$

This can be re-written as a cubic, and factored as follows:

$$(1+b)\left[\hat{a}_2 b^2 + \hat{a}_1 b + \hat{a}_0\right] = 0 \tag{96}$$

where

$$\hat{a}_2 := \alpha(\pi+\rho)(1-\phi)\Big((1-\phi)AK - \beta W\Big), \tag{97}$$

$$\hat{a}_1 := \beta(1-\phi)\big(\pi+\rho-\alpha\big)AK + \alpha\beta\Big(\beta-(1-\phi)\big(\pi+\rho+\pi v_\tau\big)\Big)W, \tag{98}$$

$$\hat{a}_0 := \beta^2\Big(\alpha W - AK - W\pi v_\tau\Big). \tag{99}$$

To focus on the positive solutions, we can factor $1+b$. This gives the quadratic equation in the proposition. □

A.13 Proof of Proposition 11

The quadratic in equation (44) has two positive solutions whenever $\hat{a}_0\hat{a}_2 > 0$ and $-\hat{a}_1/\hat{a}_2 > 0$. These conditions are satisfied whenever β is sufficiently large and α is sufficiently small:

- $\hat{a}_2 < 0$ because β is large and $\hat{a}_0 < 0$ because α is small. Hence $\hat{a}_0\hat{a}_2 > 0$.
- $\hat{a}_1 > 0$ because α is small (first term) and β is large (second term). Hence $-\hat{a}_1/\hat{a}_2 > 0$.
- $\hat{a}_0\hat{a}_2 > 0$ and $-\hat{a}_1/\hat{a}_0 > 0$ implies there are two positive roots. □

A.14 Proof of Proposition 12

Recall that the welfare is

$$U = \frac{\alpha V + \pi v_\tau}{\rho+\alpha+\pi} W_0 \tag{100}$$

by Proposition 8 and the multiple equilibria are identical for $t \geq \tau$. Hence we need to compare only V across the equilibria. We start with the expression for V in Lemma 1,

$$V = \big(R(b)-1\big)(1+b) \tag{101}$$

and use $R = A/p$ and p in equation (43) to write

$$V = \left(\frac{\big(\beta+\alpha(1-\phi)b\big)AK}{\alpha\beta(1+b)W_0} - 1\right)(1+b) \tag{102}$$

$$= \frac{\beta(AK-\alpha W_0) + \alpha\big((1-\phi)AK - \beta W_0\big)b}{\alpha\beta W_0}, \tag{103}$$

which is affine in b. It is increasing if and only if

$$\frac{1-\phi}{\beta} \geq \frac{W_0}{AK}, \tag{104}$$

which is the condition for the high-leverage equilibrium to be better in the proposition. □

A.15 Proof of Corollary 1

The result follows immediately from Proposition 12. □

B Resaleability in Discrete Time

As in the baseline model, if a bank holds cash, it gets an investment opportunity with probability α. Hence, the value of holding \$1 in cash is

$$v = \frac{1}{(1+\rho)}\Big(\alpha V + (1-\alpha)v\Big), \tag{105}$$

as in equation (10).

Differently from the baseline model, if a bank chooses to lend, it lends for sure. Then it gets an investment opportunity with probability α. In this case it can sell the loan for \$1 to invest and get V with probability ϕ. (So ϕ is literally the resaleability of the loan.) Otherwise, it earns the (endogenous) spread σ. Hence, the value of lending \$1 is

$$v^{\ell} = \frac{1}{(1+\rho)}\Big(\alpha\phi V + (1-\alpha\phi)(1+\sigma)v\Big). \tag{106}$$

Lemma 6. **(Spread in discrete time.)** *In the discrete-time version of the model described above, the equilibrium spread solves*

$$\sigma = \frac{\alpha(1-\phi)}{1-\alpha\phi}\left(\frac{V}{v}-1\right). \tag{107}$$

Combined with Proposition 1, this implies that this model is effectively nested by our baseline model:

Corollary 2. **(Nesting.)** *If $\beta = 1-\alpha\phi$, the equation for the spread in the baseline model (Proposition 1) is the same as the equation for the spread in the discrete-time version (Lemma 6).*

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