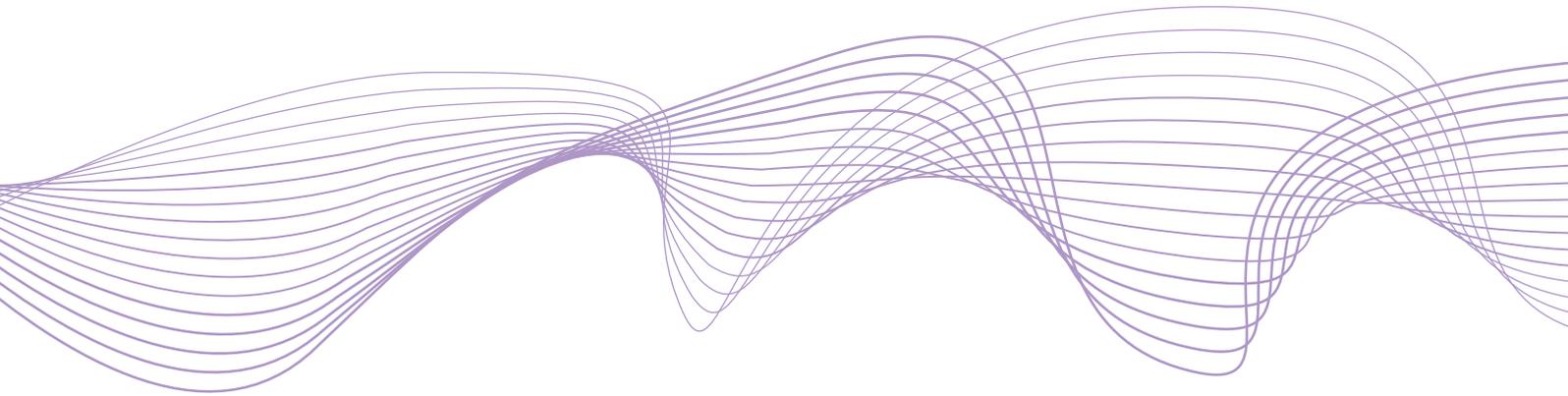


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Macroprudential policy
with liquidity panics

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Abstract

We analyze the optimality of macroprudential policies in an environment where the role of the banking sector is to efficiently allocate liquid assets across firms. Informational frictions in the banking sector can lead to an interbank market freeze. Firms react to the breakdown of the banking system by inefficiently accumulating liquid assets by themselves. This reduces the demand for bank loans and bank profits, which further disrupts the financial sector and increases the probability of a freeze, inducing firms to hoard even more liquid assets. Liquidity panics provide a new rationale for stricter liquidity requirements, as this policy alleviates the informational frictions in the banking sector and paradoxically can end up increasing aggregate investment. On the contrary, policies encouraging bank lending can have the opposite effect.

1 Introduction

How do firms react to the liquidity shortages generated by financial crises? Does the reaction by firms contribute to disrupt the financial sector? In particular, how do firms' investment decisions influence the equilibrium in the market for interbank loans and viceversa? Understanding the interaction between the supply of liquidity by the financial sector and the demand by firms is key for the analysis of macroprudential policy.

Previous empirical work has documented that firms reallocate their funds toward low-return but more liquid investments during periods of financial instability (see [Pinkowitz et al. \(2013\)](#)). In this paper we show that liquidity hoarding by firms can in turn affect the stability of the financial system, and that the responses of the two sectors can reinforce each other. This feedback loop provides an additional rationale for restrictive macroprudential policy.

We develop a model to study the interaction between the behavior of two groups of agents: firms and banks. Firms face idiosyncratic (short-term) investment opportunities which can only be fulfilled with liquid assets, in the spirit of [Kashyap et al. \(2002\)](#).¹ Firms can hold such liquid assets internally or borrow them from banks (via credit lines or loans). In normal conditions, banks efficiently channel the liquid-asset deposits of households and corporates to firms with profitable investment opportunities. However, banks are subject to informational frictions as in [Boissay \(2011\)](#). First, the lending efficiency of each individual bank is private information. Second, there is moral hazard: banks' shareholders or managers can default on their creditors. Bank heterogeneity gives rise to an interbank market where funds potentially flow from less efficient to more efficient banks, which ultimately lend to firms. Yet, informational frictions might disrupt this market when aggregate economic conditions are unfavorable. When the interbank interest rate is too low, low-efficiency banks have incentives to divert funds borrowed in the interbank market. This leads to an interbank market freeze, where banks stop trading with each other. Such an equilibrium is socially inefficient because low-efficiency banks store their assets in an unproductive technology instead of channeling them to firms.²

In response to the possibility of an interbank market freeze and the associated reduction in bank

¹We concentrate on short-term lending because it constitutes the majority of new issuances of bank loans to the corporate sector (see European Central Bank MIR statistics), and therefore is more likely to be affected by temporary financial shocks.

²We think that this framework is suitable to study the last financial recession because, according to [Brunnermeier \(2009\)](#), there was a freeze in the intermediation market rather than a run on household deposits.

lending, firms may react by accumulating more liquid assets to be able to finance their own shocks. Importantly, this reduces the demand for bank liquidity loans, which lowers the interbank interest rate and tightens banks' incentive constraint, making it more probable that an interbank market freeze effectively takes place. Firms react by accumulating even more liquid assets, entering in a feedback loop which we call a "liquidity panic". This novel mechanism leads to multiple equilibria, as a higher level of liquidity accumulation is rational when the probability of a liquidity shortage is higher. Even if we always select the best existing equilibrium, liquidity panics still occur: small aggregate shocks are amplified by the reaction of firms and it takes longer to recover from a crisis.

[Bencivenga and Smith \(1991\)](#) consider a similar economy but without disruptions in the financial sector. The study of self-fulfilling panics in financial markets is pioneered by the bank-run model of [Diamond and Dybvig \(1983\)](#) and extended by [Cooper and Ross \(1998\)](#) and [Uhlig \(2010\)](#) among others. [Gertler and Kiyotaki \(2013\)](#) and [Kashyap et al. \(2014\)](#) consider the liquidity margin embedding bank runs in a general equilibrium model. However, none of these papers study feedback effects from the corporate onto the financial sector. [Malherbe \(2014\)](#) does obtain that a feedback from liquidity accumulation can worsen adverse selection in secondary markets. However, he does not focus on financial intermediaries. [Bolton et al. \(2016\)](#) show how an increase in liquidity can lead to a decrease in the average quality of assets held by financial intermediaries, but do not study crisis states. On the other hand, [Boissay et al. \(2015\)](#) analyze the macroeconomic effects of crises in a financial intermediation sector with endogenous market freezes, but do not allow for liquidity accumulation by firms. [Freixas et al. \(2011\)](#) show that multiple equilibria also arise when liquidity shocks occur within the banking sector.

The presence of liquidity panics has central implications for the macroprudential policy debate. A common view is that macroprudential policies such as liquidity or capital requirements imply a trade-off between stability and growth or output levels. Such requirements are seen as a buffer that must be accumulated in good times, at the expense of lower investment levels, to eventually cope with financial crises by limiting banks losses or agency frictions. However, we show that this trade-off can disappear once we take into account the reaction of the corporate sector. Policies restricting bank lending, such as stricter liquidity or reserve requirements, can actually end up increasing aggregate productive investment in the economy, even in times of financial stability, as they relieve the agency problems between banks

and prevent liquidity panics.

The intuition for this result is as follows. Liquidity requirements oblige banks to set aside a fraction of their portfolio in liquid assets. This has two effects. First, it lowers the supply of interbank loans, which increases the interbank interest rate and reduces the incentives for banks to default on their creditors. This effect by itself reduces the probability of a freeze and thus lowers liquid asset accumulation by firms. But a reduction in liquidity accumulation also increases the demand for bank loans, which further relaxes the conditions for a trade equilibrium in the interbank market. The fall in the probability of a market freeze reduces inefficient storage in the economy, which is the metric for welfare losses, in a non-linear manner. As a result, a restrictive policy can lead to a higher aggregate productive investment level.³

Conversely, policies encouraging bank lending in a crises, such as subsidies to the banking sector, can make it harder for the economy to recover from a financial crisis. Such policies increase the supply in the interbank market, which may marginally raise lending to firms in the midst of a liquidity panic. However, an increased supply reduces banks' returns from lending to other banks, which makes it harder to satisfy the conditions for a trade equilibrium and thus to exit the liquidity panic. Combining bank subsidies with negative interest rates on reserves that neutralize the induced increase in the size of the banking sector can be unambiguously welfare improving, but cannot reap the potential amplification gains from preventing an expected liquidity panic.

The literature on macroprudential policy and banking has mainly focused on the moral hazard problem generated by implicit government subsidies to bank debt-holders (Kashyap et al. (2008), Admati et al. (2010), Begenau (2013)). Nevertheless, our model is in line with the view in French et al. (2010) that a central problem during the financial crisis was that disruptions in the financial system's ability to intermediate were the source of panics to other agents in the economy. We show that these panics constitute a crucial factor to consider in the design of optimal policy.

The rest of the paper is organized as follows. Section 2 sets up our theoretical model. In Section 3 we characterize the equilibrium. Section 4 analyzes the optimality of commonly discussed macroprudential policies. In Section 5 we provide empirical motivation for the mechanism analyzed. Section 6 concludes.

³Note that it is never individually optimal for banks to simultaneously borrow and store resources. This policy is only beneficial collectively due to the discontinuous change in the general equilibrium it induces.

2 Model

We develop a three-period model with endogenous banking crises and a liquidity accumulation decision by firms. This provides a relevant framework to evaluate the effects of macroprudential policy under the possibility that liquidity panics take place.

2.1 Agents and Timing

The economy is populated by a measure one of ex-ante identical agents, each endowed with N units of resources. The model lasts three periods: $t = \{0, 1, 2\}$. At the initial stage of $t = 0$ each agent decides if she starts a firm or a bank. We denote the aggregate amount of resources invested in firms by N_F and the aggregate amount invested in banks by N_B . All agents are risk neutral and consume at the end of the game ($t = 2$). Thus, they maximize expected final payoffs.

Figure 1 shows the timeline for the problem of the agents that decide to start a firm. At date $t = 0$, firm owners choose the amount invested in long-term projects and their holdings of short-term liquid assets. At date $t = 1$, firms face liquidity needs, which they cover with their holdings of liquid assets or by borrowing from the banking sector. Banks provide intermediation services and supply corporate loans to firms at $t = 1$, but the banking sector is subject to informational frictions. Banks learn their type (intermediation efficiency) privately before they trade in an interbank market at $t = 1$, and are subject to moral hazard. The combination of asymmetric information and moral hazard can disrupt the intermediation market. At date $t = 2$, investments pay off and consumption takes place.

2.1.1 Firms and Liquidity Shocks

At $t = 0$, firms have access to a short-term liquid storage technology. These liquid assets can be interpreted as cash, insured bank deposits or other riskless storage assets, so we refer to them as “cash” throughout the paper. Resources invested in cash yield a gross rate of return $R_S = 1$ and can be transformed into investment resources at zero cost, so they are useful to meet potential investment opportunities at $t = 1$. At $t = 0$, firms also have access to a long-term investment project which yields a return $R_K > 1$ in period $t = 2$ per unit invested at $t = 0$. However, long-term projects are illiquid: they cannot be transformed into resources at $t = 1$. We denote by k the amount of resources invested in the long-term project and by

c the resources invested in cash.

In period $t = 1$, firms face an idiosyncratic liquidity shock $z \sim \text{Bernoulli}(p)$. With probability p , a firm receives an investment opportunity ($z = 1$), which generates a need for liquidity. A firm that invests m units of resources in the interim project produces $F(A, m, k)$ goods at $t = 2$. Note that the output of the interim investment project may depend on k , i. e. there can be complementarities between the two investment margins available.⁴ The variable A denotes an aggregate shock that realizes at $t = 1$ and captures macroeconomic fundamentals.⁵ $\mathcal{G}(A)$ denotes the c.d.f. of A at $t = 0$. We assume that there are decreasing returns to investment in the interim project, and that the return is increasing in the aggregate state A .

Assumption 1. : $F_{mm} < 0$ and $F_{Am} > 0$.

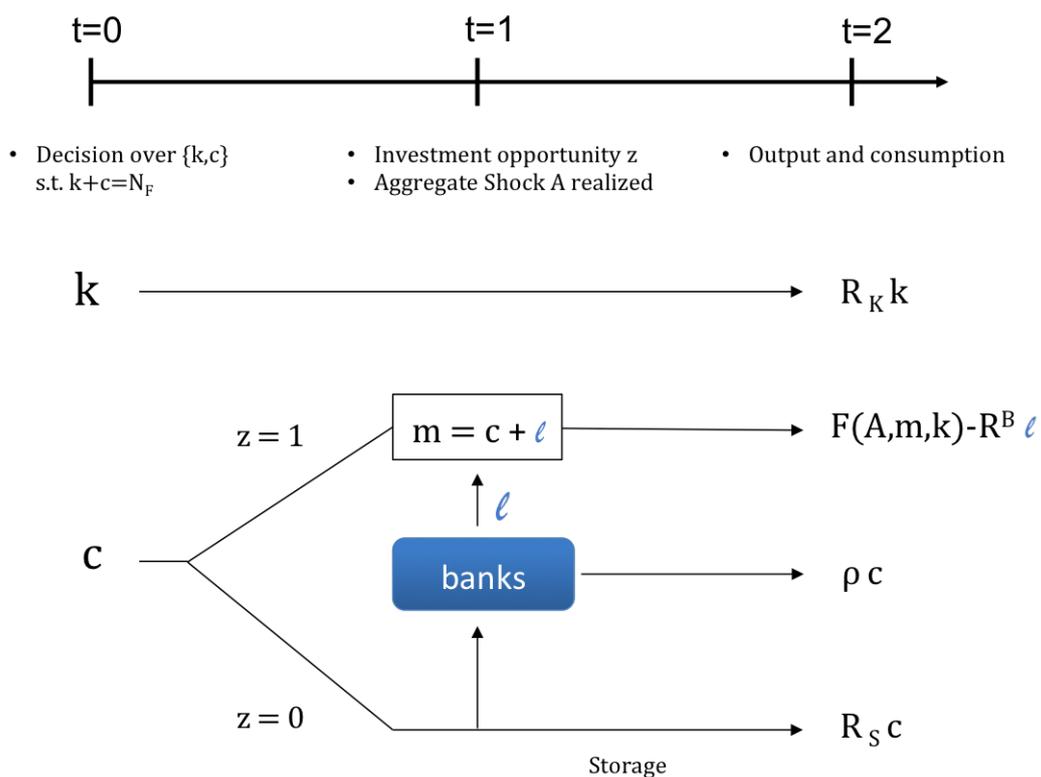
Corporate Loans At $t = 1$, firms can borrow in a competitive market where banks supply corporate loans. The (endogenously determined) interest rate of corporate loans is denoted by R^B and the amount of resources that a firm borrows is denoted by ℓ . Thus, firms can satisfy their liquidity needs with bank loans or using their liquid assets c . Importantly, corporate loans cannot be supplied by other firms. An underlying information problem creates the need for a monitoring technology to execute claims on firm loans.⁶ Hence, firms that accumulate cash and do not get access to the interim project have an excess of liquid assets which they cannot directly lend to other firms. Yet, firms can indirectly lend their excess cash through the banking system with a return ρ in a competitive interbank market, which is described in detail below. Alternatively, firms can keep their resources in the storage technology: low-yield assets that do not require private information.

⁴The form chosen for the production function is meant to model unexpected opportunities to increase production such as innovations or positive demand shocks. Bates et al. (2009) claim that growing R&D opportunities are one of the causes behind the positive trend in cash holdings as a proportion of assets in US firms for the last 20 years. The reason may be that intangible investments are harder to finance with external funds due to their lower collateralizability (see Falato et al. (2013) and Garcia-Macia (2013)). We would obtain similar results with a model where firms suffered negative liquidity shocks that they had to satisfy in order to restore production.

⁵The particular case of $F(A, m, k) = AF(m, k)$ leads to the exact same aggregate results as introducing a stochastic p , which would capture aggregate uncertainty about the proportion of firms with access to the interim investment opportunity.

⁶Other interpretations could be the existence of private signals over the return on loans, banks being better informed about firm returns than other investors (see Boissay (2011)); or networks of firm-bank connections.

Figure 1: Timeline of the Firm's Problem



2.1.2 Banks and the Interbank Market

Banks are efficient liquidity providers. They own a monitoring technology which allows them to supply corporate loans and thus provide an insurance mechanism to firms.

At $t = 0$, ex-ante identical agents that started a bank invest their initial resources per capita N , which aggregate to N_B , in liquid assets to maximize profits from intermediation services at $t = 1$. We will discuss below how banks ability to provide intermediation services is affected by their aggregate net worth N_B . Banks become heterogeneous after the realization of their monitoring technology, which is privately observed at $t = 1$. We denote banks monitoring ability by ω . Hence, at $t = 1$, banks are indexed by $\omega \in [0, 1]$. Bank ω incurs a monitoring cost $(1 - \omega)R^B$ per unit of corporate loan provided at $t = 1$, so the net return of a corporate loan is ωR^B .⁷ As an outside option, banks also have the possibility to invest in the storage technology with return R_S .

Additionally, at $t = 1$ banks have access to an interbank or wholesale financial market, where high-skill banks can borrow from low-skill banks and firms. The gross rate at which banks borrow in the interbank market is denoted by ρ . We assume that the interbank market is competitive, so banks take ρ and R^B as given, but it is subject to informational frictions. Note that:

1. ρ is the same for all borrowers, otherwise the borrowers promising the lowest return would not attract any lender, and
2. in equilibrium: $R_S \leq \rho \leq R^B$. If the first inequality was violated, no bank would supply any funds. If the second inequality was violated, no bank would demand any funds.

We denote by $\phi(\omega)$ the amount borrowed in the interbank market by bank ω per unit of initial wealth. Hence, ϕ is the ratio of interbank market funding to initial funding. The ratio ϕ is publicly observable and contractible upon. The interbank market allows banks to increase their supply of funds to the corporate sector, which raises their total returns. A bank ω that borrows ϕ in the interbank market and lends its available funds to firms gets a return $\omega R^B(1 + \phi) - \rho\phi$. Banks instead might prefer to lend their resources in the interbank market instead of issuing corporate loans. Banks prefer to be lenders rather

⁷We could also interpret ω as the idiosyncratic productivity of the firm to which the bank is connected (see Boissay (2011)); or as the signal of aggregate productivity received by the bank (see Bebhuk and Goldstein (2011)).

than borrowers in the interbank market if $\rho \geq \omega R^B(1 + \phi) - \rho\phi$, which implies a skill cut-off level

$$\bar{\omega} = \frac{\rho}{R^B}. \quad (1)$$

High-skill banks with $\omega \geq \bar{\omega}$ act as intermediaries, channeling the excess funds from low-skill banks with $\omega < \bar{\omega}$ and firms to the real economy.⁸ In a world without banking frictions, all banks with $\omega < 1$ would lend to the most efficient bank, the one with $\omega = 1$, which would ultimately supply the whole resources of the financial sector to firms. In that case, the economy would reach the first best allocation, which we characterize later on.

However, informational frictions may prevent the economy from reaching the first best. These frictions are modeled as in [Boissay \(2011\)](#). First, since ω is privately observed, there is asymmetric information and loan contracts cannot directly depend on ω . While there can exist an equilibrium where banks are separated between lenders and borrowers, there is no possible separation within borrowers, i. e. $\phi(\omega) = \phi$ is the same for all borrowers.

Second, there is a moral hazard problem. Banks may have different investment incentives than their creditors. In particular, banks have an outside “stealing” opportunity. They can divert funds at the expense of their creditors.⁹ For simplicity, we assume that diversion implies a zero return for creditors. Bank managers run away with their funds at a cost θ and can store the diverted funds for consumption at $t = 2$. Thus, the return obtained by banks from diversion is $R_S(1 + \theta\phi)$, where $\theta < 1$ captures the inefficiency of this investment. As is usual in the literature, a diversion option creates endogenous borrowing constraints that we characterize below.

To recap, at $t = 1$ banks have four possible uses for their resources N_B :

1. Invest in the storage technology, with return R_S .
2. Lend in the interbank market, with return ρ .
3. Borrow funds ϕ in the interbank market and lend to firms, with return $\omega R^B(1 + \phi) - \rho\phi$.

⁸Firms that decide to participate in the wholesale financial market or money market are equivalent to banks with $\omega = 0$.

⁹A possible interpretation is that banks do not have incentives to monitor when not enough net worth is involved, as in [Holmstrom and Tirole \(1997\)](#). Hence, they end up taking excessive risks while getting private benefits from such investments (e.g. commissions levied by brokers on abusive misselling of subprime products).

4. Borrow funds ϕ in the interbank market and divert them, with return $R_S(1 + \theta\phi)$.

Lenders supply funds only if borrowers are deterred from diverting, which happens if diversion is a dominated strategy. The banks with most incentives to divert are low-skill banks. Thus, no diversion requires

$$R_S(1 + \theta\phi) \leq \rho. \quad (2)$$

This incentive-compatibility (IC) condition implies an endogenous borrowing constraint

$$\phi \leq \bar{\phi} = \left(\frac{\rho}{R_S} - 1 \right) \frac{1}{\theta}. \quad (3)$$

Importantly, the constraint depends on the profitability of the financial sector, captured by ρ . Low values of ρ imply that banks have more incentives to look for outside inefficient opportunities that involve private benefits (diversion), instead of performing their socially beneficial intermediation services. Therefore, the ability of the best banks to intermediate more funds is hindered when profits in the banking sector are low, as bad banks will have more incentives to pretend to be good borrowers and divert the funds.

2.1.3 Interbank Market

Definition 1. Interbank Market Equilibrium For a given loan interest rate R^B , an equilibrium in the interbank market are values (ρ^*, ϕ^*) for the interbank rate ρ^* and leverage ϕ^* for each bank, such that:

1. banks optimize over their four possible actions and ϕ^* , taking ρ^* as given and subject to the IC constraint (2), and
2. the interbank market clears.

Given the IC constraint, banks that borrow in the interbank market are those with $\omega \geq \bar{\omega}$, which earn a positive spread from leveraging. Thus, borrowing banks lever up to the limit: $\phi^*(\omega) = \bar{\phi}$ for $\omega \geq \bar{\omega}$. A mass of borrowers $(1 - \mu(\bar{\omega}))$ borrow $\bar{\phi}$ per unit of net worth. It follows that the aggregate demand of interbank market funds is $(1 - \mu(\bar{\omega}))\bar{\phi}N_B$, where $\mu(\cdot)$ denotes the cdf of ω across banks. The total

supply is composed by the mass of lender banks, which supply $\mu(\bar{\omega})N_B$, plus the excess of cash from firms, $\sum_{i:z_i=0} c_i = (1-p)C$, where C denotes aggregate cash holdings while i indexes firms and we use the fact that firms are identical in their cash decision at $t=0$. From (1) and (2) we have that $\bar{\omega}$ and $\bar{\phi}$ are functions of ρ . Thus, the equilibrium rate ρ^* clears the market when the following equality holds:

$$(1 - \mu(\bar{\omega}(\rho^*))) \bar{\phi}(\rho^*) N_B = \mu(\bar{\omega}(\rho^*)) N_B + (1 - p)C. \quad (4)$$

The supply of funds is increasing in the interbank interest rate ρ , as more banks supply funds when their returns increase, i.e. $\bar{\omega}$ increases with ρ . Demand, instead, is affected by ρ through two different channels. On the one hand, demand is affected negatively by ρ as fewer banks demand funds when these become more costly (extensive margin). On the other hand, demand is affected positively by ρ due to the endogenous borrowing constraint, which allows for a higher $\bar{\phi}$ when ρ increases (intensive margin). For small values of ρ , the intensive margin affects a larger mass of borrower banks. Then, this effect dominates and the demand curve is upward sloping. For larger values of ρ , the demand curve is downward sloping. Since the supply is upward sloping, this could imply that demand and supply intersect at more than one point, leading to multiple equilibria.

In particular, supply and demand are both zero when $\rho = R_S$. This equality characterizes a market freeze or banking crisis equilibrium. When ρ is so low, the agency problems are so acute that there is no bank willing to trade in the interbank market. In a banking crisis, low-skill banks end up investing in the inefficient storage technology instead of lending to other banks. However, other equilibria with trade may exist when $\rho > R_S$ is high enough to eliminate the incentives of low-skill banks to divert funds. In an equilibrium with trade, low-skill banks lend their resources to high-skill banks, which ultimately invest in the corporate loan market, and there is no use of the storage technology.

While the banking crisis equilibrium always exists, the existence of an equilibrium with trade depends on the state of the economy. In particular, it crucially depends on the profits that banks obtain from their intermediation services, captured by R^B , and on the distribution of cash in the economy between firms and banks (C, N_B) .

Proposition 1. *There exists a threshold $\underline{R^B}(\frac{C}{N_B})$ such that for $R^B < \underline{R^B}(\frac{C}{N_B})$ the banking crisis equilibrium is the unique equilibrium in the interbank market. Moreover, the threshold $\underline{R^B}(\frac{C}{N_B})$ depends*

positively on $\frac{C}{N_B}$. (Proof in an Appendix available upon request)

- Two particular cases: $\omega \sim U(0, 1)$ and $\omega \sim \text{Bernoulli}(\pi)$

1. if $\omega \sim U(0, 1)$, then

$$\underline{R}^B = R_s \left[1 + \theta \left(1 + 2(1-p) \frac{C}{N_B} \right) + 2 \sqrt{\theta \left(1 + (1-p) \frac{C}{N_B} \right) \left(1 + \theta(1-p) \frac{C}{N_B} \right)} \right].$$

- (a) if $\omega \sim \text{Bernoulli}(\pi)$, then

$$\underline{R}^B = R_s \left[1 + \frac{\theta}{\pi} \left((1-\pi) + (1-p) \frac{C}{N_B} \right) \right].$$

– Moreover, for given $R^B \geq \underline{R}^B$, the interbank market equilibrium interest rate ρ^* solves (4),

e.g.

1. if $\omega \sim U(0, 1)$, then

$$\rho^* = 0.5 \left[R^B + R_s(1-\theta) + \sqrt{4R^B R_s(-1) \left(1 - \delta(p-1)\theta - (R^B + R_s(1-\theta))^2 \right)} \right].$$

2. if $\omega \sim \text{Bernoulli}(\pi)$, then

$$\rho^* = \underline{R}^B = R_s \left[1 + \frac{\theta}{\pi} \left((1-\pi) + (1-p) \frac{C}{N_B} \right) \right].^{10}$$

As Proposition 1 shows, when the profits generated by the intermediation services are high enough ($R^B > \underline{R}^B$), there exists an equilibrium with trade where all funds flow to the corporate sector. Otherwise, the unique equilibrium in the model is associated with a disrupted financial sector where interbank trade freezes.

When R^B is higher than the threshold \underline{R}^B , we have two equilibria. We assume that agents coordinate to select the Pareto-superior equilibrium. Thus, a banking crisis only takes place whenever $R^B < \underline{R}^B$. This method to select equilibria has the desirable feature that market runs or freezes do not occur at random times. Instead, their probability depends on the state of the economy.¹¹ In particular, note that R^B and C are equilibrium objects that depend on aggregate shocks. As we will see below, R^B is related to the return on liquid assets, which decreases with negative aggregate shocks. An increase in C directly raises the threshold \underline{R}^B , which increases the probability of a banking crisis. Additionally, there

¹⁰In this second case, there are also two equilibria, but now both are Pareto-equivalent, i.e. both feature the same $\bar{\omega}$. The first equilibrium is the one characterized above, the second one is $\rho^* = R^B$, which entails no profits from intermediation to other banks.

¹¹This property is obtained in other multiple equilibria models using global games (e.g. Bebchuk and Goldstein (2011)) or simply through an exogenously-given reduced form (e.g. Gertler and Kiyotaki (2013) and Kashyap et al. (2014)).

is a general equilibrium effect by which an increase in C pushes down R^B , which further increases the probability of a crises. The impact of C on the probability of an interbank market freeze is the source of liquidity panics in the model.

3 Equilibrium

In this section we define an equilibrium in our economy. We show that the model can deliver multiple equilibria due to self-fulfilling panics. Even when we impose that agents coordinate to achieve the best equilibrium, there is an amplification mechanism that we call a liquidity panic. Liquidity panics happen when negative aggregate shocks (low A) hit the economy. Since they are not a coordination failure, insurance devices such as the ones proposed in [Diamond and Dybvig \(1983\)](#) cannot correct them. We instead explore the role of macroprudential policy in mitigating their likelihood and consequences.

Definition 2. Full Equilibrium Given a distribution of the aggregate shock $\mathcal{G}(A)$ and initial endowments of resources N , a full equilibrium is a process for prices at $t = 1$ (R^B, ρ) and allocations at $t = 1$ (ϕ, L) for each value of the aggregate shock A , and allocations at $t = 0$ (C, K, N_F, N_B) , such that:

- At $t = 1$, in every state A :
 - For a given $R^B(A)$, firms optimally choose $\ell = L$.
 - * For a given $R^B(A)$, (ρ, ϕ) is an interbank market equilibrium.
 - * The interbank market clears at the best possible equilibrium.
 - At $t = 0$:
 - * For a given price process (R^B, ρ) , firms optimally choose $c = C$ and $k = K$.
 - * Each agent optimally decides between starting a firm or a bank, with free entry in both industries.
 - * The total amount of resources in the banking sector, N_B , is determined by the share of agents which decide to start a bank. The total amount of resources in firms, $N_F = N - N_B$, are optimally allocated between investment in long term capital and cash: $N_F = C + K$.

3.1 Corporate Loans Market

In order to characterize the equilibrium solution, we follow a backwards induction argument and start describing the solution of the corporate loans market at $t = 1$.

3.1.1 Supply of Corporate Loans

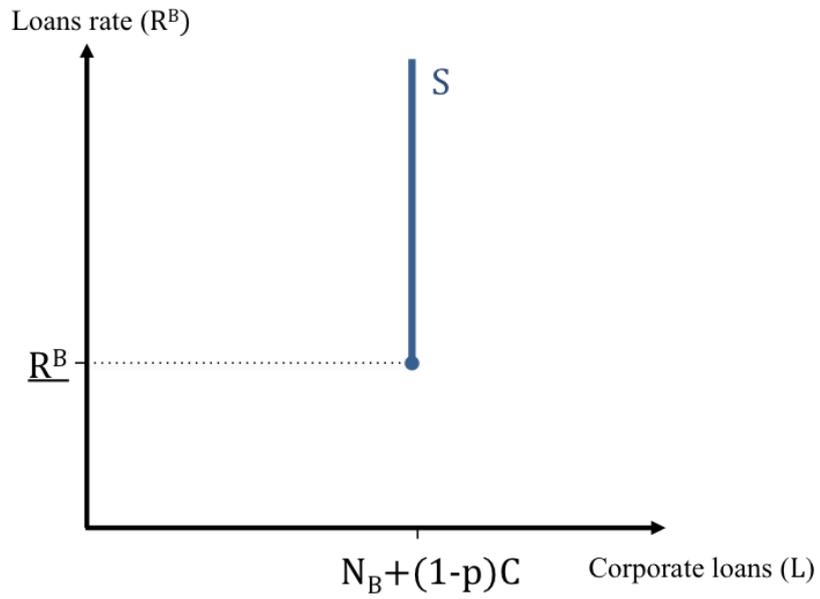
The equilibrium in the interbank market determines the aggregate supply of corporate loans. When there is trade in the interbank market, the most efficient banks channel all liquid resources from the banking sector N_B and the excess of cash from firms $(1-p)C$ to firms with liquidity needs. Thus, the supply in that case is $S = N_B + (1-p)C$. However, when a market freeze occurs, banks cannot channel resources from other agents and the supply contracts. Banks with $\omega < \frac{R_S}{R^B}$ invest in the storage technology, while the rest of banks supply their own resources to firms. The supply in that case is composed by the resources of banks with $\omega > \frac{R_S}{R^B}$, implying $S = \left(1 - \mu\left(\frac{R_S}{R^B}\right)\right) N_B$. Figure 2 depicts the supply in both cases. A market freeze in the interbank market is associated with a liquidity shortage in the corporate loans market, as the supply contracts. The supply curve in a banking crisis is upward sloping, because as the corporate loan rate increases, more banks are willing to pay the monitoring cost and lend. Note that when $R^B > \underline{R^B}$ both supply functions coexist. This is because the market freeze equilibrium always exists, while the trade-equilibrium inverse supply function exists for $R^B \geq \underline{R^B}$. Again, we select the highest supply level if the corporate loan market clears for a price higher than $\underline{R^B}$, and the reduced supply otherwise. The equilibrium price R^B depends on the aggregate demand for corporate loans, which we describe below.

3.1.2 Demand for Corporate Loans

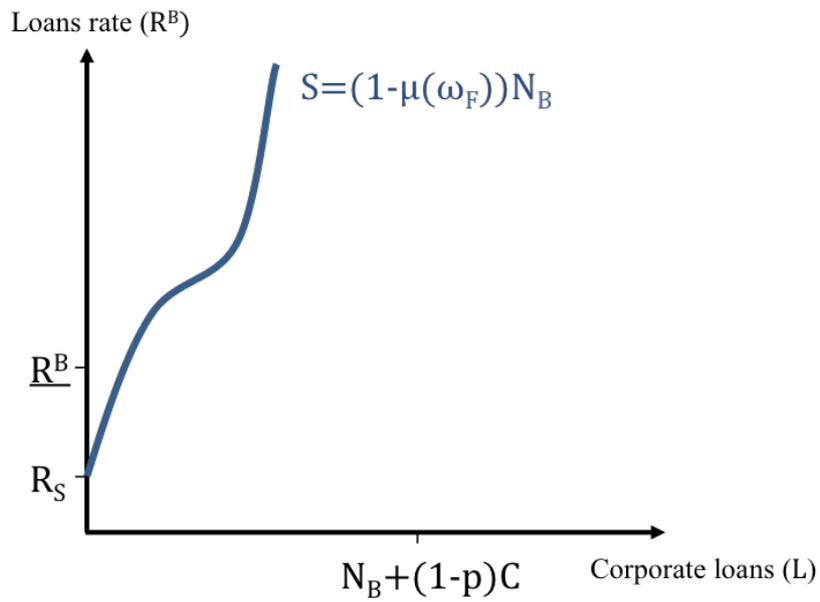
The demand for corporate loans is determined by the liquidity needs of firms. Firms enter period $t = 1$ with an endowment of cash $c = C$ and capital $k = K$. Then, the aggregate shock A and the liquidity shock z realize. Firms with $z = 1$ invest in their newly received opportunity, use their accumulated cash c and borrow ℓ from banks with the objective to maximize $F(A, m, k)$, taking as given the loan rate R^B . The optimal amount of loans demanded ℓ equates the marginal return of m to its marginal cost R^B :

Figure 2: Supply of Corporate Loans

(a) Normal Times



(b) Banking Crisis



$$F_m(A, m, k) = R^B \quad (5)$$

subject to

$$m = \ell + c. \quad (6)$$

Aggregating over all firms with $z = 1$ we obtain the inverse demand function for corporate loans

$$F_m\left(A, \frac{M}{p}, k\right) = R^B, \quad (7)$$

where M represents aggregate investment in the interim project. In (7) we use the optimality condition that every firm with access to the interim project invests the same amount of resources.

Assumption 1 implies that the demand curve is downward sloping, depends positively on the aggregate shock A , as depicted in Figure 3a, and depends negatively on aggregate cash holdings C . An increase in firms available cash holdings reduces firms demand for corporate loans, as shown in Figure 3b.

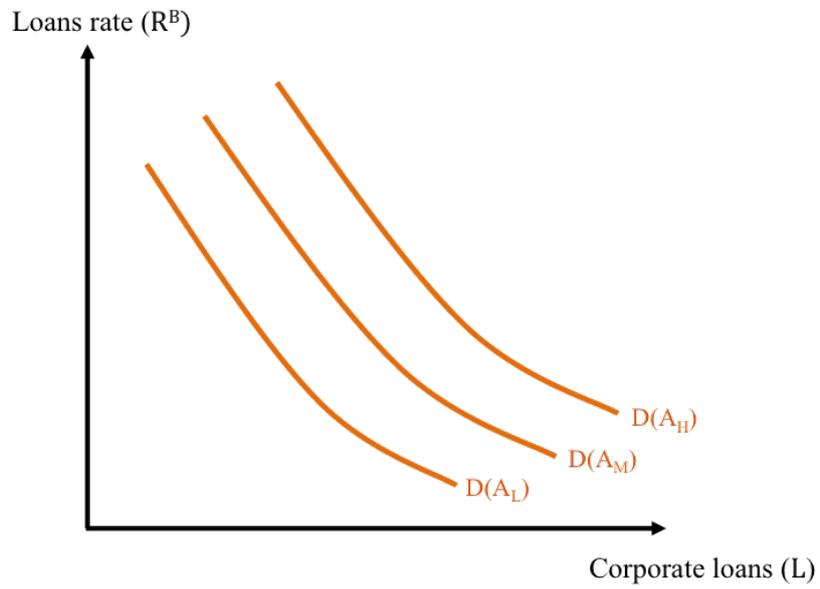
3.1.3 Equilibrium in the Corporate Loan's Market and Banking Crisis

Now we can analyze how the market for corporate loans clears. Figure 4a shows a situation which we refer to as normal times. The demand for corporate loans intersects the supply associated with trade in the interbank market at a loan rate higher than the minimum required. In contrast, Figure 4b shows the situation which we refer to as a banking crisis. The demand for corporate loans is too low to intersect with the full supply curve. In this case, the only equilibrium solution lies at the intersection between the demand and the reduced supply curve associated with a banking crisis. Note that during banking crises loan rates are high, as there is a liquidity shortage.

Banking crises arise when the demand for loans is low relative to the total supply in the banking sector. This could be caused by a low aggregate shock realization, which implies a low marginal return of liquid assets, or by a high aggregate level of cash holdings. When cash holdings are high, firms self-insure

Figure 3: Demand for Corporate Loans

(a) Demand for Corporate Loans for $A \in \{A_L, A_M, A_H\}$



(b) Demand for Corporate Loans for $C^2 > C^1$

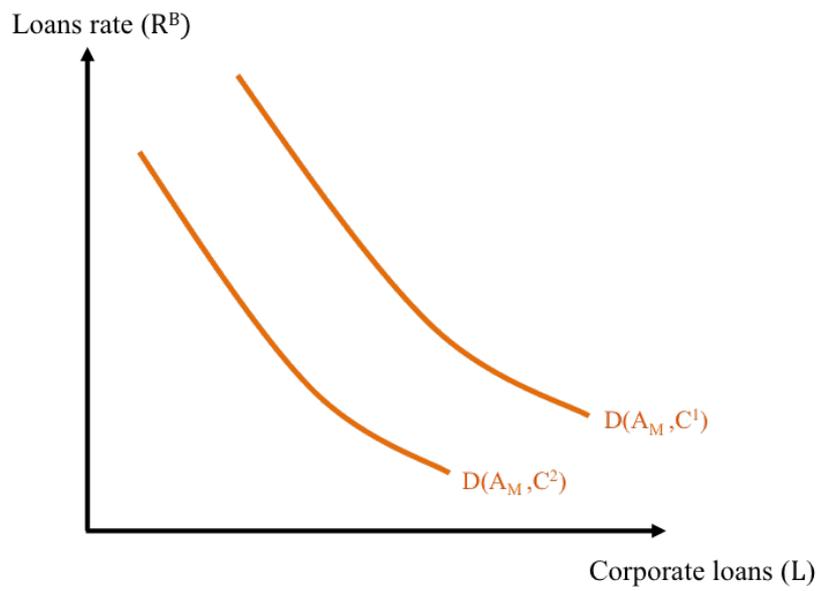
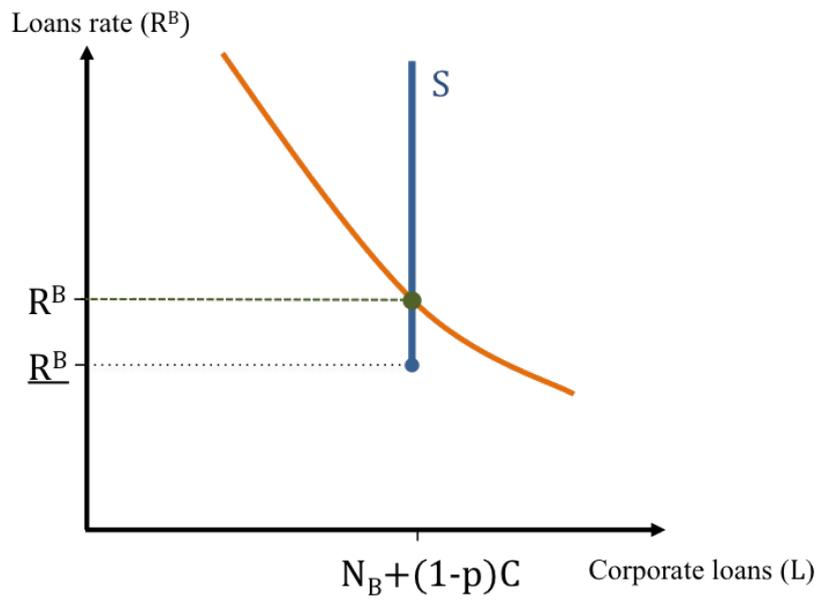
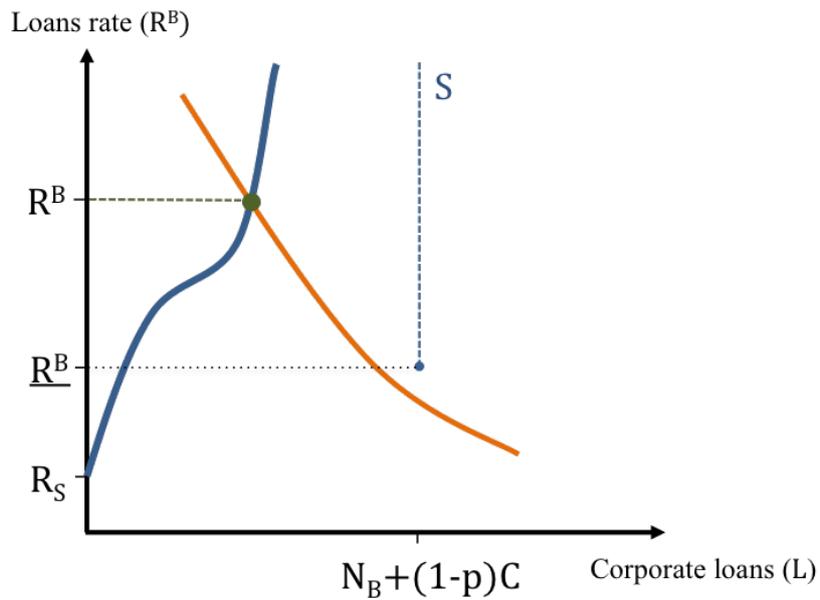


Figure 4: Equilibrium in The Corporate Loans Market

(a) "Normal Times" Equilibrium



(b) "Banking Crisis" Equilibrium



and cover their liquidity needs with their own cash. Thus, demand for loans is low, which depresses profits in the banking sector and can induce an interbank market freeze. This is precisely the force that triggers liquidity panics, as the possibility of a banking crisis incentivizes firms to hoard cash. Both effects feed back into each other and imply a self-fulfilling loop. We characterize the conditions for a liquidity panic below. We start by analyzing the state space of the aggregate shock, which can be divided in two regions according to whether a banking crisis occurs or not. The probability measure of such regions defines the probability of a banking crisis and, importantly, depends on the aggregate level of C , N_B and K at $t = 0$.

Proposition 2. *For given (C, K, N_B) there exists a threshold \underline{A} such that:*

- For $A \geq \underline{A}$, there is no banking crisis and the corporate loan rate is defined by $R^B(A) = r_{nf}(A, C, K, N_B)$, where $r_{nf} = F_m\left(A, \frac{N_B+C}{p}, K\right)$.
- For $A < \underline{A}$, there is a banking crisis and the corporate loan rate is defined by $R^B(A) = r_f(A, C, K, N_B)$ where $r_f = F_m\left(A, C + \frac{N_B}{p}\mu\left(\frac{R_S}{r_f}\right), K\right)$.

Proposition 3. *Moreover, $\underline{A}(C, K, N_B)$ is increasing in C , decreasing in K (if there are production complementarities) and ambiguous in N_B . For example:*

1. if $F(A, m, k) = A \frac{m^{1-\alpha}}{1-\alpha} k^\beta$, $\alpha < 1$, then $\underline{A} = \left[\frac{1}{K^\beta} \left(\frac{N_B+C}{p} \right)^\alpha \right] \underline{R}^B$.
 - (a) if $F(A, m, k) = A \log(1+m)k^\beta$, then $\underline{A} = \left[\frac{1}{K^\beta} \left(1 + \frac{N_B+C}{p} \right) \right] \underline{R}^B$.
- (Proof in the Appendix)

Propositions 1 and 2 characterize the solution of the equilibrium at stage $t = 1$, and define the equilibrium process for (R^B, ρ) for every realization of A and aggregate state (C, K, N_B) . Next, we proceed to solve the game at $t = 0$ and find the optimal choice of (C, K, N_B) .

3.2 Cash Holdings and Long-Term Investment Decision

At $t = 0$, each firm decides to invest its resources N in long-term illiquid capital k or in cash c in order to maximize its expected consumption at $t = 2$. Firms take the mapping of prices (R^B, ρ) to the aggregate state A as given and maximize profits

$$\Pi^F(N) = \max_{c,k} R_K k + \mathbb{E}_A \left[p \left(F(A, m, k) - R^B (m(R^B, k) - c) \right) + (1-p)\rho c \right] \quad (8)$$

subject to

$$c + k = N, \quad (9)$$

where $m(R^B, k)$ is the optimal investment at $t = 1$. In expressing (8) we already assumed that any equilibrium outcome is characterized by $\ell > 0$ (or equivalently $m > c$), since the return for storage, which constitutes the outside option for banks, is strictly lower than R_K . Hence, the marginal return of holding cash is equal to the cost of a loan R^B in case the firm has the investment option at $t = 1$ (which happens with probability p), or to the return from lending to other banks otherwise. The optimality condition equates the marginal return to cash MRC and the marginal product of capital MPK :

$$c = 0 \quad \text{if} \quad MPK > MRC, \quad (10)$$

$$c \in [0, N_F] \quad \text{if} \quad MPK = MRC, \quad (11)$$

$$c = N_F \quad \text{if} \quad MPK < MRC, \quad (12)$$

where the marginal return to cash is the value of the loan interest rate saved by the corresponding reduction in borrowing at $t = 1$

$$MRC = p\mathbb{E}_A R^B + (1-p)\mathbb{E}_A \rho, \quad (13)$$

and the marginal product of capital is

$$MPK = R_K + p\mathbb{E}_A [F_k(A, m(k), k)], \quad (14)$$

where F_k denotes the total derivative of the interim production function with respect to capital.

Equilibrium cash holdings depend uniquely on the prices of loans at $t = 1$.

3.3 Free-Entry Condition at $t = 0$

At the initial stage $t = 0$, agents decide to invest their resources N in opening a firm or a bank. By the free-entry condition, the expected total returns (or equivalently profits) in both activities are equalized:

$$\Pi^F = \Pi^B, \quad (15)$$

where the expected profits of a bank at $t = 0$ are

$$\Pi^B(N) = \mathbb{E} \left[\mu(\bar{\omega}) \rho + (1 - \mu(\bar{\omega})) \left((1 + \phi) R^B \int_{\bar{\omega}}^1 \omega d\mu(\omega) - \rho\phi \right) \right] N. \quad (16)$$

3.4 Equilibrium Solution

The equilibrium in the economy is characterized by Propositions 1 and 2 and the FOCs of agents at $t = 0$. We need to find the tuple (C, K, N_B) that solves equations (10)-(12), where R^B , ρ and \underline{A} are defined in Propositions 1 and 2.

3.4.1 Fixed Size of the Banking Sector

In order to shed light on the basic mechanism of the model, we characterize the simple case where the partition of agents that decide to go to the banking sector is exogenous, i.e. N_B and N_F are fixed and exogenous. Moreover, we consider the case without complementarities between illiquid capital and the interim project ($F_{mk} = 0$). The equilibrium in this case is characterized by equating the marginal return of cash to R_K .

Combining the FOCs of firms with propositions 1 and 2 we can express the marginal return to cash with the following function:

$$\begin{aligned} \Phi(C, \underline{A}) \equiv & p((1 - \mathcal{G}(\underline{A})) \mathbb{E}[r_{NF}(A, C) \mid A \geq \underline{A}] + \mathcal{G}(\underline{A}) \mathbb{E}[r_F(A, C) \mid A \geq \underline{A}]) \\ & + (1 - p)((1 - \mathcal{G}(\underline{A})) \rho(C) + \mathcal{G}(\underline{A}) R_S) \end{aligned} \quad (17)$$

where $r_{nf}(\cdot)$ and $r_f(\cdot)$ are the functions defined in Proposition 2, which represent the loan rate in

normal times and in banking crises respectively. The function $\Phi(C, \underline{A})$ represents the marginal return to cash for a given aggregate cash holdings level C and a given partition of the state space A , defining whether a banking crisis occurs ($A < \underline{A}$) or not ($A \geq \underline{A}$). An important result in our model is that the measure of states associated with a banking crisis depend on the level of aggregate cash holdings C . The equilibrium threshold is defined by the function $\underline{A}(C)$ from Proposition 2. Therefore, the equilibrium is pinned down by the value of C that satisfies the following condition:

$$\begin{aligned} C^* &= C \text{ if } \Phi(C, \underline{A}(C)) = R_K, \text{ and} \\ C^* &= 0 \text{ if } \Phi(0, \underline{A}(0)) < R_K. \end{aligned} \tag{18}$$

We are looking for the value of C that satisfies equation (18). A change in C has two effects on the function $\Phi(\cdot)$. First, an increase in aggregate holdings C has a negative effect on the loan rates paid in every state A , as it reduces the demand for loans. This direct effect is captured by the partial derivative $\Phi_C < 0$. Second, there is an indirect effect through the increase in the threshold $\underline{A}(C)$. This indirect effect is captured by $\Phi_{\underline{A}}(C, \underline{A})\underline{A}'(C)$ and is the source of the liquidity panic feedback which we explain below.

The Liquidity Panic Feedback The mechanism that we highlight in this paper is the feedback effect induced by the firms' reaction to a banking crisis. When firms expect a banking crisis, which is associated with a liquidity shortage and higher loan rates, they react by increasing their cash holdings. The feedback arises because the increase in aggregate cash holdings raises the threshold \underline{A} , implying a higher probability of a banking crisis, which further increases the incentives to accumulate cash. The effect described is reflected in $\Phi_{\underline{A}}(C, \underline{A})\underline{A}'(C) > 0$. From Proposition 2, $\underline{A}'(C)$ is positive, i.e. the measure of states where a banking crisis occurs expands with aggregate cash holdings. For the additional measure of states where a banking crisis appears due to the increase in C , the corporate loan rate jumps up, making it more valuable to accumulate cash. We can see this in the term $\Phi_{\underline{A}}(C, \underline{A}) = [r_f(\underline{A}, C) - r_{nf}(\underline{A}, C)] d\mathcal{G}(\underline{A}) > 0$.

This feedback is both the source of equilibrium multiplicity and amplification of shocks. We show below how multiple equilibria might coexist in the model. Yet, in this paper, we emphasize the amplification

mechanism generated by the feedback. Our policy analysis is not about coordination mechanisms between multiple sunspots equilibria. Instead, we assume the existence of a coordination device that allows agents to choose the best possible equilibrium. We find that, even in that case, liquidity panics generate inefficient amplification effects that provide a rationale for policy intervention.

Multiple Equilibria The previous paragraph described the indirect aggregate effect of hoarding cash through its impact on the probability of a banking crisis $\Phi_{\underline{A}}(C, \underline{A})\underline{A}'(C)$. On the other hand, the direct effect of an increase in cash holdings $\Phi_C(C, \underline{A})$ is the substitution away from loans. An increase in aggregate cash holdings reduces the demand for loans and the loan rate, implying decreasing incentives to accumulate cash on the aggregate. This direct effect is reflected in the term $\Phi_C(C, \underline{A}) < 0$, and it would be the total effect if the partition that defines a banking crisis did not change (i.e. if we did not take into account the feedback). The direct effect is clearly negative due to the decreasing marginal returns of liquid assets at $t = 1$. Therefore, the total marginal effect on $\Phi(C, \underline{A}(C))$ can be positive or negative, so the function $\Phi(C, \underline{A}(C))$ can display non-monotonicities in C . If that is the case, then condition (18) can be satisfied at different values of C , which implies the existence of multiple equilibria. The existence of multiple equilibria requires that the rate R_K intersects the function $\Phi(C)$ at the range where it is not monotone. Proposition 4 formalizes this idea. Next, we present examples of equilibrium multiplicity for different cases.

Proposition 4. *If the support of A is continuous and $[r_f(\underline{A}) - r_{nf}(\underline{A})] d\mathcal{G}(\underline{A})\underline{A}'(C) > -\Phi_C$, there exist values for R_K such that there exist multiple equilibria. If the support of A is discrete, then there always exist values of R_K such that there are multiple equilibria.*

We illustrate Proposition 4 with Figure 5 for the case where the support of A is discrete: $A = \{A_L, A_M, A_H\}$. In the Appendix we include the closed form solutions for the equilibria in both cases. Figure 5 plots the value of $\Phi(C)$, which represents the return to accumulating cash for a firm at $t = 0$, as a function of aggregate cash holdings C . The tone of the shaded areas indicates the number of states that are associated with a market freeze or banking crisis. We can see that $\Phi(C)$ is a piece-wise decreasing function with discontinuous positive jumps. As we explained above, the direct effect implies that a higher C is associated with lower demand for corporate loans and lower corporate rates R^B . Thus, the marginal

return to cash, $\Phi(C)$, decreases as cash holdings can be substituted with loans. For $C < C^1$, banking crises occur only when $A = A_L$. Therefore, the indirect effect is absent and the feedback effect is zero. However, when $C > C^1$, there is an excess of cash holdings which implies that the demand for loans is too low, leading to a banking crisis also in the state $A = A_M$. A banking crisis is associated with a discrete increase of the loan rate R^B for the state that turns into “crisis mode”, which generates a jump in the function $\Phi(C)$. In the example depicted in Figure 5, if $A = A_L$ a banking crisis always occurs, even when $C = 0$. As C increases, the loan rate is reduced in every state until the point C^1 . For $C > C^1$, the demand for loans is so low that a crisis is also triggered in state A_M . At point C^2 , the same thing happens for the best state (A_H).

In the particular case depicted in Figure 5 there are two equilibrium outcomes: C^* and C^{**} . C^{**} is the outcome of an equilibrium where agents accumulate an excess of cash to protect against the possibility of a banking crisis, which ends up materializing because of the excess cash accumulated. A coordination device would eliminate these kind of scenarios. For the rest of the paper, we are going to focus only in the best equilibrium outcome. Even under such a benevolent equilibrium selection criterion, liquidity panics occur in equilibrium. In Figure 5, C^* is actually the outcome of a liquidity panic. It features an excess of aggregate cash holdings, because if the agents had not reacted ($C = 0$), then a banking crisis would not have appeared in state $A = A_M$. In other words, we define a liquidity panic as a situation where the feedback mechanism affects the number of states in which a banking crises takes place. Formally, we are in a liquidity panic equilibrium if the equilibrium partition of states A associated with a banking crisis strictly contains the partition associated with fixing $C = 0$.

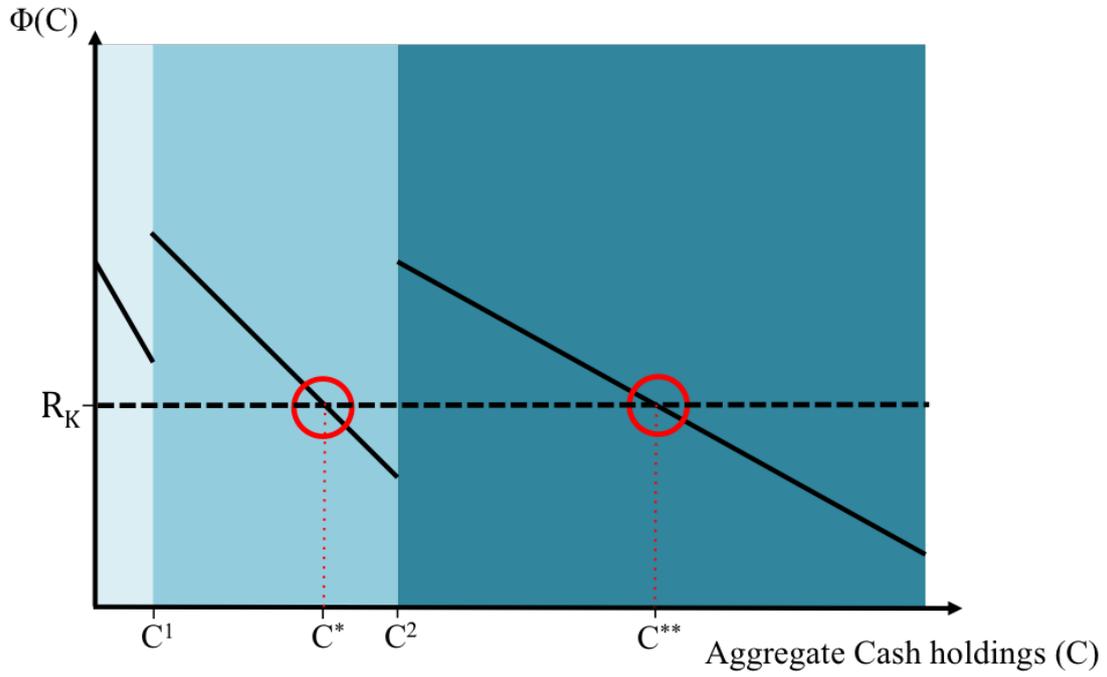
Definition 3. Liquidity Panic Equilibrium A liquidity panic equilibrium is an equilibrium characterized by C^* where $\underline{A}(C = 0) < \underline{A}(C^*)$.

3.4.2 Endogenous Size of the Banking Sector

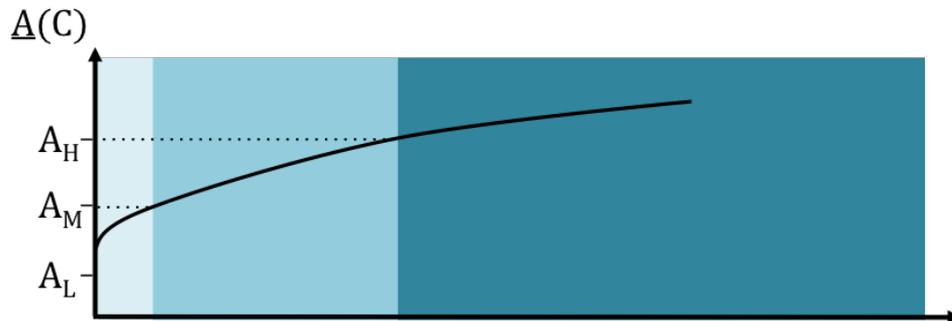
The next step for generality is to allow for a variable N_B . However, this requires the use of numerical solution methods and is still work in progress.

Figure 5: Aggregate Firms' Liquidity Holdings, Multiple Equilibria

(a) Marginal Return of Cash



(b) Threshold \underline{A}



(c) Banking Crisis States



4 Macprudential Policy

We proceed to analyze the optimality of different macroprudential policies which have recently been discussed by central banks. We deliberately abstract from important determinants of optimal macroprudential policy such as implicit bailout guarantees, to concentrate on the new mechanism in this paper: liquidity panics. Our goal is to highlight the additional effects that each policy has on the aggregate economic variables once the amplification loop between interbank market freezes and liquidity accumulation is taken into account.

For simplicity, throughout this section we analyze the case where the support of A is discrete, i.e. $A \in \{A_L, A_M, A_H\}$. Our qualitative results would still hold if the state space was continuous.

We consider the following policy interventions: liquidity requirements, subsidies to bank financing and negative interest rates on reserves.

4.1 Liquidity Requirement

The “Liquidity Coverage Ratio” (LCR) rule introduced by Basel III requires a bank to hold sufficient high-quality liquid assets to cover its total net cash outflow over 30 days. High-quality liquid assets are cash or assets that can be easily and immediately converted into cash at no value loss, e.g. central bank reserves. The rule requires liquid assets to be larger than the segment of debt that is short term and might cause an outflow in times of stress.

A common view in the macroprudential policy debate is that liquidity requirements imply a trade-off between stability and growth or output levels. Such requirements are seen as a buffer that must be accumulated in good times, at the expense of preventing banks from financing the real sector and lowering aggregate investment levels. We show that once one considers the feedback effects from the agents anticipated reaction to a liquidity crisis, liquidity requirements can have a positive effect on aggregate investment, even in normal times. Generating stability in the financial sector can correct liquidity panic situations and substitute an excess of cash hoardings with productive investment.

In our model, this policy mandates that banks keep in storage a fraction F of the debt they borrow from other banks. We assume that assets stored for regulatory compliance, $F\phi N_B$, are observable and cannot be diverted upon default. A possible interpretation is that such assets take the form of reserves

at the central bank.¹²

This policy restricts the actions of borrower banks at $t = 1$. Banks borrowing a fraction ϕ per unit of net worth in the interbank market must keep $F\phi$ invested in storage and can only lend $(1 + \phi(1 - F))$ to firms. This operation yields a return $\omega R^B(1 + \phi(1 - F)) - \rho\phi$. Moreover, banks that borrow cannot divert the funds stored to comply with the requirement. Thus, the diversion option yields $R_S(1 + \theta\phi(1 - F))$, and the incentive compatibility condition becomes

$$\phi \leq \bar{\phi} = \left(\frac{\rho}{R_S} - 1 \right) \frac{1}{\theta} \left(\frac{1}{1 - F} \right). \quad (19)$$

A liquidity requirement restricts the amount of funds that banks can lend to firms in normal times, which reduces the supply of corporate loans (see Figure 6). In a market freeze, banks cannot borrow, so the policy does not affect the supply function. As is shown in Proposition 4, a liquidity requirement reduces the region of A where there is a banking crisis for two reasons. First, it directly relaxes the incentive compatibility constraint. The fraction of assets stored in reserves cannot be diverted and thus the profits from diverting are lower (see equation (19)), which reduces \underline{R}^B . Second, increased storage means that the supply in the liquidity loans market is lower, which generates a general equilibrium effect that increases R_B and ρ and further relaxes the incentive compatibility constraint.

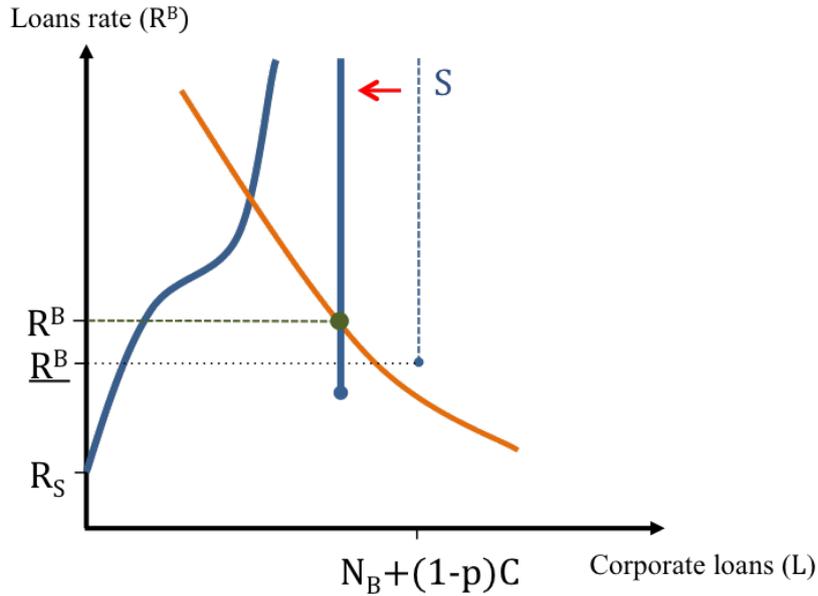
Proposition 5. $\underline{R}^B(\frac{C}{N_B}, F)$ and $\underline{A}(C, N_B, K, F)$ are decreasing in F .

Figure 6 depicts the two effects explained above at $t = 1$ of an increase in the liquidity requirement F , for a given aggregate shock A and accumulated cash C . Both effects make it more likely that the total supply and the demand curve cross at an $R^B > \underline{R}^B$, consistent with a functioning financial sector.

If the parameters are such that the policy avoids a market freeze in at least one of the states of the world where otherwise there would have been a freeze, firms will react by lowering their cash holdings. This will increase the demand for liquidity loans and make it even less probable that there is a freeze. The effects on the firms decision to hold liquid assets and the limitation of liquidity panics are shown in Figure 7. The figure displays the change in equilibrium conditions after a liquidity requirement is imposed, using the same type of diagram as in Section 3.4. The direct impact of the policy is a marginal increase in

¹²This assumption is also consistent with Calomiris et al. (2013), where safe assets limit managers discretion and alleviate moral hazard problems.

Figure 6: Liquidity Requirement: Effects on the Liquidity Loans Market



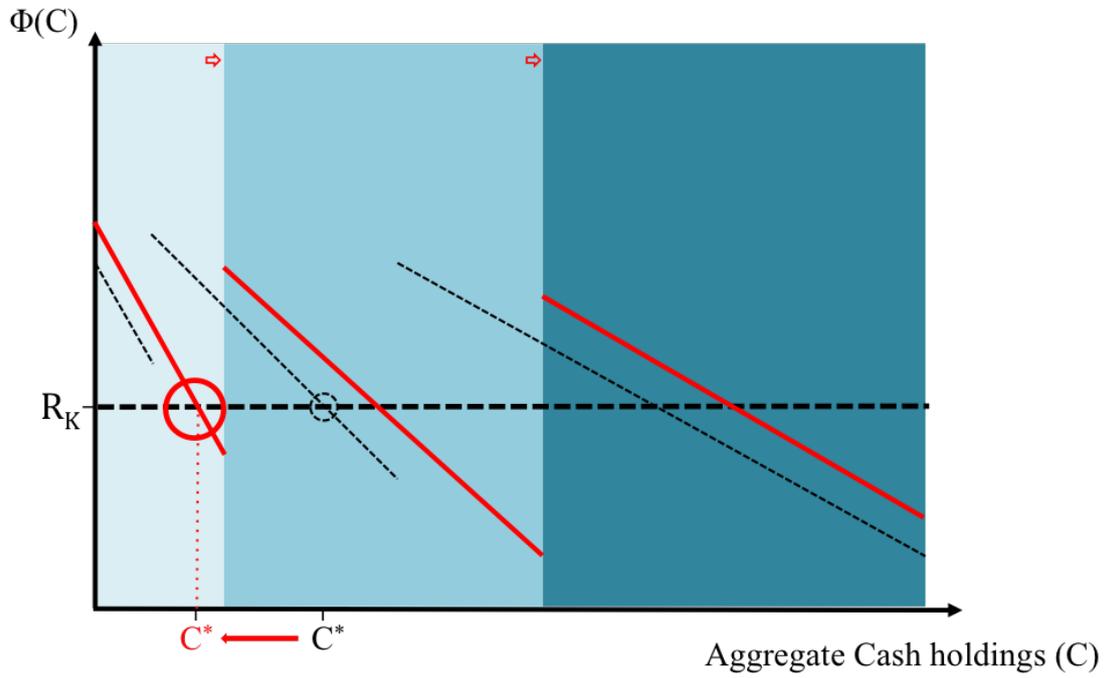
liquidity loan interest rates which tends to increase cash accumulation. However, the policy can make it possible to sustain a trade equilibrium in more states, which will reduce liquidity accumulation in a discontinuous fashion.

A reduction in storage implies a welfare improvement as it is replaced by productive investment. Figure 8 provides a diagram of the relationship between the level of liquidity requirements and the amount of assets stored. Small increases in F , the fraction of assets which have to be stored by banks according to the policy, lead to higher levels of aggregate storage. Eventually, F will be so large that it will solve the market freeze problem in an additional state of the world, which will lead to a discontinuous fall in expected storage. It is possible that the mitigation of the liquidity panic by the policy is so strong that the total amount of assets stored in the economy is reduced compared to the case $F = 0$, even if banks are being mandated to store more assets. The optimal policy F^* will be the one associated with a lower expected storage.

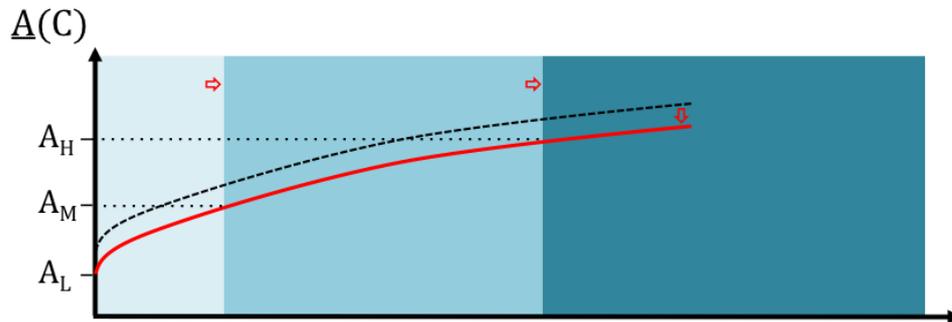
Even in the absence of a policy, banks have the option to invest in reserves and by doing so relax their borrowing constraint. However, this is never individually optimal for banks, as any additional resources borrowed against reserves would need to be stored as well, canceling any gain in net leverage. A policy mandating an increase in reserves is only beneficial collectively due to its general equilibrium effects.

Figure 7: Liquidity Requirement: Equilibrium

(a) Marginal Return to Cash



(b) Threshold \underline{A}



(c) Banking Crisis States

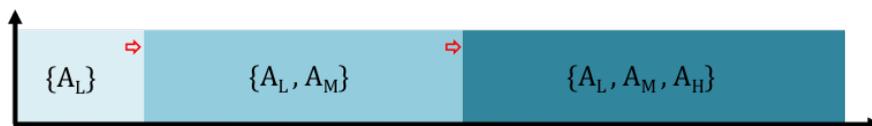
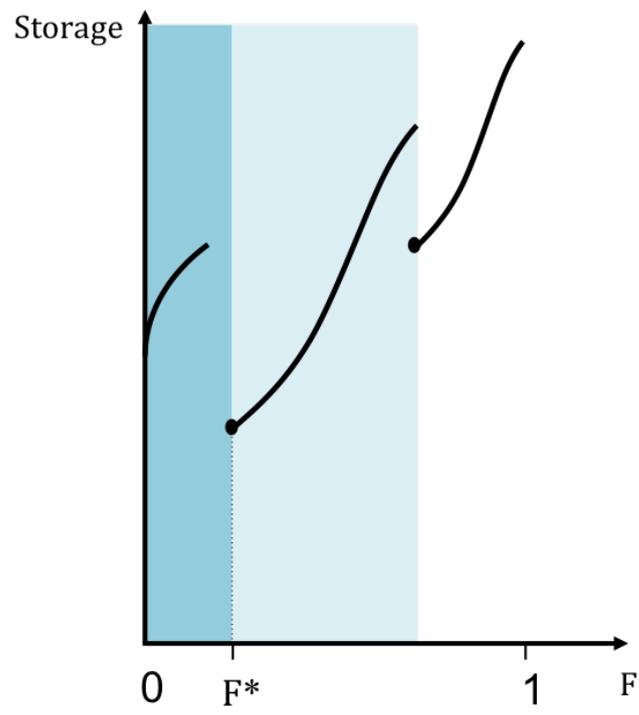
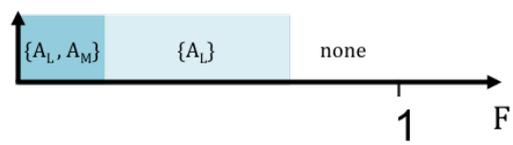


Figure 8: Liquidity Requirement: Aggregate Storage

(a) Expected Storage



(b) Banking Crisis States



In opposition to our result, Malherbe (2014) predicts that a liquidity requirement may increase financial instability. This is because in his set-up a liquidity requirement reduces the demand, rather than the supply, in the interbank market, and thus worsens the adverse selection problem.

4.2 Subsidy to Banks Financing

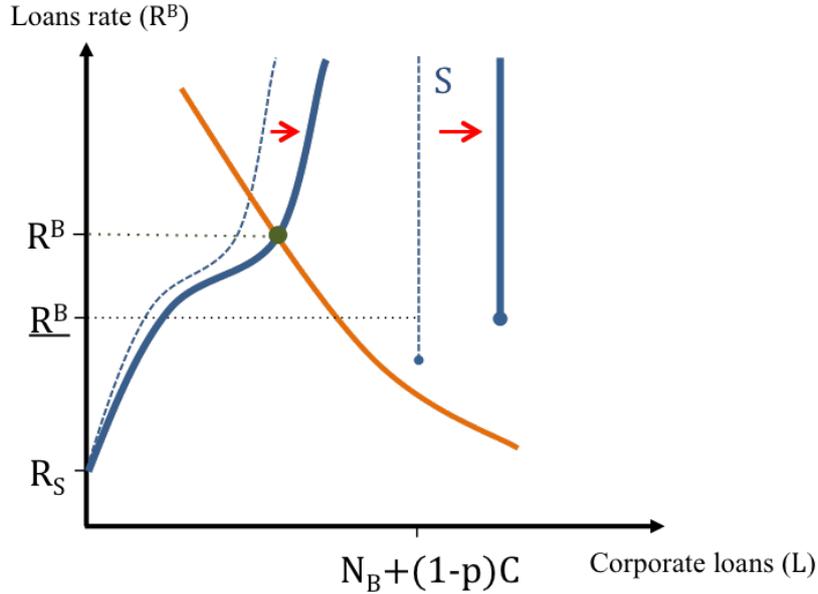
Next, we consider a policy that enhances the accumulation of liquid assets in the banking sector N_B . We can either analyze this as an exogenous change in N_B , for the case where N_B is fixed, or allow banks to set N_B endogenously at t_0 and introduce a policy inducing the same effect. For example, we can have that banks' financing is subsidized with an interest rate discount in period $t = 0$, or that there are unexpected transfers of resources at $t = 1$ to the banking sector. Policies such as Quantitative Easing may have caused an effect along these lines.

A subsidy to bank financing does not have any effect on the liquidity loans market in period $t = 1$ for given K , C and N_B . However, it does have effects through the increase in banks financing N_B it induces. A higher N_B mitigates the negative effects of a market freeze, as it increases bank lending in all states of the world, for a given partition \underline{A} . We can check that the partial derivative $\frac{\partial \Phi(C, N_B, \underline{A})}{\partial N_B} < 0$. For given (C, \underline{A}) , an increase in N_B affects markets at $t = 1$ in two ways. First, a higher N_B implies an expansion of the supply curve of liquid assets both if there is a banking crisis and in normal times (see Figure 9). Second, \underline{R}^B depends positively on $\frac{N_B}{C}$ (see Proposition 2), so a higher N_B makes a banking crisis more likely (the vertical supply line in Figure 9 starts at a higher level). Both effects imply an increase in \underline{A} , which might actually increase the probability of a banking crisis.

Therefore, while this policy alleviates banking crisis episodes by providing more liquid assets for any given partition of banking crisis states, it moves \underline{A} in the “wrong” direction. In Figure 10 we show the particular case where the subsidy is welfare improving, as it does not expand the banking crisis partition. Even in this best-case scenario, subsidies to bank financing do not have the large non-linear amplification effects that can be achieved with policies restricting lending, since they cannot correct liquidity panics.

A policy with similar results to a subsidy would be a deposit insurance. So far, we were agnostic about the composition of bank funding from households, as we assumed for simplicity that there were no frictions between households and banks. Let us now assume that a constant fraction of a bank's liabilities

Figure 9: Subsidy to Banks Financing: Effects on the Liquidity Loans Market



in the initial period t_0 takes the form of deposits from households, and that banks can default on these deposits as they can default on loans from other banks. Then, deposit insurance would augment the amount of financing available to banks, as households would be less wary to lend them funds, but the associated increase in banks leverage would give banks more incentives to default. This trade-off has been extensively analyzed in the literature, but it is important to note that it is quite orthogonal to the effects of liquidity panics.

Contrary to our result, in Freixas et al. (2011) expansionary monetary policy in the form of low interbank interest rates is unambiguously beneficial to solve liquidity panics in the interbank market. The reason is that they focus on the liquidity needs of banks, rather than the ones of the corporate sector.

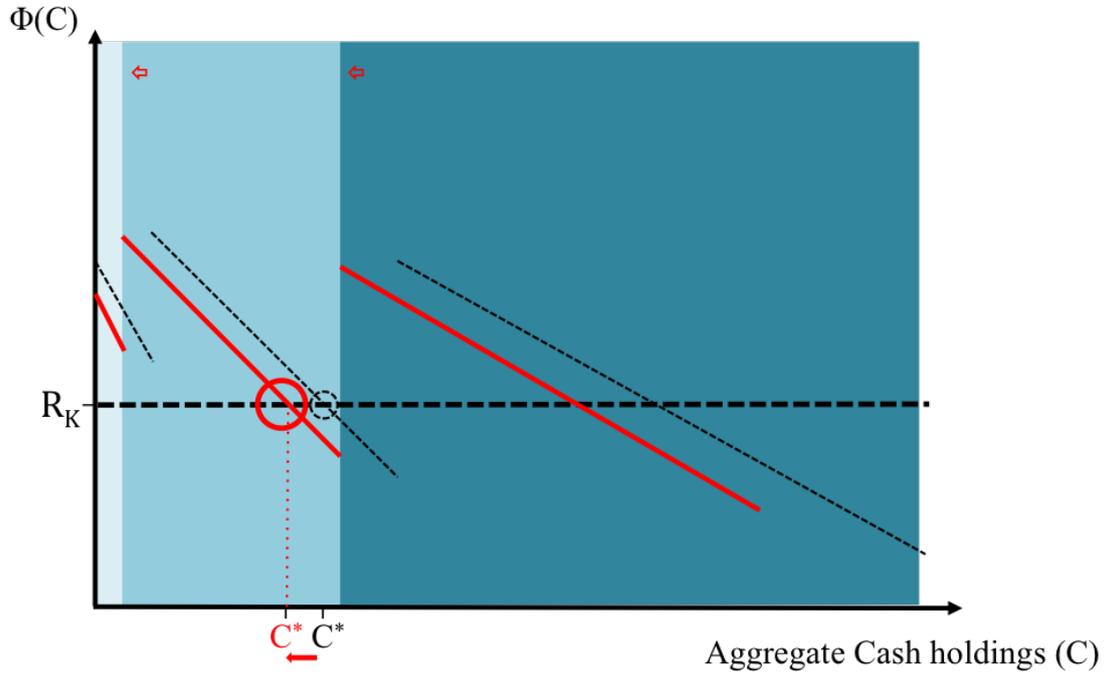
4.3 Negative Interest Rate on Reserves

A policy that has been considered by central banks after the crisis and implemented for example by the ECB or the Swedish Riksbank is to set a negative interest rate on reserves.

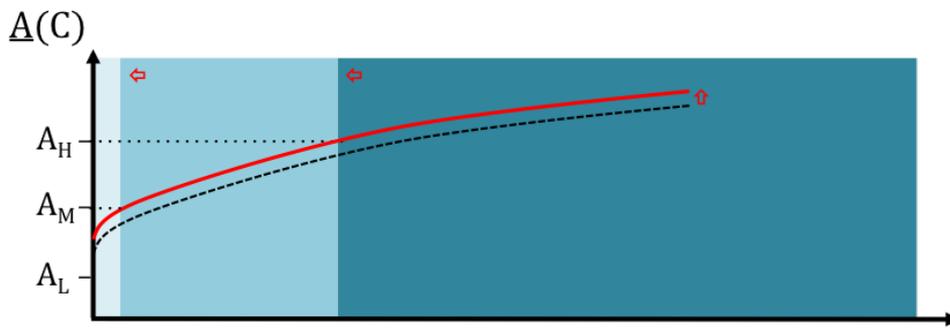
We study this policy in the model by assuming that banks storage investment takes the form of reserves at the central bank. A negative interest rate on reserves is then modeled as a lower storage return $R^R < R_S$).

Figure 10: Subsidy to Banks Financing: Equilibrium

(a) Marginal Return of Cash



(b) Threshold \underline{A}

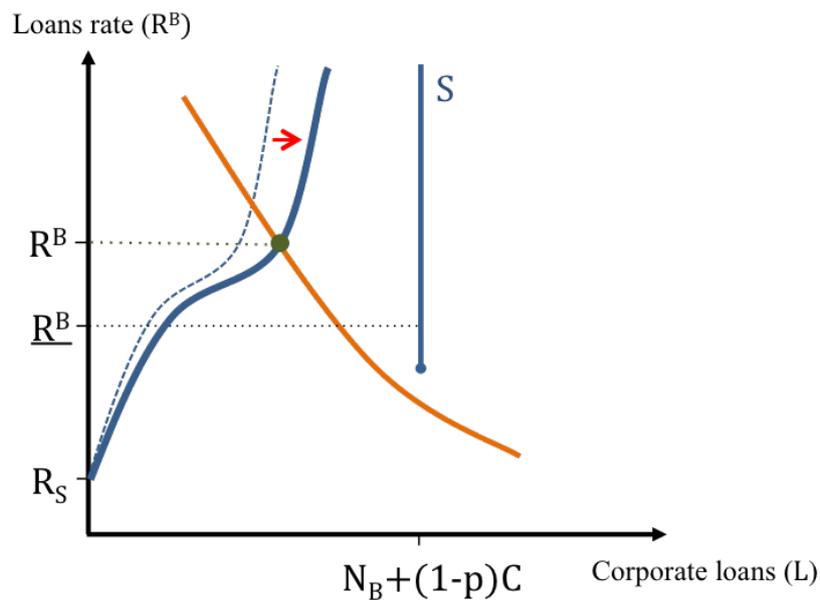


(c) Banking Crisis States



In our model, banks only store assets when there is a banking crisis. A lower return from storage implies that more banks are willing to supply loans to the corporate sector ($\bar{\omega}$ for the case of a market freeze decreases) and thus the supply of loans expands during a banking crisis. In normal times, banks do not use storage, so the policy does not affect the supply of loans. This direct effect at $t = 1$ (for fixed K , C , and N_B) is shown in Figure 11. Yet, this policy is not optimal in period $t = 1$, as conditional on being in a freeze there is no market imperfection.

Figure 11: Negative Rates on Reserves: Effect on Liquidity Loans Market



The policy reduces loan rates and the profits of banks at $t = 1$. If we allow for an endogenous N_B , the banking sector will reduce its size in response to the fall in profits. A reduction on N_B has the opposite effects than a subsidy to banks financing: it will marginally increase loan rates at every state, but it may actually solve a banking crisis for some state. The reaction of firms then depends on the total effect on loan supply. If the direct effect of the policy wins, then a larger loan supply in a freeze will mitigate liquid asset accumulation by firms, which can make the policy welfare improving. On the contrary, if the indirect effect is stronger, lending will go down. A way to make the policy unambiguously welfare improving would be to neutralize the fall in bank profits with a subsidy as in Section 4.2. In that case,

only the market-freeze relief effect would prevail and firms would reduce liquidity accumulation, which could eventually solve the banking crisis in some states.

5 Empirical Motivation

This section reviews the empirical literature on cash accumulation by firms and it presents evidence on the evolution of relevant aggregate variables around the Great Recession.

5.1 Corporate Liquidity Hoarding

There is extensive evidence in the corporate finance literature that firms react to worsened financial conditions by increasing their liquidity holdings. [Bates et al. \(2009\)](#) and [Denis and Sibilkov \(2010\)](#) analyze the secular increase of cash holdings of US firms since the 1980s. [Bates et al. \(2009\)](#) conclude that the main reason for this trend is that firm characteristics have changed: their cash flows are riskier, R&D investment has become more important and they hold less inventories, so there is a stronger precautionary motive for cash accumulation. [Denis and Sibilkov \(2010\)](#) show that higher cash holdings allow financially constrained firms to undertake value-increasing investment projects which are otherwise bypassed. Using evidence from emerging markets, [Opler et al. \(1999\)](#) conclude that the hedging role of cash holdings is more critical during states of the world with high asymmetric information and excessive costs of external finance.

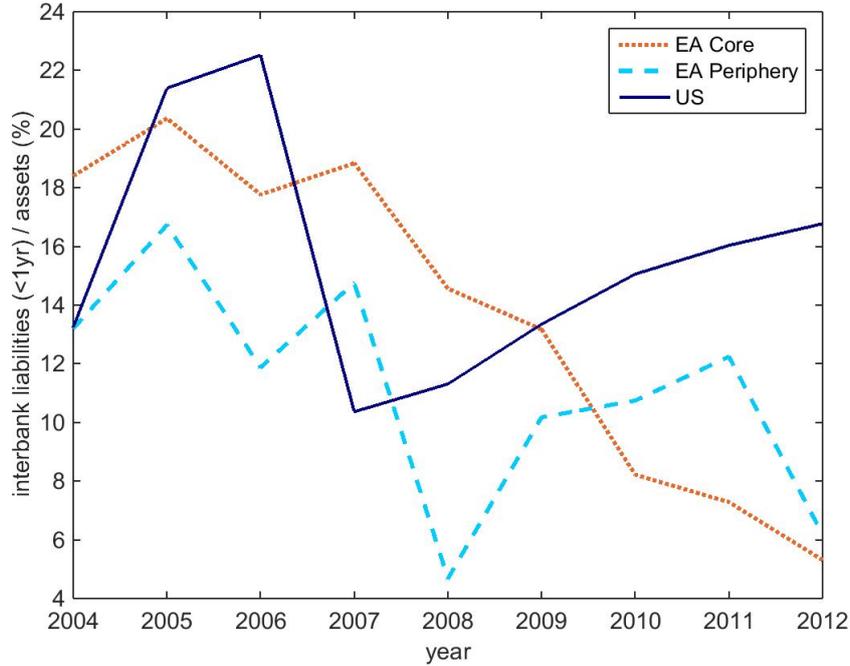
Our theoretical result that there is also a causality relationship in the other direction, i.e. that higher levels of liquidity holdings lead to worsened financial conditions, is based on a general equilibrium effect and so is harder to test directly with firm and bank-level data.

Next, we provide some suggestive evidence on the aggregate magnitude of the two-way relationship between liquidity accumulation and financial crises.

5.2 The Financial Recession and the Liquidity Panic

This section provides evidence that the theoretical phenomena analyzed in this paper had a relevant empirical magnitude during the Great Recession, both in the Euro Area (EA) and in the US. For the EA, we look at the 12 founding members and distinguish between the so-called “core” (Austria, Belgium,

Figure 12: Interbank Liabilities (<1 year) over Total Bank Assets, Data



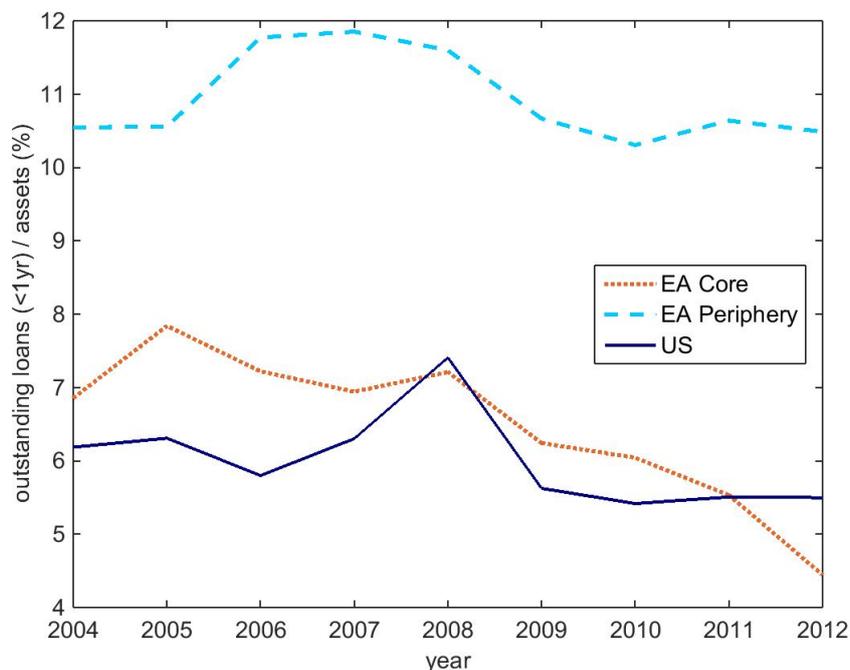
Finland, France, Germany, Luxembourg and the Netherlands) and the “periphery” (Greece, Ireland, Italy, Portugal and Spain), which have been affected by financial shocks of different nature and intensity over the last decade.

We start by showing that these economies effectively suffered from a collapse in the interbank market for short-term financing. Figure 12 plots the time series of the total outstanding liabilities in interbank loans maturing in less than one year divided by the total number of assets for the three groups: EA Core, EA Periphery and US. This data is aggregated from Bankscope, which contains balance sheet variables for a wide sample of consolidated credit institutions globally.

The data shows a sharp fall in interbank market liabilities in the US after 2007, and a more progressive decline in the Euro Area. Banks stopped using short-term borrowing from other banks after the onset of the financial crisis, even measured as a percentage of the total value of their assets, which also collapsed. In our model, this fall is captured as an interbank market freeze.

Next, we show that the interbank market freeze was accompanied by a reduction in short-term lending to the non-financial sector and an increase in liquidity accumulation by firms. To do so, we aggregate

Figure 13: Outstanding Bank Loans (<1 year) over Total Firm Assets, Manufacturing Data



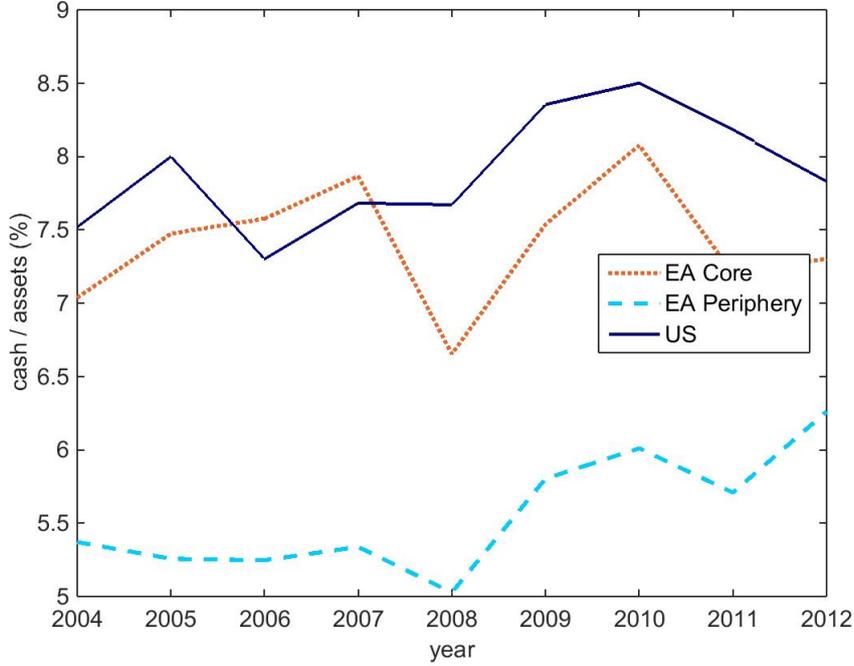
firm-level balance sheet data from Amadeus and Compustat in the manufacturing sector, for which our model has a more straightforward interpretation. Focusing on a single sector also avoids the confounding effect of changes in sector composition.

We first show in Figure 13 the total amount of outstanding bank loan liabilities of firms with a maturity lower than one year divided by firm assets. This variable declines in the three economies after 2008, having peaked in the years before. It is important to note that the variable plotted is a stock, meaning that apparently small shifts require much larger changes in investment.

Second, Figure 14 shows cash over assets of all manufacturing firms.¹³ While the supply of liquidity loans to firms was being reduced, firms started accumulating more liquid assets. In fact, they seemed to have done that after setting a low record in the beginning of the financial crisis in 2008. Actually, the cash accumulation process has been more prolonged in the Euro Area Periphery, which is consistent with the double financial recession experienced by those countries: the global financial crisis in 2009 and the sovereign debt crisis in 2012.

¹³We had to exclude Spain from the group of EA Periphery countries because of a change in accounting rules in 2007 affecting the definition of cash.

Figure 14: Total Cash over Total Firm Assets, Manufacturing Data



Again, one has to take into account that incrementing the stock of cash as a fraction of assets has a large impact on investment. For example, the increase in cash over assets in the periphery from 2008 to 2012 is consistent with a fall in productive investment of more than 20 percent.¹⁴

These empirical time series do not provide any information on the causality relationships between the three variables plotted. Yet, they show the existence of relevant aggregate trends that we aim to explain with our model.

6 Conclusion

This paper considers a theoretical set-up where banks act as efficient liquidity providers to firms, but are prone to endogenous crises due to informational frictions in the interbank market. Moreover, firms have the option to accumulate liquidity internally to insure against liquidity shortages from the financial sector. When these two elements are taken into account, the possibility of liquidity panics emerges.

¹⁴This illustrative calculation assumes an investment level equal to 18 percent of GDP and a capital-to-GDP ratio equal to 3.

Firms accumulate more liquidity in response to financial crises and this response in turn exacerbates the crises. Liquidity panics provide an additional source of equilibrium multiplicity and, even in the absence of sunspot shocks, lead to non-linear amplification of aggregate shocks.

Given the presence of liquidity panics, it is important that the normative analysis of macroprudential policy assesses not only the direct effects of policy on the interbank market, but also the response by the corporate sector. This additional decision margin leads to the paradoxical result that policies restricting lending can end up increasing aggregate investment even in times of financial stability, whereas policies encouraging lending can only act as a marginal relief in crises at the best. Liquidity panics provide thus an additional reason for stricter regulation on banks balance sheet positions.

A natural continuation of this line of research is to quantify the importance of liquidity panics in amplifying the financial recession that started in the US in 2007. A quantitative framework with a full treatment of the intertemporal problem would also make it possible to calculate the changes in optimal macroprudential policies that taking into account liquidity panics would prescribe.

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