Endogenous bank risks and the lending channel of monetary policy*

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Abstract

Banking distress is preceded by credit expansions and accompanied by the joint deterioration of credit quality, liquidity conditions, and bank solvency. This paper develops a general equilibrium banking model in which these risks are not separate frictions but jointly endogenous outcomes of bank lending. Banks create deposits when they extend credit. As deposits circulate through the payment system, banks face reserve-settlement needs, while borrowers' ability to repay depends on the flow of deposits they receive from economic activity. Lending therefore simultaneously generates liquidity risk, credit risk, and potential losses to bank capital. As a result, bank balance sheet expansion is bounded endogenously by an internal risk-profitability trade-off. We present an application of the theory that provides a new look to the bank lending channel where monetary policy operates through the endogenous generation of bank risks. Our quantitative results align with empirical observations, including declines in deposit growth after monetary policy tightening and its different impact on lending depending on the balance sheet strength of banks as well as the relation of funding costs in interbank markets with liquidity and solvency ratios.

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1 Introduction

A large empirical literature shows that banking crises and financial instability are usually preceded by rapid credit growth [**???**]. However, as pointed out by **?** bank stress is not one dimensional but rather combines liquidity strains, credit losses, and solvency concerns. In this paper, we develop a theoretical model to study how lending connects credit, liquidity and solvency risks and how monetary policy affects these linkages. We show that banks' balance sheet expansion is bounded endogenously through the joint effect of these risks on expected profitability.

We construct a general equilibrium banking model in which lending and payment flows endogenously link credit, liquidity, and solvency risks. The credibility of the model is supported by its consistency with key empirical patterns in banking data. First, a monetary tightening leads to a decline in lending and deposits, as in **?**. Second, the model produces heterogeneous lending responses to monetary shocks depending on banks' capital and liquidity positions [**????????**]. Third, in the model, wholesale funding costs are larger for banks perceived as riskier [**????**].

Existing theoretical models of banking capture important dimensions of bank fragility, but they have not yet offered a unified account of the joint emergence of credit, liquidity, and solvency risks. Banking models in the spirit of **?** concentrate on a single dimension of stress, namely, the possibility that fundamentally solvent banks fail through self-fulfilling liquidity runs. Macroeconomic models in the tradition of **?** and **?** incorporate financial frictions through agency problems or leverage constraints that operate on the solvency margin, but they treat liquidity exposure and credit losses as inputs to the balance sheet rather than as outcomes of the lending decisions that determine solvency. More recent quantitative banking models such as **?** integrate liquidity management with monetary policy in detail but characterize credit risk as an exogenous parameter instead of tying it to the same balance sheet expansion that drives liquidity exposure. This paper fills this gap by developing a framework in which the different dimensions of bank stress arise endogenously from the same lending decision, rather than entering as separate frictions or exogenous balance sheet exposures.

The central mechanism in our model is that the same lending decision simultaneously produces all three risk exposures. Loans create deposits and as these bank liabilities circulate as means of payments to settle retail transactions, payment flows between banks expose them to liquidity risk since interbank payments require reserve settlement. The realization of these payment flows condition borrower repayment and generate credit risk. Consequently, if borrowers do not receive sufficient revenues in the form of existing liquidity to repay their loans, expose bank capital to the losses, which creates a source of solvency risk.

This mechanism relies on the empirically supported description of how deposits are created and destroyed. This is a central methodological difference from the loanable funds banking view that has been modeled in much of the macroeconomic literature. Under the loanable funds view, lending is constrained by the amount of existing stock of assets saved in the economy. Thus, any expansion of credit must be funded by drawing existing savings from alternative uses to be deposited at banks. Within that framework, if, as a response to an exogenous increase in interest rates, depositors move their savings to other assets with higher remuneration, aggregate deposits are reduced and, therefore, credit shrinks if banks do not have access to other sources of funding.

In our model economy, there are three types of private agents, namely, firms, workers and banks, where specialization on production and consumption prevents firm's own claims from circulating as means of payment in line with **?**. This friction creates a role for banks as producers of inside money. When a firm demands labor but does not have the means of payment to pay for it, a bank produces transferable deposits that are loaned to that firm. This is how deposits are created, being transferred to workers in exchange for labor. Workers, in turn, spend these claims buying goods from some firms in the economy. These expenditures allow firms to get back the means of payment they need to pay for the loans they asked for previously. This is how deposits are destroyed.[1] The uneven distribution of deposits across banks, governed by an idiosyncratic taste shock, generates the payment flows from which all bank risks arise. A second independent shock affecting the liquidity management of banks perturbs the timing of these payment flows without changing their fundamentals and plays a specific role in preventing interbank lenders from perfectly disentangle the solvency and liquidity position of other banks at the time they asked for reserves in the interbank market. Our general equilibrium, thus, states that aggregate credit expansion is disciplined by the endogenous risk-profitability margin rather than by a pre-existing stock of savings.[2]

[1] The only instance in which deposits are destroyed in the aggregate arise whenever they are converted into central bank money or, else, absorbed through bank operations such as depositors repaying a loan, or buying bank debt, bank equity or a security already existing in the bank portfolio (**?**). We could incorporate other forms of deposit destruction, but all these other ways to eliminate deposits complicate the model without adding other insights to our mechanism.

[2] Under the loanable funds view, this mechanism would not be operative because the deposit base is given exogenously and the loan is constrained by it, so the lending decision no longer generates the payment flows from which the three risks arise. The risks therefore cease to be joint outcomes of credit provision and instead

We show how bank balance sheet expansion is bounded endogenously through the joint effect of these risks on expected profitability rather than through any external regulatory constraint or exogenous funding limit. As a result, there is an optimal level of credit provision for a bank that maximizes the expected profitability. This feature highlights that when bank risks are generated internally through bank operations, credit supply is endogenously restricted by bank risk exposure rather than by a decrease in the funding available to banks. Bank capital is relevant in this process because it affects the connection between loan provision and bank risks. Furthermore, we study how bank capital influences the nexus of loan provision with liquidity, credit, and solvency risks, as these are the main concerns banks have to face regarding their decisions to expand or contract their balance sheets.

The results of our model provide a new look at the bank lending channel. In our framework, deposits are a consequence rather than a constraint on lending. An implication is that the lending channel operates instead via the cost of reserve settlement. Because every loan creates a deposit whose circulation generates interbank payment flows, the policy rate is transmitted through the marginal cost of the reserves needed to support balance sheet expansion. This is in contrast with the loanable funds tradition that operates through the deposit base, since monetary tightening draws funds out of bank deposits towards higher yielding investment alternatives, which forces banks to reduce lending (**?**; **?**). As discussed above, this theory treats deposits as a binding constraint on the credit supply in a extent at which policy rates are transmitted primarily through the cost of attracting deposits.

Our interpretation of the lending channel has two dimensions. In the long run, monetary policy in the form of permanent changes in the policy rate has persistent effects on the real side of the economy. In particular, a permanent reduction of the policy rate moves the economy to a new steady state characterized by a higher price level, more labor and, consequently, more output. The reverse would follow from a permanent monetary policy contraction. The mechanism works as follows. A lower policy rate eases credit conditions increasing the supply of loans and allowing firms to borrow more to hire more labor and produce more output. Because this new lending expands the means of payments in the economy, prices also rise. The drawback of this expansion is an increase in credit and solvency risks in the form of higher non-performing loans (NPLs) ratio and a higher share of insolvent banks. This result is in line with the long lasting real effects of the monetary policy documented empirically by **?**.

The second dimension is the transition. A temporary decrease in the policy rate generates

respond separately to the exogenous supply of funds and to independently specified disturbances on the asset and liability sides.

qualitatively similar responses in terms of transitory lower market rates, as well as higher prices, labor and output. In the short-term, NPLs and bank failures also increase. Thus, in the model, an expansionary monetary policy produces data that could be interpreted as risk seeking behavior of banks, although the underlying distribution of risk has not changed.[3] Furthermore, associated with the increase in credit there is also an increase in deposits. When the monetary conditions ease, the cost of funding decreases thereby increasing expected returns to intermediation and inducing banks to increase credit supply. The increase in deposits that follows a reduction in the policy rate is a consequence of the lending expansion and not a constraint that forces it, which reverses the causal direction pointed out by the deposit channel of **?**.

The remainder of the paper proceeds as follows. Section 2 discusses related literature. Section 3 presents the styised facts from the existing empirical literature, Section 4 presents the model and equilibrium. Section 5 reports results. Finally, Section 6 concludes.

2 Related Literature

Our paper is related to the literature analyzing risk exposures through the asset and liability structure of bank balance sheets. **?** identify the dependence on short-term debt structures as the element connecting liquidity and credit risk. **?** point out the relationship between liquidity and credit risk as the fundamental cause that aggravates defaults for US commercial banks. **?** use global game methods to decompose credit risk into solvency and liquidity risk and show how both are jointly determined as a function of the balance sheet. We contribute to this literature by showing how credit provision and deposit flows endogenously connect liquidity, credit and solvency risks altogether. We show how payment shocks might produce a deterioration of economic conditions, provoking credit risk realizations when deposits do not flow back to borrowers, and leading to solvency risks that boosts the cost for wholesale funding in the interbank market. This endogenous connection among bank risks allows us to characterize the deterioration of bank fundamentals empirically identified in **?**.

Our paper also relates to the literature on endogenous risk and financial amplification in banking. Models such as **?** and **?** highlight how feedback between asset prices, leverage, and balance sheet strength can amplify shocks. We share their emphasis on endogenous risk creation but differ in focus and in the type of frictions that generates it. In our model, risk arises not from agency problems or market power but from the interaction of payment flows and balance sheet composition.

[3]The term risk-taking channel of monetary policy was first coined in **?** and has received empirical support, among others, in **?**, **?**, **?**, **?** or **?**. A theoretical model reproducing this channel is developed in **?**.

Our work is connected to the macroeconomic literature on money as a medium of exchange. Descriptions of the process of inside money creation by banks such as **?**, **?**, **?**, **?** or **?**, are used by **?** or **?** to break with the idea that deposits are needed to provide credit and to push the view that the direction of causality is exactly the opposite. We contribute to this literature by introducing a tractable approach that embeds payment flows and deposit creation and destruction into a general equilibrium setting with endogenous bank balance sheets. This allows us to study how payment flows affect bank lending and the monetary transmission. Our model jointly accounts for observed relationships between policy rates, spreads, funding costs, and heterogeneous lending responses. To our knowledge, existing macro models examine these channels separately. General equilibrium approaches such as **?** and **?** analyze individual bank risks but do not integrate the credit-liquidity-solvency triad in a single structure as we do. Furthermore, dynamic banking models like **?** also underscore the value of deposit flows as a constraint to lending.

Furthermore, our paper relates to the strand of the literature emphasizing the lending channel of monetary policy. Early contributions, such as **?** and **?**, modeled the bank lending channel through balance sheet constraints or reserve requirements that limit credit creation. More recent research has incorporated modern funding structures, including the role of wholesale markets, market-based intermediation, liquidity regulation and studies the dynamic implications for bank balance sheets and lending [e.g. **??????**]. In contrast, the key mechanism in our framework arises from the joint exposure of banks to credit, liquidity, and solvency risks that stem from payment flows and balance sheet composition. Unlike models in which credit supply is constrained by external limits on deposits, capital, or funding, banks in our model face an endogenous bound to expanding credit associated with expected profitability. Monetary policy therefore operates by influencing the cost of intermediation and the maximum level of profits, rather than by relaxing or tightening exogenous constraints.

Another strand of the literature studies banks' liquidity management and the role of reserves and interbank markets in transmitting monetary policy. Recent work, such as **?** and **?**, models the functioning of the interbank market and shows how the distribution of reserves influences interbank rates and the effectiveness of monetary policy. Our paper contributes to this literature by incorporating the interaction between interbank borrowing and the endogenous determination of liquidity and solvency risks affecting banks' funding costs.

Finally, our results connect to the deposit channel of monetary policy described by **?**. At the heart of their theory is that banks exploit market power over the deposit supply, so when the fed fund rate rises, banks widen the spread they change on deposits and cut lending as deposits flow out to other more productive alternative investments, which reduces real activity. This mechanism is used by **?** to justify how the deposit channel generates a bank lending channel of the monetary policy. Contrary to **?**, in our mechanism, changes in deposits are not the driving force for the reduction in lending but rather a by-product of the adjustments of banks and the real sector to policy changes. Because banks create deposits in the lending process, aggregate deposits drop jointly with lending but as a consequence of the contraction in intermediation, not as a cause. Of course, there are other modeling differences across both frameworks. Banks in **?** do not fail and there is no bank capital. Accordingly, they cannot account for cross-sectional differences of the responses of banks to monetary policy shocks according to their levels of capitalization and liquidity. We show, thus, another plausible driving channel for the bank lending channel. Instead of being caused by the drop of deposits that follow an increase in the policy rate as **?** argue, it is caused by the endogenous profitability-risk nexus linked to bank's lending decisions.

Taken together, our paper bridges these strands of the literature by offering a unified framework in which the provision of credit, payment flows, and bank risks are jointly determined.

3 Stylized Facts

We present existing empirical evidence documented in the literature around three stylised facts that motivate the model: credit expansions precede banking distress, credit expansion creates deposits and expands bank balance sheets, and crises jointly involve credit losses, liquidity pressures, and solvency concerns.

3.1 Credit expansions precede banking distress. A large empirical literature shows that credit growth is an important predictor of banking crises and financial instability [e.g. **????**]. This evidence suggests that bank stress is closely connected to the expansion of credit before distress materializes. Consistent with this pattern, **?** show that total loans of failing banks increase significantly in the years before failure. Figure 1 illustrates this pattern by plotting loan growth at banks that subsequently fail. A first feature of the model is therefore that bank risk builds up endogenously as lending expands.

3.2 Credit expansion creates deposits and expands bank balance sheets. The evidence also shows that bank lending is closely associated with the creation of deposits and the expansion of bank balance sheets. This feature is central to our mechanism. When banks extend credit, they create deposit liabilities that circulate as means of payment in the economy. This view is supported by evidence on money creation and bank accounting [e.g. **???**].

CreditExpansionBeforeFailureCorreiaEtAl2025FigB5.png

Figure 1: Loan Growth at Failing Banks

Notes: This figure presents the sequence of coefficients from a regression of the following form: $y_{b,t} = \alpha_b + \sum_{j=-10,j\neq 10}^{0} \beta_j \times \mathbf{1} * j = t + \epsilon * b, t$, where $y_{b,t}$ is a type of bank loan. The sample consists of failing US banks in the ten years before failure, based on the post-1959 sample. *Source:* **?**.

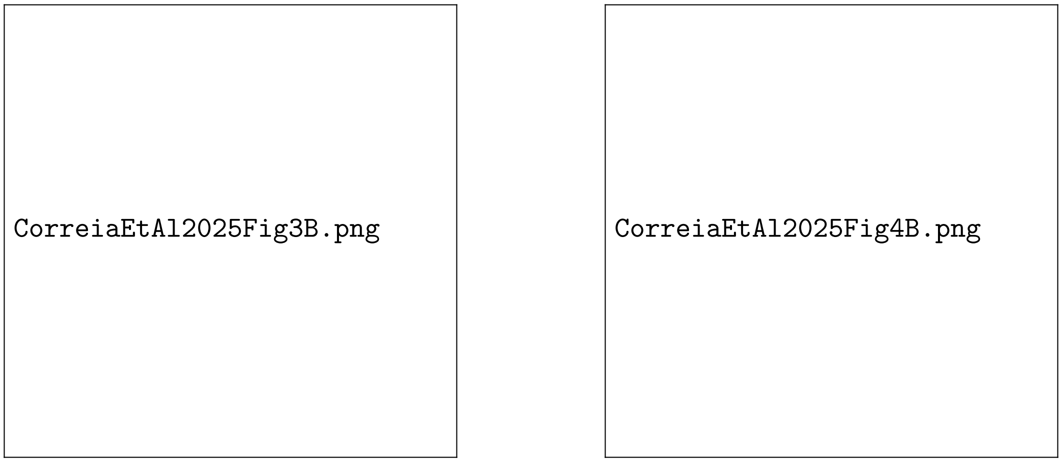
? documents the balance-sheet entries generated by the extension and disbursement of a new loan, while **?** show that around 90 percent of US bank deposits over the period 2001–2020 can be attributed to lending (Figure 2). A second feature of the model is therefore that lending simultaneously expands bank assets and creates deposit liabilities.

3.3 Banking distress combines credit, liquidity and solvency problems. A third fact is that banking distress involves the joint deterioration of credit quality, liquidity conditions, ThakorFig1B.png

Figure 2: Share of Deposits Created through Lending

Notes: The figure reports the share of aggregate deposits across US banks accounted for by lending, where lending is computed as total deposits minus cash and cash equivalents. *Source:* **?**.

and bank solvency. **?** show that failing banks experience rising asset losses and increasing funding vulnerability in the years before failure. Figure 3 summarizes this evidence. Panel (a) captures the realization of credit risk through deteriorating asset quality, while Panel (b) captures the rise in liquidity and funding pressures. Together, these patterns suggest that credit, liquidity, and solvency risks are not disconnected sources of fragility. Our model captures this interaction by showing how lending simultaneously generates repayment risk, reserve-settlement needs, and potential losses to bank capital.



(a) Asset losses before failure (b) Funding vulnerability before failure

Figure 3: Solvency and Funding Pressures before Bank Failure

Notes: Panel (a) shows the deterioration of bank asset quality before failure. Panel (b) shows the rise in funding vulnerability before failure. The data cover the period 1959-2024. Together, the two panels illustrate that failing banks experience both solvency problems and liquidity/funding pressures. *Source:* **?**.

Taken together, the evidence motivates a theory in which bank fragility arises from the joint determination of credit, liquidity, and solvency risks. Rather than viewing these risks as separate balance-sheet exposures, our model shows how they are connected through the lending process itself. Loans create deposits; deposits circulate through the payment system and generate reserve-settlement needs; and repayment shortfalls create credit losses that can erode bank capital.

4 The model

The economy is organized in a continuum of nodes, with measure one, indexed by $j \in [0, 1]$. On each of these nodes, there is a continuum of banks, a continuum of firms, and a continuum of workers each with measure one also. Banks supply means of payment. Firms demand labor and produce goods. Workers supply labor and consume. Outside these nodes there is a measure one of investors who save and invest in firms and banks. Finally, there is a government composed of a central bank and a fiscal authority.

We assume there is specialization in production, consumption and lending. With this assumption, workers and firms on each node are involved in the production of only one good. However, workers on that node consume a different good produced in a different node. This specialization in production and consumption prevents private IOUs issued by firms to circulate as a mean of payment. So, instead, workers and firms rely on private banks, which use their balance sheets to intermediate payments among them. The process works as follows. Whenever a firm demands labor from a worker but does not have enough means of payment to acquire it, a bank creates these means of payment in the form of deposits and lends them to that firm. For that, we assume the firm can only get the loan from a bank in its node. We impose these extreme specialization assumptions to simplify the exposition of the model. Below we show it would be possible to relax them as long as there is no complete diversification of firms across different goods and of banks across different nodes.

Once created, these deposits are transferred to workers in exchange for labor and circulate in the economy as workers use them to buy goods from other firms. For the original borrower (firm) to pay back the loan she asked for in the first place, the so-created deposits need to get back to her, as this firm sells whatever product she is specialized in to other workers in the economy. Regarding this payment process, we assume that workers' consumption expenditures are randomly distributed across firms. This generates two key effects. First, because workers and firms are distributed across banks, deposits flow unevenly across intermediary institutions. These interbank imbalances are settled using reserves and expose banks to liquidity risk. Second, since some firms receive more revenue than others, there is heterogeneity in loan repayment. Some firms repay in full, while others default. These defaults expose banks to credit risk. When loan losses are sufficiently large, bank capital is eroded, and solvency risk arises. In this way, liquidity, credit, and solvency risks emerge endogenously from banks' lending decisions.

Finally, there is a public sector composed of a central bank and a fiscal authority. The central bank is in charge of backing up this private monetary system through the production of outside money, i.e., cash and reserves. For that, we impose three institutional arrangements we observe in reality. First, the central bank provides commercial banks with reserves which are used to settle accounts between them derived from the asymmetric nature of payments. To manage these reserves, the central bank offers two facilities, a lending facility to provide reserves and a deposit facility to absorb excess reserves. Both facilities imply the same official rate, i^o. Second, we assume deposits to be convertible, on a one-to-one basis, into cash, i.e. the second form of outside money issued by the central bank. Finally, we impose cash to be legal tender, that is, a form of money that courts of law recognize as satisfactory payment for any monetary debt. Thus, in this model, deposits are liquid because, at any time, either can be used directly to make payments or, else, are convertible to an asset that can be used to make payments. Because of this convertibility, deposits earn the same nominal net return of cash, namely, zero. Furthermore, the fiscal authority transfers resources to workers. These transfers are financed by the central bank through reserves.

4.1 Workers. Workers are hand-to-mouth agents. At the beginning of the period, each worker supplies labor h^s to a centralized labor market within the node she lives in and is hired by one of the firms in exchange for a wage payment. Later in the period, after labor is supplied and output has been produced, the worker decides how much to consume. However, she consumes only one of the varieties produced in one of the nodes of the economy. Which variety the worker consumes is random and not known at the time labor is exerted, earlier in the period. Because there is a continuum of goods potentially demanded by workers, private IOUs issued by any single firm redeemable for output of the firm cannot be used to pay the wage bill of its workers. This is because these workers are not consuming that good, nor the firms they buy goods from assign any value to those promises.[4]

Commercial banks represent an arrangement to fill this gap. For that, these banks lend to firms enough funds in the form of nominal units of account called deposits to pay their nominal wage bill $W \times h^s$. These funds are then given to workers who use them to consume. As they consume, these deposits are transferred to the account of one other firm in another node in the economy. The receiving firm is willing to accept these deposits because, as deposits are backed by outside money, a legal tender, they are the means to cancel the debts they incurred with its respective bank at the beginning of the period. In fact, they are willing to store additional deposits over the amount needed to cancel their debts as these funds will allow them not to borrow as much the following period. As these payments are made, trade determines nominal prices of each variety of the good.

As mentioned above, at the time of consumption, each worker buys goods from a random firm in the economy. Because each firm borrows from one bank only, selecting a firm is equivalent to selecting the bank the firm has asked the loan for before consumption takes place. For that, let $c(j)$ be the consumption by a worker of goods produced by a firm who has asked a loan from a bank in node j. Preferences over consumption and labor after the taste shock is realized are described by the quasi-linear function

$$log[c(j)] - h^s, \tag{1}$$

as in **?** or **?**. Let $P(j)$ be the price of the good the worker is buying. The problem of the worker is, given the wage W as well as the price $P(j)$, to choose consumption, $c(j)$, and labor, h^s, to maximize utility (1) subject to the budget constraint

$$P(j)c(j) = Wh^s + B. \tag{2}$$

[4] In words of **?** resaleability of firms' paper is zero in this economy.

In this expression, B is a transfer from the government which also has the form of a deposit at the same bank the worker has her wage deposited in.[5] The solution to this problem is summarized by the consumption sharing rules

$$c(j) = \frac{W}{P(j)}, \tag{3}$$

and the labor supply schedule

$$h^s = 1 - \frac{B}{W}. \tag{4}$$

An important assumption of the model has to do with the distribution of worker's taste shocks over the universe of firms and banks. For that, assume these shocks are not evenly distributed in the economy but rather clustered around firms located in particular nodes and serviced by banks also located there. The result of this clustering is that banks in node $j \in [0,1]$ will see its firm clients receive a fraction γ of all expenditures in the economy where γ is a random variable with distribution function $\Phi_\gamma(\gamma)$, mean $E(\gamma) = 1$ and support $[0, \gamma_{max}]$.

The idea we want to capture with the shock γ is as follows. Banks in reality are not fully diversified. This lack of diversification arises because each bank provides loans to a different pool of borrowers regarding their geographical location, production sector, or some other characteristic. Because of these differences, revenues from selling their respective goods vary across each pool of borrowers. This variation in revenues affects the ability of those borrowers to pay back the loans they received from their respective banks. This is what generates the credit risk banks face and is what the idiosyncratic bank shock γ is trying to summarize. However, apart from the characterization of γ as a credit shock, we also want to highlight that this shock has a liquidity component as it is associated with payments done with deposits. Because these payments are uneven across banks, they have to be settled with reserves.

4.2 Investors. There is a mass one of investors outside the nodes in this economy. They do not consume and only save investing in the net worth of both banks and firms. Each of them starts the period with assets $\mathcal{A}$ split between net worth of firms, $\mathcal{N}$, and net worth of banks, $\mathcal{K}$ for all the nodes in the economy, that is,

$$\mathcal{A} = \mathcal{N} + \mathcal{K}$$

with

$$\mathcal{N} = \int_0^1 N(j)dj,$$

[5] This transfer is needed for the labor supply to respond to changes in the wage rate.

and

$$\mathcal{K} = \int_0^1 K(j)dj.$$

In these expressions, $N(j)$ and $K(j)$ are the initial net worth of each firm and bank in node $j \in [0,1]$, respectively. Because all firms and banks start identical, they distribute equally these investments across nodes so that $N(j) = N = \mathcal{N}$, and $K(j) = K = \mathcal{K}$.

Denote next period values with a prime. Then, next period wealth of investors is

$$\mathcal{A}' = \mathcal{N}' + \mathcal{K}' - \mathcal{T}$$

where $\mathcal{T}$ are lump sum taxes levied by the fiscal authority. As investors do not consume, they decide how much to invest in firms and banks so that the return on each investment is equalized. That is,

$$\frac{\mathcal{N}'}{\mathcal{N}} = \frac{\mathcal{K}'}{\mathcal{K}}. \tag{5}$$

These returns are computed below.

Because each investor is small relative to the whole pool of investors, they take decisions of firms and banks as given. Next, we describe these decisions.

4.3 Firms. Each firm produces a perishable consumption good of one variety in node $j \in [0,1]$. The firm starts the period with internal funds, N, decided by investors at the beginning of the period. As it will be clear below, these funds are in the form of deposits at a particular bank. The only input needed to produce is labor. This firm decides then how much labor, h^d, to hire to maximize expected net worth next period. However, as it was described in the problem of workers, the wage has to be paid for in advance before production takes place. Thus, in the event that initial funds N are not enough to cover for the wage bill, $W \times h^d$, the firm needs to borrow the necessary funds from the bank the firm has its initial funds deposited. This credit costs the interest i^L to be paid for at the beginning of the following period. Thus, the demand for credit by a firm is

$$L^d = max\{0, Wh^d - N\}. \tag{6}$$

After obtaining the credit and pay for the wage of its workers, the firm produces $y = (h^d)^\alpha$, where $0 < \alpha < 1$. The parameter α can be thought of as the span of control of the producer. Output is sold in the market under perfect competition at the price $P(j)$ to other workers in the economy. These revenues are obtained at the end of the period in the form of deposits in the local bank. As mentioned above, because of full convertibility into cash, deposits earn a zero net nominal rate. Firms are assumed to be risk neutral. They just accumulate wealth through producing goods and selling them.

Under limited liability, the net worth of a borrowing firm at the beginning of the following period is, then

$$N(j)' = max\{0, P(j)(h^d)^\alpha - (1+i^L)L^d\}. \tag{7}$$

Notice next period's net worth is in the form of deposits at the local bank. Given the choice of labor demand, next period's net worth is uncertain because the price of the good $P(j)$ is stochastic at the time when production takes place. Let P_L be the break even price. This is the price of the good produced for which profits are zero, that is,

$$P_L = \frac{(1+i^L)L^d}{(h^d)^\alpha}. \tag{8}$$

Any price below this number will make the firm default on the loan, while prices above P_L induce the firm to pay for the loan and obtain profits. As it will be clear below, the price level depends linearly and positively on the realization of the taste shock γ of the pool of firms producing on the same node. Thus, the break even price level P_L is associated with a break even level of the taste shock, call it, γ_L. Realizations of the shock below this level will generate revenues that will induce loan defaults while realizations above that level will make the firm to repay the loan and have profits. Using the definition for P_L in (8) we can write the expected profits of the firm as

$$E[N(j)'] = (h^d)^\alpha \left[\int_{\gamma_L}^{\gamma_{max}} P(\gamma)\Phi_\gamma(d\gamma) - P_L[1-\Phi_\gamma(\gamma_L)] \right]. \tag{9}$$

In this expression, we have used the fact that price determination depends upon the realization of the shock, $P(\gamma)$.

At the time of the hiring and borrowing decisions, firms do not know yet the demand for their goods and, therefore, the revenue they will obtain when selling it. This is to say, the taste shocks γ have not realized yet. Given the initial funds, N, the wage rate, W, the bank rate, i^L, and the distribution of taste shocks which will translate into possible prices of the good $P(j)$, the firm decides labor demand, h^d, and therefore, production, y, and borrowing, L^d, to maximize expected profits (9). Notice hiring more labor will generate higher output which produces more expected revenues increasing expected profits. However, at the same time, hiring more workers implies a larger demand for credit, L^d. Thus, the threshold price for which the firm starts making profits, P_L, also increases. This effect reduces expected profits.

The first order condition associated with the choice of labor demand is

$$\frac{\alpha}{1-\Phi_{\gamma}(\gamma_L)}\int_{\gamma_L}^{\gamma_{max}} P(\gamma)\Phi_{\gamma}(d\gamma) = (1+i^L)W(h^d)^{1-\alpha}. \tag{10}$$

Given the market wage, W and initial funds, N, labor demand implies a demand for credit as in (6).

4.4 Banks.

4.4.1 Initial state and choices. Banks are assumed not to be fully diversified and service a pool of firms producing in the same node. Banks start the period with a balance sheet derived from decisions taken by investors. On the asset side, banks hold liquid assets, A, in the form of reserves. The liability side is composed of bank capital, K, and deposits representing internal funds of all the firms serviced by the bank, N. Thus, the initial balance sheet of the bank reads

$$A = N + K. \tag{11}$$

Banks take this initial balance sheet as given. As it will be clear below, the items in the balance sheet of the bank are the only ones transiting from one period to the next.[6]

Right at the beginning of the period, the government channels transfers to workers, B, in the form of deposits. These expenditures are paid for with reserves, held at a checking account at the central bank.[7] Banks take these transfers as exogenous. After these transfers are done, banks make two decisions. First, each bank has access to the deposit and lending facilities of the central bank. With those facilities, the bank borrows, $O > 0$, or deposits $-A \leq O < 0$, units of reserves at an interest rate i^O.[8] Second, banks decide how much credit, L, to provide to the firms in their location. For that, we adhere to the idea that banks do not need existing funds to supply loans. In fact, the defining characteristics of depository institutions is precisely the ability to produce deposits when providing loans to their customers.

Thus, the balance sheet after lending is provided is

$$(O + B + A) + L = O + (N + L + B) + K = O + D + K \tag{12}$$

[6] To simplify notation, we eliminate the reference to the particular node the bank is in, $j \in [0, 1]$ and write problems for a generic bank.

[7] The public sector could also use these deposits to buy goods from the economy directly. The impact of such fiscal policy is similar to the one of direct transfers and is not pursued here.

[8] In this economy, although borrowing from the central bank is senior to all other liabilities of the bank, it is nevertheless assumed unsecured.

where $D = N + L + B$ are total deposits at the bank. All these deposits are now in the hands of workers, paid by firms as wages in exchange of labor services, $L + N$, or as direct transfers from the government, B. With all this, the bank has now two types of assets, namely, reserves, $O + B + A$, and loans provided to firms, L. On the other hand, the bank now holds three types of liabilities. The borrowing from the central bank, O, deposits owned by workers, D, and capital, K.

As mentioned above, workers spend all their deposits D to pay for their consumption. But, since expenditures by workers cover all firms in the economy and because this bank is a point in a continuum of banks, these payments imply an outflow of funds for the bank. Let $\mathbb{D} = \mathbb{N}+\mathbb{L}+\mathbb{B}$ be the aggregate flow of payments by workers for consumption goods in the whole economy. We have assumed that a random fraction of these payments are channeled to the pool of firms serviced by each bank on each node in the economy. This fraction corresponds to the realization of the shock γ of that particular node with this random variable being identically and independently distributed across nodes. Thus, firms serviced by a bank in node j receive total payments $\gamma\mathbb{D}$ for selling the good they produce. This represents an inflow of deposits by banks in that node. Then, the net inflow of funds by a particular banks j is,

$$F_\gamma = \gamma\mathbb{D} - D = \gamma(\mathbb{N} + \mathbb{L} + \mathbb{B}) - (N + L + B),$$

in the form of both, deposits and reserves. After these payments from workers, firms have $\gamma\mathbb{D}$ in deposits at their banks. Assume these funds are re-shuffled further by introducing a pure liquidity shock ϵ such that the amount

$$F_\epsilon = (\epsilon - 1)\gamma\mathbb{D}$$

is also moved across banks. As with the shock γ, the shock ϵ is identically and independently distributed across nodes with distribution $\Phi_\epsilon(\epsilon)$, mean $E(\epsilon) = 1$, and support $\epsilon \in [0, \epsilon_{max}]$. In summary, each firm ends up the period with $\gamma\mathbb{D}$ in deposits but only $\epsilon\gamma\mathbb{D}$ in the bank who obtained the loan from. The rest of deposits is scattered in accounts in other banks doing business in other nodes.[9]

The total flow of funds for a single bank after these two shocks are realized is then

$$F = F_\gamma + F_\epsilon = \gamma\epsilon\mathbb{D} - D.$$

[9]We could interpret the shock ϵ in a variety of ways. On the one hand, this shock could reflect payment delays or trade credit between firms. On the other hand, firms could have temporary deposit accounts in other banks to manage payments, although they only deal with one bank when they asked for a loan at the beginning of the period.

This flow of funds represents a net transfer of both reserves and deposits between one bank and the rest of banks. Then, bank deposits at the end of the period are

$$D + F = \gamma\epsilon\mathbb{D}.$$

The reserve position of the bank in node j at the end of the period, R, is then equal to the initial reserve, $O + B + A$, plus the net flow of funds, F,

$$R = O + B + A + F = O + B + A + \gamma\epsilon\mathbb{D} - D. \tag{13}$$

Because the realizations of both shocks are specific to each node, the balance sheet of the bank in the same node is as follows

$$R + L = O + \gamma\epsilon\mathbb{D} + K.$$

At this point, it is important to discuss the role reserves play in this economy. At the time banks have to make payments, F, they have to transfer an asset together with the deposits. Absent reserves, these banks only have loans, L. We assume this class of assets is not acceptable as general means to settle debts between banks.[10] Thus, to fulfill these payment flows, banks need a generally accepted means of payment. Central banks offer such service by providing units of account in the form of reserves, the same way private banks offer that service to the nonfinancial sector, i.e., firms and workers.

4.4.2 Interbank market. Banks cannot end up the period with a negative reserve position. To this end, an interbank market opens where banks with reserve deficits ($R < 0$) borrow funds from banks with positive reserve holdings. The interest rate received in this interbank market is i^R. Because there is possibility of default, borrowing banks pay a risk premium of $s(R)$. Notice this risk premium can depend, and, in fact, will depend, on the reserve position of the bank. Using (13), a bank will borrow funds in the interbank market when $R < 0$, or, in other words, when

$$\gamma\epsilon < \frac{D - O - B - A}{\mathbb{D}} = \frac{L + N - O - A}{\mathbb{D}} \equiv \gamma_R. \tag{14}$$

That is, producing more deposits through the provision of loans, has a liquidity cost as it increases the probability of borrowing from the interbank market. This is because it increases the threshold level γ_R. On the other hand, accumulating reserves by borrowing from the

[10] We could think of frictions such as costs to transfer ownership of information sensitive assets such as loans.

central bank, O, reduces that possibility.[11]

4.4.3 Settlement of financial positions. At the beginning of the following period, all financial positions are settled and interest is paid on them. First, interests on the central bank facilities, i^O, are paid if the bank used the lending facility, or received if the deposit facility was used instead. These payments are done in reserves. Then, the balance sheet of the bank at this point is

$$R - (1 + i^O)O + L = \gamma\epsilon\mathbb{D} + (K - i^O O).$$

Next, deposits and loans are settled. For that, the temporary liquidity shock ϵ is reversed as firms collect their deposits to pay back their loans. That is,

$$R - F_\epsilon - (1 + i^O)O + L = \gamma\mathbb{D} + (K - i^O O).$$

Then, each firm starts with deposits $\gamma\mathbb{D}$ and faces the payment of $(1+i^L)L$. Thus, the firms in this location will be able to pay the loan to the bank whenever the realization of the demand shock satisfies

$$\gamma \geq (1 + i^L)\frac{L}{\mathbb{D}} \equiv \gamma_L. \tag{15}$$

Other things equal, higher realizations of the demand shock γ induce larger revenues for firms in the same location which makes it easier for them to repay the loan. The value γ_L provides the threshold value for the demand shock γ that separates banks where firms repay their loans from banks where firms default on their loans. In this sense, assuming a symmetric equilibrium where all agents make similar choices, the non performing loan (NPL) rate for the economy as a whole would be $\Phi_\gamma(\gamma_L)$.[12]

Thus, in the event that firms are able to pay back the loan, so that they receive a realization for γ such that $\gamma \geq \gamma_L$, the beginning of period balance sheet of the bank where these firms are operating would be

$$R - F_\epsilon - (1 + i^O)O = [\gamma\mathbb{D} - (1 + i^L)L] + [K - i^O O + i^L L - \gamma\mathbb{D}].$$

That is, the bank maintains its interbank position, R, yet to be settled, while pays (receives if negative) the cost of borrowing (revenue of depositing) reserves from (at) the central bank, $(1 + i^O)O$. On the liability side, firms keep the remaining deposits after loans are paid off,

[11] Here, we assume by the time the bank realizes it has a reserve deficiency the only margin banks have is to borrow in the interbank market and cannot access the lending facility of the central bank.

[12] Notice that, for an individual bank, either all loans are repaid or, else, all of them are defaulted upon.

$\gamma\mathbb{D} - (1 + i^L)L$. To the initial capital, K, the bank then adds the remuneration of loans and subtract the costs of borrowing from the central bank and its deposits.

On the contrary, if firms' revenues are not enough to cover for the repayment of their loans, so that $\gamma < \gamma_L$, those loans are written off from the balance sheet and represent a loss for the bank. In the context of the current model, this means the beginning of period balance sheet of the bank would now be

$$R - F_\epsilon - (1 + i^O)O = K - i^O O + \gamma\mathbb{D} - L. \tag{16}$$

That is, the bank still pays the cost of reserves from the central bank, $(1 + i^O)O$. However, on the liability side, existing deposits are written off together with the loans of the firms. Whatever loans cannot be recovered with existing firms' deposits is a loss for the bank.

Clearly, firms defaulting on their loans can erase bank's capital. In fact, if banks make enough losses in their loan portfolio they could become insolvent. In other words, a bank will be solvent as long as its capital, as measured by the right hand side of expression (16), is positive. This implies a threshold value for the demand shock γ, call it, γ_K, separating solvent from insolvent banks. That is, the bank will remain solvent as long as

$$\gamma \geq \frac{L - K + i^O O}{\mathbb{D}} \equiv \gamma_K. \tag{17}$$

Notice we evaluate the possibility of insolvency only in the event that firms default on their loans, that is, whenever $\gamma < \gamma_L$. Insolvency in general will not happen otherwise.[13]

We can now understand the role of the liquidity shock ϵ. The shock γ affects the liquidity position of the bank. This is because it determines how much funds enter the bank relative to those funds leaving it. At the same time, it also determines whether the bank is solvent or not as it tells the fraction of loans that are repaid, as summarized by the threshold γ_K. If this was the only shock banks face, their demand for funds in the interbank market would be enough for lenders to know if the borrowing bank is insolvent or not. Thus, the role of ϵ is to detach liquidity positions from solvency issues at the time of trading in the interbank market.

Notably, the correlation between liquidity risk, credit risk, and solvency risk is a maintained feature of the shock structure. The common shock γ simultaneously affects borrowers' repayment capacity, payment flows across banks, and the value of banks' loan portfolios. The idiosyncratic payment shock ϵ prevents liquidity positions from being perfectly pinned down by γ, so liquidity stress is not mechanically identical to credit or solvency risk. The model

[13] Another possibility for banks to be insolvent could be that they borrow large amounts in the interbank market they will not be able to repay later. However, this will never be an optimal choice for banks and we do not consider it.

does not aim to derive the correlation among these risks from deeper primitives. Instead, the paper studies how banks' lending decisions respond when these risks are jointly present and correlated, as is commonly observed during episodes of banking distress.

Finally, there is the settlement of interbank positions, the junior asset in this economy. If the bank was borrowing in the interbank market (so that $R < 0$ because $\epsilon\gamma < \gamma_R$) the bank will pay (if solvent) the amount $[i^R + s(R)]R$.[14] On the other hand, if the bank had an excess of reserves (so that $R > 0$ because $\epsilon\gamma > \gamma_R$) and lends in the interbank market, its revenues will be $i^R R$. The balance sheet of a solvent bank at the end of settlement would then be, if firms pay back their loans ($\gamma \geq \gamma_L$),

$$\begin{aligned} R - F_\epsilon - (1+i^O)O + min[i^R R; (i^R + s(R))R] &= [\gamma\mathbb{D} - (1+i^L)L] \\ + K - i^O O + i^L L - \gamma\mathbb{D} + min[i^R R; (i^R + s(R))R]&. \end{aligned} \tag{18}$$

while if firms default but the bank is still solvent ($\gamma_K \leq \gamma < \gamma_L$),

$$\begin{aligned} R - F_\epsilon - (1+i^O)O + min[i^R R; (i^R + s(R))R] \\ = K - i^O O + \gamma\mathbb{D} - L + min[i^R R; (i^R + s(R))R]. \end{aligned} \tag{19}$$

4.4.4 Choices by banks. For a particular value of γ, call it $\underline{\gamma}$, define the function

$$G(\underline{\gamma}) = \int_{\underline{\gamma}}^{\gamma_{max}} \gamma\Phi_\gamma(d\gamma) - \underline{\gamma}[1 - \Phi(\underline{\gamma})]. \tag{20}$$

Then, as shown in the Appendix, the expected net worth of an individual bank next period equals

$$E(K') = \mathbb{D}\left[G(\gamma_K) - G(\gamma_L)\right] + \Pi(O, L) \tag{21}$$

where

$$\Pi(O, L) = i^R \int_{\gamma_K}^{\gamma_{max}} \int_0^{\epsilon_{max}} R\Phi_\epsilon(d\epsilon)\Phi_\gamma(d\gamma) + \int_{\gamma_K}^{\gamma_{max}} \int_0^{\frac{\gamma_R}{\gamma}} s(R)R\Phi_\epsilon(d\epsilon)\Phi_\gamma(d\gamma) \tag{22}$$

is the net profit of trading in the interbank market. The bank then chooses how much to borrow from, or to deposit to, the central bank, O, and the supply of credit, L, to maximize expected net worth next period (21). Notice, choosing these two variables, together with the idiosyncratic realization of the shocks γ and ϵ, determine the reserve position of the bank, R,

[14] The borrowing bank pays $i^R + s(R)$ because interbank lenders require compensation for counterparty default risk. The spread $s(R)$ is therefore not meant to represent a resource cost that disappears from the closed banking sector, but a risk premium accruing to interbank lenders as compensation for expected losses. Section 5.3 provides the derivation of $s(R)$ and makes explicit its transfer/risk-compensation interpretation.

as defined in (13). The first order conditions with respect to O, and L are, respectively,

$$i^O = i^R + \frac{1}{1-\Phi_\gamma(\gamma_K)} \int_{\gamma_K}^{\gamma_{max}} s(R)\Phi_\epsilon\left(\frac{\gamma_R}{\gamma}\right)\Phi_\gamma(d\gamma), \tag{23}$$

and

$$(1+i^L)[1-\Phi_\gamma(\gamma_L)] = (1+i^O)[1-\Phi_\gamma(\gamma_K)]. \tag{24}$$

Expression (23) relates the pricing of funds in the interbank market, as summarized by the rate i^R and the premium $s(R)$, with the cost of reserves as determined by the central bank, i^O. Although the revenue interbank lenders get is below the official rate, $i^R < i^O$, it can be easily shown that the rate borrowers pay is larger, namely, $i^O < i^R + s(R)$, for all $R < 0$. Below we show how the spread of borrowing banks, $s(R)$ responds to individual bank characteristics. On the other hand, expression (24) defines a loan supply curve. It expresses the amount of loans provided by a bank, L, as a function of the loan rate, i^L, given the policy rate, i^O, and its initial capital, K, as well as aggregate quantities like aggregate deposits, $\mathbb{D}$. The supply of loans equate the expected marginal revenue of lending, expressed by the lending rate, to the marginal expected cost. Since deposits created when lending leave the bank, the relevant cost is associated with the rate to be paid to fund this outflow of funds, i^O. Because of limited liability, both these revenues and costs are multiplied by the probability that firms repay the loan and the probability that the bank remains solvent, respectively.

4.4.5 Liquidity risk, credit risk, solvency risk and lending. At this point we see the model has produced three thresholds for the demand shock γ. These are the value separating liquid and illiquid banks, γ_R,[15] the value determining whether firms pay back their loans or not, γ_L, and the value below which banks become insolvent, γ_K. Larger values for these thresholds increase the liquidity risk, γ_R, the credit risk, γ_L, and the solvency risk, γ_K, of banks. By looking at expressions (14), (15), and (17), we can see that, given initial conditions of the bank as measured by initial assets, A, and liabilities, K and N, as well as the population value of deposits, $\mathbb{D}$, and prices, i^L, and i^O, larger loan production, L, jointly increases all of these risks for a single bank. Because these risks affect the expected profits of the bank, as summarized in (21), they are the endogenous limits to the expansion of the bank's balance sheet through the choice of loans and deposits provision. Furthermore, in general, it will be the case that $\gamma_K < \gamma_L < \gamma_R$. That is, relatively bad realizations of the demand shock first make the bank being illiquid. Worse realizations produce firms to default on their loans and only with very bad draws will the bank become insolvent.

[15] Conditioned on the pure liquidity shock ϵ to be equal to its mean, $E(\epsilon) = 1$.

To understand how these risks affect the lending decision by banks, it is useful to plot the thresholds γ_R, γ_L and γ_K from expressions (14), (15) and (17) in the (γ, ϵ) plane as done in Figure 4. First, expression (14) separates liquid from illiquid banks. It is represented by the decreasing green curve in Figure 4. Banks placed below that schedule will have relatively low realizations of payment shocks γ and ϵ so that they will be iliquid and will be borrowing funds in the interbank market. Banks placed above that schedule will be liquid and lending in that market. Second, expression (15) separates banks with defaulting loans from banks with conforming loans. It is represented by the blue vertical line. Banks whose realization for γ are placed to the left of the line have firms defaulting on their loans while those to the right have firms paying those loans back in full. Finally, expression (17) determines, given the initial situation of the bank and its choices, the level of the shock γ separating solvent and insolvent banks. It is represented as the vertical red line in Figure 4. Banks whose realization for γ are placed to the left of the line are insolvent and those to the right are solvent. In this manner, expressions (14), (15) and (17) divide the population of banks in six groups regarding their liquid/illiquid, performing/non-performing loans and solvency/insolvency situation.

Each of these six areas in Figure 4 contribute differently towards expected profits of the bank. To concentrate on some examples, the area to the left of the threshold γ_K contributes $-K$ since there the bank is insolvent and losses all capital. The area to the right of threshold γ_L and above the locus for γ_R contributes with profits from lending to firms that pay back their loans combined with revenues from lending in the interbank market. Furthermore, to the right of γ_L but below the locus γ_R the bank earns rents from lending to firms but pays the cost of borrowing from other banks. Notice, other things equal, a larger provision of credit, L, pushes expressions (14), (15) and (17) to the right increasing the areas of insolvency, firm defaults and illiquidity. Thus, given market rates, in deciding the optimal amount of lending, the bank compares the change in revenues and costs associated with this decision.

4.5 Consolidation of accounts. The settlement of individual bank and firm positions results in a distribution of net worth of banks, $K(j)'$, and firms, $N(j)'$, across all nodes in the economy. At the beginning of each period, after settling individual positions, investors pool the net worth of the distribution of banks and firms. For the conglomerate of firms, assuming all of them have taken the same decisions through the previous period, consolidating their net worth would imply an aggregate net worth for each investor of

$$\mathcal{N}' = \mathbb{D}G(\gamma_L), \tag{25}$$

Fig01Labels.png

Figure 4: Solvency, Credit, and Liquidity Risks

Notes: The figure summarizes the three endogenous risks generated by the model. For sufficiently low realizations of the shocks, borrowers default and banks are exposed to credit losses. If these losses are large enough to push bank net worth below the solvency threshold, the bank becomes insolvent. Even when the bank remains solvent, it may face liquidity risk if reserve holdings are insufficient to settle net payment outflows.

where the function $G(\gamma)$ was defined in (20). Notice the resulting net worth of the conglomerate of firms is in the form of deposits in all the banks.

Regarding the conglomerate across all banks, the next period consolidated balance sheet would be

$$\mathcal{A}' = \mathcal{N}' + \mathcal{K}' - \mathcal{T}. \tag{26}$$

In this expression

$$\mathcal{A}' = \mathcal{A} + B - i^O O - \mathcal{T}, \tag{27}$$

is the resulting accumulated level of reserves the conglomerate ends up with while

$$\mathcal{K}' = \mathbb{D}\left[G(\gamma_K) - G(\gamma_L)\right], \tag{28}$$

is the resulting accumulated bank capital next period. In these expressions we are using the fact that all firms and banks make the same decisions. Furthermore, $\mathcal{T}$ is lump sum taxes levied on investors' net worth and paid in reserves. Then, expressions (25) and (28) are used to compute the returns to firm funds and bank capital in (5).

The following period, once net worth from banks and firms are accumulated, investors allocate initial assets to each individual firm and bank. Because, ex-ante, all firms and banks are identical, these funds are equally distributed across firms and banks so that firms start next period with $N' = \mathcal{N}'$ and banks start with $K' = \mathcal{K}'$ and the process reproduces itself.

4.6 The government. The government is composed of a central bank and a fiscal authority. The central bank provides or drains reserves, $\mathbb{O}$, in the aggregate, with its two facilities at the rate i^O and monetizes the transfers to workers, $\mathbb{B}$, introduced by the fiscal authority. This fiscal authority also levies lump sum taxes on investors. Assuming a balanced budget, the government budget constraint is then simply

$$\mathbb{A}' = \mathbb{A} + \mathbb{B} - i^O \mathbb{O} - \mathbb{T}. \tag{29}$$

The left hand side represents next period liabilities in the form of reserves. The right hand side includes the initial aggregate liabilities plus aggregate transfers, $\mathbb{B}$, minus the aggregate net revenues arising from banks using the central bank facilities, $\mathbb{O}$, and the aggregate lump sum taxes imposed on the net worth of investors, $\mathbb{T}$. We assume the government treats all investors, workers, and banks equally so $\mathbb{B} = B$ and $\mathbb{T} = \mathcal{T}$.[16] Furthermore, in a symmetric equilibrium, all banks make the same decisions so $\mathbb{O} = O$.

4.7 Discussion. In this economy, each worker contributes to the production of one good but consumes from a different firm in a different node randomly assigned to her. Once all decisions are taken, consumption expenditures by workers are unevenly distributed across nodes. This crucial assumption incorporates the idea that banks are not fully diversified in

[16]The role of the tax-transfer scheme is to redistribute resources across investors and reset asset positions across periods, which keeps the model stationary and avoids introducing wealth distributions as additional state variables. The transfer B affects labor supply through $h^s = 1 - B/W$, so the real effects reported below should be interpreted under this monetary-fiscal closure rather than as a fiscal-neutral monetary-policy experiment.

their credit risks. Because production is predetermined, a larger flow of payments generates larger revenues for the corresponding firms which, in turn, will be able to pay back the loans they asked for before. On top of these payment shocks, labeled γ in the model, we incorporate other, pure liquidity shock, ϵ, to detach the liquidity position of banks from their solvency situation.

In this model, there are five important frictions we assume. First, because of the nature of production and preferences, private IOUs issued by any firm have no market value for other firms in different nodes. This is because the good is perishable and because of the continuum of workers and firms, finding the right person to trade these IOUs with would be impossible. In other words, there is no double coincidence of wants. Banks can represent a cheap and implementable alternative to these markets in firms' IOUs. In this way, banks are in charge of producing the units of account, i.e. deposits, used to keep track of trades among workers and firms. Similarly, the second friction has to do with banks not having assets generally acceptable by other banks at the time payment flows occur. For that problem, the central bank acts as a bank of banks and issue reserves tracking down the net payment flows between banks. What this model exploits is the connection between the production of inside money when producing loans and the risks associated with providing credit to the economy. Furthermore, monetary policy affects this connection by fixing the cost of the outside money needed to settle the corresponding payment flows. The third friction assumes that banks cannot infer credit risks from deposit flows. In other words, they observe the product $\epsilon\gamma$ and not each component separately.

The fourth friction has to do with restricting firms to borrow from only one bank (or a collection of banks) in its very same node. Finally, the fifth friction imposes that neither workers, firms or banks can insure against the idiosyncratic payment shocks occurring at the node level. In this sense, we could generalize the model by allowing firms to borrow from a subset of banks in different nodes or include the possibility of some insurance. We could also complicate the model by adding the possibility that firms and bankers consume too. Or by allowing workers to borrow or save. However, as long as there is no full insurance against payment shocks, agents will need financial liquidity to settle trade positions, there would be payment flows with liquidity, credit, and solvency risks involved, and the results found in this paper would still apply,

Ultimately, the risk firms face in this economy is the inability to attract enough revenue to pay back the loan they asked for. If severe enough, this credit risk can generate insolvency in the banks that created those means of payments in the first place. Notice this is not an issue of asymmetric information between borrowers and lenders but the inability of the existing financial intermediaries to fully insure against the payment risks in the economy. This is the crucial friction behind the results produced with this model.

4.8 Equilibrium. Market clearing conditions are as follows. Market clearing for labor means that

$$h^s = h^d = h \tag{30}$$

for all workers and firms where labor supply is given by (4) and labor demand by (10). Thus, output for every firm is $y = h^\alpha$ and market clearing for goods imply

$$\gamma c(j) = h^\alpha \tag{31}$$

for all $j \in [0, 1]$, where γ is the realization of taste shocks for that particular node. Furthermore, given clearing in the labor market, for the loan market to clear it has to be the case that

$$L^d = Wh - N = L, \tag{32}$$

for all banks. Finally, clearing in the interbank market implies

$$\int_0^1 R(j)dj = 0. \tag{33}$$

We define a symmetric equilibrium as follows. The appendix shows how to compute it.

Definition (Symmetric competitive equilibrium). *Given a monetary policy as defined by the official rate, i^o, and a fiscal policy as defined by equal taxes to all investors, $\mathcal{T} = \mathbb{T}$, and equal transfers to all workers, $B = \mathbb{B}$, a symmetric competitive equilibrium is a set of prices $\{P(j)\}$, for all $j \in [0, 1]$, interest rates, i^L and i^R, risk premia, $s(R)$, aggregate allocations, $\mathbb{O}$, $\mathbb{N}$ and $\mathbb{K}$, as well as individual allocations $\{c(j), h, y, K, N, O, L, R(j)\}$, for all $j \in [0, 1]$ such that, (i) given prices and risk premia, individual allocations solve the problems of all workers, investors, firms and banks, (ii) markets for goods, labor, loans and reserves clear, (iii) individual choices coincide with aggregate ones, and (iv) the government budget constraint is satisfied.*

5 Results

This section takes the theory to the data. We proceed in four steps. First, we calibrate the model to quarterly U.S. data for 1986–2021, disciplining the two shock distributions and the fiscal transfer with three targets, namely, the average TED spread, bank leverage, and the deposits-to-loans ratio. Second, we use the calibrated model to characterize the bank lending channel, both in the long run, across steady states indexed by the policy rate, and along the transition that follows a temporary policy change. Third, we show that the model generates, as untargeted implications of the same mechanism, a risk premium in the interbank market that rises with the amount a bank borrows and falls with its solvency, matching the documented solvency–funding-cost nexus. Fourth, we show that the lending response to a monetary contraction is larger for less-capitalized banks, in line with the cross-sectional evidence on the lending channel, and we trace this heterogeneity to the position of the insolvency threshold in the space of payment shocks.

5.1 Calibration. The solution is neutral with respect to the value of the initial liquid bank assets $\mathbb{A}$. For this reason, we normalize this variable to be $\mathbb{A} = 1$. Then, the model contains only one parameter, two distributions, and two policy variables to calibrate. These are the span of control, α, the distributions of shocks, $\Phi_\gamma(\gamma)$ and $\Phi_\epsilon(\epsilon)$, as well as the policy rate i^O and the transfers from the government, B.

Among the parameters of the model, we set the value of the span of control to $\alpha = 0.85$ as in **?**. The rest of parameters are calibrated using quarterly data for the US between the first quarter of 1986 until the fourth quarter of 2021. This is the period for which we could retrieve data for most of the variables considered. In the baseline, we fix the value for the policy rate, i^O, to be 3 percent which corresponds to the average of the federal funds rate (FFR) over that time period. Furthermore, we assume normal distribution functions for γ and ϵ. We truncate these distributions at 0 but given the means and standard deviations used below, the errors from imposing the truncation as compared with the untruncated densities are insignificant. We fix the means of these distributions to be $\mu_\gamma = \mu_\epsilon = 1$ so that, on average, no funds enter or leave the banks. The standard deviations, σ_γ and σ_ϵ, and the transfer from the government, B, are calibrated to match three targets. One of the targets is the average risk premium in the interbank market as measured by the TED spread, that is, the difference between the 3-month LIBOR and the 3-month T-Bill. In the model this number is approximated by the weighted average risk premia, $s(R)$, where the weights are the fraction of total borrowing by each borrowing bank, which we denote by ρ. We also use quarterly data from the Flow of funds accounts of the US to match two ratios the balance sheet of banks. These two ratios are leverage, L/K, and deposits to loans, D/L.[17]

The matching of the balance sheet of banks in the model and in the data deserves an important comment. Obviously, the balance sheet of banks in the data is a more complex object than in the model. In particular, loans in the model mature in one period while in

[17]The appendix includes information of the data used in the calibration and in the model fit below.

the data there is a whole distribution of loan maturities. Similarly, the bulk of deposits in the model are produced in one period and disappear the following one as they are used to pay for the existing loans. In reality, a large stock of deposits, saved by their owners and not used for transactions, funds a large fraction of the stock of long term loans. In this sense, the model could be interpreted in two ways. The first one, more restrictive, suggests the model is designed to reproduce the dynamics of short term borrowing such as credit card or working capital loans. The second one, more general and preferred to us, is that the model concentrates on the flow of assets and liabilities of banks rather than stocks. In this sense, every period, there is production of loans and there is a fraction of the stock that matures. At the same time, new loans add to the existing stock of deposits, a fraction of which is used to make payments generating revenue for borrowers to pay back their loans. The model is designed to analyze these flows. Of course, the dynamics of the stocks could also be important. But the message of the paper would still go through, at least qualitatively. Larger stocks of loans would generate a larger flow of loan repayments which still have to be covered with revenues obtained by borrowers from the flow of payments using a fraction of the stock of existing deposits.

Table 1 presents the calibration exercise. As the table shows, the calibrated value for the parameters are $\sigma_\gamma = 0.22$, $\sigma_\epsilon = 0.204$, and $B = 0.5$. With these values we closely match the data targets on the TED spread, bank leverage and the ratio of the ratio of deposits to loans. Below these targets we also include comparisons of other variables we have data for. First, the model gets close to the NPL ratio although it falls a little bit short of approximating the fraction of insolvent banks. In the model, these two ratios are measured by the distribution $\Phi_\gamma(\gamma)$ evaluated at the firm default threshold, γ_L, and the bank insolvency threshold, γ_K, respectively. Finally, the model also closely matches the size of the nonfinancial sector as measured by the endogenous variable N.

Figure 5 shows loan supply and demand for the calibrated values of parameters and the equilibrium values for other variables such as the net worth of firms, N, or bank capital, K.[18] We can see how supply is inelastic at the level of the official rate i^O which in this case equals 0.03 (or 3 percent). Also, loan supply is backward bending. Given the capital of the bank, increases in the lending rate i^L raise marginal revenues inducing the bank to lend more. However, more credit provision also increases risks for the bank, as measured by thresholds γ_R, γ_L and γ_K. As this process continues, there is a point where these risks have grown so much that it is not worth it for the bank to increase lending further as a response to larger lending rates. In fact, beyond that point the bank reduces its credit provision for

[18] Please notice lending rates are in the horizontal axis while loan quantities are in the vertical axis.

External parameters					
Param.	Value	Source			
α	0.85	Taken from **?**			
Targeted moments					
Param.	Value	Variable	Meaning	Data	Model
i^O	0.03	i^O	Federal funds rate	0.03	0.03
σ_γ	0.22	L/K	Bank leverage	7.3	7.2
σ_ϵ	0.204	$\int_0^1 \rho \times s(R)dj$	TED spread	0.55	0.55
B	0.5	D/L	Deposits to loans	1.2	1.9
Untargeted moments					
		Variable	Meaning	Data	Model
		$\Phi_\gamma(\gamma_L)$	NPL ratio	0.021	0.023
		$\Phi_\gamma(\gamma_K)$	Insolvent banks	0.013	0.006
		N	Size of nonfinancial sector	0.828	0.792

Table 1: Calibration and model fit

further increases in lending rates. This is the tipping point of the loan supply curve depicted in Figure 5. Notice, unlike models with agency problems, the supply schedule is backward bending despite information being symmetric between borrowers and lenders.[19]

5.2 The lending channel redux. In our model, changes in the policy rate i^O engineered by the central bank have effects in the economy. The transmission mechanism works as follows. As the central bank raises the policy rate, commercial banks find that liquidity is costlier. In terms of Figure 4, the cost associated with the area below the threshold γ_R has increased while revenues stay the same. Thus, profits decrease. Banks respond by cutting on lending. Thus, as the policy rate increases, loan demand stays the same, but loan supply moves to the right (with curves depicted as in Figure 5 where lending rates are in the horizontal axis and quantities in the vertical axis). This is shown in Figure 6 for a change of the policy rate from 3 percent to 4 percent. This increase in lending rates generates a reduction in the amount of lending along the loan demand curve. Because deposit rates are kept constant at zero, the increase in the lending rate caused by the raise in policy rates automatically widens the net interest margin of banks as well as the deposit spread with respect to the official rate.

Figure 7 shows the effect of permanently keeping the official rate at different values between

[19]The loan-supply schedule is concave because the marginal expected return to raising the lending rate declines: higher i^L increases the repayment/solvency cutoffs, generating a more-than-proportional rise in credit and solvency risk. If banks could recapitalise costlessly within the period, they would partly offset the increase in solvency risk, flattening the supply schedule and delaying the point at which it bends backward. The schedule would nevertheless remain concave, and eventually backward-bending, because higher lending rates still worsen borrower repayment probabilities.

Fig1LSLD.png

Figure 5: Loan Supply and Demand

1 percent and 10 percent. The top left Figure shows the spread between the lending rate, i^L, and the policy rate, i^O. We see the lending rate increases with the policy rate, making borrowing costlier for firms. Consequently, if we move to the right and from top to bottom in Figure 7, lending, L, decreases. Deposits, D, also fall. The reason is twofold. On the one hand, the creation of new deposits is smaller because lending has dropped. On the other hand, net worth of firms, N, which are maintained as deposits, also falls. The cut on lending also reduces bank leverage, L/K. The increase in the cost of borrowing together with the financial repression generated by the hikes in official rates, make hiring more expensive which lowers the demand for labor depressing the economy with lower levels of output, y, and prices, W. This downturn is more pronounced the more contractionary monetary policy is. Furthermore, the

Fig4LSLD.png

Figure 6: Effect of an Increase in the Policy Rate on the Lending Market

last panel presents the NPL ratio of banks, $\Phi(\gamma_L)$, as well as the fraction of insolvent banks, $\Phi(\gamma_K)$. Interestingly, looser monetary policy, generated with lower policy rates, induces an increase in risk associated with these two margins. This is what the literature has labeled the risk-taking channel of monetary policy. Importantly, in our economy, ex ante, all borrowers have the same risk. Thus, the larger exposure of banks as a response to monetary policy loosening is not due to banks reaching a pool of riskier borrowers. Instead, this increase in risk is just a consequence of the expansion of credit by banks as the cost of funds decrease. The easing of monetary policy induces banks to expand credit compensating the reduction in costs with larger values for the thresholds γ_K and γ_L.

As Figure 7 shows, in our model, monetary policy has long run effects. That is, the

Equilibrium_4x2.png

Figure 7: Equilibrium Across Policy Rates

economy sits on a different real equilibrium for each particular level of the official rate. Furthermore, in this economy, there are no transitions as we are assuming investors can reallocate funds between firms and banks instantly to equate the return on these investments. This was shown in the fourth panel of Figure 7. As the policy rate increases, the return on investing in bank capital rises above that of initial firm funds. Investors respond to this change by channeling less funds to firms and more to banks.

One way to generate transitions in our model is to shut down the possibility of investors to reallocate funds every period. Instead, assume investors start period 1 with the corresponding split of funds, $1 = N + K$ associated with the baseline policy rate $i_1^O = 0.03$. On period $t = 2$ the official rate is increased to $i_2^O = 0.04$. After that, the official interest rate slowly returns to its initial value of 3 percent assuming a smoothing parameter of $\delta = 0.75$. That is to say, the official rate follows the expression

$$i_t^O = \delta i_{t-1}^O + (1 - \delta) i_1^O,$$

for all $t \geq 3$. As official rates are moving, we do not allow investors to transfer funds between banks and firms but, instead, they just accumulate funds in each investment from profits separately.

Figure 8 traces the transition. The top left panel shows the exogenous path followed by the official rate, i_t^O, which jumps by 100 basis points in period two and reverts geometrically to its initial 3 percent. The top right panel, which shows the equilibrium lending rate, i_t^L, inherits this path almost one-for-one, so the policy impulse is passed through to the price of credit on impact and unwound gradually as the official rate returns to its original level. The two panels in the second row display the evolution of firm funds, N_t and bank capital, K_t, respectively, as proportions of the steady state associated with the initial official rate, $i_1^O = 0.03$. Because a higher policy rate raises the marginal cost of settling the deposits that loans create, intermediation becomes more profitable at the margin for banks and more expensive for firms. Bank capital rises by roughly nine percent above its initial steady state while firm internal funds fall by about two and a half percent, with both series returning to their starting values as rates normalize. This is the general equilibrium counterpart, in the time domain, of the cross-steady-state reallocation of investor wealth toward banks documented in Figure 7. The real and nominal consequences are shown in the remaining panels. The rise in the lending rate contracts credit on impact—lending falls by close to six percent—which, by reducing the demand for labor, depresses output and pushes down prices. The recession is persistent, with output and prices recovering only as fast as the policy rate itself mean-reverts, so a transitory monetary impulse produces a prolonged real downturn. This persistence is the transitional

Transitions_4x2.png

Figure 8: Transition from a Temporary Increase in the Policy Rate

analog of the long-term real effects in Figure 7 and is consistent with the evidence in **?** that monetary policy has long lasting effects on real activity.

Two features of the transition deserve some words because they are not assumed but emerge from the mechanism. First, deposits, which are equal to the sum of lending and firm net worth, D = L + N, fall throughout the episode, since both components decline, and they fall at the same time as the spread of the deposit rate over the policy rate widens. Notice that the deposit rate is fixed at zero while the official rate has risen. This is precisely the joint movement that **?** identify as the as the deposit channel of the monetary policy. In our economy, however, the direction of causation is reversed since deposits fall because banks cut the supply of loans in response to a costlier liquidity environment, not because a deposit outflow forces banks to retrench. The same observable correlation is therefore consistent with a mechanism in which credit drives deposits rather than the reverse. Second, the rise in bank capital combined with the fall in lending drives bank leverage down during the episode (bottom right), so that the model delivers a countercyclical-leverage response to a contractionary shock without any leverage constraint or capital regulation. Taken together, the transition shows that a single, transitory disturbance to the cost of liquidity generates movements in credit, deposits, spreads, output, prices, and leverage.

5.3 Risk premium in the interbank market. **?**, **?**, **?** and **?** present evidence on how solvency ratios are negatively related to bank funding costs. These authors notice that this negative relationship is stronger for funding sources more sensitive to market pressure, such as interbank lending. For example, **?** estimated that a 1 percent reduction in the level of solvency is associated with a significant increase of 4 basis points in wholesale funding costs. Interestingly, they also note that bank's liquidity position negatively affects funding costs, a result also found in **?**.

To understand the determination of the risk premium borrowing banks have to pay in the interbank market, $s(R)$, it is useful to plot the combination of realizations for the shocks γ and ϵ generating a particular reserve position. Using expression (13), a bank with a given initial state and decisions on endogenous variables would end up with a specific reserve position, call it $\bar{R}$, if the realizations of the shocks fulfill the expression

$$\gamma\epsilon = \frac{\bar{R} + D - O - A - B}{\mathbb{D}} = \frac{\bar{R}}{\mathbb{D}} + \gamma_R. \tag{34}$$

Figure 9 includes two of such schedules for two different negative levels for the reserve position of a bank, $\bar{R}_{low}$ and $\bar{R}_{high}$, such that $\left|\bar{R}_{low}\right| < \left|\bar{R}_{high}\right|$. Notice the schedule with the largest borrowing, $\bar{R}_{high}$, is below the one with banks borrowing less, $\bar{R}_{low}$. Furthermore, the section of these schedules in the region to the left of the vertical line associated with the value for γ_K, represent realizations of the shocks inducing the bank to be insolvent and, therefore, will imply a default on the interbank loan.

Then, the question for an interbank lender is: given the balance sheet of a borrowing bank (which is public information), what would be the likelihood that an interbank loan of size $\bar{R}$ will get repaid.[20] This will happen whenever the realization of the γ shock is above the

[20] Observing $\bar{R}$ reveals the interbank position of the borrowing bank, but not the separate realizations of ϵ and γ that generated it. Conditioning on $\bar{R}$ pins down the product $\epsilon\gamma$, but not its individual components. Hence, the event $\gamma \geq \gamma_K$ conditional on $\bar{R}$ can be equivalently written as a restriction on ϵ conditional on $\bar{R}$.

Fig06.png

Figure 9: Solvency Risk Across Reserve Positions

Notes: The red vertical line denotes the solvency threshold from equation (17) and the black curve denotes the liquidity cutoff from equation (14). The red segment illustrates the insolvency region from equation (35). Lower demand for reserves in the interbank market shifts this cutoff outward.

solvency threshold, γ_K, namely

$$prob\left(\gamma \geq \gamma_K | \bar{R}\right) = prob\left[\epsilon \leq \frac{1}{\gamma_K}\left(\frac{\bar{R}}{\mathbb{D}} + \gamma_R\right)\middle| \bar{R}\right] = \Phi_{\epsilon|\bar{R}}\left[\frac{1}{\gamma_K}\left(\frac{\bar{R}}{\mathbb{D}} + \gamma_R\right)\right], \qquad (35)$$

where this expression uses (34). Because the lending bank wants to receive the rate i^R in all its lending, it must be the case that, for banks borrowing a particular amount $\bar{R}$, the risk premium charged must satisfy

$$1+i^R = \left[1+i^R+s(\bar{R})\right] \times \Phi_\epsilon\left[\frac{1}{\gamma_K}\left(\frac{\bar{R}}{\mathbb{D}}+\gamma_R\right)\right]$$

or

$$s(\bar{R}) = (1+i^R)\frac{1-\Phi_\epsilon\left[\frac{1}{\gamma_K}\left(\frac{\bar{R}}{\mathbb{D}}+\gamma_R\right)\right]}{\Phi_\epsilon\left[\frac{1}{\gamma_K}\left(\frac{\bar{R}}{\mathbb{D}}+\gamma_R\right)\right]}. \tag{36}$$

Grafically, the risk premium is proportional to the density associated with the segment of schedule (34) inside the insolvency area, that is, to the left of the level γ_K. That segment is marked in red in Figure 9. As the amount borrowed gets larger, the schedule moves down and the segment representing insolvency gets larger increasing the risk premium the bank needs to pay. In other words, because banks in the market cannot differentiate between pure liquidity (ϵ) and liquidity/solvency (γ) shocks at the time they reach the interbank market, they assign a higher probability of default to those banks borrowing more wholesale funds and, therefore, a larger risk premium. Similarly, other things equal, a bank with lower capital levels will face a higher threshold for solvency, γ_K. As a consequence, there is pressure for the risk premium, $s(R)$, to be larger too.[21]

Figure 10 presents the spread over the interbank rate borrowing banks have to pay as a function of the amount they borrow. In particular, it shows the term

$$\frac{1-\Phi_\epsilon\left[\frac{1}{\gamma_K}\left(\gamma_R+\frac{R}{\mathbb{D}}\right)\right]}{\Phi_\epsilon\left[\frac{1}{\gamma_K}\left(\gamma_R+\frac{R}{\mathbb{D}}\right)\right]}$$

in (36) for different negative values of the reserve position R. These are the positions forcing banks to borrow in the interbank market. All computations are done assuming a policy rate of 3 percent. As banks borrow more, the spread they have to pay over the interbank rate increases going from a few basis points to a maximum of 1.6 percent for very large demands of reserves. We also observe how this relation is nonlinear with spreads being proportionally larger the more the bank borrows as this is a signal of higher probability of insolvency.

5.4 Balance sheet strength and the effects of monetary policy. Finally, **?**, **?**, **?**, **?**, **?**, **??**, or **?**) study how the response of banks to changes in monetary policy depends on cross-sectional differences in their balance sheets. In particular, these papers suggest that banks cut back more on their lending in response to a contractionary monetary policy shock

[21] Of course, endogenous variables will not be equal for two banks with different initial capital levels so the overall effect on the spread will depend on endogenous choices of banks.

FigsR.png

Figure 10: Risk Premium in the Interbank Market

when they are less capitalized and/or more illiquid. For example, **?** uses data for Italian banks and estimates a statistically significant drop in lending of 0.825 percent in response to a 1 percent increase in the policy rate. This drop in lending varies across the capitalization level of the bank. The average decrease is 0.622 percent for well capitalized banks while it is 0.976 percent for poorly capitalized banks. These effects remain statistically significant after the introduction of further controls and changes in the sample.

Figure 11 shows the percentage change drop in lending of an individual bank in response to an increase in the official rate i^O from 3 percent to 4 percent as a function of its capital. To produce that Figure we keep aggregate variables at the equilibrium levels and solve individual problems of banks imposing different capital levels ranging from 0.1 until 0.9. We see how the drop in lending in response to the increase in official rates is monotonically larger as banks maintain lower capital levels.

To understand this effect, notice that, other things equal, schedules γ_R and γ_L are the same for both banks, but the locus γ_K is to the left for the bank with more capital. Because the area to the left of γ_K is larger for the least capitalized bank, its supply of lending is more sensitive to increases in the cost of liquidity as summarized by the risk premium this less capitalized bank has to pay for borrowing in the interbank market. Thus, increases in the

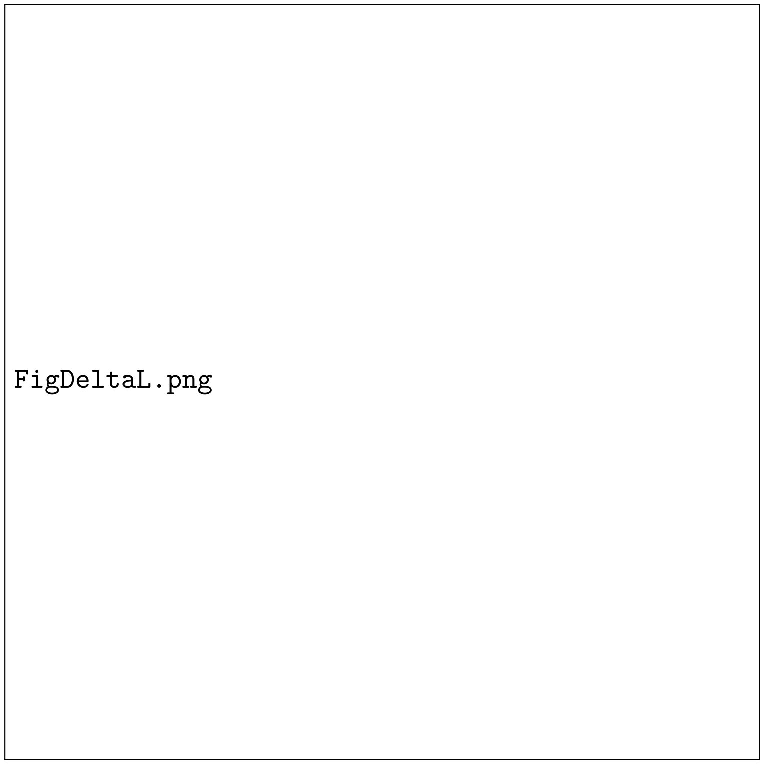


Figure 11: Changes in Lending Across Capital Levels

cost of liquidity generated exogenously by a contractionary monetary policy will have a larger effect on lending for banks with a smaller capital position.

6 Conclusions

We have constructed a model where banks endogenously decide the size of their balance sheet by providing loans to firms. In the process of providing these loans, banks also create the means of payment (deposits) that the economy uses for transactions. This process of autonomous deposit and credit creation exposes banks to liquidity, credit and solvency risks that, in turn, endogenously limit their willingness to expand their balance sheets, as these risks affect profitability. First, deposits created when loans are issued typically leave the originating bank, generating liquidity risk as reserves must be transferred to other banks to settle the transaction. Second, for borrowers to repay their loan, they must attract enough deposits by selling their output. Thus, as a bank individually increases lending, borrowers' repayment burden rises, thereby increasing credit risk. Finally, as non-performing loans rises, banks face solvency risks since loan losses leads to a reduction in bank capital.

We have shown how changes in the monetary policy stance transmit to the real economy by altering the relationship between bank risk exposures and credit provision. As monetary policy gets tighter, the cost of liquidity increases, raising the potential costs banks face when liquidity risks materialize. In response, banks increase lending rates and reduce the supply of credit and consequently the production of deposits generating a contraction in the economy. This process generates data similar to the so-called deposit channel of monetary policy but with the causality going in the opposite direction, namely, from lending to deposits.

This mechanism linking bank risks to credit provision also delivers two other empirical facts that, to the best of our knowledge, had not previously been jointly addressed in the literature. These are: (1) heterogeneous lending responses to monetary policy shocks depending on banks' capital and liquidity positions, and (2) higher wholesale funding costs for banks perceived to have weaker solvency positions. Our model provides a unified explanation for these empirical observations.

Although we do not introduce regulation explicitly, the model could also offer new insights for the design of prudential and supervisory frameworks. Currently, these frameworks design liquidity and solvency regulations in isolation. Our model demonstrates an endogenous link between liquidity and solvency risk, both of which stem from banks' lending decisions. Thus, larger liquidity needs would signal solvency distress. The interaction between these two risks and their implications for financial stability have been empirically examined by, among others, **?**, **?**, and **?**. This situation would suggest that designing prudential tools that target solvency and liquidity separately could reduce their effectiveness. As **?** pointed out a "more interesting approach would be to tie liquidity and capital standards together by requiring higher levels of capital for large firms unless their liquidity position is substantially stronger than minimum requirements. [...] While there is decidedly a need for solid minimum requirements for both capital and liquidity, the relationship between the two also matters. Where a firm has little need of short-term funding to maintain its ongoing business, it is less susceptible to runs. Where, on the other hand, a firm is significantly dependent on such funding, it may need considerable common equity capital to convince market actors that it is indeed solvent." These connections between solvency and liquidity risk have also induced a discussion to design joint stress tests (see, among others, **?**, **?**, **?**). We leave the design and evaluation of such integrated regulatory frameworks for future research.

A Derivation of (21) and (22)

According to expressions (18) and (19), we can express the expected value of next period's bank net worth as

$$
\begin{aligned}
E(K') &= \int_{\gamma_K}^{\gamma_{\max}} \int_0^{\epsilon_{\max}} K' \Phi_\epsilon(d\epsilon)\Phi_\gamma(d\gamma) \\
&= \int_{\gamma_K}^{\gamma_L} \int_0^{\gamma_R/\gamma} \left[K - i^O O + \gamma\mathbb{D} - L + (i^R + s(R))R\right] \Phi_\epsilon(d\epsilon)\Phi_\gamma(d\gamma) \\
&+ \int_{\gamma_K}^{\gamma_L} \int_{\gamma_R/\gamma}^{\epsilon_{\max}} \left[K - i^O O + \gamma\mathbb{D} - L + i^R R\right] \Phi_\epsilon(d\epsilon)\Phi_\gamma(d\gamma) \\
&+ \int_{\gamma_L}^{\gamma_{\max}} \int_0^{\gamma_R/\gamma} \left[K - i^O O + i^L L - i^D \gamma\mathbb{D} + (i^R + s(R))R\right] \Phi_\epsilon(d\epsilon)\Phi_\gamma(d\gamma) \\
&+ \int_{\gamma_L}^{\gamma_{\max}} \int_{\gamma_R/\gamma}^{\epsilon_{\max}} \left[K - i^O O + i^L L - i^D \gamma\mathbb{D} + i^R R\right] \Phi_\epsilon(d\epsilon)\Phi_\gamma(d\gamma),
\end{aligned}
$$

where the interbank rate charged or received depends on whether reserves are positive, so that $\epsilon < \gamma_R/\gamma$ or negative, so that $\epsilon > \gamma_R/\gamma$. Applying the definition of γ_K and γ_L yields (21) and (22).

B Computation of equilibrium

Using the market clearing condition for the interbank market (33) together with the expression for reserves (13)

$$
\int_0^1 R(j)dj = \int_0^1 (O(j) + A + B + \gamma\epsilon\mathbb{D} - D(j))dj = 0
$$

Because the interbank market involves the continuum of banks $j \in [0, 1]$, it spans the whole distribution of shocks γ and ϵ. With shocks normalized so that their aggregate mean is one, aggregate interbank-market clearing implies

$$
O(j) = -(A + B). \tag{A.1}
$$

As payment shocks are symmetric and banks expect a zero net reserve position at the end of the period, banks do not need to hold reserves in the symmetric equilibirum. At the initial open market operation, the central bank therefore drains the reserves previously injected with the transfer, B. Imposing symmetry, so that all banks make the same ex ante decisions and $D(j) = D = \mathbb{D}$, the liquidity threshold becomes

$$
\gamma_R = \frac{D}{\mathbb{D}} = 1, \tag{A.2}
$$

This condition characterizes the symmetric-equilibrium benchmark after aggregate clearing has been imposed.[22]

From the market clearing condition for goods (31) together with the market clearing in the labor market (30), and the choice of consumption by the worker, prices are

$$P(\gamma) = \gamma \frac{Wh + B}{h^{\alpha}}. \tag{A.3}$$

Then, plugging this expression in the definition for the break even price P_L, (8) produces the threshold value γ_L^d for firms

$$\gamma_L^d = (1 + i^L)\frac{Wh - N}{Wh + B}. \tag{A.4}$$

This threshold together with the demand for labor (10) determine the wage rate as

$$\frac{\alpha}{1 - \Phi_{\gamma}(\gamma_L^d)} \int_{\gamma_L^d}^{\gamma_{max}} \gamma \Phi_{\gamma}(d\gamma) = (1 + i^L)\frac{Wh}{Wh + B} \tag{A.5}$$

which implies a demand for credit of

$$L^d = Wh - N. \tag{A.6}$$

On the other hand, the loan supply of banks is

$$(1 + i^L)[1 - \Phi(\gamma_L^s)] = (1 + i^O)[1 - \Phi(\gamma_K)] \tag{A.7}$$

where the thresholds for banks are

$$\gamma_L^s = (1 + i^L)\frac{L}{\mathbb{D}}, \tag{A.8}$$

and

$$\gamma_K = \frac{L - K + i^O(A + B)}{\mathbb{D}}. \tag{A.9}$$

Of course in equilibrium it must be the case that $\gamma_L^d = \gamma_L^s = \gamma_L$ for all banks and firms in the economy.

One additional item has to do with default in the interbank market. In this model, banks have three types of liabilities, borrowing from the central bank, deposits, and borrowing from

[22]Equation (A.2) should not be interpreted as saying that each individual bank has a non-stochastic liquidity position ex post. Individual banks choose their balance sheets before the realization of ϵ and γ. After shocks are realized, a bank's reserve position is determined by the comparison between the realized product $\epsilon\gamma$ and the cutoff γ_R. Thus, aggregate interbank positions clear in the cross section, but individual bank-level liquidity positions remain stochastic. The condition $\gamma_R = 1$ follows from imposing symmetry and the normalization of aggregate shocks in equilibrium; it does not imply that $\epsilon\gamma = 1$ for every bank or state.

the interbank market, for those banks with negative reserve positions at the end of the period. Banks solvency issues potentially affect depositors and interbank lenders. However, a bank defaults because its firm clients (the ultimate depositors at the time solvency risks materialize) default themselves on the loans. Thus, depositors cannot be the residual claimants of the assets of the banks and there is no need for a deposit insurance scheme. Then, the ultimate residual claimants on banks are interbank lenders which impute a risk premium to lending as interbank loans are unsecured.

Finally, using the government budget constraint, (29), and the equilibrium in the interbank market, (A.1), lump sum taxes to compensate for the accumulation of reserves by investors should satisfy

$$\mathbb{T} = i^O \mathbb{A} + (1 + i^O)\mathbb{B}. \tag{A.10}$$

Because of the design of taxes and the symmetry of the solution, the equilibrium of this economy implies that, for a given level of the policy rate, i^O and fiscal transfers, B, aggregate assets $\mathbb{A}$ are constant over time, namely, $\mathbb{A} = \mathbb{A}'$. This also means that the split between funds going to firms, N, and banks, K, is also constant but could differ for each monetary policy stance or fiscal transfer.

C Data sources

Computations for the calibration in table 1 are as follows. We compute averages with quarterly data from the first quarter of 1986 until the fourth quarter of 2021. This is the period we have data for most of the following variables. For variables with a higher frequency we produce quarterly data by averaging over the corresponding quarter.

1. The TED rate approximates the risk premium in the interbank market and is obtained from the FRED database of the Federal Reserve Bank of St.Louis (with acronym TEDRATE). This is a series starts on January 1986 and was discontinued in January 2022.

2. Data for the federal funds rate is taken from the Effective federal funds rate series from the FRED database of the Federal Reserve Bank of St.Louis (FEDFUNDS).

3. Data on loans, deposits and capital to compute bank leverage and the deposits to loans ratio use table L111 of the Financial accounts of the United States (Z.1). Loans (L) are measured as Loans in that table (FL764023005). Deposits (D) is the sum of Checkable deposits (FL763127005) and Time and savings deposits (FL763130005). Capital (K) is represented by Total equity (FL763181105).

4. For the NPL ratio, we use Nonperforming Loans (past due 90+ days plus nonaccrual) to Total Loans for all U.S. Banks from the FRED database (acronym USNPTL). This series was discontinued on July 2020. In table 1 we include the average from January 1986 until that date.

5. For the fraction of insolvent banks, we looked at the Bank Failures and Assitant Data section of the BankFind Suite data application of the FDIC. For each year between 1986 and 2021 we manually downloaded data on the balance sheet of failed banks. The number in table 1 corresponds to the ratio of the deposits of these failed banks over total deposits of depository institutions obtained from table L111 of the Financial accounts of the United States (Z.1).

6. Finally, the size of the real sector is approximated as the ratio of equity of Nonfinancial business to the sum of equity of Nonfinancial business plus equity of the Financial sector. For Nonfinacial business we use table L102 of Financial accounts of the United States (Z.1), column FL143181105. For the Financial sector we use equity of the Domestic financial sector (table L108 column FL793181105) minus equity of the Monetary authority (table L109, column FL713164005).