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

We develop a general equilibrium banking model in which liquidity, credit and solvency risks are endogenously connected to banks' lending decisions. In this framework, monetary policy is transmitted to the economy because it affects the link between bank risks and credit provision. The model provides a unified explanation for several empirical facts documented in the literature. Our results highlight the importance of incorporating endogenous risk interactions into the analysis of monetary transmission through the banking sector.

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

The supply of credit plays a prominent role in the transmission of monetary policy to the real economy. There is now a vast literature where this transmission works through the balance

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sheet of banks and their willingness to provide credit.[1] Within this view, the existing theories have generally followed a deposit-driven narrative. The idea is that a contractionary monetary policy drains deposits from the banking system as depositors decide to hold other assets with higher returns. The reduction in deposits forces banks to cut on lending if these deposits cannot be replaced by other forms of funding. Different papers highlight particular channels by which the monetary policy stance may impact the amount of deposits savers want to hold such as, among others, binding reserve requirements (Bernanke and Blinder [1988, 1992]), market power by banks in local deposit markets, (Drechsler et al. [2017]), or the level of net worth of banks (Gertler and Karadi [2011, 2013], Gertler and Kiyotaki [2010, 2015]).

In this paper, we claim that placing the reduction in deposits as the center cause of the transmission mechanism of monetary policy could be misguided. Our motivation relies on the dynamics of deposit creation and destruction. First, the narrative that banks have to collect deposits beforehand in order to lend does not align with actual practices performed by these financial intermediaries in our economies. As reported in communications of central bankers, such as McLeay et al. [2014], Bundesbank [2017], Jordan [2018], Bailey [2020] and Brainard [2021], and argued in Disyatat [2011], the process of credit provision in modern economies actually works in reverse as depository institutions are, to a large extent, autonomous in the production of deposits. In fact, broad monetary aggregates are mostly formed by deposits originated within the banking system due to its lending activities, something that has been considered by recent research (Donaldson et al. [2018], Bolton et al. [2020], or Thakor and Yu [2023]). Second, the idea that aggregate deposits get reduced when households decide to hold other types of assets is at odds with the life cycle of deposits, as documented in Bindseil and Senner [2024]. When households buy a nonbank asset, such as a T-Bill or a private security, deposits are generally reshuffled but not destroyed. They simply leave the account of the buyer (the household in this case) and are transferred to the account of the seller (government, nonfinancial company, or nonbank financial intermediary). This reshuffling of liquidity maintains constant the aggregate amount of deposits and, thus, the aggregate ability of the banking system to fund lending.[2]

We present a different mechanism that, consistent with the dynamics of deposit creation and destruction, is based on the costs of bank intermediation and how changes in these costs,

[1]For an recent survey of the theoretical and empirical work on this topic, see Claessens and Kose [2018].

[2]The only channels by which the aggregate amount of deposits can be reduced are either, (i) when deposit holders use them to pay for existing loans, (ii) when they transform these deposits into another bank liability, such as bank equity or bank debt, or else, (iii) when they buy an asset originally held by a bank. This third option includes withdrawing deposits in the form of banknotes. Notice none of these channels seem to be what proponents of the bank lending channel have in mind. Furthermore, at face value, none of these mechanisms need to affect, necessarily, the part of the balance sheet banks use to fund lending.

driven by shifts in the monetary policy stance, affect the willingness of banks to leverage and to take on risks. In the model, households rely on private credit to fulfill their consumption and investment needs. Banks satisfy this private demand for liquidity with the creation of means of payment (deposits) when providing credit. As these deposits circulate throughout the economy, banks need also to make payments among themselves to clear the payment orders of their clients, which generates a need for central bank reserves for interbank settlement. This flow of payments generates *liquidity risk* for banks.[3] Likewise, deposits are destroyed when used to pay for the loan which created them in the first place.[4] For that to happen, a borrower needs to receive a sufficient amount of the deposits the banking system produces through its lending activity. Thus, the very same payment flows generate *credit risk*.[5] 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 risks* faced by banks.[6]

Although in the model there are no exogenous restrictions to banks' balance sheet growth, there exist endogenous limits associated with how expanding the balance sheet of a bank impact solvency, credit, and liquidity risks which jointly determine profitability. We show how all these risks endogenously increase when banks decide to expand their balance sheet by providing more credit. As a result, there is an optimal level of credit provision for a bank, which maximizes expected profits. Bank capital and monetary policy are relevant in this process of credit production as they affect this connection between loan provision and bank risks.[7] We believe understanding the connection of loan provision with liquidity, credit and solvency risks is important as these three risks are the main concerns banks have to face in their business, in particular, regarding their decisions to expand or contract their balance sheets.

Apart from being consistent with the life cycle of deposits and to generate an endogenous link between bank risks and lending, an additional advantage of our mechanism with respect to other existing models is that it can jointly reproduce four empirical facts about the role of the banking system in the transmission of monetary policy. These facts are: (1) the interbank rate is positively related with the deposit spread and negatively related with the growth rate

[3] In our setting, liquidity risk is related to the possibility that a bank does not have generally accepted means of payments to settle orders of payment when they are due.

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

[5] Credit risk is realized when a borrower of the bank does not repay the loan in a timely manner.

[6] Solvency risk has to do with the event in which the value of the bank's liabilities is larger than the value of its assets.

[7] This mechanism by which monetary policy shocks do not affect aggregate lending through changes in the amount of reserves or deposits but instead works through the cost of liabilities is empirically corroborated by Carpenter and Demiralp [2012] and Halvorsen and Jacobsen [2016].

of deposits, (2) the response of lending by individual banks to monetary policy shocks depends on their levels of capital and liquidity, (3) there is a positive relation between monetary policy shocks and net interest margins, and (4) wholesale funding costs increase for banks perceived as having weaker solvency positions. As discussed in the next section, to our knowledge, this is the first paper to provide a unified framework to explain these four facts together.

On the other hand, it is important to notice that our framework is built on a perfectly competitive environment with symmetric information and flexible prices. These features allow us to illustrate our results as just the consequence of the provision of credit with endogenous banks' balance sheets and not generated through agency problems, market power, or sticky prices. Of course, all these frictions could provide amplification but the idea pursued in this paper is that they are not fundamental for the mechanism considered here.

The remaining of the paper is as follows. The next section presents the four empirical facts mentioned above and connects them to the relevant literature. Section 3 presents the model while section 4 provides the main results. Finally, section 5 concludes.

2 Literature review

In this section we review four empirical facts about the connection between monetary policy and bank intermediation in the context of previous research and in connection to our setting. We also include a discussion of papers where banks create deposits in the process of loan provision.

2.1 The deposit channel

Drechsler et al. [2017] empirically observe that, when the Fed funds rate rises, banks widen the spreads they charge on deposits and there is a reduction in the amount of deposits banks hold. Figures 1 and 2 reproduce the aggregate evidence. Both figures show data for the United States between January 1986 and October 2013, the original sample in Drechsler et al. [2017]. Figure 1 shows quarterly data on the federal funds rate (FFR in the figure) against the deposit spread, that is, the difference between the federal funds rate and the deposit rate. The deposit rate is computed as the weighted average of the interest paid by checking and saving accounts. The weights are the standing amounts of these two bank liabilities. This figure suggests a strong positive correlation between the federal funds rate and the deposit spread.

On the other hand, Figure 2 includes the year-to-year change in the federal funds rate against the growth rate of deposits with respect to their level in the previous year. The data

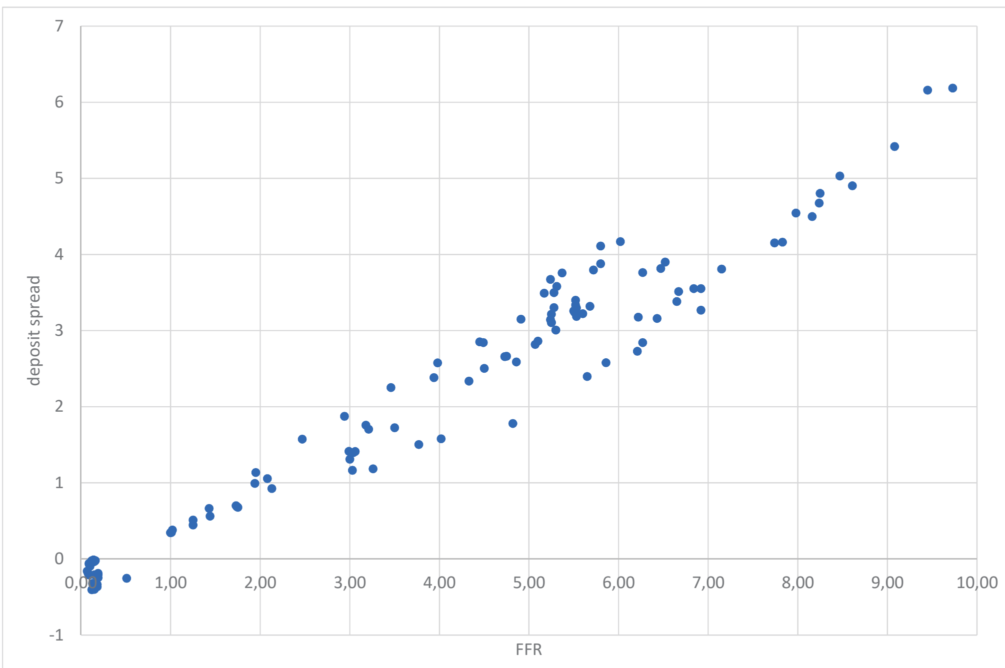

Figure 1: Federal funds rate and deposit spread

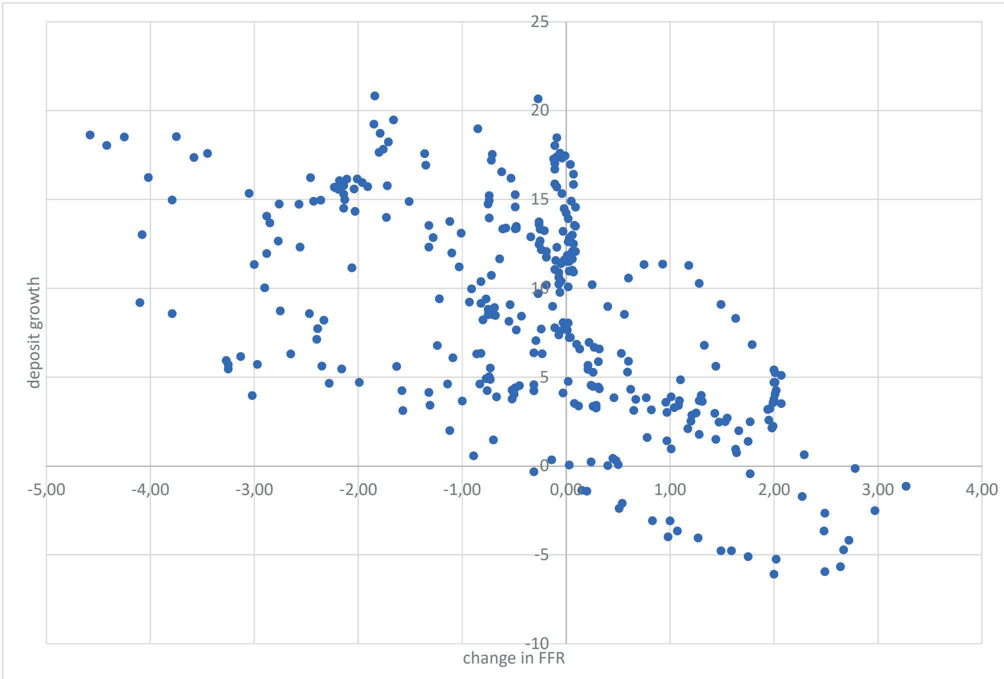

Figure 2: Federal funds rate and deposit growth

in this case are monthly and cover the same period as in Figure 1. We observe there is a strong negative relation between these two variables, namely, larger increases in the federal funds rate are associated with lower growth of deposits being this growth even negative for sufficiently high changes in the market rate.

Drechsler et al. [2017] empirically connect these two facts to the degree of market power of banks in local deposit markets and to consequent reductions in lending. They find evidence that counties with more concentrated deposit markets experience larger increases in deposit spreads, together with larger reductions in deposits and lending in response to the same monetary policy tightening. They also provide a theory to explain this connection which they label the deposit channel of monetary policy. Because of their market power, banks do not pass-through completely the increase in policy rates to deposit rates. As the opportunity cost of deposits increases, depositors seek other forms of investment and reduce their holdings of deposits. Because banks cannot perfectly substitute deposits for other forms of funding, they are forced to reduce lending. This theory, though, has been criticized on several grounds. In a search-theoretic model, Choi and Rocheteau [2023] characterize the bank deposit spread as an intermediation premium and argue that bank market power is not sufficient for the deposit channel to operate. Furthermore, Repullo [2020] questions the theoretical underpinnings of Drechsler et al. [2017] by showing a U-shaped relationship between the policy rate and the equilibrium amount of deposits.

Other studies also cast doubt on the empirical findings of Drechsler et al. [2017]. Although Wang et al. [2022] provide empirical support for the relevance of bank market power on the monetary policy transmission, Begenau and Stafford [2023] calls into question the identification assumption that banks exploit variation in local deposit market concentration at the time of pricing decisions by showing evidence on uniform deposit rate pricing for US commercial banks. Begenau and Stafford [2023] also show that Drechsler et al. [2017] excludes over 90 percent of all US commercial bank branches and when these excluded bank branches are included in the analysis the deposit channel mechanism is absent in the majority of branches.

Our paper differentiates from the previous studies in several aspects. First, while the literature on the deposit channel focuses on bank's market power and the role it plays in the transmission of monetary policy, we replicate the main results of Drechsler et al. [2017] in an environment with perfect competition, which allows us to abstract from market power as a mechanism to explain the effects of the monetary policy on the real economy through the supply of deposits. Second, studies about the deposit channel are built from the premise that banks need to attract deposits as a precondition to lend. Contrary to Drechsler et al. [2017], in our mechanism, changes in deposits are not the driving force for the reduction in lending but rather a by-product of the adjustments of banks and the real sector to policy changes. Because banks create deposits in the lending process, aggregate deposits drop jointly with lending but as a consequence of the contraction in intermediation, not as a cause. These two differences allow us to offer an alternative theoretical explanation for the bank lending channel that works through the dynamic flow of deposits without the need of further frictions such as imperfect competition, sticky prices, or asymmetric information.

Furthermore, as it stands, the model in Drechsler et al. [2017] does not account for the rest of empirical facts listed below. Banks in their model do not fail and there is no bank capital. Thus, they cannot account for the cross-sectional differences of the response of banks to a contractionary monetary policy shock according to their levels of capitalization and liquidity (section 2.2). Additionally, the lending interest rate as well as the interbank rate are exogenously linked to the amount of lending as well as to the amount borrowed in wholesale markets. Without these ad-hoc connections, the model cannot explain the link between reductions in deposit funding and provision of loans since the bank would compensate the drop in deposits one-to-one with wholesale funding. However, adding these features prevent their model from explaining how net interest margins respond to changes in the policy rate (section 2.3) or to risk premia in the interbank market (section 2.4). Interestingly, we can explain these other facts endogenously as a by-product of our model.

2.2 Balance sheet strength

Altunbaş et al. [2002], Ehrmann et al. [2001], Gambacorta and Mistrulli [2004], Gambacorta [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. Furthermore, highly liquid banks drop their lending by 0.414 percent in response to the same increase in the policy rate. The reduction in lending is 1.285 for banks with low liquidity. These effects remain statistically significant after the introduction of further controls and changes in the sample.

Kishan and Opiela [2000] present a simple model to rationalize why less capitalized banks are more affected by monetary policy than banks with more capital. This effect crucially depends on assuming market power of banks in the market for uninsured deposits as well as in the market for loans, and on imposing that the interest elasticity of uninsured deposits positively depends on the capitalization of the bank. In our model, the mechanism is endogenous. Less capitalized and/or more illiquid banks have weaker balance sheets. Thus, contractionary monetary policy has a larger impact on solvency and liquidity risks and generates a larger decline in lending for these banks. Furthermore, the model in Kishan and Opiela [2000] imposes an ad-hoc negative relationship between deposits and the overnight rate as well as a constant spread between the lending and deposit rates and, therefore, cannot explain the empirical facts in sections 2.1 and 2.3. Finally, their model does not include an interbank market and is not suited to study the evidence in section 2.4.

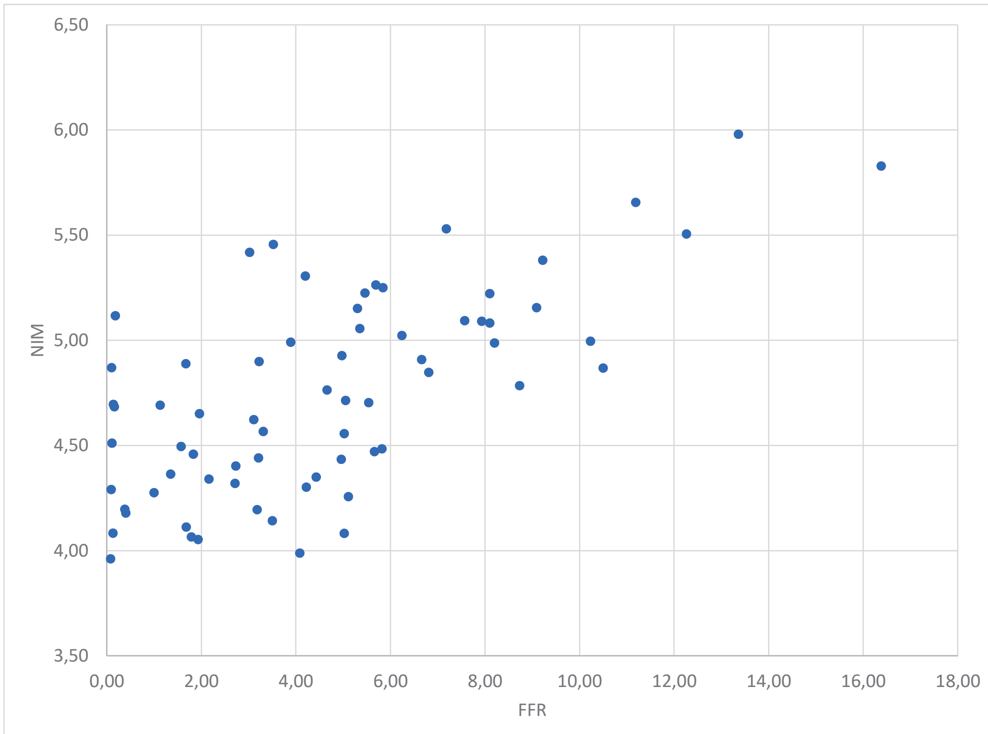

Figure 3: FFR and net interest margin

2.3 Net interest margins

Figure 3 presents annual data for the federal funds rate (labeled FFR in the figure) against the net interest margin (NIM) of commercial banks in the US. The net interest margin is computed as the difference between the average rate of return on loans minus the average rate paid to checking and saving accounts. The data cover the period from 1955 until 2023 and are collected from the Federal Deposit Insurance Corporation's (FDIC) Historical Data on Banking. There is a positive relationship between these two variables; higher levels of the interbank market rate are associated with a larger NIM.

As commented by English et al. [2018], the relationship between these two variables is complicated to analyze as it is plagued with endogeneity issues. Furthermore, there is a myriad of channels through which they are related. This could explain the mixed results the empirical literature has found on this topic. In this way, Ennis et al. [2016] cast doubt about a clear relationship between the average NIM and the fed funds rate over time, suggesting that the effect of monetary tightening in net interest margins is unclear for the US. Drechsler et al. [2021] state that there is no relationship between the level of nominal rates and banks' net interest margins. Specifically, they claim that bank aggregate profits are insensitive to large fluctuations in interest rates and that banks with less sensitive interest expenses also have a one-for-one less sensitive interest income, which makes their profits fully hedged against interest rate shocks. However, Begenau and Stafford [2021] find evidence against a stable NIM, and Eichenbaum et al. [2025] find that the impact on NIMs depends on whether monetary policy interest rate shocks realize after periods of low or high nominal interest rates.

Drechsler et al. [2021] present a model to rationalize their empirical finding that net interest margins are not related to the level of interest rates. However, their model does not include bank capital (so it cannot account for the empirical facts in section 2.2) as they abstract from solvency risk. In their model, banks can hedge any interest rate risk associated with their maturity transformation by properly choosing the maturity of their asset portfolio. Interestingly, these authors mention that this hedging would be incomplete in the presence of solvency risk. In other words, when banks hold capital, their NIM could fluctuate with the level of interest rates but the paper does not analyze this possibility. Furthermore, Drechsler et al. [2021] impose an exogenous spread between the deposit rate and the federal funds rate and, thus, their model cannot generate the evidence presented in section 2.1 endogenously. Finally, the model does not include an interbank market and, therefore, it is silent on the evidence presented in section 2.4.

On the other hand, Borio et al. [2017] or Claessens et al. [2018] find a statistically significant positive relationship between net interest margins and levels of interbank market interest rate. English et al. [2018] link this positive relationship to exogenous shocks to monetary policy. Thus, the positive relationship depicted in Figure 3 is still present after controlling for endogeneity issues. Our model reproduces this positive relationship; as monetary policy gets tighter, funding of loans becomes more expensive. Banks react to this increase in costs through a combination of prices (i.e. NIM) and quantity (i.e. amount of credit) adjustments.

2.4 Risk premia in the interbank market

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].

Freixas and Jorge [2008] construct a model of the interbank market with asymmetric information. In that model, the spread between the interbank rate and the T-Bill rate increases with the demand for funding. In our model, there is a positive relationship between the liquidity demand in the interbank market and the probability of bank default. This is because, conditional on capital levels, the demand for funds in the interbank market provides a signal of weaker solvency positions. Furthermore, as solvency risks deteriorate with lower capital levels, conditional on the amount borrowed, funding costs in the interbank market also increase for less-capitalized banks.

2.5 Endeogenous money creation

The importance of endogenous money creation is emphasized by Jakab and Kumhof [2018], who argue that a central function of banks is to provide financing to agents who simultaneously act as borrowers and depositors. In this framework, loan creation inherently generates deposit creation, as lending increases both sides of the bank's balance sheet. This perspective, supported by communications from central bankers such as McLeay et al. [2014], Bundesbank [2017], Jordan [2018], Bailey [2020], and Brainard [2021], as well as the analysis of Disyatat [2011], suggests that depository institutions exercise substantial autonomy in the creation of deposits. Jakab and Kumhof [2018] show that this view aligns more closely with empirical observations, such as procyclical bank leverage and credit rationing during economic downturns.

Building on this framework, and similar to Bianchi and Bigio [2022], our model features banks that create deposits in the act of lending by simultaneously recording loan and deposit entries on their balance sheets in the name of the same agent. These deposits serve as a medium of exchange, enabling households to purchase goods. The core mechanism of our model centers on the costs of bank intermediation and how changes in these costs, induced by shifts in the monetary policy stance, alter banks' incentives to take on risk and expand their balance sheets. In doing so, the model captures the dynamics of deposit creation and destruction as endogenous outcomes of banks' profit-maximizing behavior.

3 The model

We develop a model that incorporates several key features of modern economies. First, there is specialization in production: each agent produces only one good or service but consumes a different one. Because of informational and enforcement frictions, individual IOUs cannot circulate as a mean of payment. Instead, households rely on private banks, which use their balance sheets to intermediate payments. The process works as follows. When someone demands a resource but does not have the means of payment to acquire it, a bank creates these means of payment in the form of deposits and lends them to that agent. Once created, these deposits circulate in the economy as agents use them to buy goods and services. For the original borrower to pay back the loan she asked for in the first place, the deposits so-created need to get back to her, as this agent sells whatever product she is specialized in to other agents 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 need to also make payments among themselves to clear the payment orders of their clients.

The model focuses on how banks decide to expand their balance sheets when issuing loans that create deposits. For analytical clarity, we model banks in detail and abstract from the internal complexity of other sectors, whose role is primarily to generate a loan demand. We later discuss which frictions are essential for our results and which features of the real economy can be simplified without loss of generality.

To formalize these ideas, we consider an economy with a continuum of banks of measure one, indexed by $j \in [0,1]$. These banks are owned by bankers and manage the payment system. A continuum of entrepreneurs (also of measure one) is responsible for production, while a continuum of workers demands goods and supplies labor. In addition, there is a public sector composed of a central bank and a fiscal authority. Time is discrete.

Entrepreneurs 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 entrepreneurs' deposit accounts with the corresponding deposits. These deposits are transferred to workers, who receive them as wages in their bank accounts at the same bank and use them to purchase goods from other entrepreneurs. Through these purchases, deposits return to entrepreneurs which they need to repay their loans.

We assume that workers' consumption expenditures are randomly distributed across entrepreneurs. This generates two key effects. First, because workers and entrepreneurs are distributed across banks, deposits flow unevenly across institutions. These interbank imbalances are settled using reserves and expose banks to liquidity risk. Second, since some entrepreneurs receive more revenue than others, there is heterogeneity in loan repayment. Some entrepreneurs 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.

3.1 Workers

Workers are hand-to-mouth agents. Each worker supplies labor to a centralized labor market within the location she lives in and receives the current nominal wage $W \times h$, in the form of a deposit at one of the banks, from the firm hiring her. After receiving these funds, workers consume. At the time of consumption, a worker receives a taste shock that commands her to buy goods from a particular entrepreneur. Because each entrepreneur deals with one bank only, selecting an entrepreneur is equivalent as selecting the bank the entrepreneur 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 entrepreneur who has asked a loan from bank j. Let h be the labor supply of the worker. Preferences over consumption and labor after the taste shock is realized are described by the quasi-linear function

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

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 to maximize utility (1) subject to the budget constraint

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

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.[8] The solution to this problem is summarized by the consumption sharing rules

$$c(j) = \frac{Wh + B}{P(j)}, \tag{3}$$

and the labor supply schedule

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

An important assumption of the model has to do with the distribution of worker's taste shocks over the universe of entrepreneurs and banks. For that, assume these shocks are not evenly distributed in the economy but rather clustered around particular groups of en-

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

trepreneurs serviced by particular banks. The result of this clustering is that a particular bank $j \in [0,1]$ will see its entrepreneur 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 Entrepreneurs

Each entrepreneur is in charge of a firm producing a perishable consumption good. They start 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, 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, $W \times H$, the entrepreneur 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

$$L^d = max\{0, WH - N\}. \tag{5}$$

After obtaining the credit and pay for the wage of its workers, the firm produces $y = H^\alpha$, 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 earning the interest rate i^D overnight. Entrepreneurs are assumed to be risk neutral and infinitely patient so they do not consume. They just accumulate wealth through producing goods and selling them.

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

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

Notice next period's net worth are 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. Assume the entrepreneur asks for a loan. Let P_L be the break even price. This is the price of the good produced for which profits are zero, that is,

$$P_L = \frac{(1+i^L)(WH - N)}{(1+i^D)H^\alpha}. \tag{7}$$

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 entrepreneurs serviced by the same bank. 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

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

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 rates, i^L and i^D, and the distribution of taste shocks which will translate into possible prices of the good $P(j)$, the firm decides labor demand, H, 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

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

which implies a demand for credit of

$$L^d = max\{0, WH - N\}.$$

3.3 Bankers

3.3.1 Initial state

Each banker is in charge of the decisions of a single bank. Banks are assumed not to be fully diversified and service a pool of entrepreneurs with correlated revenue risks. Banks starts the period with a balance sheet derived from decisions taken the previous period. On the asset side, banks hold two types of assets. On the one hand, there are illiquid, productive assets, A, such as physical capital or intangibles with zero financial return.[9] On the other hand, there are initial reserves M. These initial reserves are held at a checking account in the central bank. The liability side is composed of bank capital, K, and deposits representing internal funds of the firms, N. Thus, the initial balance sheet of the bank reads

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

3.3.2 Dealing with the public sector

Right at the beginning of the period, the government channels transfers to workers, B. These expenditures are financed by selling government debt, B, to banks. In exchange, banks pay with deposits created for that purpose.[10] Public debt B pays the interest rate i^B. Also, each bank has access to an open market operation (OMO) conducted by the central bank. In that operation, the bank borrows O units of reserves at an interest rate i^O.[11] Then the balance sheet of the bank is

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

[9]We can think of these initial assets as the nonfinancial resources needed for the bank to start operating. The idea is that revenues and profits arise from the intermediation activity of the bank, and not from these initial funds.

[10]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.

[11]In this economy, although borrowing from the central bank is senior to all other liabilities of the bank, it is nevertheless assumed unsecured. We could introduce the idea that public debt B is needed as collateral for the OMO. However, we do not pursue that idea here to simplify the model and its exposition.

3.3.3 Credit provision, deposits, and payments

After the OMO, banks decide how much credit to provide to the firms in their location. For that, we adhere to the idea that banks do not need existing funds to supply loans. In fact, the defining characteristics of depository institutions is precisely the ability to produce deposits when providing loans to their customers. Thus, the balance sheet after lending is provided is

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

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 public securities. 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 four types of assets, namely, reserves, $O+M$, public securities, B, loans provided to firms, L, and the initial illiquid assets, A. 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 entrepreneurs 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 entrepreneurs serviced by each bank. This fraction corresponds to the realization of the shock γ of that particular bank with this random variable being identically and independently distributed across banks. Thus, firms serviced by bank j receive total payments $\gamma\mathbb{D}$ for selling the good they produce. This represents an inflow of deposits by that bank. 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 banks 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.

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, $M + O$, plus the net flow of funds, F,

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

Because the realizations of both shocks are bank specific, the balance sheet of the bank is as follows

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

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 will borrow funds in the interbank market when $R < 0$, or, in other words, when

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

That is, producing more deposits, either by buying public debt or through the provision of loans, has a liquidity cost as it increases the probability of borrowing from the interbank market. This is because both actions increase the threshold level γ_R. On the other hand, accumulating reserves in the OMO, reduces that possibility.[12]

[12]Here, we assume by the time the bank realizes it has a reserve deficiency the only margin banks have to revert the situation is to borrow in the interbank market or that repo markets are not available at that time.

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 public debt, i^B, and on the OMO, i^O, are paid. These payments are done in reserves. Then, the balance sheet of the bank at this point is

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

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,

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

Then, each firm starts with deposits $(1+i^D)\gamma\mathbb{D}$ 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

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

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 $\Phi_\gamma(\gamma_L)$.[13]

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

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

That is, the bank maintains its initial assets, A, and its interbank position, R, yet to be settled, while obtains the proceeds from the investment in public securities, $(1+i^B)B$ and pays the cost of borrowing reserves from the central bank, $(1+i^O)O$. On the liability side, firms keep the remaining deposits after loans are paid off, $(1+i^D)\gamma\mathbb{D}-(1+i^L)L$. To the initial capital, K, the bank then adds the remuneration of public securities and loans and

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

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

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

That is, the bank still obtains the proceeds from the investment in public securities, $(1+i^B)B$, together with 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. That is, the bank will remain solvent as long as

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

Notice we evaluate the possibility of insolvency only in the event that firms default on their loans. Insolvency in general will not happen otherwise.[14]

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 ($\gamma \geq \gamma_L$),

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

[14]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.

while if firms default ($\gamma < \gamma_L$),

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

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

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

$$E(K') = \mathbb{D}\left[G(\gamma_K) - (1+i^D)G(\gamma_L)\right] + \Pi(O, L) \tag{21}$$

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, purchase of public securities, B, and the supply of credit, L, to maximize expected net worth next period (21). Notice, choosing these three variables determines the reserve position, R, as defined in (13). The first order conditions with respect to O, B, and L are, respectively,

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

$$i^O = i^B, \tag{24}$$

and

$$(1 + i^L)[1 - \Phi(\gamma_L)] = (1 + i^O)[1 - \Phi(\gamma_K)]. \tag{25}$$

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. Expression (24) defines a perfectly elastic demand for public securities at the rate $i^O = i^B$. Thus, the amount of public securities purchased by banks is determined by how much transfers the government decides to allocate to workers and is assumed exogenous. Finally, expression (25) 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 other prices such as the deposit rate, i^D, the public debt rate, i^B, or 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 4 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 deposit rate.[15] We can see how supply is inelastic at the level of the official rate i^O which in this case equals 0.04 (or 4 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.

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

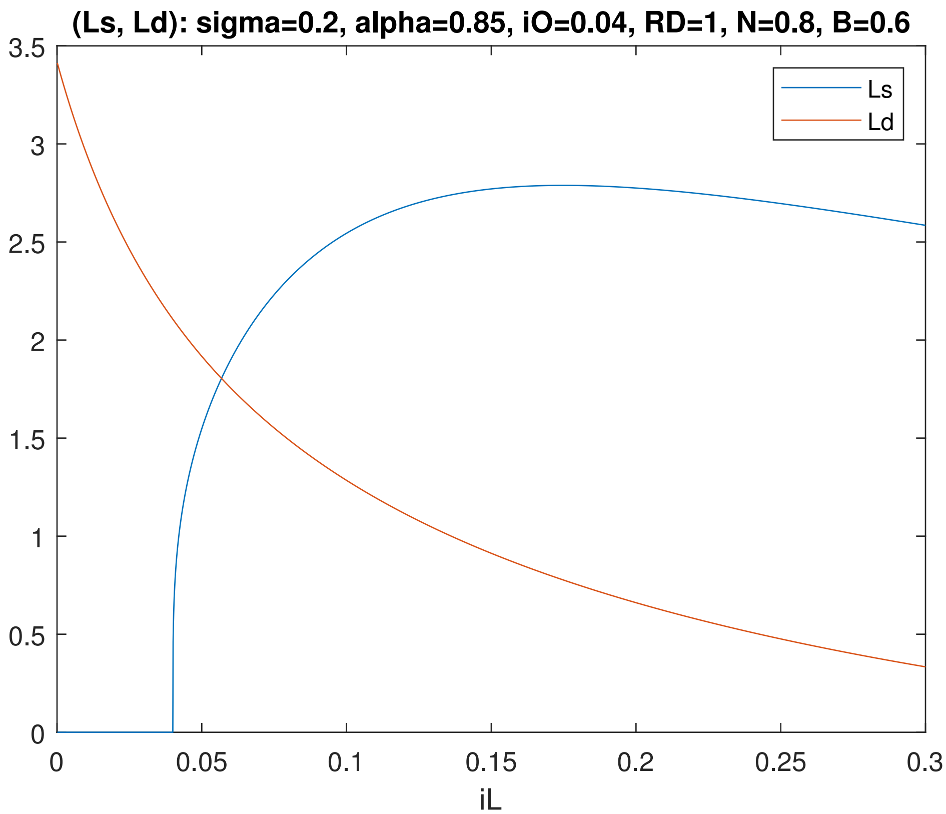

Figure 4: Loan supply and demand

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,[16] γ_R, 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, M and A, and liabilities, K and N, as well as the population value of deposits, $\mathbb{D}$, and prices, i^L, i^D, i^O, and i^B, 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 5. 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 5. 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 5. 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

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

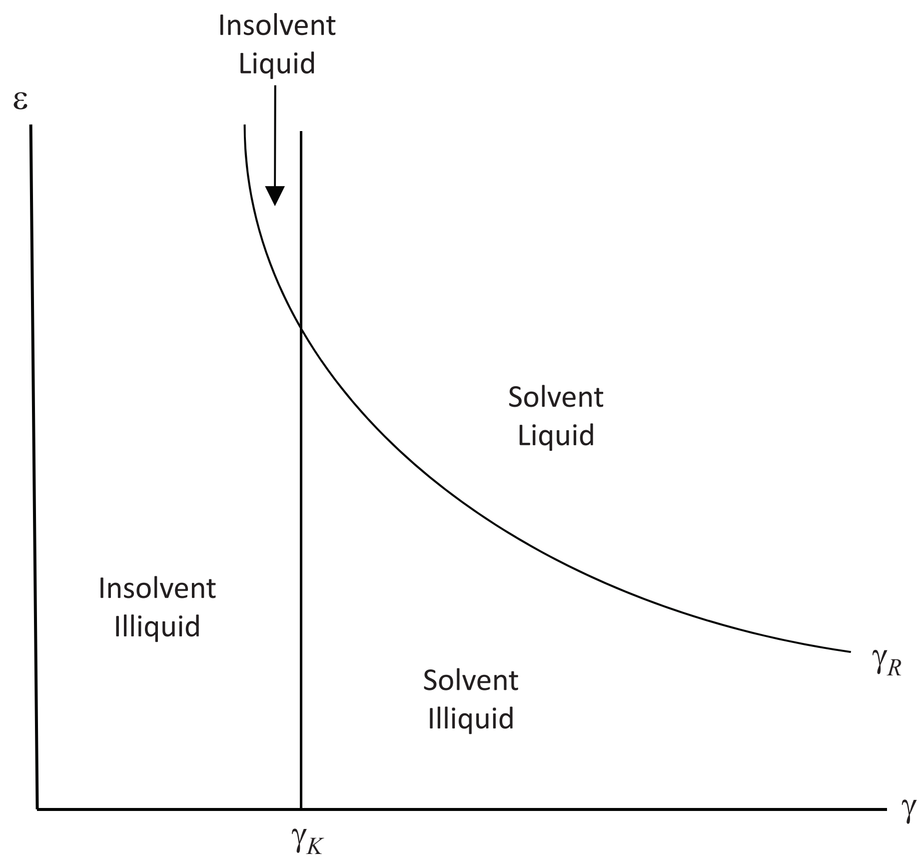

Figure 5: Solvency and liquidity risks

choices of a bank, expression (13) can be used to produce combinations of these two shocks 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

$$\gamma\epsilon = \frac{\bar{R} + D - O - M}{\mathbb{D}} = \frac{\bar{R}}{\mathbb{D}} + \gamma_R. \tag{26}$$

Figure 6 includes two of such schedules for two different negative levels for the reserve position of a bank, $\bar{R}_{low}$ and $\bar{R}_{high}$, such that $\left|\bar{R}_{low}\right| < \left|\bar{R}_{high}\right|$. Notice the schedule with the largest borrowing, $\bar{R}_{high}$, is below the one with banks borrowing less, $\bar{R}_{low}$. Furthermore, the section of these schedules in the region to the left of the vertical line associated with the value for γ_K, represent realizations of the shocks inducing the bank to be insolvent and, therefore, will imply a default on the interbank loan.

Then, the question for an interbank lender is: given the balance sheet of a borrowing bank (which is public information), what would be the likelihood that a loan of size $\bar{R}$ will get repaid, namely

$$prob\left(\gamma \geq \gamma_K | \bar{R}\right) = prob\left[\epsilon \leq \frac{1}{\gamma_K}\left(\frac{\bar{R}}{\mathbb{D}} + \gamma_R\right)\middle| \bar{R}\right] = \Phi_\epsilon\left[\frac{1}{\gamma_K}\left(\frac{\bar{R}}{\mathbb{D}} + \gamma_R\right)\right], \tag{27}$$

where this expression uses (26). 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

$$s(\bar{R}) = (1 + i^R)\frac{1 - \Phi_\epsilon\left[\frac{1}{\gamma_K}\left(\frac{\bar{R}}{\mathbb{D}} + \gamma_R\right)\right]}{\Phi_\epsilon\left[\frac{1}{\gamma_K}\left(\frac{\bar{R}}{\mathbb{D}} + \gamma_R\right)\right]}. \tag{28}$$

Grafically, the risk premium is proportional to the density associated with the segment of schedule (26) inside the insolvency area, that is, to the left of the level γ_K. That segment is marked in red in figure 6. 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,

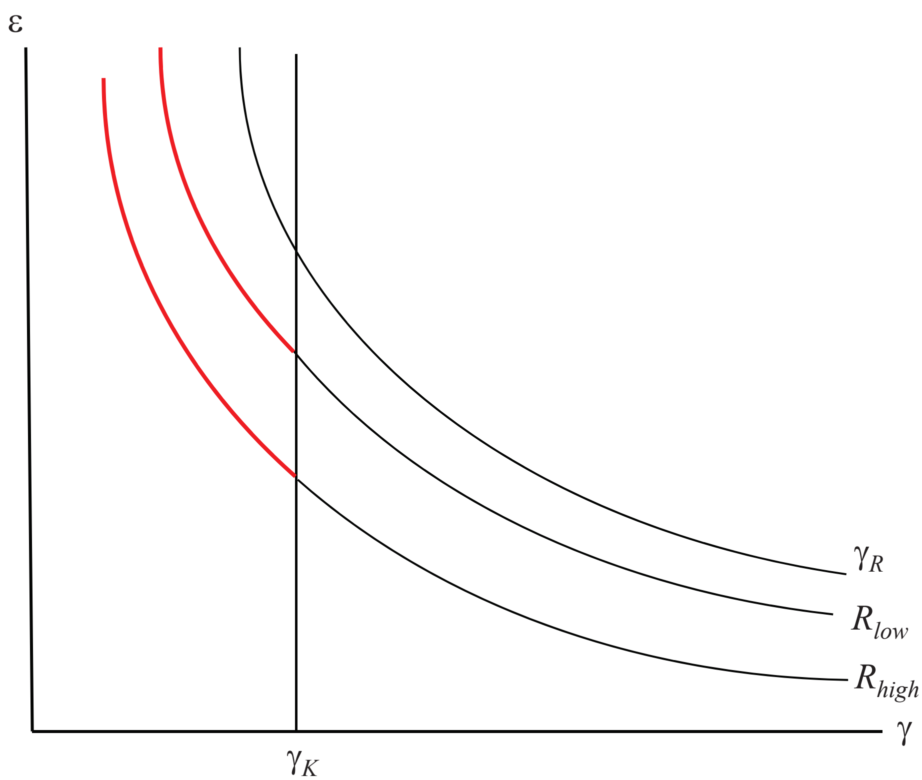

Figure 6: Different reserve positions

a larger risk premium. Similarly, other things equal, a bank with lower capital levels will face a higher threshold for solvency, γ_K. As a consequence, there is pressure for the risk premium, $s(R)$, to be larger too.[17]

3.4 Consolidation of balance sheets

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 belong to a conglomerate so that, after settling individual positions, they pool resources. 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

$$\mathbb{N}' = \mathbb{D}(1 + i^D)G(\gamma_L) - \mathbb{T}, \tag{29}$$

where $\mathbb{T}$ represents lump sum taxes charged on the aggregate profits of the firm conglomerate. Notice the resulting net worth of the conglomerate of firms is in the form of deposits in the bank. Also, because taxes are lump sum and paid by the conglomerate after pooling resources, individual firms do not take them into account when making decisions on labor demand and production.

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

$$\mathbb{M}' + \mathbb{A} = \mathbb{N}' + \mathbb{K}'. \tag{30}$$

In this expression

$$\mathbb{M}' = \mathbb{M} - (1 + i^O)\mathbb{O} + (1 + i^B)\mathbb{B} - \mathbb{T} - \mathbb{Q}, \tag{31}$$

and

$$\mathbb{K}' = \mathbb{D}\left[G(\gamma_K) - (1 + i^D)G(\gamma_L)\right] - \mathbb{Q}, \tag{32}$$

where, the function $G(\gamma)$ is defined in (20) and $\mathbb{N}'$ is defined in (29). In this expression, $\mathbb{Q}$ are lump sum taxes charged to the bank conglomerate. Banks are in charge of executing the payment of taxes for themselves and firms by using reserves.

The following period, the conglomerates allocate initial assets to each individual entrepreneur 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

[17] 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.

banks start with $K' = \mathbb{K}'$.

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 an infinitely elastic supply at the rate i^O. The fiscal authority sells public debt, B, to banks in exchange for deposits. This public debt pays the rate i^B. The government also levies taxes on firms and banks, $\mathbb{T}$ and $\mathbb{Q}$. The government budget constraint is then

$$(1 + i^O)\mathbb{O} + \mathbb{T} + \mathbb{Q} = (1 + i^B)\mathbb{B}, \tag{33}$$

where bold letters represent economy-wide values of the corresponding variable. Looking at (31) and (33), it must be the case that $\mathbb{M}' = \mathbb{M}$ so that reserves in the aggregate are constant. Furthermore, assume the government sets taxes on firms, $\mathbb{T}$, and banks, $\mathbb{Q}$ so that $\mathbb{N}' = \mathbb{N}$ and $\mathbb{K}' = \mathbb{K}$. This way, there are no dynamics in the balance sheets of firms and banks.[18]

3.6 Discussion

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

Given wages, W, prices of each good to be produced by the pool of entrepreneurs serviced by bank $j \in [0, 1]$, $P(j)$, market interest rates i^L, i^D, i^R, and i^B, as well as the official rate, i^O, workers decide on labor supply, h, and the consumption, c, they will buy from a randomly assigned entrepreneur. Entrepreneurs decide labor demand, H, loan demand, L^d, and output, y. Notice production decisions are taken before shocks are realized. On the other hand, each banker $j \in [0, 1]$ decides reserve demand, $O(j)$, bond demand, $B(j)$, and loan supply, $L^s(j)$. These choices, together with the realizations of the payment shocks γ and ϵ, determine the reserve position of each bank, $R(j)$.

Notice each worker contributes to the production of one good (that of the entrepreneur who hired her) but will consume from a different entrepreneur. Once all decisions are taken, consumption expenditure by workers would be unevenly distributed across firms and correlated within the pool of entrepreneurs serviced by each bank. This crucial assumption incorporates the idea that banks are not fully diversified in their credit risks. Because production

[18] In reality, balance sheets of banks present dynamics associated with choices and realization of shocks. However, our model concentrates on the origination of new loans and its connection to the financial risks banks face with respect these new loans. For this reason, we have focused on the static relation between risks and lending and leave the dynamics for future research.

is predetermined, a larger flow of payments generates larger revenues for the corresponding entrepreneurs who, 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.[19]

In this model, there are three important frictions we assume. First, firms have to pay labor when hiring, in advance of production. Second, workers are not able to effectively insure directly among each other against taste shocks. Third, entrepreneurs can only borrow from one bank. One can think of an economy where firms issue private IOUs to pay for labor. These IOUs could be redeemed later on for a portion of the output of the firm. Furthermore, we could also include a market where the IOUs from some entrepreneurs owned by a worker can be exchange with other workers to obtain goods from the entrepreneurs these workers want to buy goods from. However, because of the continuum of workers and entrepreneurs we can think finding the right person to trade 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 private IOUs and insurance. 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 entrepreneurs. Additionally, all these assumptions could be relaxed as long as banks are not fully diversified and maintain some credit risk associated with the random nature of the revenues of their borrowers.

Because payments are not coordinated among locations, the central bank produces the units of account, i.e. reserves, to keep track of payments among banks. A second level of frictions prevents these banks from effectively insure this payment uncertainty. We can also think that transaction, verificability or enforceability costs stops these insurance arrangements from happening. As with bank intermediation among agents in the real sector, the central bank offers a cheap and implementable alternative to keep track of trades between commercial banks by supplying units of account in the form of reserves.

We could complicate the model by adding the possibility that entrepreneurs and bankers consume too. Or by allowing workers to borrow or save. Or entrepreneurs borrowing from several banks. However, as long as these frictions mentioned above are in place, 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 entrepreneurs 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

[19] We can think of ϵ shocks as delays in the flow of payments as discussed in Copeland et al. [2025].

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 sort of frictions we want to reproduce with this model.

3.7 Equilibrium

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

$$h = H \tag{34}$$

for all workers and entrepreneurs where labor supply is given by (4) and labor demand by (9). Thus, output for every entrepreneur 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

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

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

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

implies

$$O(j) = -M.$$

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, the central bank drains initial reserves, M, with the initial OMO. Then, the threshold γ_R equals,

$$\gamma_R = \frac{D}{\mathbb{D}} = 1, \tag{38}$$

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

$$P(\gamma) = \gamma \frac{Wh + B}{h^{\alpha}}. \tag{39}$$

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

$$\gamma_L^d = \left(\frac{1 + i^L}{1 + i^D}\right) \frac{Wh - N}{Wh + B}. \tag{40}$$

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

$$\frac{\alpha}{1 - \Phi_{\gamma}(\gamma_L^d)} \int_{\gamma_L^d}^{\gamma_{max}} \gamma \Phi_{\gamma}(d\gamma) = \left(\frac{1 + i^L}{1 + i^D}\right) \frac{Wh}{Wh + B} \tag{41}$$

which implies a demand for credit of

$$L^d = Wh - N. \tag{42}$$

On the other hand, the loan supply of banks is

$$(1 + i^L)[1 - \Phi(\gamma_L^s)] = (1 + i^O)[1 - \Phi(\gamma_K)] \tag{43}$$

where the thresholds for banks are

$$\gamma_L^s = \left(\frac{1 + i^L}{1 + i^D}\right) \frac{L}{\mathbb{D}}, \tag{44}$$

and

$$\gamma_K = \frac{L - K + i^O O - i^B B}{\mathbb{D}}. \tag{45}$$

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.

Furthermore, we close the model assuming that at the beginning of the period, entrepreneurs could invest their initial funds, N, in bank capital, K, and bankers could do the opposite and invest bank capital as deposits in the firm. In order to prevent that, the expected return on both types of investments should be equalized, namely,

$$E(N') = E(K'), \tag{46}$$

where these returns are given by (8) and (21), respectively.

One last item has to do with default in the interbank market and aggregate returns on bank capital. 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. Because banks form a conglomerate in which they pool resources, ultimate residual claimants are interbank lenders.

4 Simulations

4.1 Calibration

The model contains only one parameter, two distributions, and a policy variable. These are the span of control, α, the distributions of shocks, $\Phi_\gamma(\gamma)$ and $\Phi_\epsilon(\epsilon)$, and the policy rate i^O. Furthermore, we have to provide a value for the initial funds of firms, $\mathbb{N}$, and banks, $\mathbb{K}$, as well as initial reserves $\mathbb{M}$, illiquid bank assets $\mathbb{A}$ and holdings of public securities $\mathbb{B}$.

We use the following values. For the span of control, we set $\alpha = 0.85$ as in Atkeson and Kehoe [2005]. Furthermore, we assume normal distribution functions for γ and ϵ. We fix the means of these distributions to be $\mu_\gamma = \mu_\epsilon = 1$. These means imply that, on average no funds enter or leave the banks. The standard deviations together with the initial balance sheet of banks are calibrated to match data for banks as follows. 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. Figure 7 shows quarterly data on this variable between 1986 and 2021 (the period with available data). The shaded areas correspond to recessions. Excluding the four recessions in the sample, the average for this indicator is 50 basis points.

We also use quarterly data from the Flow of funds accounts of the US to calibrate the initial 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 real data, we approximate ratios of the items included in the theory. In particular, we use data on loans to securities (L/B in the model), leverage (L/K in the model), and deposits to loans (D/L). The Appendix includes the details of these computations. Figure 8 shows these three series between 1986 and 2021, the same sample period as in figure 7. The averages of these ratios, excluding recessionary periods, are equal to 3.3, 7.3 and 1.2 for L/B, L/K, and D/L, respectively.

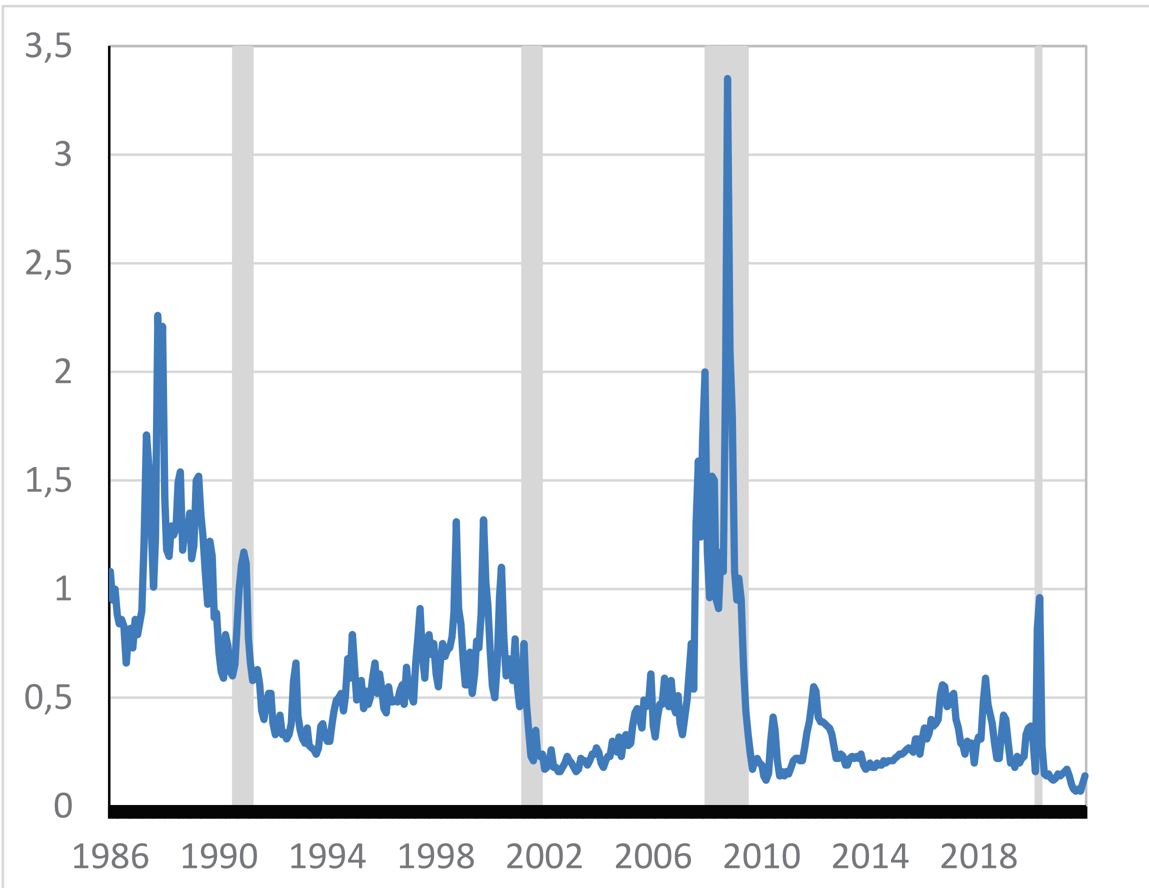

Figure 7: TED spread

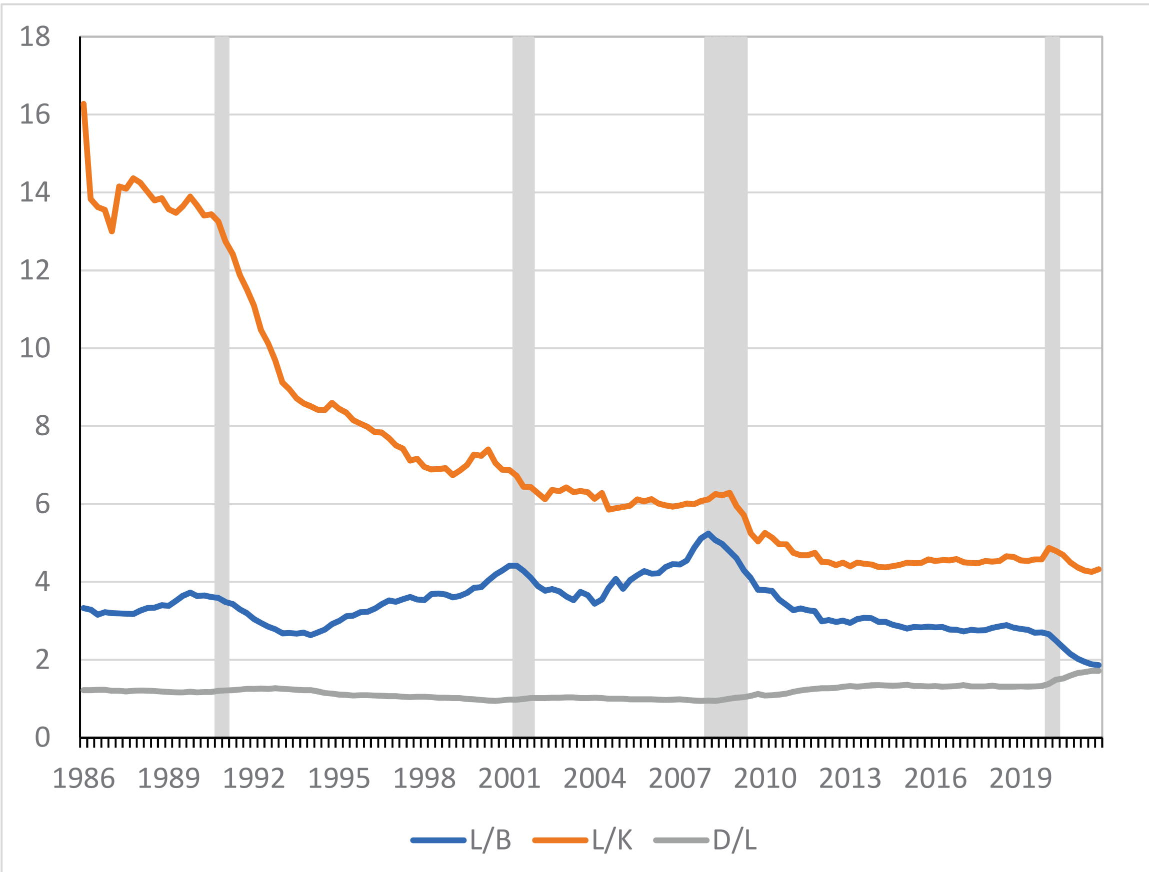

Figure 8: Ratios for the US banking sector

Regarding the initial balance sheet of banks, we impose $\mathbb{M} = 0$ since there are no required reserves in the model. We also normalize initial illiquid assets to be $\mathbb{A} = 1$ since the solution is neutral with respect to the value of this variable. On this matter, it is important to point out that there is an equilibrium for a continuum of splits of initial assets between firm funds, $\mathbb{N}$, and bank capital, $\mathbb{K}$, as long as their sum is constant. Of course, equilibria is different for different values of this portfolio. Because prices adjust so that the return on these two investments are equalized, the economy just sits on different equilibria depending on the initial split of these two investments.

In sum, we fix the standard deviations of the two shocks, σ_γ and σ_ϵ, together with the initial split between firm funds, $\mathbb{N}$, and bank capital, $\mathbb{K}$, as well as holdings of public securities, $\mathbb{N}$, to match the three ratios presented above and to have a risk premium in the interbank market similar to the TED spread. This implies $\sigma_\gamma = \sigma_\epsilon = 0.2$, $\mathbb{N} = 0.8$, $\mathbb{K} = 1 - \mathbb{N} = 0.2$, and $\mathbb{B} = 0.6$. In any case, none of the effects we show below depend qualitatively on these initial values.

4.2 Results

Figure 9 shows the resulting net interest margin in equilibrium, as measured by the difference between the lending and deposit rates together with the deposit spread, as measured by the difference between the deposit rate and the policy rate, for different values of the policy rate i^O between 1 percent and 10 percent. Figure 10 includes the corresponding amount of lending. As the policy rate increases, loan demand stays the same, but loan supply moves to the right, 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. The increase in the lending rate and the drop in the amount loaned makes that the pass-through to the deposit rate need not be as large as the pass-through to lending rates. As a result, the net interest margin of banks as well as the deposit spread with respect to the official rate widen.

As banks provide with less loans, deposits also decrease since deposits are equal to loans, L, which decrease with the rise in policy rates, plus two constants, $\mathbb{N}$ and $\mathbb{B}$. 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. However, our results show that the same correlation can be obtained with the reverse causation where it is changes in loan supply by banks what is driving the drop in deposits and the rise in the difference between deposit rates and official rates. As figure 11 shows, the ratio of lending to securities (L/B), leverage (L/K) and deposits to lending (D/L) align with the corresponding values for US data shown in figure

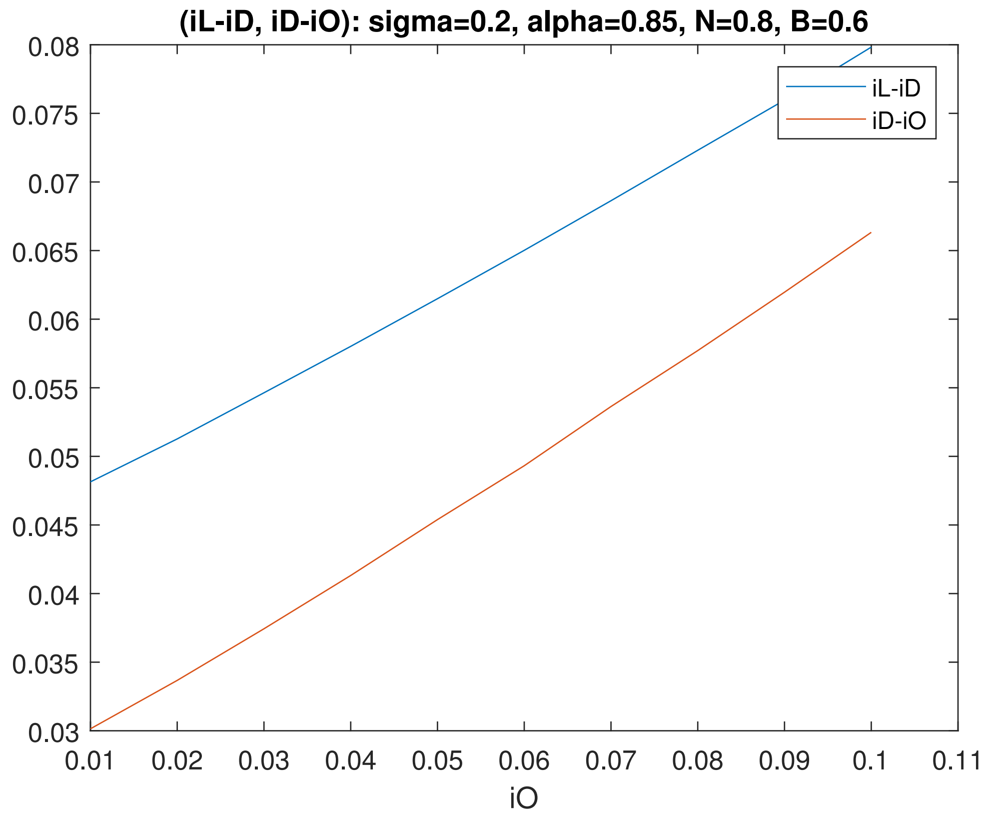

Figure 9: NIM and deposit spread

8. 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 12 and 13.

Furthermore, figure 14 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). The NPL moves around values of 2 percent while the size of bank insolvencies stays in the neighborhood of 0.5 percent. 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.[20] In our economy, this increase in risk is just a natural consequence of the expansion of credit by banks as the cost of funds decrease.

Figure 15 shows the percentage change drop in lending of an individual bank in response to an increase in the official rate i^O from 4 percent to 5 percent as a function of its capital. To

[20]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].

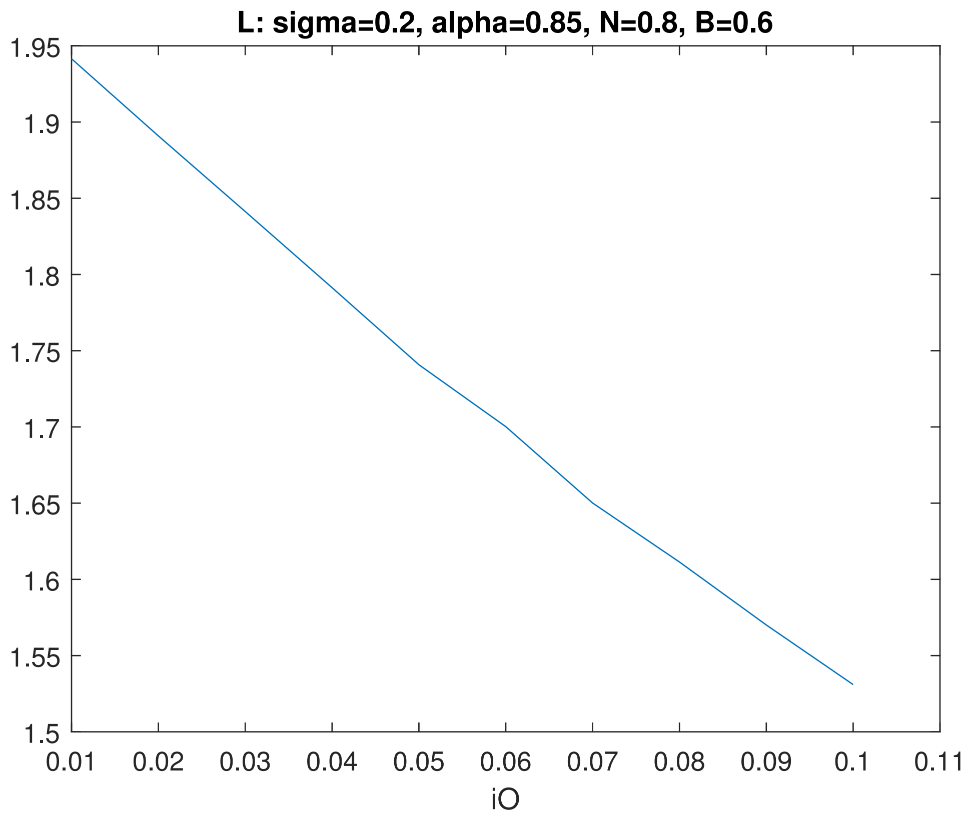

Figure 10: Amount of lending

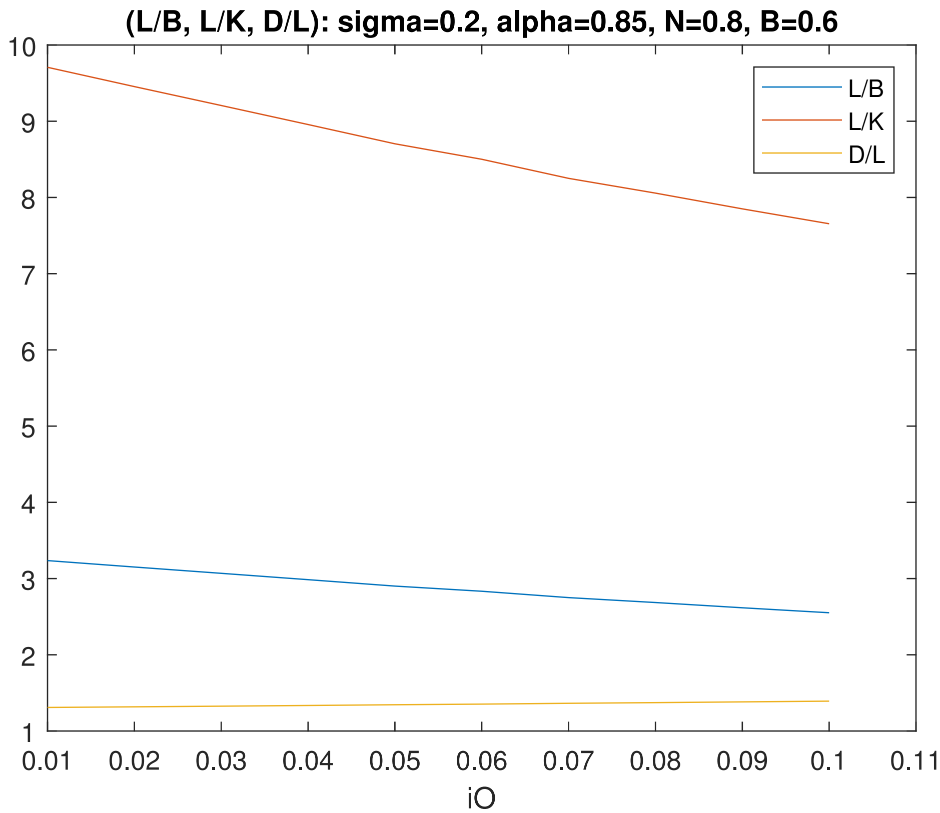

Figure 11: L/B, L/K and D/L ratios for banks in the model

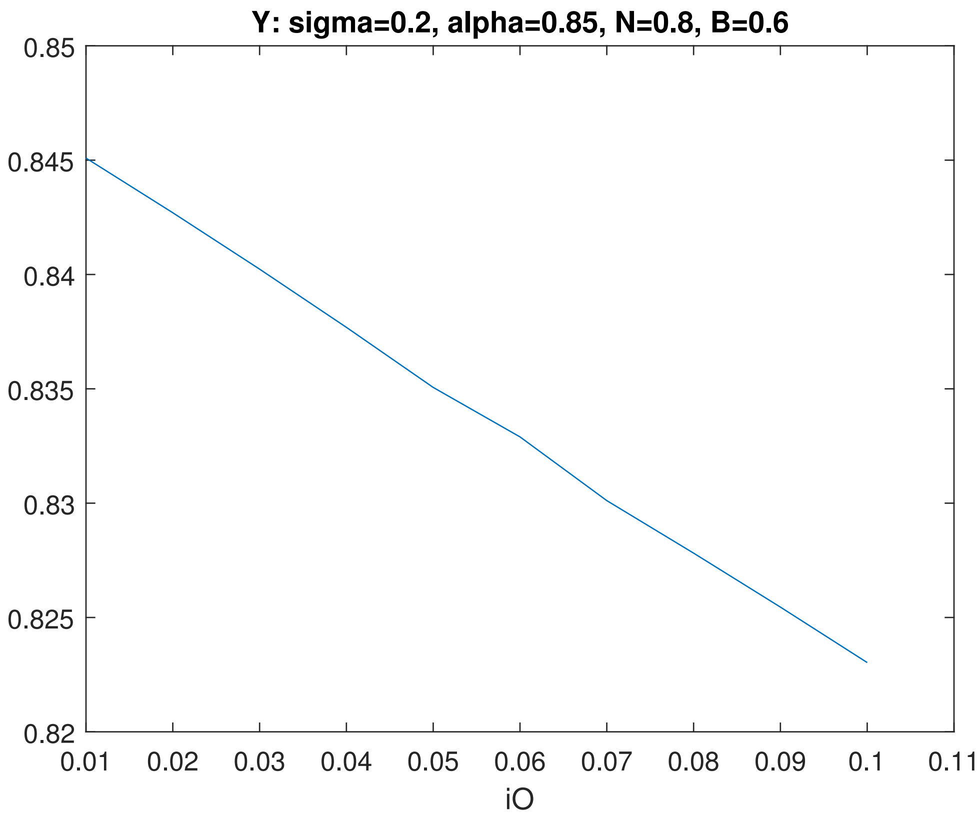

Figure 12: Output

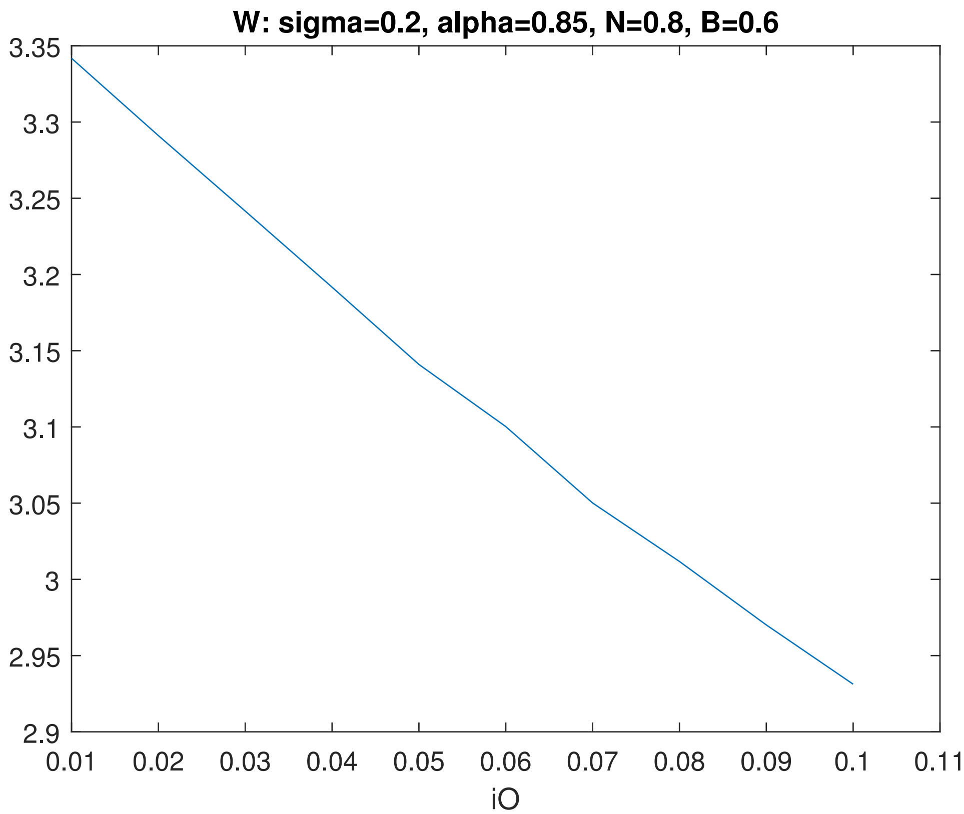

Figure 13: Wages

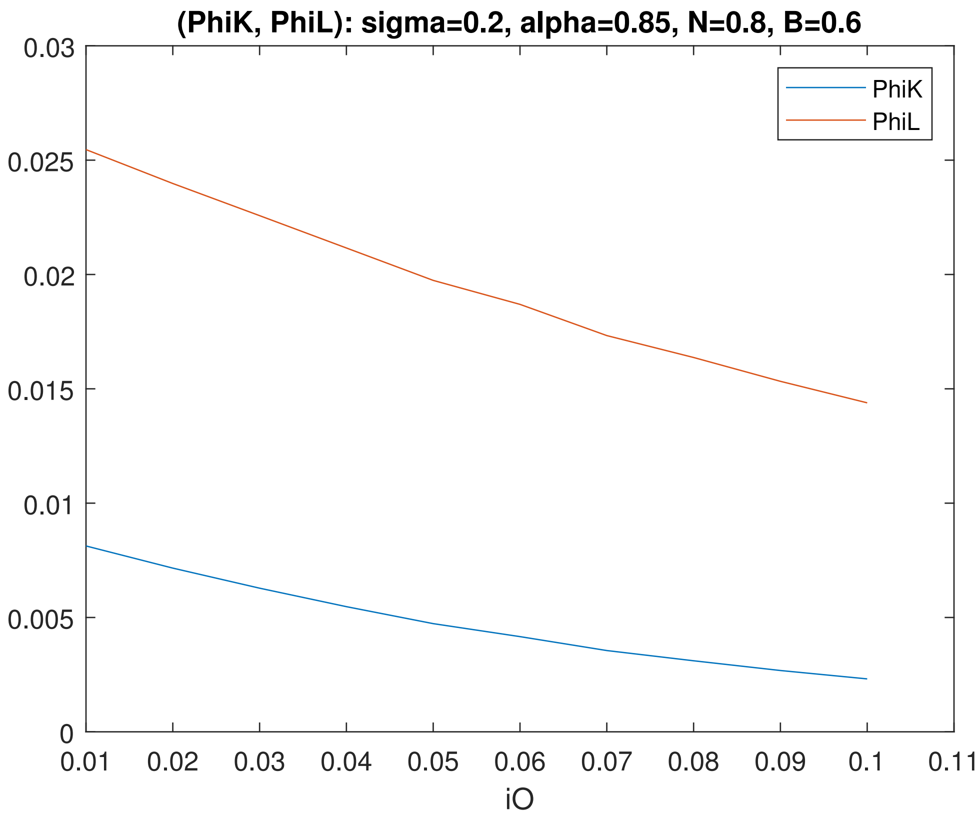

Figure 14: NPL ratios and fraction of insolvent banks

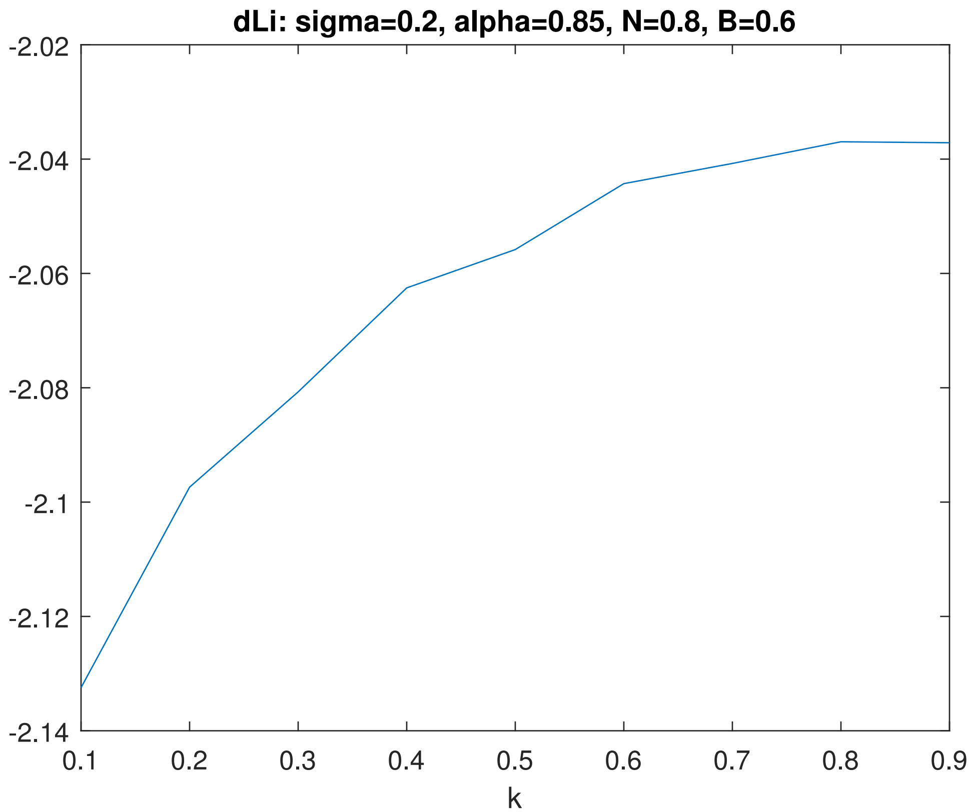

Figure 15: Changes in lending for different capital levels

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.

Finally, figure 16 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 (28) for different negative values of the reserve position R. These are the positions forcing banks to borrow in the interbank market. All computaions are done assuming a policy rate of 4 percent. As banks borrow more, the spread they have to pay over the interbank rate increases going from a few basis points to a maximum of 2.5 percent for very large demands of reserves. We also observe how this relation is nonlinear with spreads being proportionally

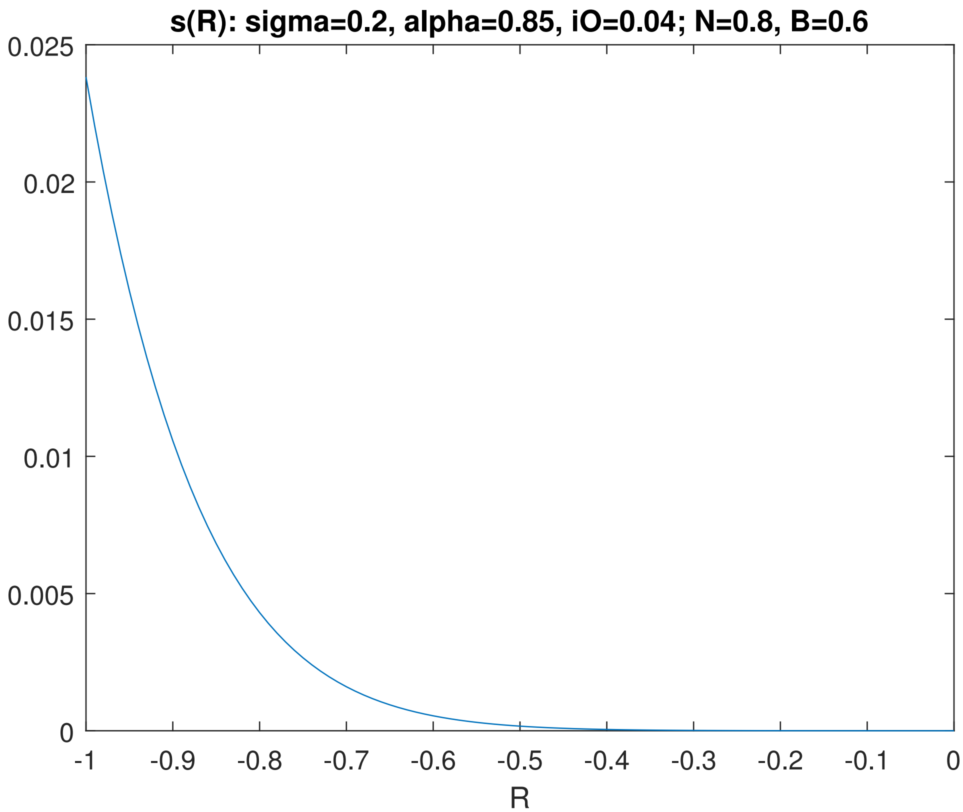

Figure 16: Risk spread in the interbank market

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.

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A Derivation of (21) and 22)

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

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

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 22).

B Data sources

Data for figures 1, 2 and 3 are computed as follows:

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.

The net interest margin shown in figure 3 is computed as the difference between the remuneration of loans minus the cost of deposits. For that, we use 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”).

The TED rate of figure 7 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. Data on recessions is also taken from that database as the NBER based Recession Indicators for the United States from the Period following the Peak through the Trough (with acronym USRECM).

Finally, for figure 8 we use table L111 of the Financial accounts of the United States (Z.1). 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). Capital (K) is represented by Total equity (FL763181105).