Endogenous bank risks and the lending channel of monetary policy*

Gabriela Araujo
Universitat Autonoma de Barcelona
and Barcelona School of Economics

David Rivero-Leiva
Universidad de Navarra

Hugo Rodríguez Mendizábal
Instituto de Análisis Económico (CSIC)
and Barcelona School of Economics

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Abstract

This paper develops a general equilibrium banking model where credit creation and payment flows endogenously link credit, liquidity, and solvency risks. Banks issue deposits at loan origination. As deposits circulate, reserve settlement creates liquidity exposure and repayment shortfalls generate credit and solvency risk. These risks are jointly determined by credit provision and bound balance sheet expansion at an internally determined profitability threshold rather than an external funding or capital limit. We present an application of the theory that provides a new look to the bank lending channel where monetary policy operates through the pricing of bank liabilities, compressing margins and curbing credit. Our quantitative results align with empirical observations, including co-movement of policy rates with deposit spreads and net interest margins and a decline in deposit growth after tightening. The mechanism speaks to policy: calibrating liquidity and capital tools in isolation can blunt their effectiveness.

Keywords: Monetary policy; banks; payments; liquidity risk; credit risk; solvency risk; risk premium; interbank market.
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1 Introduction

A clear understanding of the risk exposures linking loan assets and liabilities is essential for addressing the determinants of bank failures. Episodes such as the Global Financial Crisis of 2007 and the 2023 US regional bank failures suggest that liquidity strains, credit losses, and solvency concerns are interconnected and rarely arrive alone, yet most models treat these channels separately or impose external balance sheet constraints. On one hand, macroeconomic models following the tradition of the New Keynesian framework (Woodford [2003]; Smets and Wouters [2007]; Gali [2015]) present difficulties to represent a coherent role for money and banking.[1] On the other hand, the tradition of banking models have been the study of bank risks to explain turmoils in terms of runs among depositors (Diamond and Dybvig [1983]; Goldstein and Pauzner [2005]) or poor fundamentals (Gorton [1988]; Calomiris and Mason [2003]), but without considering liquidity-insolvency issues as terms of the same coin. At policy level, this distinction is important for the design of stress tests and resolution mechanisms because it is hard to identify, even ex-post, whether a bank failure is illiquid-based or insolvency-based. Empirical evidence by Correia et al. [2025] suggests that, across the period 1863-2024, US commercial failing banks commonly occurred over several years because of insolvency and funding vulnerability. This gradual deterioration in bank fundamentals challenges the endogenous evaluation of bank risk exposures and calls for conceptual frameworks addressing the joint determination between illiquidity and insolvency.

We propose a tractable general equilibrium model of banking that is consistent with the dynamic flows of deposits. In the model, commitment problems between workers and entrepreneurs prevent individual IOUs to circulate as means of payment for retail transactions. Banks arise to solve this friction by creating demand deposits at the moment loans are extended. This way, when a non-financial agent demands a resource but does not have the means of payment to acquire it, a bank creates a transferable private IOU in the form of deposits. Credit provision expands bank's balance sheet by crediting the entrepreneur's deposit account. When entrepreneurs hire workers in advance to produce, these deposits are transferred to workers, who receive their earned wages in the form of deposits at the local bank and then spend these resources buying goods from all entrepreneurs in the economy. These expenses allow borrowers to get back the means of payment they need to repay the loans they obtained previously.

A novel feature of our analysis is the endogenous connection of bank risk exposures through

[1] Chari et al. [2009] conclude that New Keynesian models are not well motivated by microeconomic facts and are not useful for policy analysis. Of course, some macroeconomic frameworks are an exception in this regard, such as [Kiyotaki and Moore, 1997]; [Kiyotaki and Moore, 2002]; [Gertler and Kiyotaki, 2010]; or [Gertler and Kiyotaki, 2015].

the payment system. As demand deposits circulate, payment flows between banks expose them to liquidity risk—the need to obtain reserves in the interbank market to settle net outflows. Likewise, deposits are destroyed when used to pay for the loan which created them in the first place.[2] This way, the same deposit flows generate credit risk since borrowers must receive sufficient liquidity to repay their loans. Furthermore, if the payment flows in the economy are such that enough borrowers cannot pay back their loans, banks could fail. Therefore, payment flows are also behind solvency risk faced by banks.

Although in the model there are no exogenous restrictions to bank's balance sheet growth, there exist endogenous limits associated with how expanding the balance sheet of a bank impact risk exposures. We show how payment-flow induced reserve needs, together with credit and solvency risk, endogenously shape bank profitability and loan supply. As a result, there is an optimal level of credit provision for a bank, which maximizes expected profits. Bank capital is relevant in this process of credit provision as it affects this connection between loan provision and bank risks. We believe understanding the nexus of loan provision with bank risk exposures is paramount as these risks, namely, liquidity, credit, and solvency risks, are the main concerns banks have to face in their business, in particular, regarding their decisions to expand or contract their balance sheets.

We present an application of the theory that provides a new view of the bank lending channel where monetary policy affects credit supply through its impact on the cost of bank liabilities and the expected returns to intermediation. A contractionary policy increases the cost of reserves and wholesale funding, reducing banks' net interest margins and thereby lowering the profitability of additional lending. Conversely, an expansionary stance increases margins and induces banks to leverage more, even as liquidity and solvency risks rise. The lending limit is therefore not imposed by exogenous balance sheet constraints but arises from the trade-off between profitability and risk. This mechanism complements deposit-driven narratives by operating through the pricing of liabilities and the endogenous exposure to liquidity and solvency risks. And, a key advantage is that it disciplines the quantitative response of credit supply to policy by linking it to observable margins (funding costs, deposit spreads, and measured capital and liquidity buffers) without invoking market power, sticky prices, or ad hoc constraints.

Quantitatively, we calibrate the model to bank-level data and show that it can reproduce several empirical facts within a unified and internally consistent framework. The model matches (1) the positive relationship between the policy rate, the deposit spread, and the net

[2] We could incorporate other forms of deposit destruction such as currency withdrawal, or conversion in other bank or liability. These other ways to eliminate deposits complicate the model without adding other insights to our mechanism.

interest margin [Borio et al., 2017, Claessens et al., 2018]; (2) the negative response of deposit growth to policy tightening [Drechsler et al., 2017]; (3) heterogeneous lending responses to monetary shocks depending on banks' capital and liquidity positions [Altunbaş et al., 2002, Ehrmann et al., 2001, Gambacorta, 2005, Gambacorta and Mistrulli, 2004, Kashyap and Stein, 1995, Kishan and Opiela, 2000, 2006, van den Heuvel, 2002]; and (4) the rise in wholesale funding costs for banks perceived as riskier [Arnould et al., 2022, Aymanns et al., 2016, Carvalho et al., 2022, Schmitz et al., 2017]. These moments are untargeted and emerge from the mechanism. Capturing these patterns simultaneously within one parsimonious model underscores the explanatory strength and coherence of the proposed mechanism.

The model also offers new insights for the design of prudential and supervisory frameworks. Because credit creation simultaneously generates liquidity and solvency risk, prudential tools that target them separately—such as the Liquidity Coverage Ratio (LCR) and the Basel III leverage ratio—can interact in ways that blunt their effectiveness. Raising the LCR increases the share of low-yield liquid assets on bank balance sheets. For a given loan book, this compresses margins and slows internal capital accumulation, which can raise effective solvency exposure even as liquidity coverage improves. Although we do not model regulation explicitly, this suggests that calibrating liquidity and capital requirements in isolation may blunt their effectiveness. Coordinated calibration can better align incentives with the joint liquidity and solvency risks that accompany credit creation.

The analysis is conducted in a perfectly competitive environment with symmetric information and flexible prices. And, results arise from the internal interaction of risks rather than market power, agency frictions, or nominal rigidities. By integrating credit, liquidity, and solvency considerations into a single theoretical structure, the model provides a tractable baseline to study how monetary conditions shape bank behaviour, credit supply, and policy transmission.

The remaining of the paper is as follows. The remainder of the paper proceeds as follows. Section 2 discusses related literature. Section 3 presents the model and equilibrium. Section 4 describes the quantitative implementation and calibration. Section 5 reports results and policy implications. Section 6 concludes.

2 Related literature

The paper is related to banking studies that have explored the roots of risk exposures. Diamond and Dybvig [1983] explain the self-fulfilling component of liquidity risk as a cause for runs even for solvent banks. Goldstein and Pauzner [2005] provide a central role to solvency concerns as fundamental factor explaining coordination failures. While this bank-run view puts the focus on the liability side of bank's balance sheet due to the runable nature of demand deposits, the fundamental view of banking crises, in contrast, emphasizes the fall in asset value as the main determinant of bank failures independently of the occurrence of runs (Gorton [1988]).

The closest papers to us are those that have assessed the nexus of risk exposures through the asset and liability structure of bank balance sheets. He and Xiong [2012] identify the dependence on short-term debt structures as the element connecting liquidity and credit risk. Imbierowicz and Rauch [2014] point out the relationship between liquidity and credit risk as fundamental cause that aggravates bank default for US commercial banks. Morris and Shin [2016] use global game methods to decompose credit risk into insolvency and illiquidity risk and show how both are jointly determined as a function of the balance sheet. We contribute to this literature by showing the interrelation between bank risk exposures through its connection with the payment system. A novel feature of our mechanism is that credit provision and deposit flows create spillover effects that endogenously connect liquidity, credit and solvency risks altogether. We show, in a frictionless setting, how a simple initial taste shock might serve to deteriorate economic conditions, provoking credit risk realization when deposits do not flow back to borrowers, and leading to solvency risk that boosts the cost for wholesale funding in the interbank market. This endogenous connection among bank risk exposures allows us to characterize the gradual deterioration of bank fundamentals empirically identified in Correia et al. [2025].

Our paper also relates to the literature on endogenous risk and financial amplification in banking. Models such as Brunnermeier and Sannikov [2014] and He and Krishnamurthy [2013] 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 friction that generates it. In our model, risk arises not from agency problems or market power but from the internal consistency of payment flows and balance sheet composition. This friction, rooted in the need to settle payments using reserves, links banks' liquidity exposure to their solvency and credit risks, giving rise to an endogenous mechanism that constrains or amplifies lending depending on policy and financial conditions.

Our paper is also related to the strand of literature that studies banks' liquidity management and the role of reserves and interbank markets in transmitting monetary policy. Early analyses by Poole [1968], Ennis and Keister [2008], and Bech and Klee [2011] describe how the demand for reserves and the implementation of interest-rate policy depend on banks' payment needs. More recent work, such as Afonso et al. [2019] and Di Tella and Kurlat [2021], 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 reserve demand and interbank settlement as endogenous outcomes of banks' lending and payment activity. In the model, when banks experience a net payment outflow, they must obtain reserves in the interbank market to settle these payments. Interbank borrowing interacts with existing credit and liquidity risks by affecting banks' funding costs and profitability. Through this channel, payment flows and reserve needs transmit changes in interest rates to banks' credit supply decisions, linking the functioning of the interbank market directly to the monetary policy transmission process.

Our work is connected to the macroeconomic literature on money and the role of payments as well. Following foundational models of money in general equilibrium that formalize the role of money as a medium of exchange and a transaction-enabling friction [e.g. Friedman, 1969, Kiyotaki and Moore, 1997, Lagos and Wright, 2005], more recent research has emphasized the importance of bank-created money as both a means of payment and a source of financial frictions. Studies such as Disyatat [2011], McLeay et al. [2014], and Jakab and Kumhof [2018] describe the process of endogenous money creation, in which lending simultaneously generates deposits used for payments. 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 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 Bianchi and Bigio [2022] and Di Tella and Kurlat [2021] analyze individual risk margins but do not integrate the credit-liquidity-solvency triad in a single coherent structure. Our framework fills this gap by linking internal bank-level risk interactions to aggregate monetary outcomes.

Furthermore, dynamic banking models like Bolton et al. [2025] also underscore the value of deposit flows as lending constraint. Our contribution is to explicitly link payment flows to the joint determination of credit, liquidity, and solvency risk and to show how these interactions govern banks' optimal lending and the transmission of monetary policy to the real economy.

Finally, our paper relates to the strand of the literature emphasizing how changes in policy rates affect banks' willingness and ability to lend. Early contributions, such as Bernanke and Blinder [1988] and Kashyap and Stein [2000], 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. Adrian and Shin, 2010, Bianchi and Bigio, 2022, Bolton et al., 2025, Diamond and Kashyap, 2016, Heider et al., 2015, Van den Heuvel, 2008]. In contrast, the key friction 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 internal trade-off: expanding credit increases expected profits but also raises their exposure to these interrelated risks. Monetary policy therefore operates by influencing the cost of intermediation and the balance between profitability and risk, rather than by relaxing or tightening exogenous constraints. This mechanism is related to the illiquidity and solvency problems studied in classic models of banking, but our contribution is to bring these insights into a general-equilibrium setting where liquidity, solvency, and credit risks co-evolve endogenously and jointly shape banks' credit supply and the transmission of policy to the real economy.

Our results relate to the deposit channel in Drechsler et al. [2017]. Their paper empirically shows that, when the federal funds rate rises, banks widen deposit spreads and cut lending as deposits flow to higher-yield alternatives. Our perfectly competitive framework reproduces these facts without market power, casting doubt on that mechanism as the channel's driver. In our model, falling deposits are a by-product, not the cause, of reduced intermediation: because banks create deposits when they lend, deposits decline with lending after a tightening. Unlike Drechsler et al. [2017], we allow for bank failure and capital, generating cross-sectional responses by capitalization and liquidity. Their model ties lending and interbank rates to quantities via exogenous links; these ad hoc features limit its ability to match movements in net interest margins and interbank risk premia, which our model explains endogenously.

Taken together, our paper bridges these literatures by offering a unified analytical framework in which bank credit creation, payment flows, and risk interactions are jointly determined. This approach provides a new perspective on how monetary policy and the structure of bank balance sheets interact to shape credit supply and financial stability, without relying on exogenously imposed constraints or ad hoc financial frictions.

3 The model

In this economy there are workers, investors, and a government composed of a central bank and a fiscal authority. Workers supply labor and consume. Investors save and invest in firms and banks. We assume there is specialization in production, namely, workers and firms are involved in the production of one good or service only but the workers consume a different one. This specialization in production 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. Once created, these deposits circulate in the economy as workers use them to buy goods and services from other firms. For the original borrower (firm) to pay back the loan she asked for in the first place, the deposits so-created need to get back to her, as this firm sells whatever product she is specialized in to other workers in the economy. Furthermore, every agent only deals with a very small subset of banks as compared with the total existing number of these depository institutions. This implies banks also need to make payments among themselves to clear the payment orders of their clients. At this point, banks do not have assets that are acceptable as a means of payment by other banks. To solve this problem, banks borrow reserves from the central bank.

To formalize these ideas, we consider the set up that follows. Time is discrete. The economy consists of a continuum of nodes, with measure one, index 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. The measure of each of these decision making units is also one. Furthermore, we assume firms on each node are specialised in the production of one single perishable good. These firms can only borrow from banks in the same node and can only hire workers living there. We impose these extreme specialisation 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 goods and of banks across nodes.

As discussed in the problem of workers, firms must pay workers in advance of selling their output. To do so, they borrow from local banks in the form of newly created deposits. Banks expand their balance sheets by recording these loans as assets and crediting the firms' deposit accounts with corresponding deposits. These deposits are transferred to workers, who receive them as wages in their bank accounts at the same bank in exchange for labor services. Workers use deposits to purchase goods from other firms. Through these purchases, deposits return to firms who, in turn, use them to repay their loans.

Regarding the 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. Lastly, the fiscal authority transfer resources to workers. These transfers are financed by the central bank.

3.1 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.[3]

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

[3]In words of Kiyotaki and Moore [2002] resalability of firms' paper is zero in this economy.

nominal wage bill $W \times h^s$. These funds are then transferred 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 convertible with cash, 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 deals with one bank only, selecting an firm is equivalent as 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 an firm who has asked a loan from bank 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 Rogerson [1988] or Williamson [2008]. 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

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

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.[4] 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

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

$j \in [0, 1]$ 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.

3.2 Firms

Each firm produces a perishable consumption good of one variety in node $j \in [0, 1]$.[5] The firm starts the period with internal liquid funds, n, accumulated from the previous period in the form of deposits at a particular bank. The only input needed to produce is labor. This producer decides how much labor, h^d, to hire but the wage has to be paid for in advance before production takes place. 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

$$l^d = max\{0, Wh^d - n\}. \tag{5}$$

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

[5] Since the problem is symmetrical for all firms, we omit the index j in the text.

period is, then

$$n' = max\{0, P(j)(h^d)^\alpha - (1+i^L)l^d\}. \tag{6}$$

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,

$$P_L = \frac{(1+i^L)l^d}{(h^d)^\alpha}. \tag{7}$$

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 (7) we can write the expected profits of the firm as

$$E(n') = (h^d)^\alpha \left[\int_{\gamma_L}^{\gamma_{max}} P(\gamma)\Phi_\gamma(d\gamma) - P_L[1-\Phi_\gamma(\gamma_L)] \right]. \tag{8}$$

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 (8). 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

$$\frac{\alpha}{1-\Phi_\gamma(\gamma_L)} \int_{\gamma_L}^{\gamma_{max}} P(\gamma)\Phi_\gamma(d\gamma) = (1+i^L)W(h^d)^{1-\alpha} \tag{9}$$

which implies a demand for credit of

$$l^d = max\{0, Wh^d - n\}.$$

3.3 Banks

3.3.1 Initial state

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 the previous period. 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

$$A = N + K. \tag{10}$$

Banks take this initial balance sheet as given.

3.3.2 Dealing with the public sector

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.[6] Additionally, each bank has access to the deposit and lending facilities of the central bank. With those facilities, the bank borrows or deposits O units of reserves at an interest rate i^O.[7] Then the balance sheet of the bank is

$$(O + B + A) = O + (N + B) + K. \tag{11}$$

That is, the reserve balance of the bank is now $O+B+A$. On the liability side, the bank now has an amount O of borrowing (deposits if negative) from the central bank, N in deposits from firms, and a net worth of K.

3.3.3 Credit provision, deposits, and payments

After dealing with the public sector, 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

[6] In addition of giving transfers, 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.

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

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

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

where $D = N+L+B$ are total deposits at the bank. Part of those deposits was initially at the bank and were owned directly by firms, N. The last bit, B, was created for the government to spend in exchange for reserves. All these deposits are now in the hands of workers, paid by firms as wages in exchange of labor services or as direct transfers from the government. 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 expenditure 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 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. Thus, 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.[8]

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

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

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

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

The reserve position of the bank 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 bank specific, the balance sheet of the bank 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.[9] Thus, to fulfill these payment flows, banks need a generally accepted means of payments. 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.

3.3.4 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

[8] 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.

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

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 central bank, O, reduces that possibility.[10]

3.3.5 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 $\Phi_\gamma(\gamma_L)$.[11]

Thus, in the event that firms are able to pay back the loan, so that they receive a realization

[10] 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.

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

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, $\gamma\mathbb{D} - (1 + i^L)L$. 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.[12]

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

[12] 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.

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.

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 $[i^R + s(R)]R$. 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 ($\gamma_K \leq \gamma < \gamma_L$),

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

3.3.6 Choices by bankers

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 borrowing from the central bank, O, and the supply of credit, L, to maximize expected net worth next period (21). Notice, choosing these two variables determines the reserve position, R, 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 banks 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.

Figure 1 shows loan supply (denoted Ls in the figure) and demand (denoted Ld) for the calibrated values of parameters and the equilibrium values for other variables such as the net worth of firms, N.[13] 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 increase marginal revenues and induces the bank to lend more. However, more credit provision also increases credit risk for the bank, as measured by γ_L as well as its solvency risk, γ_K. In general, there is a point where lending more funds increases firm default rates faster than solvency risks and it is not worth for the bank to lend more at higher rates. Notice, unlike models with agency problems, the supply schedule is backward bending despite information being symmetric between borrowers and lenders.

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

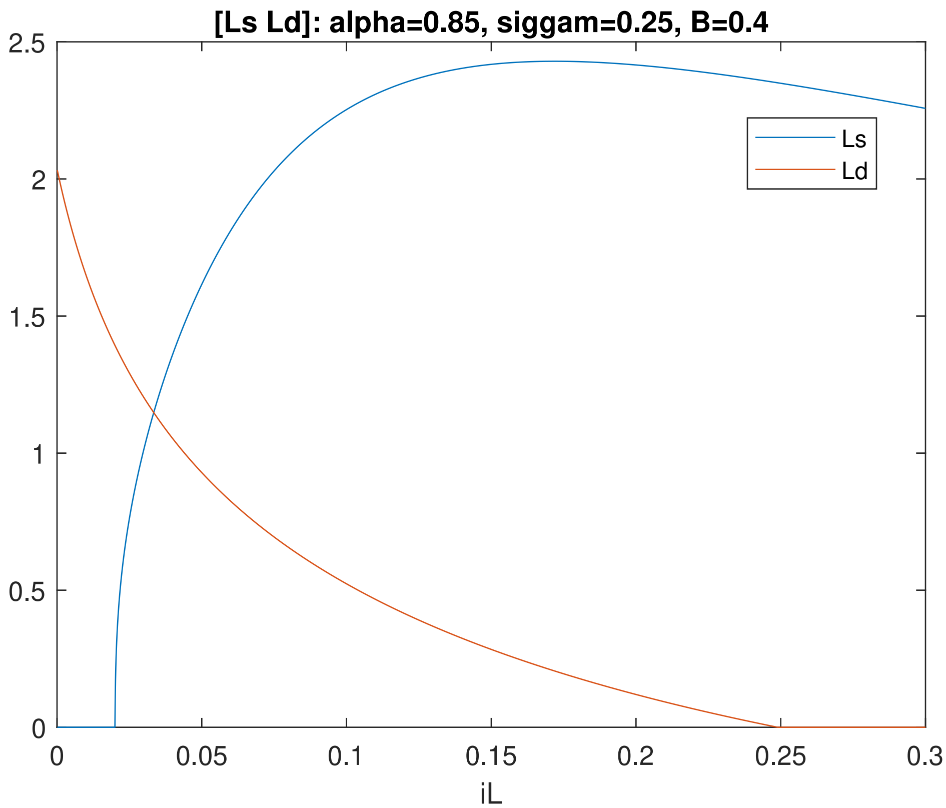

Figure 1: Loan supply and demand

3.3.7 Liquidity risk, credit risk, solvency risk, and interbank premia

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,[14] 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.

At the same time, having less capital, that is, a lower level of K, only has a direct effect on the threshold γ_K, worsening the solvency risk of the bank. Of course, apart from this direct effect, there are also indirect consequences as the choices of the bank regarding lending and reserve positions are also affected.

To understand how these risks affect the premium borrowing banks have to pay in the interbank market, $s(R)$, it is useful to plot the thresholds γ_R and γ_K from expressions (14) and (17) in the (γ, ϵ) plane as done in Figure 2. 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 line in Figure 2. Banks whose realization for γ are placed to the left of the line are insolvent and those to the right are solvent. On the other hand, expression (14) separates liquid from illiquid banks. It is represented by the decreasing curve in Figure 2. Banks placed below that schedule will have relatively low realizations of shocks γ and ϵ so that they will be borrowing funds in the interbank market. Banks placed above that schedule will be lending. In this manner, expressions (14) and (17) divide the population of banks in four groups regarding the solvency/insolvency and liquid/illiquid statuses. Notice, other things equal, a larger provision of credit, L, pushes expression (17) to the right and expression (14) up increasing the area of insolvency and illiquidity.

Just as expression (14) produces the combination of realizations for the shocks γ and ϵ generating a zero demand for reserves in the interbank market given the initial situation and choices of a bank, expression (13) can be used to produce combinations of these two shocks

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

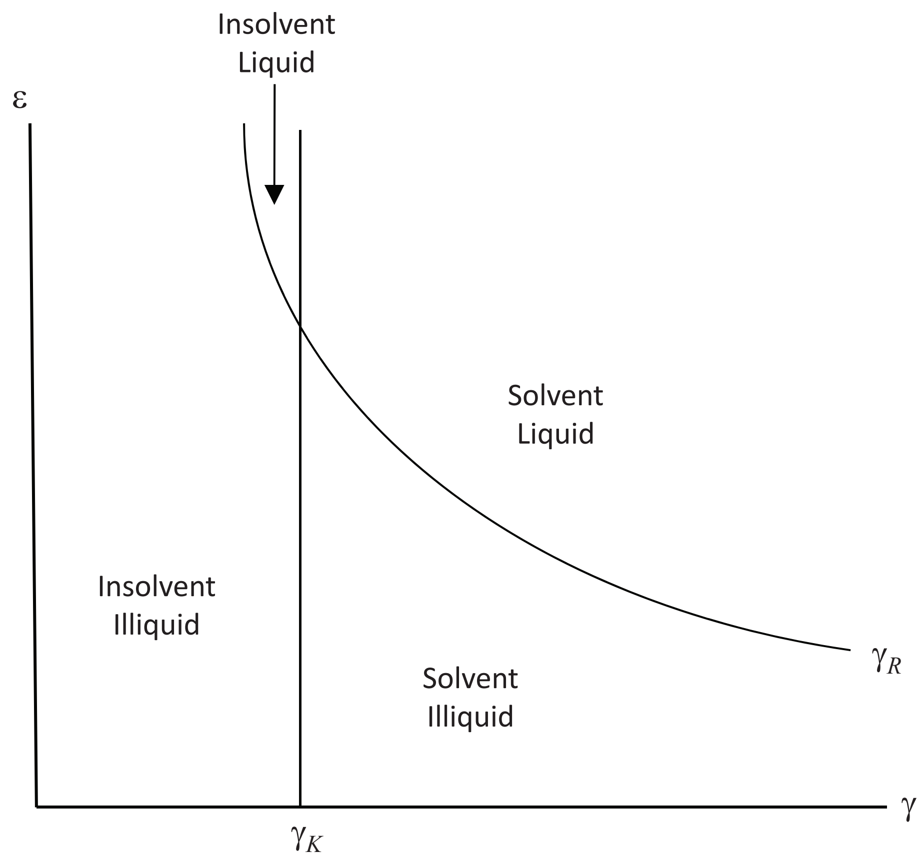

Figure 2: Solvency and liquidity risks

that would generate a particular reserve position. That is, 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

$$\gamma\epsilon = \frac{\bar{R} + D - O - A - B}{\mathbb{D}} = \frac{\bar{R}}{\mathbb{D}} + \gamma_R. \tag{25}$$

Figure 3 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 $|\bar{R}_{low}| < |\bar{R}_{high}|$. 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 a loan of size $\bar{R}$ will get repaid, namely

$$prob\left(\gamma \geq \gamma_K | \bar{R}\right) = prob\left[\epsilon \leq \frac{1}{\gamma_K}\left(\frac{\bar{R}}{\mathbb{D}} + \gamma_R\right) \middle| \bar{R}\right] = \Phi_\epsilon\left[\frac{1}{\gamma_K}\left(\frac{\bar{R}}{\mathbb{D}} + \gamma_R\right)\right], \tag{26}$$

where this expression uses (25). 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

$$s(\bar{R}) = (1 + i^R)\frac{1 - \Phi_\epsilon\left[\frac{1}{\gamma_K}\left(\frac{\bar{R}}{\mathbb{D}} + \gamma_R\right)\right]}{\Phi_\epsilon\left[\frac{1}{\gamma_K}\left(\frac{\bar{R}}{\mathbb{D}} + \gamma_R\right)\right]}. \tag{27}$$

Grafically, the risk premium is proportional to the density associated with the segment of schedule (25) inside the insolvency area, that is, to the left of the level γ_K. That segment is marked in red in Figure 3. 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

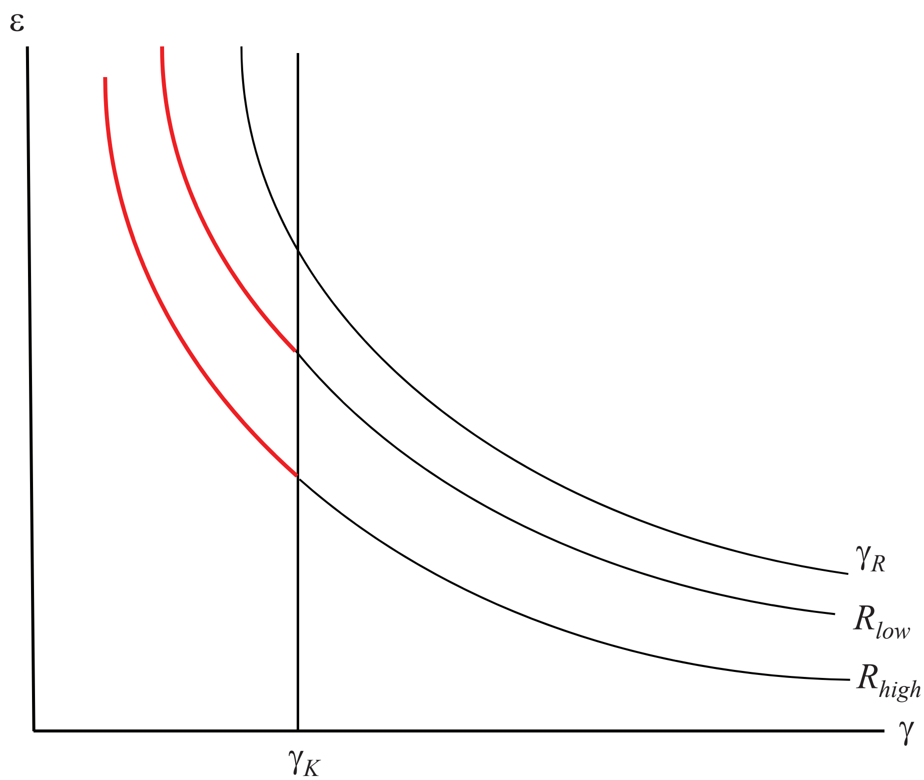

Figure 3: Different reserve positions

a higher threshold for solvency, γ_K. As a consequence, there is pressure for the risk premium, $s(R)$, to be larger too.[15]

3.4 Investors

The settlement of individual bank and firm positions results in a distribution of net worth across all banks (K') and firms (N') in the economy. To avoid these distributional consequences, assume these banks and firms are owned by a continuum of investors, with measure 1, all having symmetric ownership over them. 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 of

$$\mathbb{N}' = \mathbb{D}G(\gamma_L) - \mathbb{Q}, \tag{28}$$

where the function $G(\gamma)$ was defined in (20) and $\mathbb{Q}$ are lump sum taxes. Notice the resulting net worth of the conglomerate of firms is in the form of deposits in the bank.

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

$$\mathbb{A}' = \mathbb{N}' + \mathbb{K}'. \tag{29}$$

In this expression

$$\mathbb{A}' = \mathbb{A} + \mathbb{B} - i^O\mathbb{O} - \mathbb{T}, \tag{30}$$

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

$$\mathbb{K}' = \mathbb{D}\left[G(\gamma_K) - (1 + i^D)G(\gamma_L)\right] - \mathbb{T}, \tag{31}$$

is the resulting aggregate bank capital next period. In these expressions $\mathbb{T}$ is lump sum taxes levied on capital gains by investors and paid in reserves.

The following period, the conglomerates allocate initial assets to each individual firm and banker. Because, exante, all firms and banks are identical, these funds are equally distributed across firms and banks so that firms start next period with $N' = \mathbb{N}'$ and banks start with $K' = \mathbb{K}'$. When allocating these funds, investors just make sure the return on these two investments are equalized, namely,

$$\frac{\mathbb{K}'}{\mathbb{K}} = \frac{\mathbb{N}'}{\mathbb{N}}, \tag{32}$$

[15] 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.

3.5 The government

The government is composed of a central bank and a fiscal authority. The central bank provides reserves, O, in the OMO with its two facilities inelastically at the rate i^O and monetizes the transfers to workers, B, introduced by the fiscal authority. This fiscal authority also levies lump sum taxes on investors. The government budget constraint is then simply

$$\mathbb{A}' = \mathbb{A} + \mathbb{B} - i^O \mathbb{O} - \mathbb{T} - \mathbb{Q}. \tag{33}$$

The left hand side represents next period liabilities in the form of reserves. The right hand side includes the initial liabilities minus the revenues arising from lending to banks through the lending facility, $\mathbb{O}$, and the taxes imposed on the conglomerates of firms and banks.

3.6 Discussion

Summarizing, the economy starts each period with the same amount of aggregate assets in the form of initial bank reserves, $\mathbb{A}$, and a combination of firms initial funds, $\mathbb{N}$, and bank capital, $\mathbb{K}$. These assets are distributed equally among all banks and firms in the economy at the beginning of each period.

Given wages, W, prices of each good to be produced by the pool of firms serviced by bank $j \in [0, 1]$, $P(j)$, market interest rates i^L, and i^R, as well as the official rate, i^O, workers decide on labor supply, h^s, and the consumption, $c(j)$, they will buy from a randomly assigned firm. Firms decide labor demand, h^d, loan demand, l^d, and output, y. On the other hand, each bank decides reserve demand, O, and loan supply, L^s. These choices, together with the realizations of the payment shocks γ and ϵ, determine the reserve position of each bank, $R(j)$. Notice labor supply, production and intermediation decisions are taken before shocks are realized and, therefore, are assumed symmetric across workers, firms and banks. Consumption and reserve position are taken after the shocks are realized and, therefore, could be node dependent.

Each worker contributes to the production of one good (that of the firm who hired her) but will consume from a different firm in a different node. Once all decisions are taken, consumption expenditure by workers would be unevenly distributed across nodes. This crucial assumption incorporates the idea that banks are not fully diversified in 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 four 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 has to do with restricting firms to borrow from only a bank (or a collection of banks) in its very same node. Finally, the fourth 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 borrowing 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.

3.7 Equilibrium

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

$$h^s = h^d = h \tag{34}$$

for all workers and firms where labor supply is given by (4) and labor demand by (9). Thus, output for every firm is $y = h^{\alpha}$ and market clearing for goods imply

$$c(j) = h^{\alpha} \tag{35}$$

for all $j \in [0, 1]$. Furthermore, given clearing in the labor market, for the loan market to clear it has to be the case that

$$L^d = Wh - N = L^s(j) = L, \tag{36}$$

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

$$\int_0^1 R(j)dj = 0. \tag{37}$$

We define a symmetric equilibrium as follows:

Definition (Symmetric competitive equilibrium). *Given initial funds for firms and banks, $\mathbb{N}$ and $\mathbb{K}$, a monetary policy as defined by the official rate, i^o, a fiscal policy as defined by taxes to banks, $\mathbb{T}$ and transfers to workers, $\mathbb{B}$, a symmetric competitive equilibrium is a set of prices $\{P(j), i^L, i^R\}$, for all $j \in [0, 1]$, aggregate allocations, $\mathbb{N}'$ and $\mathbb{K}'$, and individual allocations $\{c(j), h, H, L^d, y, N(j)', L^s, R(j), K(j)'\}$, for all $j \in [0, 1]$ such that, starting all firms and banks with the same initial funds, $\mathbb{N}$ and $\mathbb{K}$, (i) given prices, allocations solve the individual problems of all workers, firms and banks, and (ii) markets for goods, labor, loans and reserves clear, and (iii) individual choices coincide with aggregate ones.*

Using the market clearing condition for the interbank market (37) together with the expression for reserves (13)

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

implies

$$O(j) = -(A + B). \tag{38}$$

Because the interbank market involves the continuum of banks $j \in [0, 1]$, it spans the whole distribution of shocks γ and ϵ. As payment shocks are symmetric and banks expect a zero net reserve position at the end of the period, banks do not need to accumulate reserves and, in fact, at the initial OMO, the central bank drains the reserves previously injected with the transfer, B. Then, the threshold γ_R equals,

$$\gamma_R = \frac{D}{\mathbb{D}} = 1, \tag{39}$$

which assumes a symmetric equilibrium where all banks make the same decision $D(j) = D = \mathbb{D}$, given that they start from the same situation.

From the market clearing condition for goods (35) together with the market clearing in the labor market (34), and the choice of consumption by the worker, prices are

$$P(\gamma) = \gamma \frac{Wh + B}{h^{\alpha}}. \tag{40}$$

Then, plugging this expression in the definition for the break even price P_L, (7) produces the threshold value γ_L^d for firms

$$\gamma_L^d = (1 + i^L)\frac{Wh - N}{Wh + B}. \tag{41}$$

This threshold together with the demand for labor (9) determine the wage rate as

$$\frac{\alpha}{1 - \Phi_\gamma(\gamma_L^d)} \int_{\gamma_L^d}^{\gamma_{max}} \gamma \Phi_\gamma(d\gamma) = (1 + i^L)\frac{Wh}{Wh + B} \tag{42}$$

which implies a demand for credit of

$$L^d = Wh - N. \tag{43}$$

On the other hand, the loan supply of banks is

$$(1 + i^L)[1 - \Phi(\gamma_L^s)] = (1 + i^O)[1 - \Phi(\gamma_K)] \tag{44}$$

where the thresholds for banks are

$$\gamma_L^s = (1 + i^L)\frac{L}{\mathbb{D}}, \tag{45}$$

and

$$\gamma_K = \frac{L - K + i^O(A + B)}{\mathbb{D}}. \tag{46}$$

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 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. Thus, 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, (33), and the equilibrium in the interbank market, (38), lump sum taxes to compensate for the accumulation of reserves by investors should satisfy

$$\mathbb{T} + \mathbb{Q} = i^O(\mathbb{A} + \mathbb{B}). \tag{47}$$

Because of the design of taxes and the symmetry of the solution, the equilibrium of this economy implies state variables to be constant over time, namely, $\mathbb{N} = \mathbb{N}'$ and $\mathbb{K} = \mathbb{K}'$.

4 Simulations

4.1 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, $\mathbb{B}$.

Among the parameters of the model, we set the value of the span of control to $\alpha = 0.85$ as in Atkeson and Kehoe [2005]. 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 2 percent which corresponds to the average of the federal funds rate (FFR) over the time period considered. 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. We also use quarterly data from the Flow of funds accounts of the US to match two items in the balance sheet of banks. Because the balance sheet of banks in the model are a extremely simplified version of the balance sheet of banks in reality, we target ratios of the items included in the theory. In this sense, there is no data regarding transfers to households which could provide a value for B. Instead, we use data on public securities held by banks and use as target the average ratio of loans to securities. We interpret this ratio in the data as L/B in the model. For the third target we use the average ratio of deposits to loans denoted by D/L in the model.[16]

Table 1 presents the calibration exercise. As the table shows, the calibrated value for the parameters are $\sigma_\gamma = 0.2$, $\sigma_\epsilon = 0.2$, and $B = 0.6$. With these values we closely match the data targets on the TED spread, the ratio of loans to securities of depository institutions as well as the ratio of deposits to loans. Below these targets we also include comparisons of other variables we have data for. First, the model falls a little bit short of approximating leverage as measured by loans to bank capital. On the other hand, it gets close to the NPL ratio and 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 reproduces the size of the nonfinancial sector as measured by the endogenous variable N.

External parameters					
Param.	Value	Source			
α	0.85	Taken from Atkeson and Kehoe [2005]			
Targeted moments					
Param.	Value	Variable	Meaning	Data	Model
i^O	0.02	i^O	Federal funds rate	0.02	0.02
σ_γ	0.25	L/K	Bank leverage	7.3	7.8
σ_ϵ	0.206	$\int_0^1 s(R)Rdj$	TED spread	0.54	0.55
B	0.4	D/L	Deposits to loans	1.2	1.7
Untargeted moments					
		Variable	Meaning	Data	Model
		$\Phi_\gamma(\gamma_L)$	NPL ratio	0.021	0.021
		$\Phi_\gamma(\gamma_K)$	Insolvent banks	0.009	0.009
		N	Size of nonfinancial sector	0.83	0.85

Table 1: Calibration and model fit

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

4.2 Results

In this section we present results for several applications of the model.

4.2.1 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 and cut 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 1 where lending rates are in the horizontal axis and quantities in the vertical axis), as banks now translate the increase in the cost of liquidity to higher loan rates. 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 rise in policy rates automatically widens banks' net interest margin as well as the deposit spread with respect to the official rate. Figure 4 shows the spread between the lending rate, i^L, and the policy rate, i^O, for values of the policy rate between 1 percent and 10 per cent. Figure 5 includes the corresponding amount of lending in equilibrium.

Notice the combination of a drop in deposits together with a widening of deposit spreads is what Drechsler et al. [2017] identify as the deposit channel of monetary policy. However, our results show that the same correlation can be obtained with reverse causation where it is changes in loan supply by banks what is driving the drop in deposits. As Figure 6 shows, leverage (L/K) also drops. 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 and prices as shown in Figures 7 and 8.

Furthermore, Figure 9 presents the NPL ratio of banks, $\Phi(\gamma_L)$ (denoted as PhiL) as well as the fraction of insolvent banks, $\Phi(\gamma_K)$ (denoted as PhiK). 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.[17] 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.

[17] The term risk-taking channel of monetary policy was first coined in Borio and Zhu [2012] and has received empirical support in, among others, Maddaloni and Peydro [2011], Buch et al. [2014], Jiménez et al. [2014], Ioannidou et al. [2015], or Bubeck et al. [2020]. A theoretical model reproducing this channel is developed in Dell'Ariccia et al. [2014].

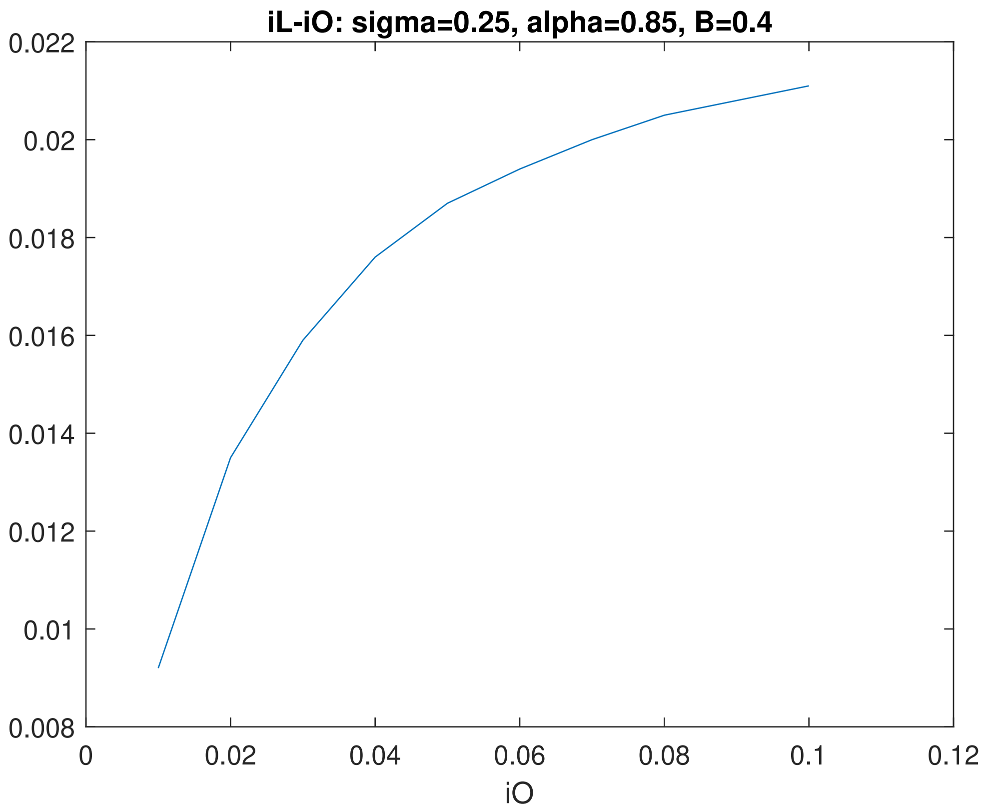

Figure 4: Lending and policy rate spread

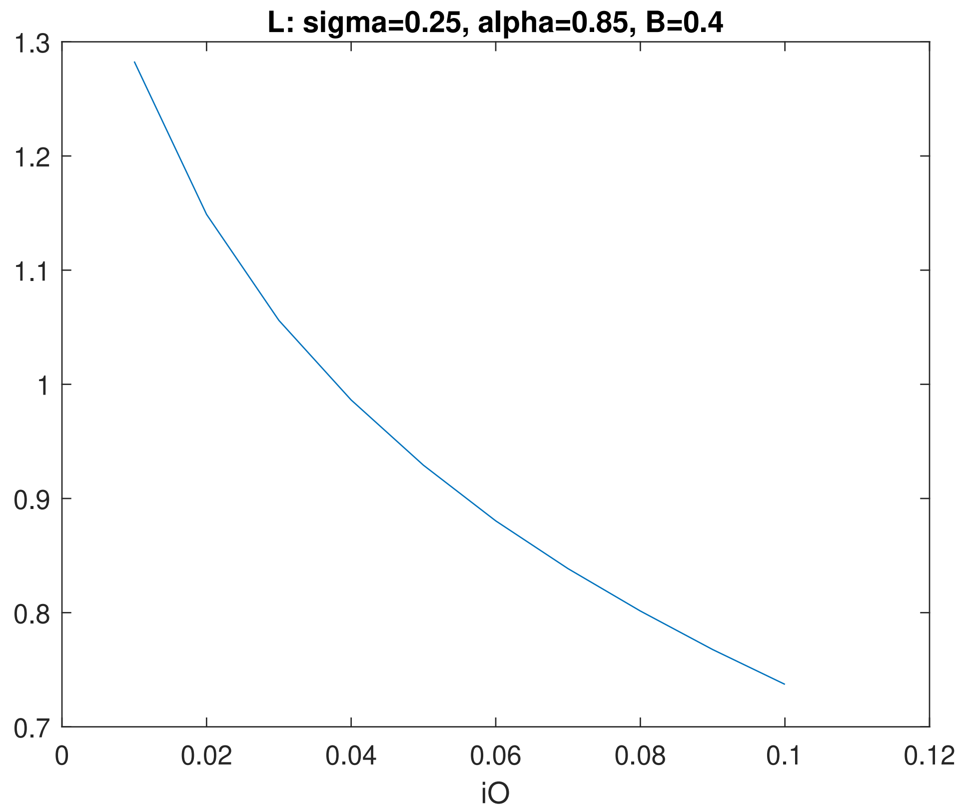

Figure 5: Amount of lending

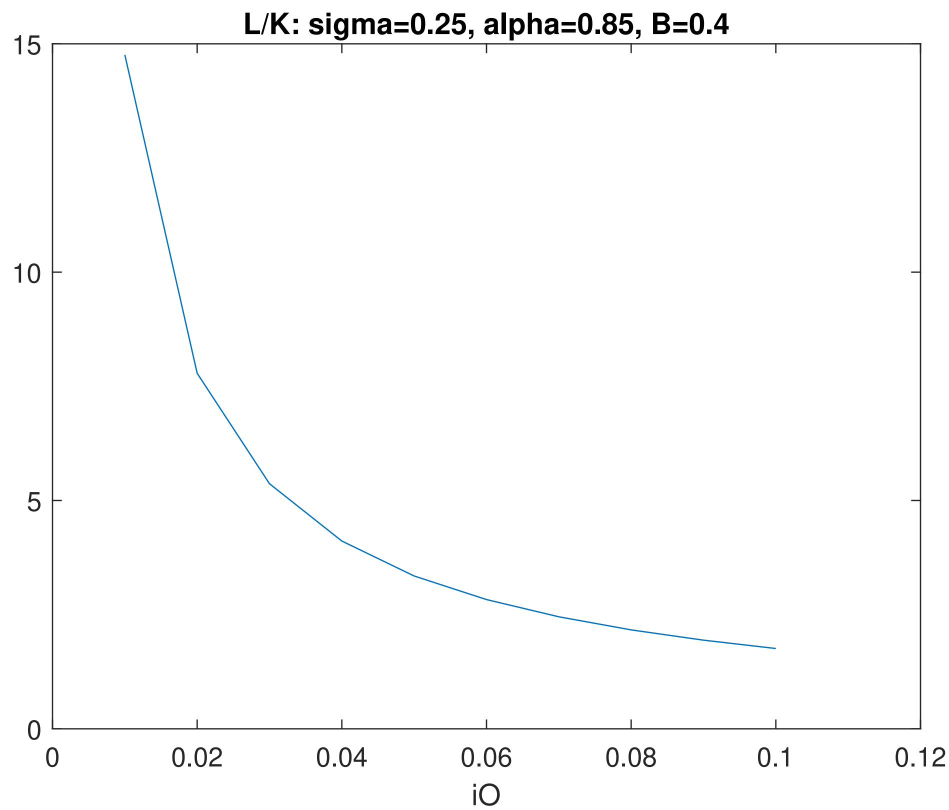

Figure 6: Leverage

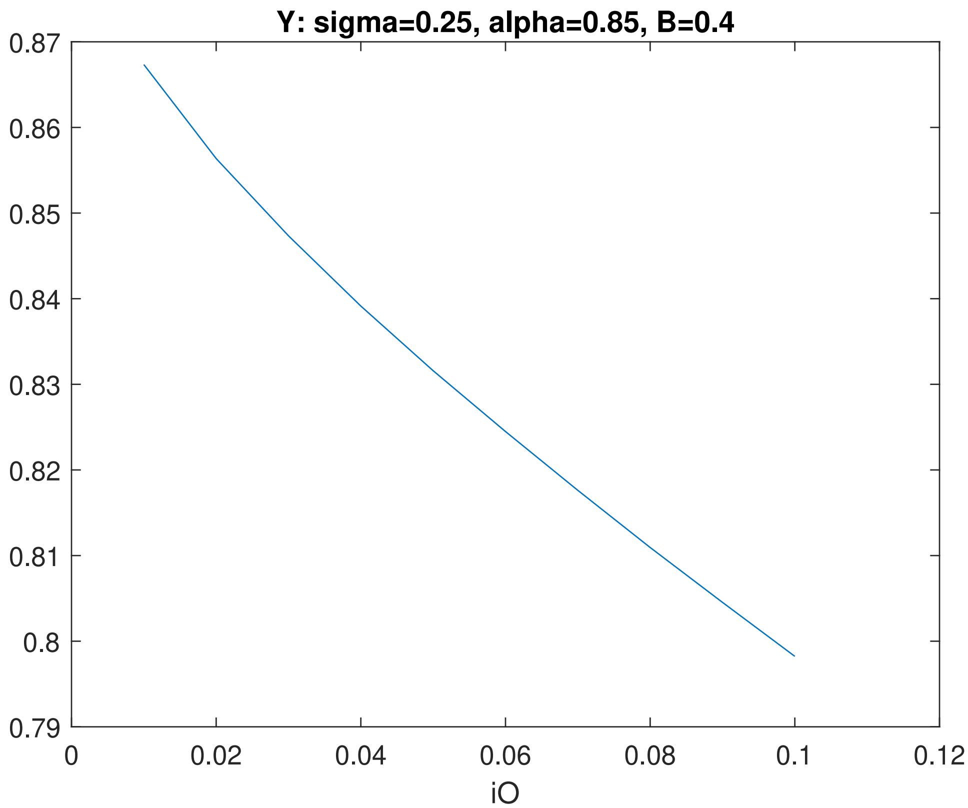

Figure 7: Output

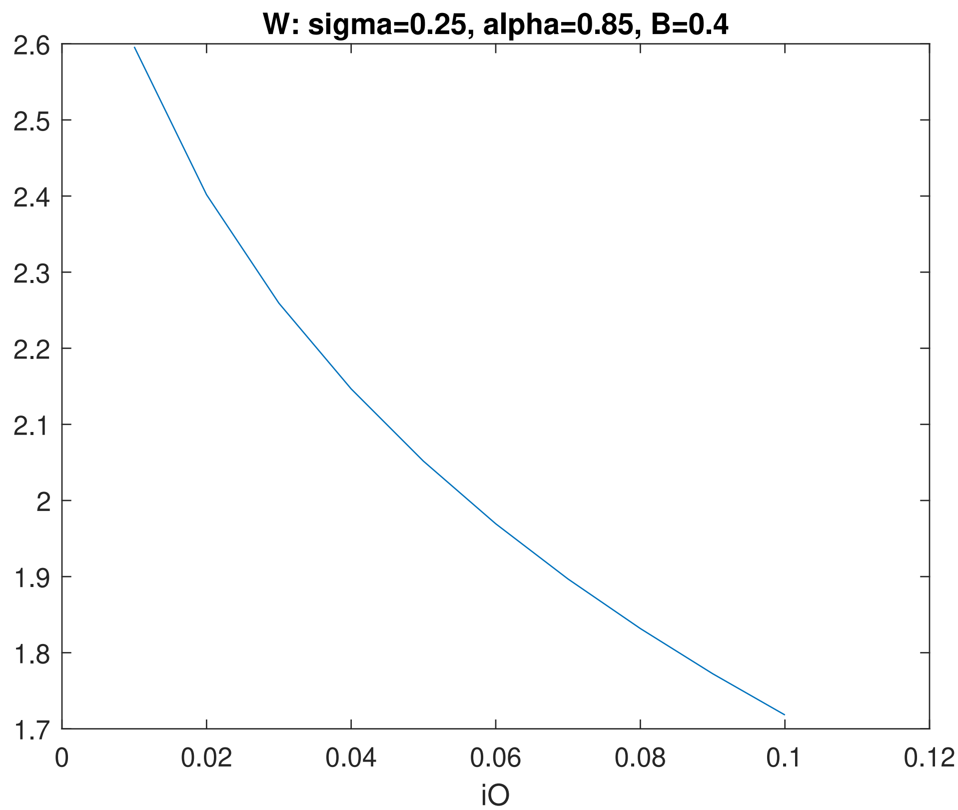

Figure 8: Wages

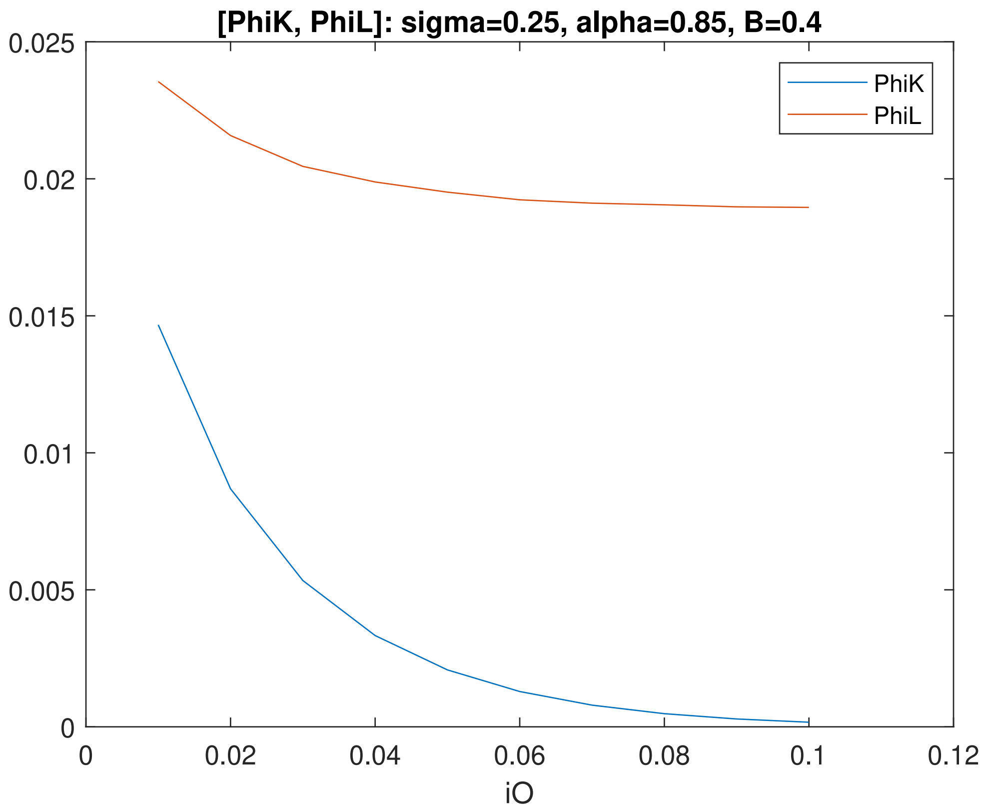

Figure 9: NPL ratios and fraction of insolvent banks

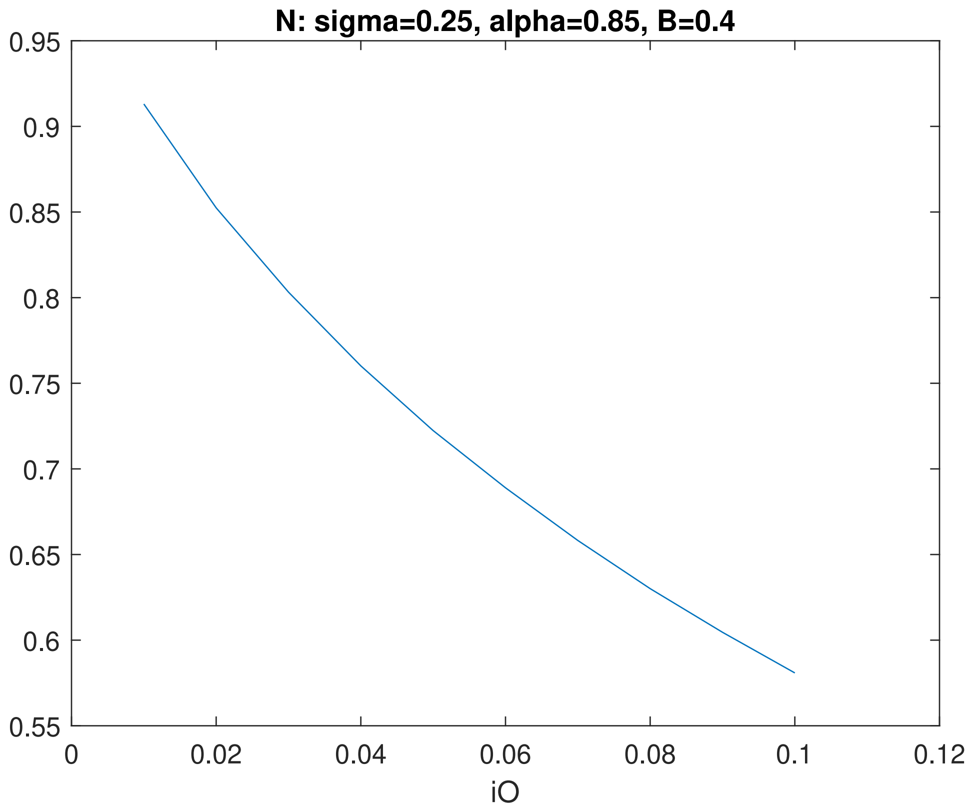

Figure 10: Initial funds for firms

As Figures 4 to 9 show, in our model monetary policy has long run effects. That is, the 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 is shown in Figure 10. 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 $i_1^O = 0.02$. On period $t = 2$ the official rate is increased to $i_2^O = 0.03$. After that, the official interest rate slowly returns to its initial value of 2 percent assuming a smoothing parameter of $\rho = 0.75$. That is to say, the official rate follows the expression

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

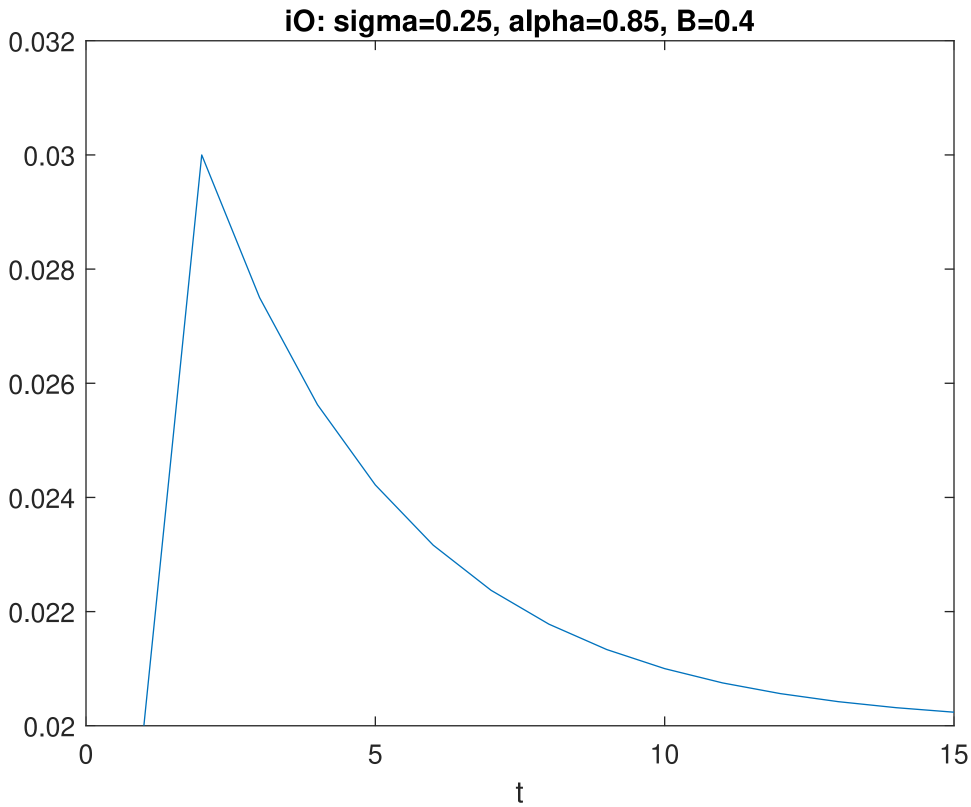

Figure 11: Policy rate

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.

Figures 11 to 9 show the transition. Figure 11 shows the exogenous path followed by the official rate, i_t^O. Figure 12 presents the equilibrium lending rate, i_t^L. This rate follows the path of the official rate. Figures 13 and 14 include 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, $i_1^O = 0.02$. As mentioned above, raising interest rates is profitable for banks and costly for firms. Accordingly, net worth of firms decrease and that of banks increase. As interest rates return to their original levels, so does net worth. The rising interest rates generates a reduction in lending (Figure 15) causing a recession with a temporary drop in output (Figure 16) and prices (Figure 17). The rise in bank capital and the drop in lending reduces bank leverage (Figure 18).

4.2.2 Balance sheet strength and the effects of monetary policy

Altunbaş et al. [2002], Ehrmann et al. [2001], Gambacorta and Mistrulli [2004], Gambacorta

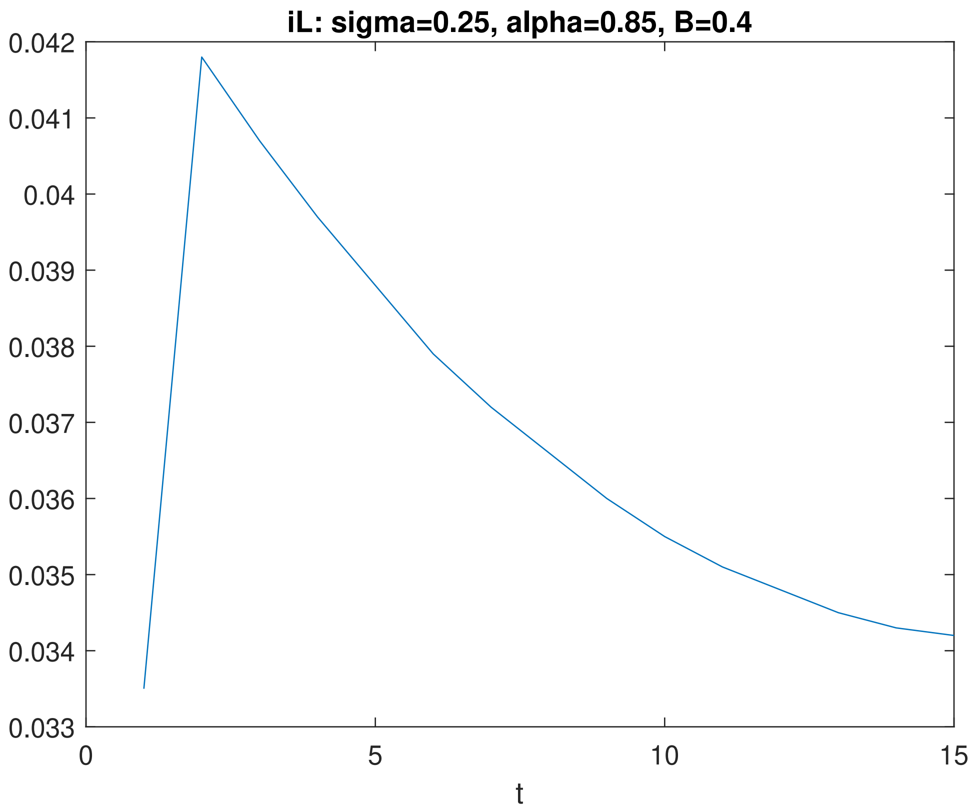

Figure 12: Lending rate

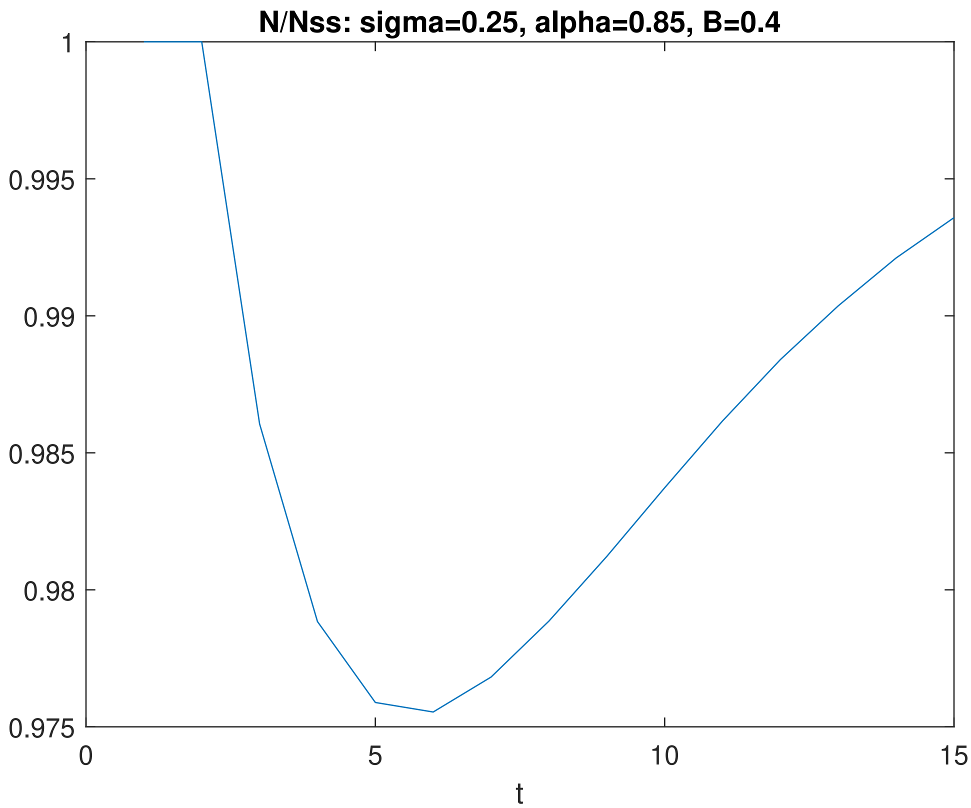

Figure 13: Initial funds for firms

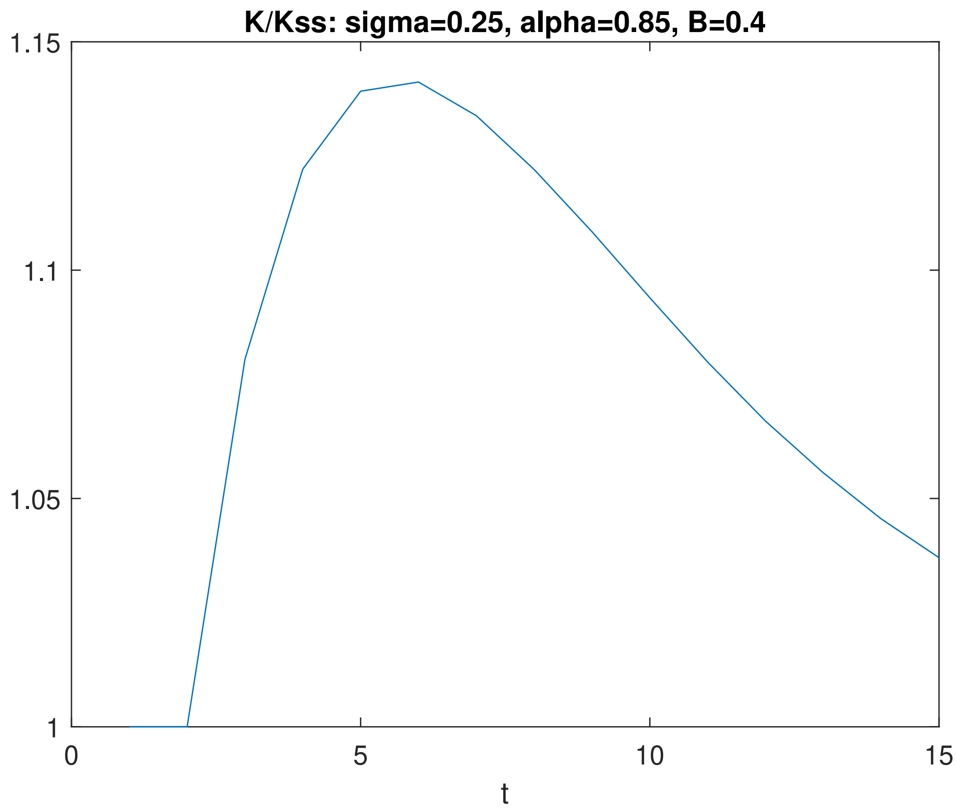

Figure 14: Bank capital

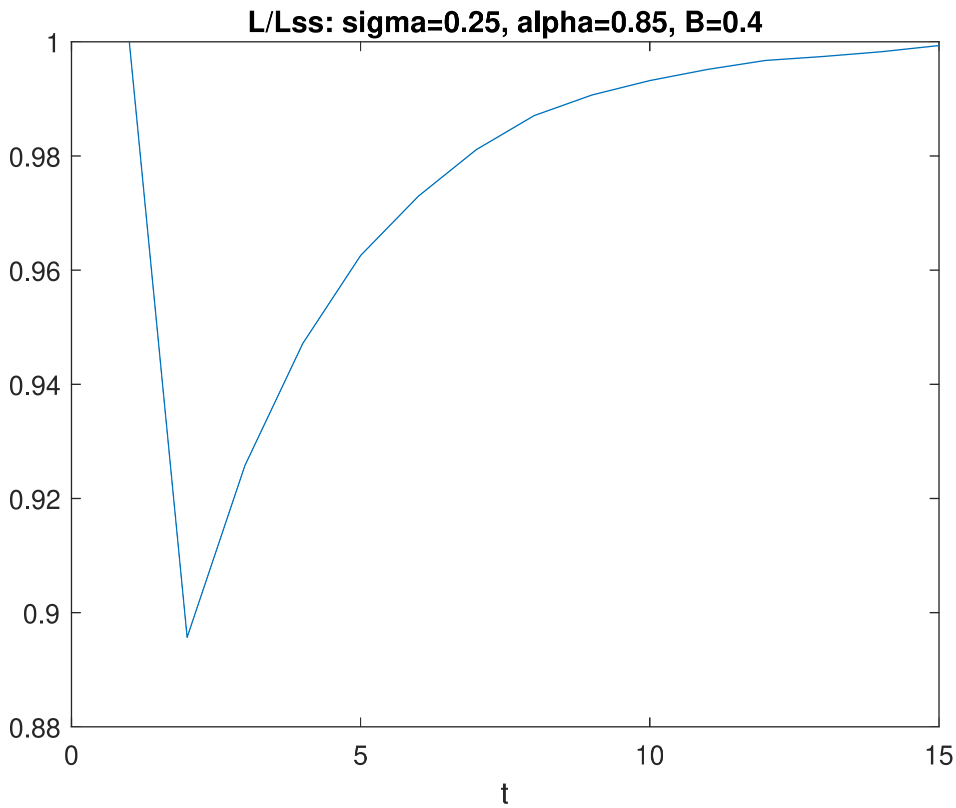

Figure 15: Amount of lending

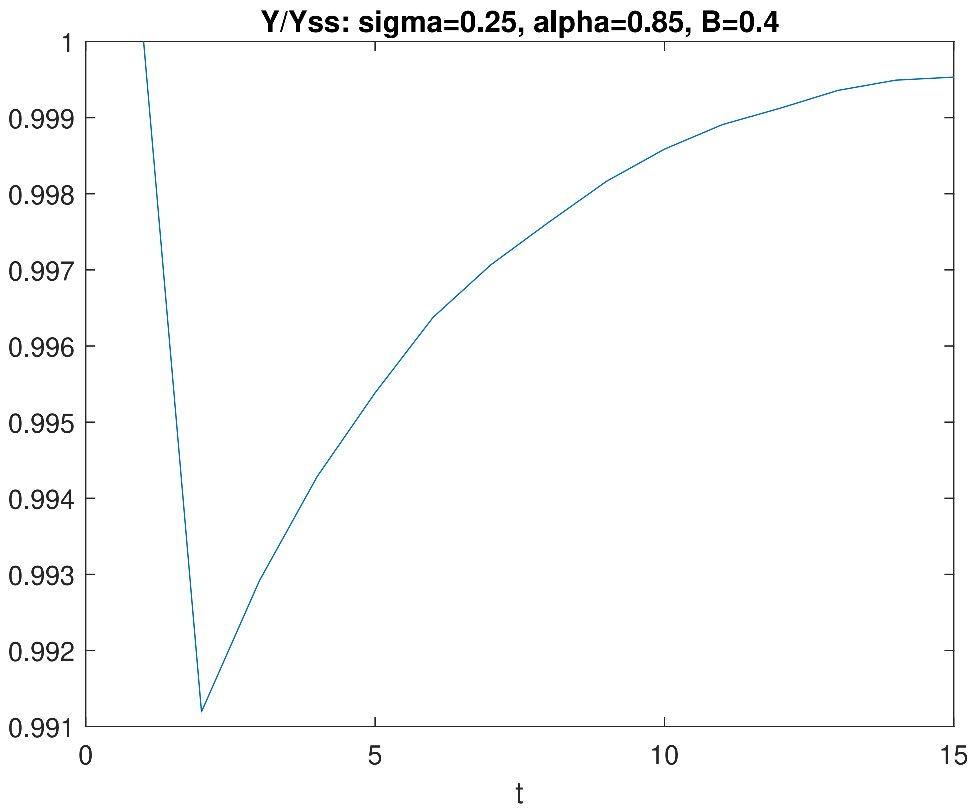

Figure 16: Output

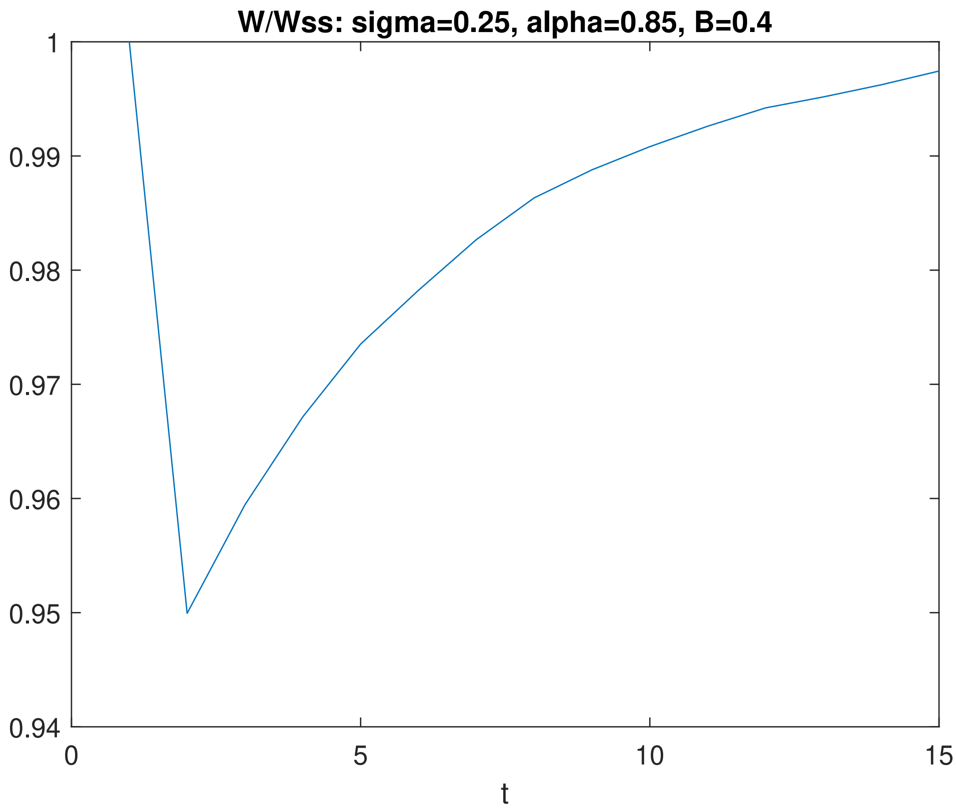

Figure 17: Wages

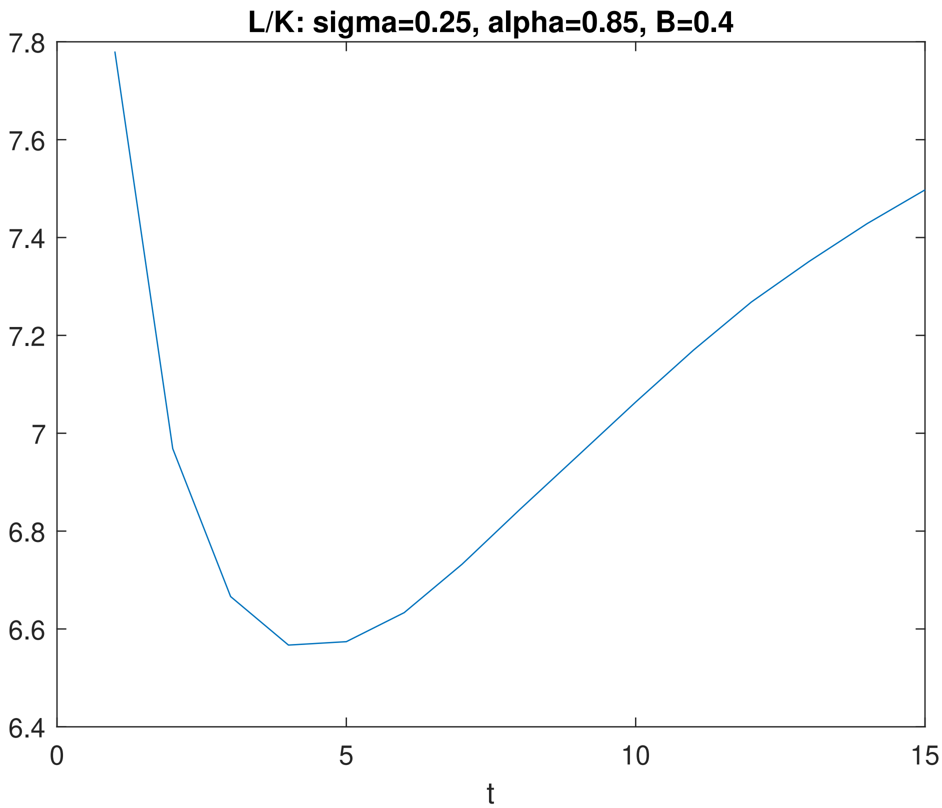

Figure 18: Leverage

[2005], Kashyap and Stein [1995], Kishan and Opiela [2000, 2006], or van den Heuvel [2002]) 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 when they are less capitalized and/or more illiquid. For example, Gambacorta [2005] 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 19 shows the percentage change drop in lending of an individual bank in response to an increase in the official rate i^O from 2 percent to 3 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.

4.2.3 Risk premium in interbank markets

Finally, Carvalho et al. [2022], Aymanns et al. [2016], Schmitz et al. [2017] and Arnould et al. [2022] 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, Aymanns et al. [2016] 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 Ashcraft and Bleakley [2006].

Figure 20 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 Equation (27) 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 2 percent. As banks borrow more, the spread they have to pay over the interbank rate

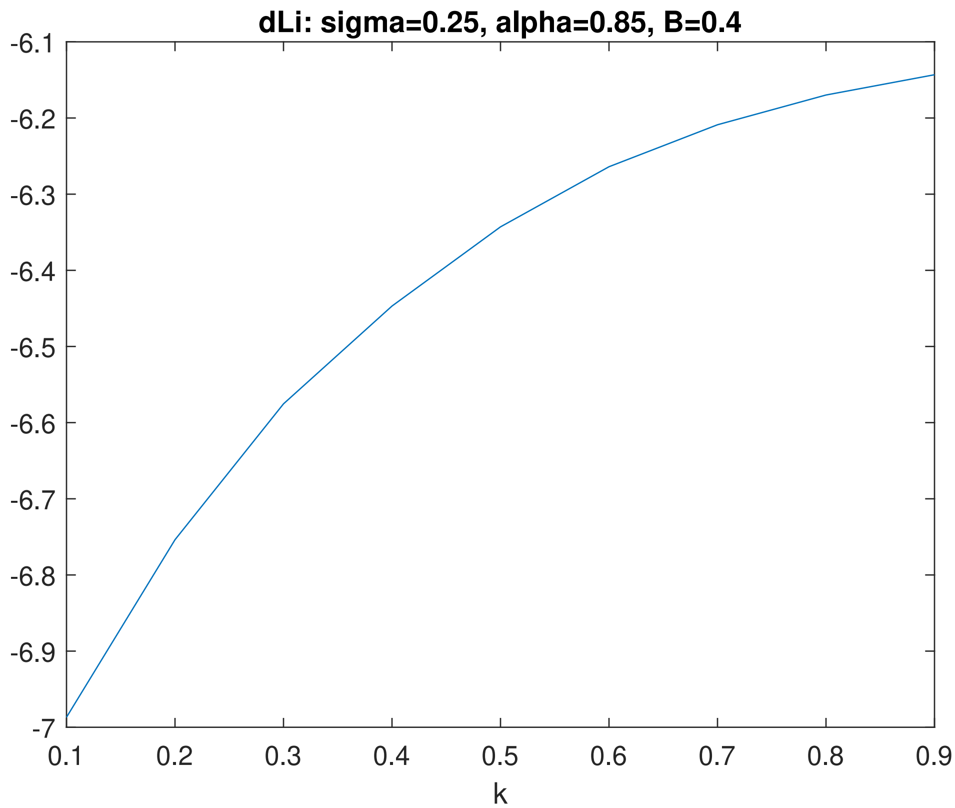

Figure 19: Changes in lending for different capital levels

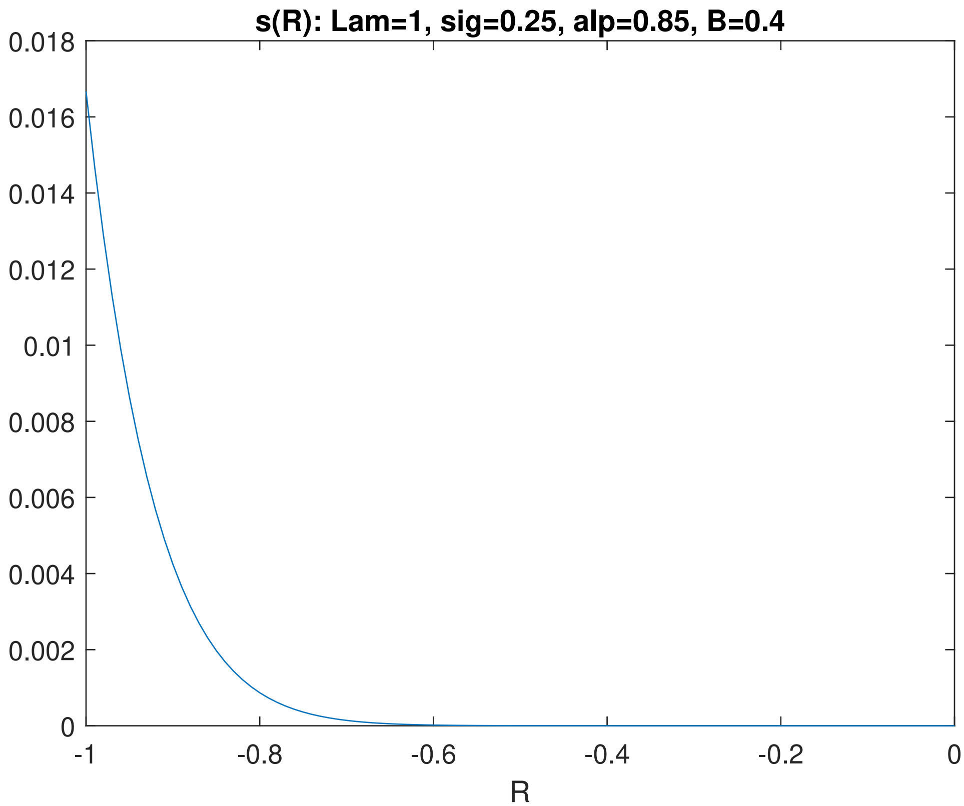

Figure 20: Risk spread in the interbank market

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 Conclusions

We have constructed a model where banks endogenously decide the size of their balance sheet by providing loans to entrepreneurs. In the process of providing these loans, banks also create the means of payments (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 reduce 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, which in turn feeds back into higher credit and solvency risks. Following a monetary policy shift, banks must reoptimize their lending behavior across liquidity, credit, and solvency margins in an environment where credit becomes more costly and scarce.

This mechanism also delivers several empirical facts that, to the best of our knowledge, had not previously been jointly addressed in the literature. These are: (1) a positive relationship between the interbank rate and the deposit spread and a negative relationship with deposit growth; (2) heterogeneous lending responses to monetary policy shocks depending on banks' capital and liquidity positions; (3) a positive relationship between monetary policy shocks and net interest margins; and (4) higher wholesale funding costs for banks perceived to have weaker solvency positions. Our model provides a unified and micro-founded explanation for these empirical observations.

A key policy implication of our model concerns the design of stress testing frameworks. Currently, supervisory authorities typically conduct solvency and liquidity stress tests separately as part of the bank supervision process. In line with this approach, liquidity and capital regulations are also designed in isolation. Our model demonstrates an endogenous link between liquidity and solvency risk, both of which stem from banks' lending decisions. The interaction between these two risks and their implications for financial stability have been empirically examined by, among others, Imbierowicz and Rauch [2014], Pierret [2015], and Schmitz et al. [2019]. These findings suggest the value of integrating liquidity and solvency considerations into a unified regulatory and supervisory framework. For instance, Tarullo [2013] proposes linking liquidity and capital requirements by imposing higher capital standards on large banks unless their liquidity positions substantially exceed minimum thresholds. We leave the design and evaluation of such integrated regulatory frameworks for future research.

References

Adrian, T. and Shin, H. S. (2010). Liquidity and leverage. Journal of financial intermediation, 19(3):418–437.

Afonso, G., Armenter, R., and Lester, B. (2019). A model of the federal funds market: yesterday, today, and tomorrow. Review of Economic Dynamics, 33:177–204.

Altunbaş, Y., Fazylov, O., and Molyneux, P. (2002). Evidence on the bank lending channel in europe. Journal of Banking & Finance, 26(11):2093–2110.

Arnould, G., Avignone, G., Pancaro, C., and Żochowski, D. (2022). Bank funding costs and solvency. The European Journal of Finance, 28(10):931–963.

Ashcraft, A. B. and Bleakley, H. (2006). On the market discipline of informationally opaque firms: evidence from bank borrowers in the federal funds market. Staff Reports 257, Federal Reserve Bank of New York.

Atkeson, A. and Kehoe, P. J. (2005). Modeling and Measuring Organization Capital. Journal of Political Economy, 113(5):1026–1053.

Aymanns, C., Caceres, C., Daniel, C., and Schumacher, M. L. B. (2016). Bank Solvency and Funding Cost. IMF Working Papers 2016/064, International Monetary Fund.

Bech, M. L. and Klee, E. (2011). The mechanics of a graceful exit: Interest on reserves and segmentation in the federal funds market. Journal of Monetary Economics, 58(5):415–431.

Bernanke, B. S. and Blinder, A. S. (1988). Credit, money, and aggregate demand.

Bianchi, J. and Bigio, S. (2022). Banks, liquidity management, and monetary policy. Econometrica, 90(1):391–454.

Bolton, P., Li, Y., Wang, N., and Yang, J. (2025). Dynamic banking and the value of deposits. The Journal of Finance.

Borio, C., Gambacorta, L., and Hofmann, B. (2017). The influence of monetary policy on bank profitability. International Finance, 20(1):48–63.

Borio, C. and Zhu, H. (2012). Capital regulation, risk-taking and monetary policy: A missing link in the transmission mechanism? Journal of Financial Stability, 8(4):236–251.

Brunnermeier, M. K. and Sannikov, Y. (2014). A macroeconomic model with a financial sector. American Economic Review, 104(2):379–421.

Bubeck, J., Maddaloni, A., and Peydró, J. (2020). Negative Monetary Policy Rates and Systemic Banks' Risk-Taking: Evidence from the Euro Area Securities Register. Journal of Money, Credit and Banking, 52(S1):197–231.

Buch, C. M., Eickmeier, S., and Prieto, E. (2014). In search for yield? Survey-based evidence on bank risk taking. Journal of Economic Dynamics and Control, 43(C):12–30.

Calomiris, C. W. and Mason, J. R. (2003). Fundamentals, panics, and bank distress during the depression. American Economic Review, 93(5):1615–1647.

Carvalho, H., Avezum, L., and Silva, F. (2022). The solvency and funding cost nexus - the role of market stigma for buffer usability. Working Papers w202211, Banco de Portugal, Economics and Research Department.

Chari, V. V., Kehoe, P. J., and McGrattan, E. R. (2009). New keynesian models: Not yet useful for policy analysis. American Economic Journal: Macroeconomics, 1(1):242–66.

Claessens, S., Coleman, N., and Donnelly, M. (2018). "Low-For-Long" interest rates and banks' interest margins and profitability: Cross-country evidence. Journal of Financial Intermediation, 35(PA):1–16.

Correia, S., Luck, S., and Verner, E. (2025). Failing banks*. The Quarterly Journal of Economics, page qjaf044.

Dell'Ariccia, G., Laeven, L., and Marquez, R. (2014). Real interest rates, leverage, and bank risk-taking. Journal of Economic Theory, 149(C):65–99.

Di Tella, S. and Kurlat, P. (2021). Why are banks exposed to monetary policy? American Economic Journal: Macroeconomics, 13(4):295–340.

Diamond, D. W. and Dybvig, P. H. (1983). Bank runs, deposit insurance, and liquidity. Journal of Political Economy, 91(3):401–419.

Diamond, D. W. and Kashyap, A. K. (2016). Liquidity requirements, liquidity choice, and financial stability. In Handbook of macroeconomics, volume 2, pages 2263–2303. Elsevier.

Disyatat, P. (2011). The bank lending channel revisited. Journal of Money, Credit, and Banking, 43(4):711–734.

Drechsler, I., Savov, A., and Schnabl, P. (2017). The deposits channel of monetary policy. The Quarterly Journal of Economics, 132(4):1819–1876.

Ehrmann, M., Gambacorta, L., Martínez Pagés, J., Sevestre, P., and Worms, A. (2001). Financial systems and the role of banks in monetary policy transmission in the euro area. Working Paper Series 105, European Central Bank.

Ennis, H. M. and Keister, T. (2008). Understanding monetary policy implementation. FRB Richmond Economic Quarterly, 94(3):235–263.

Friedman, M. (1969). The Optimum Quantity of Money and Other Essays. Aldine Publishing Company, Chicago.

Gali, J. (2015). Monetary Policy, Inflation, and the Business Cycle: An Introduction to the New Keynesian Framework and Its Applications Second edition, volume None of Economics Books. Princeton University Press, 2 edition.

Gambacorta, L. (2005). Inside the bank lending channel. European Economic Review, 49(7):1737–1759.

Gambacorta, L. and Mistrulli, P. E. (2004). Does bank capital affect lending behavior? Journal of Financial Intermediation, 13(4):436–457.

Gertler, M. and Kiyotaki, N. (2010). Financial Intermediation and Credit Policy in Business Cycle Analysis. In Friedman, B. M. and Woodford, M., editors, Handbook of Monetary Economics, volume 3 of Handbook of Monetary Economics, chapter 11, pages 547–599. Elsevier.

Gertler, M. and Kiyotaki, N. (2015). Banking, liquidity, and bank runs in an infinite horizon economy. American Economic Review, 105(7):2011–43.

Goldstein, I. and Pauzner, A. (2005). Demand–deposit contracts and the probability of bank runs. The Journal of Finance, 60(3):1293–1327.

Gorton, G. (1988). Banking panics and business cycles. Oxford Economic Papers, 40(4):751–781.

He, Z. and Krishnamurthy, A. (2013). Intermediary asset pricing. American Economic Review, 103(2):732–770.

He, Z. and Xiong, W. (2012). Rollover risk and credit risk. The Journal of Finance, 67(2):391–430.

Heider, F., Hoerova, M., and Holthausen, C. (2015). Liquidity hoarding and interbank market rates: The role of counterparty risk. Journal of Financial Economics, 118(2):336–354.

Imbierowicz, B. and Rauch, C. (2014). The relationship between liquidity risk and credit risk in banks. Journal of Banking & Finance, 40(C):242–256.

Ioannidou, V., Ongena, S., and Peydró, J.-L. (2015). Monetary Policy, Risk-Taking, and Pricing: Evidence from a Quasi-Natural Experiment. Review of Finance, 19(1):95–144.

Jakab, Z. and Kumhof, M. (2018). Banks are not intermediaries of loanable funds—facts, theory and evidence.

Jiménez, G., Ongena, S., Peydró, J., and Saurina, J. (2014). Hazardous Times for Monetary Policy: What Do Twenty-Three Million Bank Loans Say About the Effects of Monetary Policy on Credit Risk-Taking? Econometrica, 82(2):463–505.

Kashyap, A. K. and Stein, J. C. (1995). The impact of monetary policy on bank balance sheets. Carnegie-Rochester Conference Series on Public Policy, 42(1):151–195.

Kashyap, A. K. and Stein, J. C. (2000). What do a million observations on banks say about the transmission of monetary policy? American Economic Review, 90(3):407–428.

Kishan, R. P. and Opiela, T. P. (2000). Bank Size, Bank Capital, and the Bank Lending Channel. Journal of Money, Credit and Banking, 32(1):121–141.

Kishan, R. P. and Opiela, T. P. (2006). Bank capital and loan asymmetry in the transmission of monetary policy. Journal of Banking & Finance, 30(1):259–285.

Kiyotaki, N. and Moore, J. (1997). Credit cycles. Journal of political economy, 105(2):211–248.

Kiyotaki, N. and Moore, J. (2002). Evil is the root of all money. American Economic Review, 92(2):62–66.

Lagos, R. and Wright, R. (2005). A unified framework for monetary theory and policy analysis. Journal of political Economy, 113(3):463–484.

Maddaloni, A. and Peydro, J.-L. (2011). Bank Risk-taking, Securitization, Supervision, and Low Interest Rates: Evidence from the Euro-area and the U.S. Lending Standards. The Review of Financial Studies, 24(6):2121–2165.

McLeay, M., Radia, A., and Thomas, R. (2014). Money creation in the modern economy. Quarterly Bulletin 2014 Q1 1, Bank of England.

Morris, S. and Shin, H. S. (2016). Illiquidity component of credit risk – the 2015 lawrence r. klein lecture. International Economic Review, 57(4):1135–1148.

Pierret, D. (2015). Systemic Risk and the Solvency-Liquidity Nexus of Banks. International Journal of Central Banking, 11(3):193–227.

Poole, W. (1968). Commercial bank reserve management in a stochastic model: implications for monetary policy. The Journal of finance, 23(5):769–791.

Rogerson, R. (1988). Indivisible labor, lotteries and equilibrium. Journal of Monetary Economics, 21(1):3–16.

Schmitz, M. S. W., Sigmund, M., and Valderrama, M. L. (2017). Bank Solvency and Funding Cost: New Data and New Results. IMF Working Papers 2017/116, International Monetary Fund.

Schmitz, S. W., Sigmund, M., and Valderrama, L. (2019). The interaction between bank solvency and funding costs: A crucial effect in stress tests. Economic Notes, 48(2).

Smets, F. and Wouters, R. (2007). Shocks and frictions in us business cycles: A bayesian dsge approach. American Economic Review, 97(3):586–606.

Tarullo, D. (2013). Evaluating progress in regulatory reforms to promote financial stability. Speech given at the Peterson Institute for International Economics, May 05, Washington, DC.

van den Heuvel, S. J. (2002). Does bank capital matter for monetary transmission? Economic Policy Review, 8(May):259–265.

Van den Heuvel, S. J. (2008). The welfare cost of bank capital requirements. Journal of Monetary Economics, 55(2):298–320.

Williamson, S. D. (2008). Monetary policy and distribution. Journal of Monetary Economics, 55(6):1038–1053.

Woodford, M. (2003). Interest and Prices: Foundations of a Theory of Monetary Policy. Princeton University Press.

A Derivation of Equations (21) and (22)

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

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

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 (c 22).

B Data sources

1. 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).

2. The deposit spread as well as the amount of deposits are taken from the data provided by Drechsler et al. [2017] in their dedicated webpage as a weighted average of rates for checking and savings accounts with the corresponding proportion of deposits being the weights.

3. Data on net interest margin is taken from the Historical Bank Data database provided by the FDIC. We compute the remuneration of loans as the interest income of loans and leases (labeled "Int Inc - Total Loans & Leases") over total loans (labeled "Total Loans and Leases"). Cost of deposits is computed as the interest expense on deposits (labeled "Int Exp - Total Deposits") divided by total deposits (labeled "Total Deposits").

4. The TED rate is obtained from the FRED database of the Federal Reserve Bank of St.Louis (with acronym TEDRATE). This is a series that was discontinued in January 2022.

5. Finally, we use Table L111 of the Financial accounts of the United States (Z.1) to obtain data on: public securities (B) are computed as the sum of Treasury securities

(LM763061100), agency-and GSE-backed securities (LM763061705), and municipal securities (LM763062000); 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), and; capital (K) is represented by total equity (FL763181105).