Universitat Autònoma de Barcelona

Three Essays on Financial Intermediation

David Rivero Leiva

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Universitat Autònoma de Barcelona

Doctoral Thesis

Three Essays on Financial Intermediation

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Dedicado a mis padres
José y María del Carmen.

Declaration of Authorship

I, David Rivero Leiva, declare that this thesis titled "Three Essays on Financial Intermediation", and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

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Summary

This Ph.D. thesis consists of three essays on financial intermediation, having the goal of contributing to the scientific discussion, and shed new light on the configuration of banking. The main orientation of this dissertation is theoretical. All three essays are connected in that they deal with important features related to the literature on financial intermediation.

Chapter 1 develops a model of financial intermediation to evaluate the impact of the monetary policy stance in the credit quality of loans extended in a bank-dependent economy. An important lesson from the Great Recession 2007-2009 is that the monetary policy stance may spur the risk appetite of the banking industry. This chapter explores the agency view of the so-called monetary policy risk-taking channel focusing on frictions in the lender-borrower relationship. Based on the costly state verification paradigm, I present a theoretical model with heterogeneous loan applicants and costly information acquisition in which financial intermediation activity is driven by a trade-off between processing information prior or after loan origination. Through changes in the diligence to determinate the credit standards, information processors shift the probability of the bankruptcy state and the riskiness in the composition of the pool of borrowers. Under this environment, a loose monetary policy decreases the diligence devoted by intermediaries to verify the creditworthiness of loan applicants, increasing the leverage of the non-financial sector. Moreover, it leads to a deterioration of the credit quality in the composition of the pool of borrowers which increases the likelihood of the bankruptcy state. All in all, I explore how a drop in interest rates spurs the risk-taking behavior at bank-firm level via endogeneous variations in their balance sheet strength. This study could be considered as a starting point for a more ambitious project in which to evaluate whether the easiness of lending standards is excessive or not, as well as its welfare implications.

Chapter 2 evaluates the role of Central Bank intermediation during solvency crises to restore the efficient allocation of capital in the economy when the interbank money market freezes. On the policy front, the tensions originated in financial markets after the bank run of Lehman Brothers required monetary authorities to go beyond conventional policy measures. To sustain financial intermediation activity in the interbank money market, Central Banks in advanced economies

implemented a variety of unconventional policies in line with its role of lender of last resort. To study how monetary authorities can replace the role of the extinguished interbank money market to allocate efficiently capital in the economy during systemic times, this chapter explores the subsidization of counterparty risk via credit policies. The basic idea is that Central Banks can intervene in the economy to reallocate savings to those banks with liquidity needs. When tensions in the money market arise due to the uncertainty about the solvency situation of specific counterparties, Central Banks can absorb the credit risk perceived in the market and subsidize the asymmetry in the marginal funding cost across regions. Using a credit policy, the monetary authority can absorb the excess of funds through the deposit facility, and reallocate it via a fixed-rate full allotment policy. Furthermore, different scenarios are simulated to illustrate the interaction of a larger Central Bank intermediation with the market allocation, and its implications for liquidity allocation.

A model of liquidity and fears about bank runs is presented in chapter 3. In this chapter I, along with Hugo Rodríguez, study self-fulfilling panics in a modern banking system wherein nominal deposit arrangements are designed as means of payment. In an economy exposed to pure liquidity risk with endogeneous money creation, we show that classical bank runs caused by panics do not occur. A relevant discussion about financial instability is whether the failure of banking institutions is driven by sudden panics that force solvent banks to fail, or it is reflected by the fundamental deterioration in bank specific variables. Based on the traditional liquidity problem of Diamond and Dybvig (1983), our framework incorporates three elements into the theoretical literature of bank runs. First, the chain of intermediation starts when borrowers need money to make payments. Once a loan is originated, the bank creates deposits that borrowers use as means of payments that circulate through the economy as broad money. Second, depositors withdraw money making electronic transfers to other banking institutions or when they decide to hoard cash. To offset this liquidity risk, banks manage a demand for reserves from the central bank. Third, the maturity mismatch between banks assets and liabilities is inherent to the creation of new loans, and the liquidation of bank assets implies the redistribution of future flows between market participants. Under such setting, there is a unique equilibrium with nominal contracts explained by price adjustments in the goods market. Unlike Diamond and Dybvig (1983), there is a price mechanism that adjusts the demand for consumption each period, making the real value of deposit contracts contingent on the mass of withdrawals. This result does not support the self-fulfilling hypothesis of bank runs.

Chapter 1

Information Acquisition, Agency Costs, and Risk-Taking Behavior

1.1 Introduction

There exists a strong link between short-term interest rates and bank risk appetite. The recent banking crisis has identified the easing of lending standards before the financial collapse of 2007 as one of the roots for the excessive accumulation of risk on bank's balance sheet.[1] A new strand of literature, called the *risk-taking channel of the monetary policy* (Borio and Zhu (2012)), has emerged to discuss the impact of monetary policy conditions on the willingness of market participants to absorb risk.[2] Recent studies like Jiménez et al. (2014) have tried to identify empirically this channel. Using a confidential credit register from Spain, their estimates suggest that lower overnight interest rates prior to loan origination lead banks to lend more to borrowers with a worse credit history. Ioannidou et al. (2015) exploit a Bolivian credit register to investigate how exogeneous changes in the monetary policy rate affect the quality of new loans. They find that lower interest rates foster the risk appetite of banks and increase the probability of granting lower quality borrowers. Consistent with these findings, Dell'Ariccia et al.

[1] Low short-term interest rates, high levels of securitization activity, and the lack of a proper prudential regulation are considered as the main factors that explain the softening of credit standards. For further details see Maddaloni and Peydró (2011).

[2] Prior to the financial turmoil the literature recognized competition as the main driving force for the cyclicality of credit standards. See Broecker (1990), Ruckes (2004), and Hauswald and Marquez (2006).

(2017) also present evidence of a negative association for ex-ante bank risk-taking and short-term interest rates in the U.S. banking system using data from lending surveys.

To identify bank risk-taking, the theoretical foundations in this area are based on an agency problem in the banking sector. Banks operating under limited liability will tend to absorb more risk than is socially optimal. The rationale of this mechanism is fundamented on the presence of government backed programmes, such as deposit insurance or the possibility of bank bailouts, which intensify the moral hazard problem between banks and their depositors since banks do not internalize the potential losses they impose on creditors.[3]

The aim of the present paper is to rationalize this agency view of risk-taking from a different angle, focusing on frictions in the lender-borrower relationship. The link between the monetary policy stance and lending standards can be explained from agency problems in the credit demand. Indeed, the expansion of non-performing loan contracts seems to support the idea that the large indebtedness of non-financial borrowers reported before the Great Recession can be related to the easing in the standards of credit and the softening of monetary conditions.

For this purpose, I develop a theoretical model of financial intermediation to characterize the conflict of interests faced by information processors when they intermediate in the credit market. I am primarily interested in the impact of short-term interest rates on the diligence devoted by financial intermediaries to verify the creditworthiness of loan applicants.

To study formally this point, I modify the financial contracting problem of Carlstrom and Fuerst (1997), based on the costly state verification (CSV) paradigm.[4] By adding an uncertain, idiosyncratic production technology with different expected returns to the pool of entrepreneurs, the model captures one of the essences of banking: the evaluation of whether potential borrowers satisfy some minimum standards of credit.[5] The novelty of this framework is that the pool of potential borrowers face a different creditworthiness, which introduces the importance

[3]This impact is more intense in less capitalized banks. See Adrian and Shin (2011) and Diamond and Rajan (2012), among others.

[4]The CSV model of Townsend (1979) is based on the presumption that firms observe the realization of their projects privately and have incentives to divert information.

[5]An assumption associated to the setup of Carlstrom and Fuerst (1997) comes from the *"empirical implausability of the implication that the bankruptcy probability is the same across entrepreneurs"*, as they state in their footnote 6, page 896. Considering that the pool of entrepreneurs is alike ex-ante, the role of financial managers is limited to monitoring functions, so they cannot take ex-ante decisions that affect to the magnitude of the agency friction.

of screening in the model. This consideration makes that financial intermediaries play an active role to sort loan applications and offset the magnitude of the agency problem in the economy.

Under this setting, intermediation activity is not only constrained by ex-post verification costs, but also by costs associated with the discrimination of loan applicants before the debt contract is formalized.[6] The coexistence of incomplete information about types, with the asymmetric information about stochastic realizations of projects reproduces a trade-off for bank decision making between processing information prior or after loan origination.

I refer to risk-taking as actions that increase the predisposition to accumulate or absorb risk. An advantage of this framework is that risk appetite behavior can be modeled in terms of the accuracy of the information processed before the extension of the loan contract. In other words, changes in credit standards are captured through variations in the screening strategy selected by the intermediary.[7] By choosing the accuracy of the information processed ex-ante, financial intermediaries determine the magnitude of the moral hazard problem in the economy. In particular, a weak diligence before loan origination deteriorates the allocation of credit in the economy, and increases the leveraging of the non-financial sector.

There are a few theoretical models that have considered the importance of agency frictions in the information processed by the financial intermediary sector. For instance, Dell'Ariccia and Marquez (2006) examine the strategic behavior of lenders to set the standards of credit. However, they focus on the size of adverse selection problems to determine the deterioration of bank portfolios. Assuming that bankers only know perfectly the characteristics of the proportion of borrowers reported by credit registers, they find that changes in the distribution of information about borrowers among banks shift lending standards. This mechanism relies on a switch between a separating and a pooling equilibrium. Another paper that takes into account the size of information acquisition in the credit market is Dell'Ariccia et al. (2014). They formalize the impact of interest rates in bank risk-taking through a model where banks only can monitor to reduce credit risk in their portfolios. An important contribution is that they are able to isolate the impact of the reference rate on bank risk-taking, but they do not capture ex-ante risk

[6] The first generation of banking models based on the delegated monitoring approach developed by Diamond (1984) and Diamond (1991) highlight the importance of financial intermediaries in bank-based systems as information collectors to solve informational problems. The present paper focuses explicitly on this role.

[7] The term lending or credit standards refers to all the elements affecting the credit decision, i.e. the criteria or rule by which banks determine the creditworthiness of the loan application.

appetite. They identify that banks change their risk taking behavior through two opposite channels: a risk-shifting incentive via bank's liability side, and a pass-through channel which operates through the asset side of bank's balance sheet, and take into account the importance of capital structures to consider the role of bank leverage. Martinez-Miera and Repullo (2017) study the relationship between real interest rates, credit spreads, and the risk of the banking system. Following the moral hazard setup of Holmstrom and Tirole (1997), they find that a fall in credit spreads reduces monitoring.

The model presented in this paper reproduces some interesting results. First, it sheds light about the trade-off faced by information processors when intermediate in bank-dependent economies. When loan officers take decisions about lending, they incorporate the inherent asymmetries that loan applicants present prior and after loan origination. The more accurate the screening to identify the best investment projects, the lower the moral hazard problem, and the fewer the deadweight losses associated to monitoring in the ex-post bankruptcy state. Second, the stance of monetary policy makes a direct influence on this trade-off. Changes in the reference rate shift the magnitude of the agency problem in the economy through variations in the information strategy. The model reproduces a direct link among the diligence to verify the creditworthiness of entrepreneurs, the quality in the composition of the pool of borrowers, and the riskiness of the credit demand. In particular, it captures how the monetary policy stance influences the strategic interaction between lenders and borrowers in the credit market to determine the optimal debt contract under which financial intermediaries economize the provision of financial services, and the pool of borrowers reveal truthfully the realization of their projects in the bankruptcy state.

The remaining of the paper is organized as follows. Section 1.2 describes the theoretical model. Section 1.3 explains the characterization of equilibrium in the credit market and shows how lending standards are determined through the strategic behavior of credit market participants. Section 1.4 talks about several determinants that contribute to the easing of lending standards in the economy. Finally, concluding remarks are included in Section 1.5.

1.2 The model

The basic setup is based on a modification of the partial equilibrium model with ex-post verification costs described in Carlstrom and Fuerst (1997). This section explains the incorporation of ex-ante heterogeneity and incomplete information about the distribution of investment projects into this setting. Then, the financial contract that solves the conflict among borrowers and lenders in the credit market is described.

1.2.1 The environment

Consider a static economy with two periods, $t = 0, 1$, inhabited by a pool of risk neutral entrepreneurs, savers, and financial intermediaries, each one with unit mass. Choices are taken ex-ante ($t = 0$), whereas production realizes ex-post ($t = 1$). Entrepreneurs, endowed initially with the same level of net worth, k, operate under limited liability and have access to a stochastic capital technology to transform i consumption goods at $t = 0$ into qiz units of capital in the next period, where z is a random variable which represents a idiosyncratic realization, and the parameter q denotes the price of capital.[8] To undertake the investment project, entrepreneurs have to raise external funds since $i - k > 0$.[9] The opportunity cost of implementing these business ideas is investing the initial net worth in a riskless asset with return kr, where r represents the reference or risk-free interest rate, which is set exogenously. Agency issues are introduced with the following assumption.

Assumption A1. Stochastic realizations of individual projects are privately observed by each capital producer when z realizes in $t = 1$.

I modify this standard moral hazard problem through two considerations. First, the quality of the production technology is different, which allows for ex-ante heterogeneity among loan applicants. A portion ϕ of entrepreneurs is endowed with a high capital technology denoted by θ_H, whereas the remaining fraction $(1 - \phi)$ have access to a low capital technology, θ_L. Moreover, there is a larger fraction of bad projects available in the economy, i.e. $\frac{(1-\phi)}{\phi} > 1$. Second, the portion of good projects, $\phi \in (0, 1)$, is perfectly observable by all economic agents at $t = 0$. However, they cannot verify if the entrepreneur is endowed with either a low or high quality technology without gathering information, which introduces incomplete information about the ex-ante distribution of projects, and incorporates the importance of screening in the model.

[8] In this paper I abstract from aggregate uncertainty, considering exclusively idiosyncratic risk.

[9] Hereafter, the terms capital producer or loan applicant are used to make reference of entrepreneurs.

Let Φ_L denote the c.d.f of θ_L, and Φ_H the c.d.f of θ_H, where $\forall z \in (0, \infty)$, $\Phi_n(z)$ is continuous and differentiable over a non-negative support, with $\Phi_n(0) = 0$ and $\Phi_n(\infty) = 1$, $\forall n \in \{L, H\}$. I write the density functions of Φ_L and Φ_H as φ_L and φ_H. I make the following assumption about the distribution of stochastic projects.[10]

Assumption A2. The ex-ante distribution of projects is such that:

i) The idiosyncratic disturbance z is i.i.d. across the pool of entrepreneurs as follows,

$$z \sim \begin{cases} \Phi_L & \text{if } \theta = \theta_L \\ \\ \Phi_H & \text{if } \theta = \theta_H. \end{cases}$$

ii) The continuum of projects differ in terms of expected returns, with $E(\theta_L) = \int_0^\infty z \mathrm{d}\Phi_L(z) = \underline{z} < 1$, and $E(\theta_H) = \int_0^\infty z \mathrm{d}\Phi_H(z) = 1$.

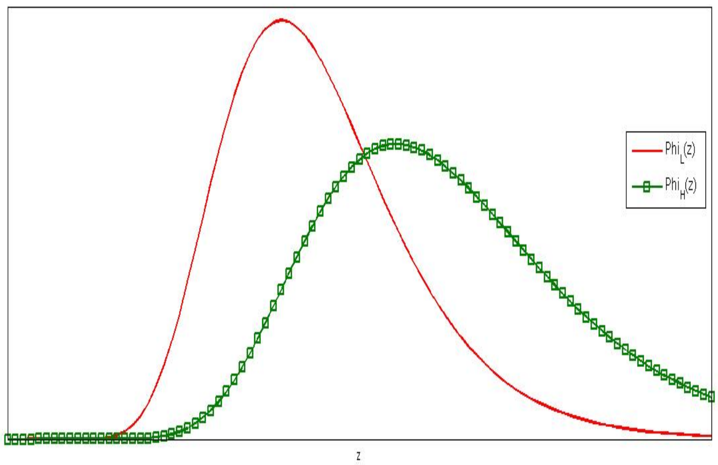


Figure 1.1: Distribution of projects

The first condition ensures a mixture distribution of projects such that $(1 - \phi)\int_0^\infty \mathrm{d}\Phi_L(z) + \phi\int_0^\infty \mathrm{d}\Phi_H(z) = 1$. Figure 1.1 depicts the differences between both technologies. Importantly, when the entrepreneur observes her realization, z, she does not know if it comes from the distribution function of a low, $\Phi_L(z)$, or

[10] Considering a degenerate distribution, e.g. with $\phi = 1$, then the financial contract is parallel to the partial equilibrium setting of Carlstrom and Fuerst (1997), and screening would not be required.

high capital technology, $\Phi_H(z)$. That is, she cannot recognize her type even after the ex-post realization of the idiosyncratic shock. The second condition guarantees that entrepreneurs face different creditworthiness, so investing the same inputs in both technologies does not report the same expected capital return. It introduces a stochastic ordering among projects since

$$\Phi_L(z) = \int_0^\infty \mathrm{d}\Phi_L(z) > \int_0^\infty \mathrm{d}\Phi_H(z) = \Phi_H(z).$$

In particular, note that low quality projects present a higher failure rate since

$$h_L(z) = \frac{\Phi'_L(z)}{1 - \Phi_L(z)} > \frac{\Phi'_H(z)}{1 - \Phi_H(z)} = h_H(z).$$

To make the agency friction relevant, entrepreneurs have to borrow funds. Savers, endowed initially with consumption goods, normalized to one, can invest in the uncertain risky business projects with the help of intermediaries. Otherwise, they do not have access to an information technology to discriminate the quality of the different investment projects.[11] Savings can be allocated through a competitive credit market in which each loan applicant is randomly matched with a large fraction of identical investment funds. Think about the figure of intermediaries as simple investment vehicles specialized in the acquisition of information on behalf of savers (Diamond (1984)).[12] They decide to intermediate in the economy and fund non-syndicated loans when information acquisition is economized. Financial managers have access to costly information technologies to verify the creditworthiness and realizations of loan applicants.[13]

1.2.2 The financial contracting

I focus on the contracting aspects of the agency relationship. The short-term contractual relation that formalizes the interaction among borrowers and lenders in the credit market is set through a standard debt contract. Loan applicants ask

[11]The role of savers in this model is trivial. I abstract from informational problems between depositors and lenders considering that intermediaries are able to elastically issue managed liabilities to fund risky loans. These deposits are repaid with probability one at the reference rate r, since there is not exist the possibility of bank run in equilibrium. To be clear, in the agency relationship considered throughout this paper the loan applicant is treated as an agent, and the information processor as a principal.

[12]In the rest of the paper, the terms financial managers, investment funds, and lenders are used indistinctly to make reference of financial intermediaries.

[13]A detailed explanation of the information technology is described in Section 1.3.1.

to raise external funds, $(i-k)>0$, and have to repay $R(i-k)$ at $t=1$, where $(i-k)$ is the loan size and R is the loan rate. A borrower succeeds whenever $qiz > R(i-k)$. From this financial arrangement, the minimum realization that the borrower has to obtain to avoid default is given by the cutoff value

$$\bar{z} = R(\frac{i-k}{i})\frac{1}{q}. \tag{1.1}$$

When borrowers fail to repay the loan obtained, i.e. $\forall z < \bar{z}$, financial intermediaries have to verify project's returns. Auditing the project destroys a fraction μ of the project's size i.[14] Let $\Lambda_L(\bar{z})$ and $\Lambda_H(\bar{z})$ be the gross share of rents appropiated by the lender from funding a low or high quality entrepreneur, with

$$\Lambda_n(\bar{z}) = \underbrace{\int_0^{\bar{z}} z\mathrm{d}\Phi_n(z)}_{rents\ from\ failure\ projects} + \underbrace{\bar{z}[1-\Phi_n(\bar{z})]}_{loan\ repayment}, \forall n \in \{L,H\}$$

and limiting properties

$$\lim_{\bar{z}\to 0}\Lambda_n(\bar{z}) = 0,\ \lim_{\bar{z}\to\infty}\Lambda_L(\bar{z}) < 1,\text{ and }\lim_{\bar{z}\to\infty}\Lambda_H(\bar{z}) = 1,$$

with $\Lambda_L^{'}(\bar{z}) = 1-\Phi_L(\bar{z}) < \Lambda_H^{'}(\bar{z}) = 1-\Phi_H(\bar{z})$.

Given an optimal debt contract, $\forall n \in \{L,H\}$, the expected returns for borrowers are specified as follows

$$qi\{\underbrace{\int_{\bar{z}}^{\infty} z\mathrm{d}\Phi_n(z)}_{succesful\ project} - \underbrace{\bar{z}[1-\Phi_n(\bar{z})]}_{loan\ return}\} = qi \underbrace{[1-\Lambda_n(\bar{z})]}_{surplus\ to\ borrowers},$$

whereas the expected capital income for the lender under such debt contract is given by

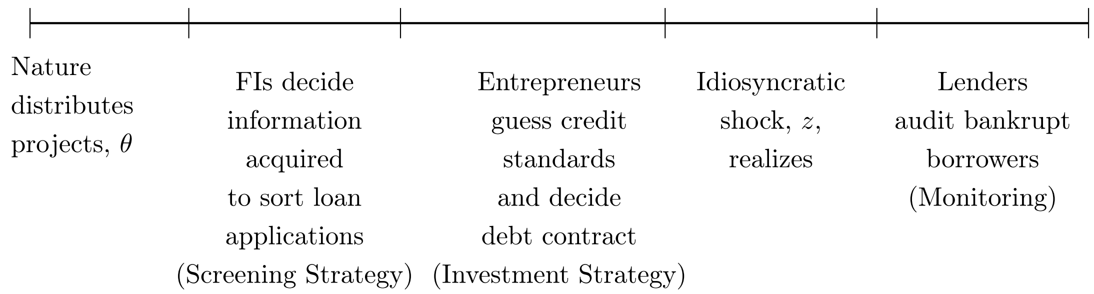
$$qi\underbrace{\{\Lambda_n(\bar{z}) - \mu\Phi_n(\bar{z})\}}_{net\ surplus\ to\ lenders}.$$

[14] Various assumptions can be made on the monitoring technology and timing of observations. For simplicity, I consider that ex-post realizations are perfectly observable using a deterministic technology which destroys a fraction μ of the project in line with Townsend (1979).

1.3 Information acquisition and credit market equilibrium

In this section I analyze the equilibrium in the credit market through the strategic interaction of lenders and borrowers. The timing of the game is described in Figure 1.2. The screening of projects is conducted at $t = 0$ to reduce the uncertainty about the initial distribution of projects. The lender decides the diligence to screen out the heterogeneous pool of potential borrowers, who infer the accuracy of the information collected by the intermediary to decide the demand for capital. The financial contract is solved backwards, and determines the lending standards derived for the optimal debt contract. Once production realizes at $t = 1$, each borrower observes her realization, and the intermediary audits, due to the agency problem, the mass of bankrupt entrepreneurs.

Figure 1.2: Timeline of Events



1.3.1 Screening strategy

Financial intermediaries manage a continuum of loan applications and have to decide whether funding the investment project is profitable or not. When solving this binary choice problem, they have the possibility to gather information and verify the quality of the application. The value of being informed ex-ante is that a lower fraction of riskier entrepreneurs would be granted, reducing the ex-post deadweight losses associated to monitoring.

To sort loan applications, lenders are endowed with a screening device.[15] By investing resources at $t = 0$, they are able to process signals, $s \in S$, that reveal information about borrowers' type. These signals are binary random variables which indicate whether the loan applicant is either a good or bad capital producer.

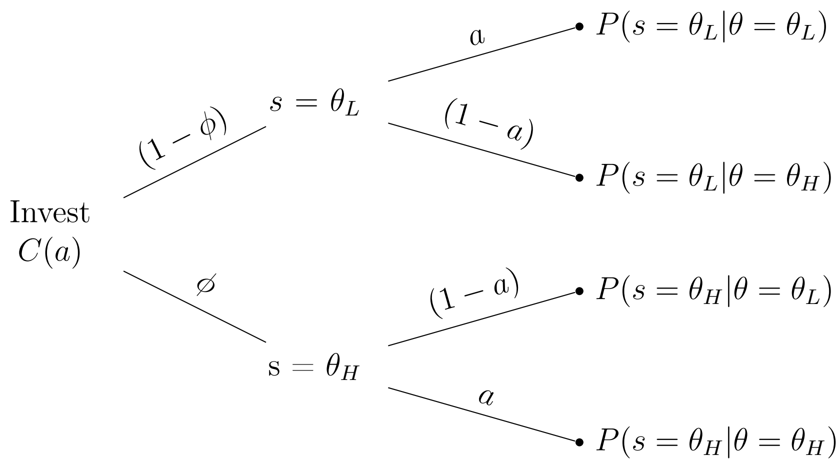
[15] This screening device can be thought as a technology to generate information with a different degree of accuracy that is used to infer the creditworthiness of loan applicants.

The lending rule is pretty simple: the lender accepts to extend credit when the signal processed indicates that the loan applicant is a good borrower. Otherwise, the loan proposal is rejected. The accuracy contained in each element of the signalling set S depends on $a \in [\frac{1}{2}, 1]$, which sets the diligence followed by the lender to verify the quality of loan applications,

$$a = P(s = \theta_H | \theta = \theta_H) = P(s = \theta_L | \theta = \theta_L), \tag{1.2}$$

i.e. it determines the probability of making a correct evaluation. The distribution of signals is represented in Figure 1.3.

FIGURE 1.3: Signaling Distribution



The cost derived from processing ex-ante information, $C(a)$, is described in the following assumption.

Assumption A3. The function $C(a)$ is such that,

i) $\forall a \in [\frac{1}{2}, 1]$, C(a) is strictly convex and increasing in a.

ii) C(a) is a C^2 class function, with $C'(\frac{1}{2}) = 0$, and $C'(1) = \infty$

I consider the following functional form for the screening cost function which fulfills with *A3*,

$$C(a) = \tau \frac{(\frac{1}{2} - a)^2}{(1 - a)}, \tag{1.3}$$

where the parameter τ represents the unit cost of screening. Following *A3*, it is clear that loan applications are never verified under perfect information because processing full informative signals is unfeasible.

According to the pieces of information collected, the financial intermediary is able to update beliefs and form a posterior knowledge. The set of posterior distributions, represented by $\Gamma(a)$, can be obtained from Bayes' Law,

$$\Gamma(a) = P_a(\theta = \theta_H | s = \theta_H) = \frac{a\phi}{a\phi + (1-a)(1-\phi)}, \tag{1.4}$$

which is an increasing function of the information processed by the lender, with

$$\lim_{a \to \frac{1}{2}} \Gamma(a) = \phi,$$

and

$$\lim_{a \to 1} \Gamma(a) = 1.$$

Thus, it is clear that prior and posterior beliefs only coincide when lenders do not acquire ex-ante information in the economy.[16]

A key characteristic in the behavior of financial intermediaries is that, by determining the accuracy of the signaling distribution, they choose the riskiness of its portfolio composition and, consequently, its risk-taking capacity. Note that the ex-post deadweight losses associated to monitoring are proportional to the bankruptcy probability of the pool of borrowers

$$B(a, \bar{z}) = \Gamma(a)\Phi_H(\bar{z}) + [1 - \Gamma(a)]\Phi_L(\bar{z}), \tag{1.5}$$

which represents the likelihood of the ex-post bankruptcy state and sets the size of the agency problem, with limiting properties

$$\lim\nolimits_{\bar{z} \to 0} B(a, \bar{z}) = 0,$$

$$\lim\nolimits_{\bar{z} \to \infty} B(a, \bar{z}) = 1,$$

and

$$\lim\nolimits_{a \to 1/2} B(a, \bar{z}) = (1 - \phi)\Phi_L(\bar{z}) + \phi\Phi_H(\bar{z}),$$

$$\lim\nolimits_{a \to 1} B(a, \bar{z}) = \Phi_H(\bar{z}).$$

[16]Note that the way that lenders have to attend the available information about borrowers' type is treated abstractly. First, they form a prior belief observing the probability of being of a particular type and, then, choose the amount of information that is processed to update such beliefs.

Let $\Pi(a,\bar{z})$ be the expected share of returns for the financial intermediary, described by

$$\Pi(a,\bar{z}) = \underbrace{[(1-\Gamma(a))]\Lambda_L(\bar{z}) + \Gamma(a)\Lambda_H(\bar{z})}_{gross\ share\ returns} - \underbrace{\mu B(a,\bar{z})}_{monitoring\ costs} .$$

The fraction of rents appropiated by the financial manager at $t = 1$ is strictly increasing in $a \in [\frac{1}{2}, 1)$ and $\bar{z} \in [0, \bar{z}^*)$, and decreasing for $\bar{z} \in [\bar{z}^*, \infty)$, with $\bar{z}^*$ indicating the maximum level for risk linked to the demand for capital from which the expected returns for the intermediary are decreasing.[17]

The lender's screening strategy is equivalent to decide the conditional probability a, i.e. it is based on probabilistic choices specified by the following problem,

$$V^F(i,\bar{z}) = \underset{a}{\text{Max}} \quad \underbrace{qi\Pi(a,\bar{z})}_{expected\ capital\ return} - \underbrace{(i-k)r}_{deposit\ repayment} - \underbrace{C(a)}_{screening\ cost} . \tag{1.6}$$

The optimal screening strategy chosen by the lender is given by the level of attention, a, that solves the following condition,

$$qi\underbrace{\Gamma'(a)\{\Lambda_H(\bar{z}) - \Lambda_L(\bar{z}) + \mu[\Phi_L(\bar{z}) - \Phi_H(\bar{z})]\}}_{\Pi'(a):\ marginal\ screening\ benefits} - \underbrace{C'(a)}_{mg.\ screening\ cost} = 0. \tag{1.7}$$

The optimal diligence, a, is implicitly defined in equation (1.7), and it is a function of the screening gains, measured by the distance among the marginal benefit of screening and the marginal cost of processing an additional unit of information.

Lemma 1. *The diligence to sort loan applications is an increasing function of the riskiness associated to the debt contract, $\bar{z}$.*

Proof. See Appendix A. □

Obviously, the quality in the composition of the pool of loan applicants has a direct impact on the cost of making a wrong evaluation. Given a demand for capital, the larger the default risk differential $\Phi_L(\bar{z}) - \Phi_H(\bar{z})$ among funding a low and high quality project, the more the incentives to process a tighter signaling distribution. Hence, it is clear that the amount of information acquired by the intermediary in the screening stage is driven by those factors that intensify the agency problem.

[17]Note that, in equilibrium, the financial intermediary cannot lend an infinite amount of funds to potential borrowers, i.e. $\forall \bar{z} \geq \bar{z}^*$ the loan applicant is rationed since the lender has no incentives to intermediate for such expected costs.

1.3.2 Investment strategy

Entrepreneurs know that their applications will be either accepted or rejected. The action of granting or rejecting a loan proposal sends information to potential borrowers about the information gathered by the financial institution. In addition, the entrepreneurs know that the accuracy of such information is increasing in a, but they cannot observe it directly. Thus, they infer the diligence devoted by information processors in equilibrium before deciding how much to invest in the uncertain project. Letting $\hat{a} \in [\frac{1}{2}, 1]$ denote the attention guessed by loan applicants, they design a menu of debt contracts for which the financial intermediary economizes the provision of financial services. Let $\Gamma(\hat{a})$ be the posterior knowledge of the financial intermediary guessed by the loan applicant, i.e. it is what the entrepreneur believes about what the lender knows about her, with

$$\Gamma(\hat{a}) = P_{\hat{a}}(\theta = \theta_H | s = \theta_H) = \frac{\hat{a}\phi}{\hat{a}\phi + (1-\hat{a})(1-\phi)}.$$

The entrepreneur's belief about the expected share of surplus acquired by the lender can be denoted as follows,

$$\Pi(\hat{a}, \bar{z}) = [1 - \Gamma(\hat{a})][\Lambda_L(\bar{z}) - \mu\Phi_L(\bar{z})] + \Gamma(\hat{a})[\Lambda_H(\bar{z}) - \mu\Phi_H(\bar{z})].$$

To formulate the investment strategy, I consider the following parametric expressions. Let $\eta = \frac{q}{r}$ be the discounted return to capital, and $\iota = \frac{i}{k}$ be the capital-wealth ratio, i.e. how much consumption goods are demanded by the entrepreneur given the initial level of net worth, k.[18]

Using this new notation, the contingent debt contract that specifies how surplus is split in the economy can be characterized as follows,

$$V^E(\hat{a}) = \underset{\{\iota, \bar{z}\}}{\text{Max}} \quad \eta\iota[(1-\phi)(1-\Lambda_L(\bar{z})) + \phi(1-\Lambda_H(\bar{z}))]\} \tag{1.8}$$

subject to:

$$\eta\iota\Pi(\hat{a}, \bar{z}) - (\iota - 1) - \frac{C(\hat{a})}{kr} \geq 0. \tag{1.9}$$

Loan applicants seek to maximize expected returns under uncertainty, considering the average return of having either a low or high quality project. The debt contract

[18] Note that a parametric condition is $\eta > 1$. Otherwise, loan applicants would have incentives to allocate the initial level of net worth, k, at the reference rate, r.

must compensate lenders for the costs of gathering information prior and after the extension of the loan contract. These costs of intermediation are reflected by the bank's participation constraint (1.9). Given a set of guesses, $\hat{a} \in [\frac{1}{2}, 1]$, the investment strategy designed by the entrepreneurs is defined by the first order conditions:

$$\eta(\bar{z}, \hat{a}) = \frac{\lambda(\bar{z}, \hat{a})}{(1-\phi)(1-\Lambda_L(\bar{z})) + \phi(1-\Lambda_H(\bar{z})) + \lambda(\bar{z}, \hat{a})\Pi(\bar{z}, \hat{a})}, \tag{1.10}$$

$$\iota(\bar{z}, \hat{a}) = \frac{[kr - C(\hat{a})]}{kr[1 - \eta\Pi(\bar{z}, \hat{a})]}, \tag{1.11}$$

and

$$\lambda(\bar{z}, \hat{a}) = \frac{1 - (1-\phi)\Phi_L(\bar{z}) - \phi\Phi_H(\bar{z})}{(1-\Gamma(\hat{a}))[1 - \Phi_L(\bar{z}) - \mu\varphi_L(\bar{z})] + \Gamma(\hat{a})[1 - \Phi_H(\bar{z}) - \mu\varphi_H(\bar{z})]}. \tag{1.12}$$

Equation (1.10) defines an implicit function to set the cutoff value $\bar{z}$ that determines the division of the surplus generated between borrowers and lenders. The amount of consumption goods demanded per unit of net worth, which sets entrepreneurs' indebtedness, is given by equation (1.11). Note that the capital-wealth ratio $\iota(\bar{z}, \hat{a})$ depends on the expected rents appropiated by the intermediary. The larger the guess about the information gathered ex-ante, the lower the rents going to the entrepreneur, and the lower her leverage incentives.

It is important to remark two observations about the investment strategy chosen by the capital producers. First, the optimal debt contract $(\bar{z}, \iota)$ binds the bank's participation constraint (1.9), which guarantees that all the surplus generated flow to entrepreneurs.[19] The agency friction allows the entrepreneur to appropiate all the rents from the intermediary, so they form a credit demand for which the net interest income of intermediation is equal to the cost of acquiring information. That is, whenever the marginal borrowing propensity $\lambda(\bar{z}, \hat{a})$ is positive, the debt contract designed by loan applicants satisfies the bank's zero profit condition.[20] Second, due to limited liability, entrepreneurs are willing to borrow funds indefinitely in equilibrium since their expected returns are unbounded above. In this

[19] I assume, following the literature on agency theory, that entrepreneurs have all the bargaining power in this economy when setting the financial contract.

[20] The marginal borrowing propensity is increasing in $\bar{z}$, and decreasing in $\hat{a}$, with $\lim_{\bar{z}\to 0} \lambda(\hat{a}, \bar{z}) = 1$, $\lim_{\bar{z}\to \bar{z}^*} \lambda(\hat{a}, \bar{z}) = \infty$. Moreover, can be observed that $\lim_{\hat{a}\to \frac{1}{2}} \lambda(\hat{a}, \bar{z}) > \lim_{\hat{a}\to 1} \lambda(\hat{a}, \bar{z})$.

sense, given the initial net worth, k, project's size $i(\bar{z}, \hat{a})$ sets the capital-wealth ratio and how the borrower is levered, where $\frac{i-k}{k} = \iota(\bar{z}, \hat{a}) - 1$ represents the leverage of capital producers with access to credit.

Lemma 2. *The demand for capital and borrowers' leverage is decreasing w.r.t guesses, $\hat{a}$.*

Proof. See Appendix A. □

The demand for capital responds strategically to changes in the information processed. It is clear that the larger the attention guessed, the lower the credit demand, and the lower the leverage is. Thus, the expected return for internal funds decreases as long as entrepreneurs believe that financial intermediaries collect more information to verify the creditworthiness of loan applications.

1.3.3 Market equilibrium

Once the strategic behavior of potential borrowers and lenders has been described, a formal definition of equilibrium in the credit market is provided to close out the model. To sum up, prior to loan origination, each agent takes optimal decisions. The debt contract that determines the distribution of rents among lenders and borrowers is solved backwards. Entrepreneurs decide the demand for capital according to the information collected by the lender to discriminate their applications. For each guess $\hat{a} \in [\frac{1}{2}, 1]$, potential borrowers design an individual debt contract, $\{\iota(\hat{a}), \bar{z}(\hat{a})\}$ with different default risk. Financial intermediaries decide the optimal diligence, $a \in [\frac{1}{2}, 1)$, to evaluate the creditworthiness of loan applications based on the riskiness associated to the demand for capital. Then, after loan origination the idiosyncratic shock, z, realizes and the investment fund monitors the fraction of bankrupt borrowers. As a result, a fraction μi of units of capital is destroyed.

Definition 1. *Lending standards are given by the triplet $\{i(\hat{a}), R(\hat{a}), a(\hat{a})\}$.*

A formal definition of equilibrium is described as follows.

Definition 2. *The credit market equilibrium is specified by a guess $\hat{a}^* \in [\frac{1}{2}, 1]$, and strategies $\{a(\hat{a}^*), \iota(\hat{a}^*), \bar{z}(\hat{a}^*)\}$, such that* *i) given an optimal screening $a(\hat{a}^*)$, the pair $\{\iota(\hat{a}^*), \bar{z}(\hat{a}^*)\}$ solves the expected optimization problem* (1.7) *for capital producers, i.e.*

$$\eta[\bar{z}(\hat{a}^*), \hat{a}^*] = \frac{\lambda[\bar{z}(\hat{a}^*), \hat{a}^*]}{(1-\phi)[1-\Lambda_L(\bar{z}(\hat{a}^*))] + \phi[1-\Lambda_H(\bar{z}(\hat{a}^*))] + \lambda[\bar{z}(\hat{a}^*), \hat{a}^*]\Pi[\bar{z}(\hat{a}^*), \hat{a}^*]}$$

and

$$\iota[\bar{z}(\hat{a}^*), \hat{a}^*] = \frac{[kr - C(a(\hat{a}^*))]}{kr[1-\eta\Pi(\bar{z}(\hat{a}^*), \hat{a}^*)]};$$

ii) given the debt contract $\{\iota(\hat{a}^*), \bar{z}(\hat{a}^*)\}$, the financial intermediary decides the optimal screening strategy, $a(\hat{a}^*)$, that maximizes problem (1.6)*, i.e.*

$$\Gamma'[a(\hat{a}^*)]\{\Lambda_H(\bar{z}(\hat{a}^*)) - \Lambda_L(\bar{z}(\hat{a}^*)) + \mu[\Phi_L(\bar{z}(\hat{a}^*)) - \Phi_H(\bar{z}(\hat{a}^*))] - \frac{C'[a(\hat{a}^*)]}{qi(\hat{a}^*)} = 0;$$

iii) the guess $\hat{a}^*$ is consistent with the optimal screening, $a(\hat{a}^*)$, such that $a(\hat{a}^*) - \hat{a}^* = 0$.

In equilibrium, the optimal debt contract determines the standards of credit that the pool of potential borrowers must fulfill, which include the price characteristics of the loan contract, $R(\hat{a})$, and the non-price characteristics, $i(\hat{a})$ and $a(\hat{a})$. It provides the proper incentives under which financial intermediaries economize the information acquisition from screening and monitoring. Moreover, it ensures that the mass of bankrupt borrowers always reveal the realization of failure projects in the bankruptcy state.

Proposition 1. *There exists a unique guess, $\hat{a}$, for which the debt contract, $\{\bar{z}(\hat{a}), \iota(\hat{a})\}$, clears the credit market such that $a(\hat{a}) = \hat{a}$.*

Proof. See Appendix A. □

The equilibrium in the credit market is fundamented by the common knowledge hypothesis.[21] In a rational expectations setting, the lending decision reveals information to loan applicants about what the financial intermediary knows about

[21] The concept of common knowledge is based on the idea that when two agents have the same priors and each obtains private information about an event, if each knows the posterior belief of the other, each knows that the other knows her beliefs, and so on, then these posteriors beliefs must be identical. See Aumann (1976), Milgrom (1981), and Milgrom and Stokey (1982). For a survey in this area see Geanakoplos (1992).

them, and the size and riskiness of the demand for capital reveals information to the financial intermediary about what the loan applicants guess about its diligence to discriminate applications. Figure 1.4 depicts the strategic interaction between lenders and potential borrowers that leads to the unique equilibrium in the credit market.

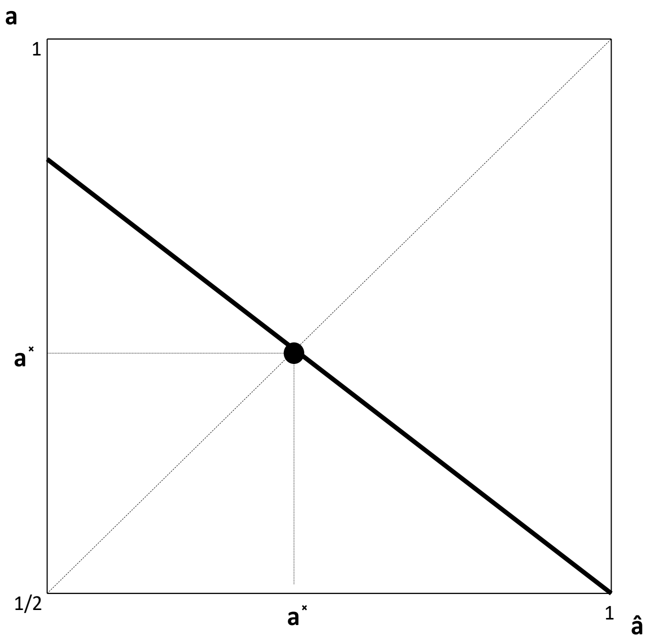


FIGURE 1.4: Credit Market Equilibrium

The posterior knowledge of the financial intermediary depends on prior beliefs, ϕ, and the attention devoted to sort loan applications, a, which is increasing in the demand for credit. At the same time, prior beliefs, ϕ, and the inference about the information gathered by the financial intermediary, $\hat{a}$, sets what the entrepreneur believes about what the lender knows about the quality of her investment project. Under common priors, loan applicants make revisions that converge to the common posterior knowledge $\Gamma(a^*) = \Gamma(\hat{a^*})$. Otherwise, the credit market does not clear since the information guessed by the loan applicant is inconsistent with the screening strategy selected by the financial intermediary. To illustrate the intuition of this equilibrium, assume that the loan applicant believes the attention of the intermediary is $\hat{a}_0$. Any debt contract $\{i(\hat{a}_0), \bar{z}(\hat{a}_0)\}$ associated to $\hat{a}_0 < a^*$ implies that the intermediary gathers more information than expected since $a_0 > a^* > \hat{a}_0$, i.e. $\Gamma(a_0) > \Gamma(\hat{a}_0)$. If it is the case, the fraction of the surplus appropiated by the financial intermediary is larger than the distribution of rents guessed by the entrepreneur for such debt contract since $\Pi(a_0, \bar{z}) > \Pi(\hat{a}_0, \bar{z})$. Similarly, a demand for capital associated to $\hat{a}_0 > a^* > a_0$ implies that the entrepreneur thinks the financial intermediary knows more about her than it actually does, so the credit market does not clear since $\Gamma(a_0) < \Gamma(\hat{a}_0)$ leads to $\Pi(a_0, \bar{z}) < \Pi(\hat{a}_0, \bar{z})$.

It is important to remark that, in equilibrium, financial intermediaries do not extract informational rents from using the screening technology at $t = 0$ since the event of granting a loan contract given that the entrepreneur is actually endowed with a high-quality business project is common knowledge, i.e. the attention, a, is indirectly observable by the pool of potential borrowers.

Hence, note that in equilibrium each set of screening strategies $a(\hat{a})$, and investment strategies $\{\iota(\hat{a}), \bar{z}(\hat{a})\}$ has associated an expected capital output given by

$$I[\hat{a}, k, q] = i(\hat{a})\{[1 - \Gamma(a(\hat{a})]E(\theta_L) + \Gamma(a(\hat{a})E(\theta_H) - \mu B(a(\hat{a}), \bar{z}(\hat{a}))\}. \quad (1.13)$$

This expected capital output is a function of the amount of assets intermediated, i, and the probability of the bankruptcy state, $B(a, \bar{z})$. Analogous to the agency-cost model of Carlstrom and Fuerst (1997), the supply curve for new capital depends positively on changes in net worth, k, and capital value, q. However, now it is also shifted with the information structure achieved in the economy. In particular, increases in the level of information acquired shift the supply curve to the right, i.e. $I_1[a(\hat{a}), k, q] > 0$, since more informative signals allows lenders to fund a lower portion of bankruptcy borrowers, decreasing ex-post deadweight losses. Consequently, it sheds light about the implications of poor screening strategies for the expected capital output generated in the economy.

1.4 Determinants of equilibrium

In practice, several factors can intensify the agency problem in a bank-dependent economy. So far, I have exposed the incentives to acquire information in the economy prior to loan origination as a mechanism to limit the deadweight losses implied by agency issues. A novel element of the modeling exposed above is that, in a heterogeneous economy, financial intermediaries take decisions that affect the magnitude of the agency problem, and by setting the accuracy of the signaling distribution, their risk appetite is determined. I focus below on a particular factor, the monetary policy stance, to explore its influence on the bankruptcy probability and the quality of assets' portfolio formed by lenders through changes in the amount of information processed in the market. In particular, section 1.4.1 studies endogeneous changes in the risk-taking behavior of credit market participants through variations in the monetary conditions.

1.4.1 Monetary conditions and risk-taking

In this section I study how changes in interest rates affect the risk-taking behavior of credit market participants. In particular, I deal with its impact on the risk composition of bank credit. The mechanism explored is similar to the one underlying the credit channel.[22] In a nutshell, the credit channel operates through the indirect impact that changes in interest rates have on the pricing for risk by affecting cash flows and profits. When the policy rate is reduced, the borrower's net worth increases, which stimulates the demand for investment. The increase in net worth also drops the expected default probability and, by reducing the incidence on verification costs, allows borrowers to take on more debt and expand the investment.

One limitation associated with the financial accelerator mechanism to evaluate risk-taking is that, by considering homogeneous investment projects, interest rates affect the quantity but not the quality of credit extended. In turn, this model deals with a balance sheet channel at the bank-firm level which enables to examine the impact of monetary conditions on the credit quality of the composition of the pool of borrowers. In particular, it allows to evaluate the impact of a loose monetary policy on lending standards through variations in the bank screening strategy.

To understand this mechanism, it is important to characterize, in first instance, how changes in the policy rate pass through short-term interest rates.

Lemma 3. *In equilibrium, the loan rate R is increasing in the policy rate r.*

Proof. See Appendix A. □

[22] See Bernanke and Gertler (1989), Bernanke and Gertler (1995), and Bernanke et al. (1996) for further details about the financial accelerator mechanism.

First I start with the impact of interest rates on firm's balance sheet. Due to limited liability, interest rates have an indirect implication in the demand for capital. Loan applicants rely on a mix of debt and own equity to implement their private investment projects. As the agency friction allows that all surplus flow to them, entrepreneurs always choose a debt contract for which the expected returns for internal funds are greater than one, i.e.

$$\eta\iota[(1-\phi)(1-\Lambda_L(\bar{z}))+\phi(1-\Lambda_H(\bar{z}))]>1.$$

Thus, it is clear that a softening in the monetary conditions spurs the incentives to be more levered, since it increases the return to capital, which is a function of $\eta(\bar{z},\hat{a})$. Note that the discounted return to capital is increasing in $\bar{z}\in(0,\bar{z}^*)$, and decreasing in $\hat{a}\in[\frac{1}{2},1]$, with $\eta_1(\bar{z},\hat{a})>0$, and $\eta_2(\bar{z},\hat{a})<0$. Formally, equation (1.9) allows to observe the relationship among $\bar{z}$ and η. By inverting this equation, note that the cutoff value $\bar{z}$ is a function of the discounted return to capital, $\eta=\frac{q}{r}$, i.e. $\bar{z}(\eta,\hat{a})$. In particular, it is increasing in η, with $\bar{z}^{'}(\eta)>0,\forall\eta\in(1,\eta^*)$, where η^* indicates the maximum return to capital for which the information processor is willing to intermediate in the economy. Taking limits,

$$\lim_{\bar{z}\to 0}\eta(\bar{z},\hat{a})=1;\lim_{\bar{z}\to\bar{z}^*}\eta(\bar{z},\hat{a})=\frac{1}{\Pi(\bar{z},\hat{a})}=\eta^*;\lim_{\bar{z}\to\infty}\eta(\bar{z},\hat{a})=\frac{1}{1-\mu},$$

and

$$\lim_{\hat{a}\to 1/2}\eta(\bar{z},\hat{a})>\lim_{\hat{a}\to 1}\eta(\bar{z},\hat{a}).$$

Hence, everything else equal, a drop in the policy rate exarcebates the moral hazard problem among loan applicants and intermediaries in the credit market, since the leverage capacity of entrepreneurs spurs with increments in the discounted return to capital, making the riskless alternative investment less attractive.

Now I turn to explore how, given the riskiness associated with the demand for capital, the softening of the monetary conditions lead to the easing in the standards of credit. To illustrate how this channel works, I consider an acommodative monetary policy. The risk-free interest rate, r, sets the cost of raising deposits from savers at retail level. A reduction in the policy rate allows to reduce the liability side of the lender, since gathering these funds is relatively cheaper after this change. However, in net terms, the expected returns from the debt contract must compensate the delegated monitoring role of the intermediary. Given a debt contract, borrowers have to return a loan rate at $t=1$ equivalent to

$$R = q\bar{z}\frac{\iota}{\iota-1}.$$

The pass through channel turns down loan rates, lowering the net expected returns from providing financial services. Rewriting the bank's problem in terms of the discounted return to capital, η, the optimal problem (1.6) can be expressed as follows,

$$\eta\iota\Pi(\bar{z},a) - (\iota - 1) - C(a)/kr,$$

and the optimal condition to determine the informativeness of the screening strategy is such that,

$$\Pi^{'}(\bar{z},a) = C^{'}(a)/qi.$$

Thus, it is clear that screening gains fluctuate with shifts in the monetary conditions. That is, the marginal benefit from screening,

$$\Pi^{'}(\bar{z},a) = \Gamma^{'}(a)\{\Lambda_H(\bar{z}) - \Lambda_L(\bar{z}) + \mu[\Phi_L(\bar{z}) - \Phi_H(\bar{z})]\}$$

is increasing in the loan rate, R, for all $\eta \in (1,\eta^{*})$.

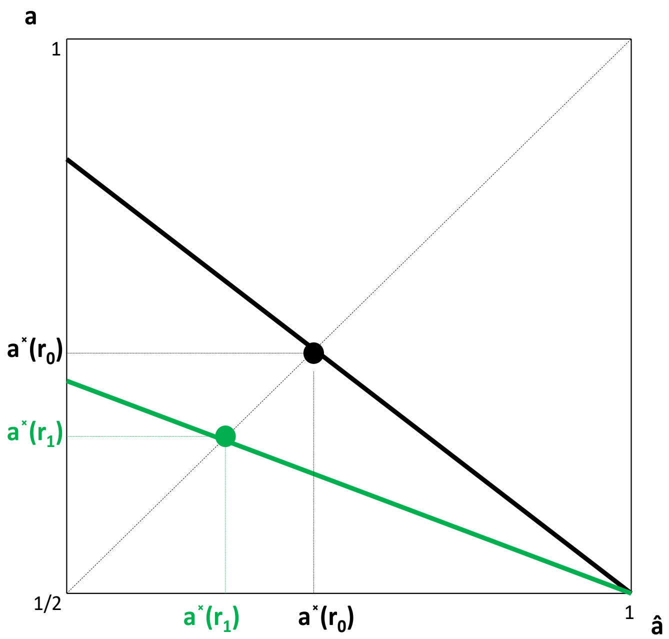


FIGURE 1.5: Softening Monetary Conditions

Figure 1.5 depicts this change. Hence, the decrease in loan rates reduces the net margin of intermediation and, subsequently, the incentives to be more attentive prior to loan origination. When interest rates are high, lenders have more incentives to screen out applicants and detect the most productive investment projects. However, as interest rates approach to its zero lower bound, the net margin of intermediation falls, reducing the attention allocated to verify borrower's type and granting a larger portion of low quality borrowers.

Consequently, a decrease in the policy rate leads to lower loan rates, higher leverage for entrepreneurs, and a riskier composition in the pool of borrowers through less screening. The economic intuition behind this mechanism is that the softening of the monetary policy conditions leads to the easing of lending standards, which contributes to a higher probability of the bankruptcy state.

1.5 Concluding remarks

An important lesson from the Great Recession 2007-2009 is that the monetary policy stance may spur the risk appetite of the banking industry. Recent empirical research on banking suggests that lending policies in periods of low interest rates can be consistent with the existence of a risk-taking channel of monetary policy in advanced economies. This paper explores the agency view of such channel focusing on frictions in the lender-borrower relationship. Based on the costly state verification paradigm, I present a theoretical model with heterogeneous loan applicants and costly information acquisition in which financial intermediation activity is driven by a trade-off between processing information prior and after loan origination. Under this environment, a loose monetary policy decreases the diligence devoted by intermediaries to verify the creditworthiness of loan applicants, increasing the leverage of the non-financial sector. Moreover, it leads to a deterioration of the credit quality in the composition of the pool of borrowers which increases the likelihood of the bankruptcy state.

To analyze the normative aspects of this framework, a natural extension for the approach developed in this paper is to embed this partial equilibrium into a general equilibrium setting to test the welfare implications of processing different information structures along the credit cycle. A particular question of interest is to evaluate whether the easing of lending standards is excessive or not. Financial crises can be seen as *credit booms gone wrong*, and the costs associated to controversial bank resolution policies could be amiliorated through effective and active due diligence policies. Hence, more emphasis in the supervision of the information processed in credit markets might be important to improve the allocation of assets in the economy, reduce households and fims leverage, and to promote financial stability.

Appendix A: Proofs

Lemma 1. The attention dedicated to discriminate loan applications is an increasing function of the riskiness associated to the demand for capital. For any $\bar{z} \in (0, \bar{z}^*)$,

$$\frac{da}{d\bar{z}} = qi\{\phi[\Lambda_H^{'}(\bar{z}) - \mu\Phi_H^{'}(\bar{z}) - (1-\phi)[\Lambda_L^{'}(\bar{z}) - \mu\Phi_L^{'}(\bar{z})]\}.$$

For any debt contract for which the expected margin of intermediation for the financial manager is non-negative, can be observed that a necessary condition to guarantee that information processors process more informative signaling distributions in response to a riskier demand for capital is

$$\frac{\Lambda_H^{'}(\bar{z}) - \mu\Phi_H^{'}(\bar{z})}{\Lambda_L^{'}(\bar{z}) - \mu\Phi_L^{'}(\bar{z})} > 1,$$

which satisfies since $\Phi_L(\bar{z}) > \Phi_H(\bar{z})$.

Lemma 2. The proof of Lemma 2 is straightforward. To show that the demand for capital is decreasing in $\hat{a}$, we need to test whether the larger the $\hat{a}$, the lower the i is. From equation 1.10 is easy to observe that

$$\frac{d\iota(\bar{z}, \hat{a})}{d\hat{a}} < 0.$$

Proposition 1. It is known that a^* is determined by the optimal condition for which $\Pi(a^*) = 0$. Let $\hat{a_a}$ and $\hat{a_b}$ be two guesses for which the information structure $a(\hat{a}) \in [\hat{a_a}, \hat{a_b}]$ is defined. We know that guesses are defined on the closed interval $\hat{a} \in [\frac{1}{2}, 1]$. For its lower bound, its associated debt contract $\{i(\hat{a_a} = \frac{1}{2}), \bar{z}(\hat{a_a} = \frac{1}{2})\}$ leads to an information structure $a(\hat{a_a} = \frac{1}{2})$ for which $\Pi(\hat{a_a} = \frac{1}{2}) > 0$, since $V'(\hat{a_a} = \frac{1}{2}) > 0$ and $C'(\hat{a_a} = \frac{1}{2}) = 0$. Thus, for $\hat{a_a} = \frac{1}{2}$ we observe that the lender has incentives to process a non-negative amount of information, and $a(\hat{a_a}) > \hat{a_a}$. Now, for its upper bound, $\hat{a_b} = 1$, the information structure $a(\hat{a_b})$ processed for the financial arrangement $\{i(\hat{a_b} = 1), \bar{z}(\hat{a_b} = 1)\}$ has associated negative screening gains, such that $a(\hat{a_b}) < 1$, since for such contract processing information is so costly that the lender has no incentives to process informative signals. Since $a(\hat{a})$ is a continuous function $\forall \hat{a} \in [\hat{a_a}, \hat{a_b}]$, then by the intermediate value theorem there exist an additional guess $\hat{a_c} \in [\hat{a_a}, \hat{a_b}]$ for which $a(\hat{a_c}) - \hat{a_c} = 0$, so there must be an alternative guess $\hat{a_c}$ for which a fixed point exist, and $a(\hat{a_c}) = \hat{a_c}$.

Lemma 3. The loan rate that borrowers have to return is given by $R = \bar{z}q\frac{\iota}{\iota-1)}$. From the optimal investment strategy of the loan applicant, it is known that the amount of consumption goods demanded is

$$\iota(\bar{z}, \hat{a}) = \frac{[kr - C(\hat{a})]}{kr[1 - \eta\Pi(\bar{z}, \hat{a})]}.$$

Replacing this equation into R, the following expression can be obtained,

$$R = \bar{z}q\{\frac{kr - C(\hat{a})}{kr\eta\Pi(\hat{a}, \bar{z})}\}.$$

Then, the positive relationship between policy rates and the loan interest rate can be directly observed,

$$\frac{dR}{dr} = \underbrace{\frac{k}{kr\eta\Pi(\hat{a}, \bar{z}) - C(\bar{a})}}_{>0} \underbrace{\{1 - \underbrace{\frac{\eta\Pi(\hat{a}, \bar{z})[kr - C(\hat{a})]}{kr\eta\Pi(\hat{a}, \bar{z}) - C(\hat{a})}}_{<1}\}}_{>0} \bar{z}q > 0.$$

Chapter 2

Central Banking and Money Market Freezes

2.1 Introduction

In this paper I evaluate the role of central bank intermediation during solvency crises to restore the efficient allocation of capital in the economy when the interbank money market freezes. The depth of the financial crisis of 2007 and its aftermath have called for unprecedent policy responses by monetary authorities worldwide that has shed new light on central bank's role in promoting financial stability. This intervention has raised again the important debate to what extent a price stability mandate is compatible with monetary policy decisions oriented to alleviate financial distress (Smets (2014)). In addition to the standard measures used to achieve price stability in the medium term, a set of non-standard tools were designed to be commensurate with the abnormal functioning of some market segments, namely to restore the transmission of the monetary policy, and to sustain financial intermediation in the money markets. For instance, according to the ECB these unusual actions were designed *"to mantain liquid markets, reduce systemic risk and, ultimately, restore stability in financial markets"*.

On the policy front, the tensions originated in financial markets after the bank run of Lehman Brothers required monetary authorities to go beyond conventional policy measures. To sustain financial intermediation activity in the interbank money market, central banks in advanced economies implemented a variety of unconventional policies in line with its role of lender of last resort (Bagehot (1873)). In particular, within the non-standard toolbox applied, credit policies were intended to replace the missing intermediation in the interbank market by increasing intermediation through the central bank.[1] The way to think of pure credit policy is a debt-financed fiscal policy. It works when the regulatory authority acts as a middle man between private borrowers and lenders in the market. In doing so, the authority uses its creditworthiness to facilitate the flow of funds in the economy and offsets illiquidity concerns.

To study how monetary authorities can replace the role of the extinguished interbank money market to allocate capital efficiently in the economy, I explore the subsidization of counterparty risk via the combination of credit and monetary policy. To do so, I incorporate explicitly the role of a monetary authority into the general equilibrium model of money market freezes of Bruche and Suarez (2010). The model is characterized by two specialized regions with different capabilities to attract deposits. Retail markets are segmented and banks are interconnected via a wholesale interbank money market. The basic premise is that money markets allow the transfering of liquid financial instruments with short-term maturities from regions with a liquidity surplus to those with liquidity needs. Counterparties negotiate terms bilaterally at wholesale level, exposing trading to credit risk. Frictions that undermine the efficiency of money markets, however, might provoke the lack of risk-sharing and the misallocation of capital in the economy. In such a case, resources do not travel to most productive regions and sectors, which has a direct impact on economic activity. Under such scenario, I show how the central bank can subsidize credit risk to restore the optimal risk-sharing across regions.

Following Bruche and Suarez (2010), the fundamental reason that breaks down the well functioning of the money market is the coexistence of solvency concerns and the asymmetric provision of a deposit insurance scheme at retail but not at wholesale level. The literature has identified, however, different roots that might help to explain the collapse in interbank money markets. In broad terms, two main factors explain the volatility observed in the volume of transactions in the money market. One set of theories are based on the asymmetric information problems among counterparties. Flannery (1996), Freixas and Jorge (2008), Malherbe (2014), and Heider et al. (2015) focus on adverse selection when investors cannot distinguish the credit risk exposure of counterparties. A second set of theories

[1] The distinction between monetary policy and credit policy was employed initially by Goodfriend and King (1987). See Goodfriend (2011) for an explicit classification of the core central banking initiatives. In broad terms, monetary policy refers to open market operations that expand or contract high-powered money (bank reserves and currency) by buying or selling Treasury securities. Credit policy shifts the composition of central bank assets, holding their total fixed. Interest on reserves policy involves adjusting interest paid on bank reserves to influence the level of short-term interest rates.

focuses on the incentives of the banking system to hoard liquidity as the main root that justifies the freeze of the interbank market. The intuition of Caballero and Krishnamurthy (2008), and Gale and Yorulmazer (2013) is that banks prefer to hold liquidity even when lending to high-quality counterparties is possible. The reason is that financial institutions follow a precautionary behavior and accumulate liquid assets in anticipation of future liquidity needs or higher volatility and uncertainty in the market. In a similar way, Acharya et al. (2011) describe the market freeze as resulting from the lack of arrival of good news about the fundamental value of the debt. They emphasize the need to address the problem of rollover risk in short-term financing of long-term assets in order to avoid the financial instability observed during the crisis of 2007. In line with this discussion, Afonso et al. (2011) study the disruptions in the United States interbank market after the bankruptcy of Lehman Brothers, and observe that counterparty risk plays a larger role than does liquidity hoarding. Moreover, they observe a partial, but not complete collapse of the federal funds market in the United States.

In addition to the causes that freeze money markets, a parallel strand of literature has studied the optimal response of the monetary authorities to undermine frictions in interbank markets. The seminal work of Bhattacharya and Gale (2011) explains from a mechanism design perspective the role of central bank for risk-sharing across banks that are subject to privately observed liquidity shocks. Allen et al. (2009) develop a model with an incomplete interbank market in which a central bank can implement open market operations to fix the short term interest rate in which banks hoard liquidity and reduce their lending between them for a large uncertainty about aggregate liquidity demand compared to idiosyncratic liquidity demand. Following this tradition, Freixas et al. (2011) provide microfoundations for the interbank market role for allocating liquidity. They state that because the inelasticity of the short-term market for liquidity assets, the central bank can set an optimal equilibrium from a set of equilibria by setting the interest rate in the interbank market appropiately. The small contribution of the present paper to this strand of literature is that central banks can intervene in the economy to reallocate savings to those banks with liquidity needs. When tensions in the money market arise due to the uncertainty about the solvency situation of specific counterparties, central banks can absorb the credit risk perceived in the market and subsidize the asymmetry in the marginal funding cost across regions. Using a combination of monetary policy and credit policy, the monetary authority can absorb the excess of funds through the deposit facility, and reallocate it via a fixed-rate full allotment policy.[2] To see the implications of the central bank intervention, I simulate different scenarios in which the monetary authority can implement policies that achieve superior liquidity allocations when interbank trading in the money market falls. As in Bruche and Suarez (2010), a level of systemic risk close to 3% is sufficient to collapse the money market. In such situation, the numerical example suggests that the central bank can implement a full-allotment policy setting a close to zero spread for the facilities provided in order to absorb counterparty risk and improve the market allocation when the money market is either stressed or frozen.

The rest of the paper is organized as follows. Section 2.2 describes the behavior of the different agents that interact in the model. In section 2.3 the equilibrium of the economy is characterized, focusing on the existing relationship between the financial and non-financial sector. Moreover, the characterization of interbank equilibrium for different levels of counterparty risk is analyzed, as well as the efficient central bank intervention during a solvency crisis. Section 2.4 is devoted to the numerical simulation. Finally, section 2.5 concludes.

2.2 The model

The model follows heavily the core framework developed by Bruche and Suarez (2010). There are two dates $t = 0, 1$. The economy is inhabited by a continuum of regions $j \in J = [0, 1]$ with measure one and different savings, where retail financial markets are regionally segmented, and there is a deposit insurance programme at retail level. Each region j is inhabited by a representative household, a continuum $i \in I = [0, 1]$ of non-financial firms with investment opportunities in the region, and a representative financial firm.[3] All of them are risk-neutral agents. In addition, a central bank operates at supraregional level. Its aim is to supervise the efficient allocation of liquidity in the economy. Regions are interconnected through an unsecured wholesale money market where financial intermediaries can demand and supply liquidity.

[2] Indeed, on January 2012 the president of the ECB Mario Draghi exposed that *"in terms of this roundtrip redeposit in the deposit facility, it is actually quite interesting to see that, by and large, the banks that have borrowed the money from the ECB are not the same as those that are depositing the money with the deposit facility of the ECB"*.

[3] In this paper I use the terms bank and financial intermediary indistinctly.

2.2.1 The households

All households receive at $t = 0$ an initial endowment S_j. Because of market segmentation, each representative household in region j is matched with a financial intermediary in the same region. They start at $t = 0$ with the given level of endowment S_j, and seek to maximize their expected net worth at $t = 1$. To do so, they deposit their savings in the bank in form of retail deposits, d_j, which are fully insured by the government, and provide equity, e_j, to her financial intermediary as shareholders. This is the only way of transferring wealth from $t = 0$ to $t = 1$. Thus, the exogeneous initial savings must be equal to the funds that they can provide to financial intermediaries in each region j. That is,

$$S_j = d_j + e_j. \tag{2.1}$$

Regions differ in terms of the initial endowment of savings. A fraction π of regions is cash-rich, S_H, whereas the remaining portion $(1 - \pi)$ is cash-poor, S_L, with $S_H > S_L$. The total amount of savings for the whole economy is set exogenously as

$$\bar{S} \equiv \pi S_H + (1 - \pi) S_L. \tag{2.2}$$

2.2.2 Non-financial firms

Each firm $i \in I = [0, 1]$ is managed by an entrepreneur who needs to obtain funds at $t = 0$ to finance her investement project. All the investment opportunities are homogeneous for each region j since all of them are equally profitable. Firms operate under an identical technology with constant returns to scale that transforms capital, k_{ij}, at $t = 0$ into units of consumption goods at $t = 1$ as follows,[4]

$$y_{ij} = z_{ij}[AF(k_{ij}) + (1 - \delta)k_{ij}] + (1 - z_{ij})(1 - \lambda)k_{ij}, \tag{2.3}$$

where $F(k_{ij}) = k_{ij}^{\alpha}$, $\alpha \in (0, 1)$, δ and λ represent the rates at which capital depreciates when the firm's project succeeds or fails respectively, and z_{ij} is a

[4]For simplicity, I assume that there is no labor in the economy. Moreover, the technology A is constant and equal across regions.

binary variable specified as follows,

$$z_{ij} = \begin{cases} 0 & \text{if firm } i \text{ fails} \\ 1 & \text{if firm } i \text{ succeeds.} \end{cases} \tag{2.4}$$

Notice that the second term of expression (2.3) reflects the physical capital that firm i owns, which could be interpreted as the bank's recovery in case of default.

Firms in region j can default in two different ways at $t = 1$. First, in the non-systemic state (normal times), which happens with probability $(1-\epsilon)$, non-financial corporations fail idiosyncratically with probability $p > 0$. Second, in the systemic state, which occurs with probability $\epsilon \in [0, 1]$, firms fail simultaneously with a default rate equal to one. By the law of large numbers, the distribution of the fraction of failing firms in region j is given as follows

$$x_j = \begin{cases} p & \text{with probability} \quad (1-\epsilon) \\ 1 & \text{with probability} \quad \epsilon. \end{cases} \tag{2.5}$$

The aim of entrepreneurs is to maximize their expected net worth at $t = 1$. They have no initial resources at $t = 0$, and need to borrow funds from the financial intermediary located in the same region to finance their activity. They use the loan l_{ij} to pay in advance for the inputs used at $t = 0$, where the size of the loan contract is $l_{ij} = k_{ij}$. In return of such loan, the promise of repayment will be equal to $l_{ij}R_{ij}$ if the firm succeeds, or to the collateral $(1-\lambda)k_{ij}$ if it fails.[5]

2.2.3 Central bank

There is a central bank that operates at supraregional level. Its aim is to preserve financial stability in the economy. To guarantee the efficient allocation of capital across regions, it intermediates in the economy during turbulent times to hedge the consequences of variations in counterparty risk. I consider that an active intermediation of the monetary authority in the economy is channeled through two tools. One set of activities is the access to two standard facilities. First, there is a deposit facility, m, in order to make overnight deposits with the central bank

[5] Notice that, in equilibrium, all firms $i \in I = [0, 1]$ in a region j are funded under exactly the same contract (k_{ij}, l_{ij}, R_{ij}). Thus, the reference to the index i can be omitted from now on.

at the interest rate r_m. It represents the riskless asset of the economy. Second, there is a marginal lending facility, l_f, through which credit institutions can obtain liquidity directly from the monetary authority at rate r_{lf}. A second tool is the use of a credit policy. I assume that the central bank can inject liquidity in the economy via a full-allotment policy, labeled by O, at a fixed-rate r_o.[6] This type of policy allows depository institutions to have continued access to funds in order to satisfy liquidity needs.[7] Note that the total amount of savings available in this economy is given exogeneously by $\bar{S}$, which fits with the no effect of pure credit policies on the aggregate bank reserves (Goodfriend (2011)).

According to this, central bank intermediation in the economy is constrained by the following balance sheet identity

$$O + l_f = m + n_{CB}, \tag{2.6}$$

where n_{CB} represents the central bank's net worth. Thereby, during turbulent times characterized by an excessive counterparty risk, the monetary authority expands its liability side absorbing the excess of liquidity in the system via the deposit facility and reallocates it to most deficit intermediaries through the refinancing facilities

2.2.4 Financial intermediaries

A representative bank intermediates between households and the continuum of non-financial firms in each region j, channeling pre-existing funds between savers and debtors. Each financial intermediary is owned by a household, who can participate either as shareholders providing equity, e_j, or as depositors through retail deposits, d_j. These deposits are insured by the government and financed via lump sum taxes. Financial intermediaries can finance their activity also participating in the unsecured interbank money market where they can borrow a volume of funds, a_j, from banks located in other regions, or using the liquidity provision from the Central Bank, O_j.[8]

[6] According to the evidence, the use of the lending facility is negligible since $r_o < r_{lf}$.

[7] The full-allotment policy was a significant non-standard measure used by the ECB in the first stage of the financial crisis, 2007-2011.

[8] In practical terms, banks provide collateral to have access to central bank liquidity. This collateral is temporarily deposited in the central bank and it is returned when the bank pays back its loan. In the present version of this model I abstract from the explicit incorporation of elegible collateral. Its incorporation and the relevance of haircuts is a natural extension of this paper.

For a given systemic risk, ϵ, the bank decides the optimal portfolio of assets that maximize the expected net worth of shareholders at $t = 1$. They can invest in a risky asset either issuing loans to local non-financial firms, with $l_j = \int_0^1 l_{ij} d_i$, or lending to other banks in return of the interbank rate, r. In addition, they can invest in a riskless asset using the deposit facility to allocate their liquidity excess at the central bank at price r_m.

Then, the behavior of each financial intermediary is subject to the following balance sheet constraint

$$l_j + a_j + m_j = d_j + e_j + O_j, \tag{2.7}$$

where a_j indicates the exchange of funds between financial firms at wholesale level, which takes positive or negative value according whether the bank is a money market lender or borrower, respectively. Since trading at wholesale level is unsecured, money market lenders can charge a spread, s, for interbank transactions with other banks. The money market spread charged in the interbank transactions must satisfy the following condition

$$(1 - \epsilon)(1 + r + s) = 1 + r, \tag{2.8}$$

where the first term refers to the payment received by lenders when default does not occur, and the second term $(1+r)$ describes the lender expected return. Notice that when the counterparty defaults at wholesale level, the money market lender obtains a zero return. Specifically, when the level of systemic risk ϵ is negligible, then the spread s charged into money market transactions is very low, while as long as this risk is far from zero, the reclaimed spread s increases.

Lastly, banks have to satisfy the following capital adequacy constraint

$$e_j \geq \rho l_j, \tag{2.9}$$

where the parameter ρ denotes the capital requirement.

2.3 The characterization of equilibrium

In this section I analyze the main ingredients that explain the equilibrium of the model. The only difference as compared to the modeling of Bruche and Suarez (2010) is the inclusion of a monetary authority. I start describing the first-best allocation derived from a planner's problem who chooses the optimal amount of liquidity invested in each region. Next, the market allocation for a different counterparty risk is evaluated. The collapse of the interbank money market is driven by increases in counterparty risk, and follows the same reasoning as in Bruche and Suarez (2010). Then, I explore central bank intermediation to describe its interaction with the money market, analyzing the credit policy response that the monetary authority can implement during a solvency crisis.

2.3.1 The efficient allocation

To find the efficient allocation of capital in the economy I consider the problem of a benevolent planner. The social planner tries to solve the intertemporal problem that maximizes the expected return of entrepreneurs at $t = 1$. It decides the optimal amount of capital k_j invested in each region j. The only restriction that it faces is the feasibility constraint. The problem can be stated as follows

$$k_j \in argMax(1-\epsilon)(1-p)[Ak_j^{\alpha} + (1-\delta)k_j] \tag{2.10}$$

subject to:

$$k_j \leq \bar{S}$$
$$k_j \geq 0$$

The first constraint reflects the idea that capital has to be feasible, while the latter states the non-negative condition. It is straightforward to observe that, considering an interior solution, the first-order condition for the centralized problem (2.10) is given by

$$k_j = \bar{S}, \tag{2.11}$$

which reflects the first-best capital allocation in the economy. Equation (2.11) states that the pair of liquidity allocations $(k_H^*, k_L^*) = (\bar{S}, \bar{S})$ is efficient. Given the assumption that there are two regions with heterogenous savings, i.e., $S^H > S^L$, it follows that liquidity transfers from cash-rich to cash-poor regions are needed to achieve the efficient allocation. In the next section I analyze the several market allocations that can be achieved for different credit risk levels.

2.3.2 The competitive market equilibrium

The contents of this subsection are organized as follows. First, I describe the decision's problem between households and financial firms, and the contract problem that sets the relationship between non-financial corporations and bankers. Then, I analyze whether the interbank market can reallocate capital efficiently for different levels of credit risk that distort the well functioning of the money market.

2.3.2.1 The banker's portfolio problem

The households are the owners of the entire economy. In equilibrium, the household's decision between providing deposit or equity funding to the representative financial intermediary is given by the following bank's participation constraint,

$$\begin{aligned} &(1-\epsilon)[(1-p)(1+R)l_j + p(1-\lambda)k_j + (1+r+\xi s)a_j \\ -&(1+r_d)d_j + (1+r_m)m_j - (1+r_o)O_j] - \epsilon(1+r_o)O_j \geq (1+r_d)e_j \end{aligned} \tag{2.12}$$

where the indicator function

$$\xi = \begin{cases} 0 & \text{if bank j is a lender} \\ 1 & \text{if bank j is a borrower} \end{cases}$$

shows whether the financial intermediary that operates in region j participates lending or borrowing funds at wholesale level.

Notice that the expected return for shareholders is linked with the probability that a systemic event occurs in the financial system. The bank's participation constraint (2.12) states that when firms do not fail simultaneously, then the expected payoffs at $t = 1$ must be sufficiently large to compensate shareholders for their capital provision. To be precise, the first two terms in equation (2.12) state that the returns from the loans issued to non-financial firms are equivalent to the return of bank lending plus the collateral in case of default at $t = 1$; the third term reflects the expected returns from interbank participation; the fourth term corresponds to the payoff derived from deposit retail funding; whereas the fifth and sixth terms are based on the bank's use of the marginal facilities provided by the monetary authority, where financial intermediaries always have to return the funds to the central bank independently of the realization of the systemic event.

To be consistent, the equilibrium requires the non-arbitrage condition $r+\xi s = r_d$. That is, the deposit funding cost for financial firms must be equal to r for money market lenders ($\xi = 0$), and to $r + s$ for money market borrowers ($\xi = 1$). Otherwise, there exist an arbitrage opportunity and the bank's owner strictly prefers either deposit or equity financing. For instance, a money market lender ($\xi = 0$) would obtain profits reducing the amount of deposits collected from households if $r_d > r$, or increasing its interbank lending when $r_d < r$. Alternatively, a money market borrower ($\xi = 1$) would make profits using arbitrage opportunities borrowing from the interbank money market when the rates are $r_d > r + s$, such that the deposits collected are equal to zero in that case, or borrowing through retail intermediation from households if $r_d < r+s$, increasing its demand for retail deposits indefinitely.

2.3.2.2 The lending contract

The bank-firm relationship is characterized by a lending contract that sets the optimal portfolio of assets $\{l_j, a_j, m_j, O_j, d_j, e_j\}$ for a given rate of systemic failure, ϵ, that maximizes the expected net worth of banks' owners at $t = 1$. Formally, this lending contract problem can be defined as follows

$$k_j \in argMax(1-\epsilon)(1-p)[Ak_j^{\alpha} + (1-\delta)k_j - (1+R_j)l_j] \tag{2.13}$$

subject to:

$$(1-\epsilon)[(1-p)(1+R)l_j + p(1-\lambda)k_j + (1+r+\xi s)(d_j+e_j+O_j-l_j-m_j) - (1+r_d)d + (1+r_m)m_j - (1+r_o)O_j] - \epsilon(1+r_o)O_j \geq (1+r_d)e_j$$

$$l_j = k_j$$

$$e_j \geq \rho l_j.$$

The objective function of the lending contract problem (2.13) states the expected return for the non-financial firm i when production succeeds. In the non-bankruptcy case, the profits are equivalent to the output Ak_j^{α} generated plus the depreciated capital $(1-\delta)k_j$, less the return of the loan debt that has to be repaid to the bank. This problem is restricted by a set of constraints. The first restriction is given by the bank's participation constraint explained in the previous subsection. The second restriction is given by the size of the loan's contract, that is assumed to be equivalent to the capital required to produce. The third expression corresponds to the capital adequacy constraint, which regulates the required equity that banks must hold.

The constrained optimization problem can be simplified considering the non-arbitrage condition for which banks' owners are indifferent between deposit and equity funding, i.e. $r_d = r + \xi s$.[9]

$$k_j \in argMax(1-\epsilon)(1-p)Ak_j^{\alpha} + (1-\epsilon)[(1-p)(1-\delta) + p(1-\lambda)]k_j - \\ -(1 + r + \xi s)[1 - \epsilon(1-\rho)]k_j \quad (2.14)$$

The unconstrained lending contract problem (2.14) states the optimal sequence of capital $k_j(\epsilon; r + \xi s)$ that maximizes the expected profits for non-financial firms. Obviously, the optimal plan for capital in each region j depends on the level of credit risk latent in the economy. Intuitively, the larger the counterparty risk, the lower the capital invested in region j is. Given the optimal plan k_j, the financial intermediary in region j will operate as a money market lender ($\xi = 0$) if $k_j(\epsilon, r) < S_j + O_j - m_j$, and as a money market borrower ($\xi = 1$) when $k_j(\epsilon, r+s) > S_j + O_j - m_j$. In case that $k_j(\epsilon, r + \xi s) = S_j + O_j - m_j$, then the bank is autarkic, and it does not participate actively in the interbank money market.

2.3.2.3 The interbank money market allocation

I turn now to study the equilibrium in the interbank money market. It is characterized by the interbank rate r that matches the demand and supply of interbank funds. The market clearing condition is given by

$$\pi a_H + (1-\pi)a_L = 0. \quad (2.15)$$

The aggregate supply of liquidity in the interbank market increases monotonically with the interbank rate r, and the aggregate demand behaves in the opposite way.

[9] The different steps to convert the original constrained lending contract problem (2.13) into the shorten unconstrained optimization problem (2.14) are detailed in the appendix B.1.1.

Definition 1. *The competitive market equilibrium in each region j, with $j \in \{L, H\}$, is characterized by the set of prices $\{r\}$, and allocations $\{k_j, l_j, a_j\}$ such that*

i) given the set of prices, all non-financial firms $i \in I = [0,1]$ in region j are funded under the same lending contract l_j, where the optimal sequence of capital k_j solves the unconstrained optimization problem (14).

ii) at given prices, the capital allocation (k_H, k_L) satisfies $\pi k_H + (1-\pi)k_L = \bar{S}$.

iii) the interbank rate, r, satisfies the interbank money market clearing condition $\pi a_H + (1-\pi)a_L = 0$.

The fragility of the interbank money market is driven by the tensions created by deposit insurance. The sudden freeze in this market is characterized, in line with Bruche and Suarez (2010), as an excessive increase in counterparty risk that leads to limited risk-sharing, leading to differences in the marginal funding cost across regions.

In the absence of central bank intervention, shifts in counterparty risk are an important root that explain the inefficient distribution of capital through the economy.[10] When default risk is negligible, liquidity is allocated symmetrically and efficiently across regions, i.e. $k_H = k_L = \bar{S}$. The marginal funding cost for liquidity provision at retail and wholesale level is the same, and the market liquidity distribution coincides with the efficient allocation. When the money market faces a positive credit risk, however, the risk sharing through the money market decreases, which contributes to important asymmetries in the marginal returns across regions, i.e. $k_H(r) > \bar{S}$ for $\xi = 0$, and $k_L(\frac{r+\epsilon}{1-\epsilon}) < \bar{S}$ for $\xi = 1$. In such situation, the interbank market can restore the efficient liquidity allocation only if credit risk dissipates. At that point, the provision of central bank facilities becames a key source of liquidity for financial intermediaries that face solvency problems.

[10]The basic focus of Bruche and Suarez (2010) is on the distortions created by deposit insurance. In particular, they show that when governments do not provide a deposit insurance scheme in the retail market, then solvency concerns do not collapse the well functioning of the money market.

2.3.3 Central bank intermediation

In this section I evaluate how capital is distributed across regions when the central bank participates actively in the economy. Indeed, I try to figure out whether the monetary authority can implement a credit policy that improves the market allocation for different credit risk levels for which the interbank trading falls. The role of the monetary authority is the supervision of the efficient distribution of capital across regions. The way in which the central bank intermediates in this economy is by shifting the policy rates, i.e. the deposit rate r_m, and the fixed-rate r_o for the full-allotment policy.

During normal times characterized by the absence of counterparty risk, the money market works efficiently and the central bank sets a positive corridor between its facilities that does not affect the market allocation.

Lemma 1. *In equilibium, with $\epsilon = 0$ and $a_j > 0$, the central bank does not distort the market allocation if, given the money market rate, r, the policy rates (r_m, r_o) are such that,*

$$(1 + r_m) \leq (1 + r + \xi s) \leq (1 + r_o). \tag{2.16}$$

Proof. See Appendix B.2 □

Intuitively, equation (2.16) states the non-arbitrage conditions for which the monetary authority does not affect the competitive allocation of capital. In absence of counterparty risk, the monetary authority does not intermediate actively since optimal risk-sharing is achieved by the money market. It is clear that setting a positive corridor between the main refinancing operations and the deposit facility, i.e. $(r_o - r_m) > 0 = s$, money market participants have no incentives to use the facilities provided by the monetary authority, and prefer to use the competitive money market to reallocate liquidity. Nevertheless, when solvency concerns are significant to either stress or freeze the money market, the monetary authority can intermediate in the economy using a credit policy to absorb the excess of liquidity from cash-rich regions via the deposit facility, and reallocate it to those cash-poor regions through a full-allotment policy.

Proposition 1. *In equilibrium, with $\epsilon > 0$ for which the money market is stressed or inoperative, central bank intermediation restores the efficient allocation of capital if,* *i) policy rates (r_m, r_o) satisfy $(1 + r_m) > (1 + r)$ for MM lenders $(\xi = 0)$, and $(1 + r + s) > (1 + r_o)$ for MM borrowers $(\xi = 1)$,*

ii) the capital allocation $\{k_H(r_m; r_o), k_L(r_m; r_o)\}$ satisfies the market's clearing condition $\pi k_H(r_m; r_o) + (1 - \pi)k_L(r_m; r_o) = \bar{S}$, with $k_H = k_L$.

Proof. See Appendix B.2 □

To restore the efficient allocation, the central bank can subsidize the increase in counterparty risk collecting the excess of liquidity from cash-rich regions through the deposit facility, m, and reallocating such capital to banks located in cash-poor regions via a full-allotment policy, O. This risk-absorption policy alleviates the distortions derived from the fragmentation of the interbank money market, and provides an insurance to banks against the risk of having a liquidity shortage. To implement this credit policy, the spread latent in the money market, $s(\epsilon)$, must be higher than the spread applied between the central bank facilities. Through this active intermediation, the monetary authority subsidizes the underlying asymmetries in the marginal funding cost across regions, eliminates interbank trading in the money market, and substitutes the market to implement the first-best allocation.

2.4 Numerical exercise

In this section I design a numerical experiment to simulate a crisis that leads to an asymmetric distribution of capital across regions. The claim is to observe how a monetary authority can restore the efficient equilibrium. To do so, a risk-absorption policy intervention is simulated considering two alternative scenarios. First, I evaluate the volume of interbank transactions for different degrees of solvency risk about specific counterparties. Second, I show how the monetary authority can play the role of the entinguished wholesale market to implement the efficient allocation.

2.4.1 Baseline parameterization

The parameters of the calibration appear in Table 2.1. I use the set of standard values assigned by Bruche and Suarez (2010), since I follow their modelization for the money market in which it collapses for an spread close to 2% in wholesale transactions. The technological parameters are set according the traditional macroeconomic practice. The value for capital elasticity parameter α of 0.3 corresponds to the conventional one. The values for the depreciation rates for non-financial firm success, δ, and failure, λ, equal 0.045 and 0.35 in order to produce a loss default on loans to non-financial firms equivalent to 0.45. In addition, the capital requirement ρ is set equal to 0.08, which adjusts to the standard requirements of Basel accords. Moreover, I assume that banks intermediate the same fraction of high and low-saving regions, i.e. $\pi = 0.5$. The asymmetric allocation for liquidity across regions is given by the parameter μ, which is equal to 0.6. Finally, the idiosyncratic default probability in each region j is set to be equal to $p = 3\%$. The technology is considered to be homogenous a constant across regions, $A = 1$. According to this calibration, savings are distributed as follows. Banks located in high-saving regions have access to a pool of cash $S_H = \frac{\bar{S}\mu}{\pi} = 6.02$, whereas cash-poor regions are endowed with $S_L = \frac{\bar{S}(1-\mu)}{(1-\pi)} = 4.01$, with $\bar{S} = \pi S_H + (1-\pi)S_L = 5.01$.

2.4.2 Counterparty risk and market allocation

In order to evaluate the role of the interbank market to reallocate liquidity across regions, Table 2.2 reports the market allocation achieved for different levels of systemic risk. In a normal scenario characterized by the absence of credit risk, i.e. $\epsilon = 0$, the interbank market is able to reallocate liquidity in an efficient way across regions. Capital is distributed symmetrically and the marginal returns are equal for all the regions, which allows the implementation of the first-best. Notice that when solvency risk is negligible, the monetary authority sets a positive spread for the facilities. In this case, I consider a spread $(r_o - r_m) = 2\%$, with $r_m = 5\%$ and $r_o = 3\%$, which is larger than the zero-spread charged for unsecured interbank transactions. Obviously, for such spreads banks located in cash-poor regions prefer to obtain capital at the prevailing interbank rate $r = 4\%$, and the use of the standard facilities is zero.

In a crisis scenario given by positive rates of systemic failure, $\epsilon > 0$, the interbank market distributes capital inefficiently. As in Bruche and Suarez (2010), for any $\epsilon \in (0, 3\%)$ the interbank market is stressed but still active. Interbank trading drops due to the larger spread $s > 0$ reclaimed for interbank borrowing. For instance, for $\epsilon = 1\%$ cash-rich banks charge a spread close to 1% to compensate for the larger solvency risk of cash-poor banks, dropping the volume of interbank transactions. If the probability of the systemic state is close to 3%, however, the market freezes and interbank trading is nule as can be observed in Table 2.2. In such autarkic scenario, liquidity cannot be transferred to cash-poor regions in absence of central bank intermediation.

Table 2.3 describes how the central bank can implement a credit policy to redistribute savings to liquidity shortage regions during a solvency crisis. To subsidize the increase in credit risk, the central bank can replace the role of the extinguished market and act as counterparty between money market borrowers and lenders. In practice, the monetary authority can set a close to zero spread between the refinancing and the deposit facilities provided. Implementing this policy, the central bank stops the activity in the money market when it is stressed but still operative for $\epsilon \in (0, 3\%)$. For instance, cash-poor banks have to pay a rate close to 5.8% when the money market freezes for $\epsilon \equiv 3\%$, whereas cash-rich banks can obtain funds at a lower rate of 2.62%. To solve the asymmetry in the marginal funding cost across regions, the liquidity excess from high-saving banks can be deposited at rate $r_m = 3.9\%$, and reallocate it to liquidity shortage banks at a similar rate $r_o \equiv 3.9\%$, setting a zero spread between the standard facilities which is clearly lower than the market spread 3.17% charged for interbank trading. Thus, the amount of capital reallocated through the refinancing facilities increases with the solvency concerns. As depicted in Table 2.3, the higher the perceived credit risk, the larger the use of the facilities.

2.5 Concluding remarks

The financial crisis and its aftermath have called for unprecedent policy responses that have raised the debate about the central bank's capacity in promoting financial stability. This paper sheds light about the important function played by monetary authorities during financial turbulent periods to redistribute liquidity through the financial system. I incorporate central bank intermediation to expand the macroeconomic model with counterparty risk developed by Bruche and Suarez (2010) in order to understand the interaction of central banking with the interbank money market during systemic times.

In a crisis scenario, and in order to change the competitive market allocation, monetary authorities can implement a credit policy in order to offset the distortions created in the money markets because of the increase in solvency concerns. The basic premise is that, due to the framegtation of the money market, a larger central bank intermediation has to absorb the credit risk perceived in the money market and subsidize the existing asymmetry in the marginal funding cost that arise across regions. I consider a full-allotment policy where the central bank expands its liability side absorbing the excess of liquidity through the deposit facility, and reallocates it via lending facilities. Using a standard calibration, the results suggest that the monetary authority has to set a spread between the standard facilities that is lower than the spread required in the market for interbank transactions to restore the efficient allocation.

Appendix B

B1.1: Derivation of the optimal contract

The bank's optimal financing structure decision can be derived observing the bank's participation constraint (2.12). Intuitively, any decision on the pair (d_j, e_j) that increases the shareholder's expected net worth at $t = 1$ would be optimal. A money market lender, ($\xi = 0$), has the balance sheet identity $a_j = d_j + e_j + O_j - l_j - m_j$, and its bank's participation constraint can be expressed as follows,

$$\begin{aligned}&(1-\epsilon)[(1-p)(1+R)l_j + p(1-\lambda)k_j + (1+r)(e_j + O_j - l_j - m_j)\\ &+(r-r_d)d + (1+r_m)m_j - (1+r_o)O_j] - \epsilon(1+r_o)O_j \geq (1+r_d)e_j. \qquad (2.17)\end{aligned}$$

For a given counterparty risk ϵ, and given the linearity of equation (2.17), two different cases for which $d > 0$ is not satisfied can be distinguished. First, for $r_d > r$ the term $(r - r_d)d$ decreases. In such a case, the financial intermediary can make profits decreasing the amount of deposits collected from households via retail intermediaiton and increasing equity financing, so $d = 0$ and $e \to \infty$ is optimal for the money market lender. At the same time, for $r_d < r$, it is quite intuitive that the term $(r - r_d)d$ increases and the bank can raise its profits increasing money market lending, so $d \to \infty$ and $e = 0$ is the optimal decision.

The reasoning for a money market borrower $\xi = 1$ is quite similar. The bank's participation constraint (2.12) can be rewritten as follows,

$$\begin{aligned}&(1-\epsilon)[(1-p)(1+R)l_j + p(1-\lambda)k_j - (1+r+s)(l_j + m_j - e_j - O_j)\\ &+(r+s-r_d)d + (1+r_m)m_j - (1+r_o)O_j] - \epsilon(1+r_o)O_j \geq (1+r_d)e_j. \quad (2.18)\end{aligned}$$

First, for $r_d > (r+s)$, the optimal decision for the bank is raising the interbank funding such that $d=0$ and $e \to \infty$. Doing so, the term $(r+s-r_d)d$ decreases, so it can make profits reducing the deposit funding at retail level, whereas for $r_d < (r+s)$ the term $(r+s-r_d)d$ increases, so $d \to \infty$ and $e=0$ is the optimal choice. Thus, the money market borrower can maximize the expected return of shareholders increasing the amount of deposit funding, such that it is strictly preferred to equity funding. Therefore, in equilibrium $r+\xi s = r_d$ is a necessary condition to guarantee that $d>0$, $\forall \xi = 0,1$. With this condition, any decision about equity, e, that satisfies the capital adequacy constraint (2.9) is optimal.

To rewrite the constrained optimization problem (2.13) into its unconstrained version (2.14), the following steps can be followed. First, since $r_d = r+\xi s$ must be satisfied in equilibrium, the term $(1+r_d)d$ can be cancelled out from the bank's participation constraint (2.12). Second, the different constraints of the lending contract problem (2.13) can be rearranged. From the assumption that there is no labor in the economy, then the loan size needed to fund the investment projects in each region j is equivalent to the capital that non-financial firms use in their production process, so $l_j = k_j$. Moreover, the presence of credit risk in the economy leads to financial intermediaries to strictly prefer deposit to equity financing for $\epsilon > 0$, so the capital adequacy constraint (2.9) binds $e_j = \rho l_j$. Combining both restrictions (loan's size and capital requirement constraints) the following form for the bank's participation constraint is obtained,

$$\begin{aligned}(1-\epsilon)[(1-p)(1+R_j)k_j] &\geq \epsilon(1+r+\xi s)k_j(\rho-1)\\ &+(1+r+\xi s)k_j - (1-\epsilon)p(1-\lambda)k_j, \end{aligned} \tag{2.19}$$

and replacing into the constrained problem (2.13), the unconstrained form (2.14) is obtained,

$$\begin{aligned}k_j \in argMax(1-\epsilon)(1-p)Ak_j^{\alpha} &+ (1-\epsilon)[(1-p)(1-\delta)+p(1-\lambda)]k_j\\ &-(1+r+\xi s)[1-\epsilon(1-\rho)]k_j.\end{aligned}$$

The first order condition for an interior solution is

$$\begin{aligned}(1-\epsilon)[(1-p)Ak_j^{\alpha-1} + (1-\epsilon)[(1-p)(1-\delta)+p(1-\lambda)] &=\\ &= (1+r+\xi s)[1-\epsilon(1-\rho)]. \end{aligned} \tag{2.20}$$

And solving for k_j, it is clear that the capital is a decreasing function for the marginal funding cost in the interbank market, and the counterparty risk, i.e.

$$k_j(r+\xi s) = \left[\frac{(1-p)\alpha A}{\frac{(1+r+\xi s)}{(1-\epsilon)}[1-\epsilon(1-\rho)] - (1-\epsilon)[(1-p)(1-\delta)+p(1-\lambda)]}\right]^{\frac{1}{(1-\alpha)}}. \tag{2.21}$$

Moreover, the expected output in each region j is set according the following equation,

$$y_j(r+\xi s) = \left[\frac{(1-p)\alpha A}{\frac{(1+r+\xi s)}{(1-\epsilon)}[1-\epsilon(1-\rho)] - (1-\epsilon)[(1-p)(1-\delta)+p(1-\lambda)]}\right]^{\frac{\alpha}{(1-\alpha)}}, \tag{2.22}$$

which is also a decreasing function for the interbank rate r and the counterparty risk ϵ.

B1.2: Derivation of the interbank equilibria

The balance sheet constraint (2.7) that restricts the behavior of financial intermediaries is given by,

$$a_j = d_j + e_j + O_j - k_j - m_j. \tag{2.23}$$

Following the assumption that there are two different regions with heterogenous savings, a bank operating in a cash-rich region will present

$$a_j^H = S_j^H + O_j(r_o) - m_j(r_m) - k_j(r+\xi s;\epsilon) > 0, \tag{2.24}$$

whereas if it operates in a cash-poor region

$$a_j^L = S_j^L + O_j(r_o) - m_j(r_m) - k_j(r+\xi s;\epsilon) < 0. \tag{2.25}$$

It follows that the money market clearing condition (2.15) can be rewritten as follows,

$$\pi a_j^H(r + \xi s; \epsilon) + (1 - \pi)a_j^L(r + \xi s; \epsilon) = 0. \tag{2.26}$$

Plugging equation (2.26) with (2.25) and (2.24), the interbank market condition can be rewritten as follows,

$$\begin{aligned} &\pi[S_j^H + O_j(r_o) - m_j(r_m) - k_j(r + \xi s; \epsilon)] \\ +&(1 - \pi)[S_j^H + O_j(r_o) - m_j(r_m) - k_j(r + \xi s; \epsilon)] = \bar{S}. \end{aligned} \tag{2.27}$$

And operating it collapses into the following market clearing condition in the goods market,

$$\bar{S} = k_j(r + \xi s; \epsilon) + m_j(r_m) - O_j(r_o). \tag{2.28}$$

Notice that in order to have a consistent interbank equilibrium, the interbank rate r must be such that $a_j^H > 0$ and $a_j^L < 0$ for cash-rich and cash-poor regions respectively. Thus, with an operative interbank market there exists a unique interbank rate $\hat{r}$ of equilibirum that clears the market condition fulfilling with an operative interbank market. Thereby, for an interbank rate $\hat{r}$ such that $S^H - k_j(\hat{r}; \epsilon) - m_j(r_m) > 0$, the market clearing condition (2.15) implies that $S^L - k_j(\hat{r} + s; \epsilon) + O_j(r_o) < 0$. This situation is consistent with an operative money market and it corresponds with a well-defined interbank equilibrium. However, for an interbank rate $\hat{r}$ for which $S^H - k_j(\hat{r}; \epsilon) - m_j(r_m) \leq 0$, equation (2.15) leads to $S^L - k_j(\hat{r} + s; \epsilon) + O_j(r_o) \geq 0$, which is inconsistent with an operative interbank market in which liquidity flows from high to low saving regions.

Appendix B2: Proofs

Lemma 1

This proof explains the necessary conditions for which central bank intermediation does not distort the market allocation. We can distingush two cases. First, when there exist trading in the interbank market ($a_j > 0$), then the central bank can distort the market equilibria only if it generates arbitrage opportunities from using the central bank facilities. We can rewrite the bank's participation constraint

(2.12) as follows

$$(1-\epsilon)[k_j[(1-p)(1+R)l_j + p(1-\lambda) - (1+r+\xi s)] + (1+r+\xi s)(e_j)] \\ +m_j[(1-\epsilon)(1+r_m) - (1-\epsilon)(1+r+\xi s)] \\ +O_j[(1+r+\xi s) - (1-\epsilon)(1+r_o)] \geq (1+r_d)e_j. \quad (2.29)$$

Then, it is clear that $\forall(1+r_m) \geq (1+r+\xi s)$ we have that the term $[(1-\epsilon)(1+r_m) - (1+r+\xi s)]m_j$ increases, so the financial firm can use the price differential between both markets to make profits increasing the use of the deposit facility at the rate r_m. In such case, the use of the deposit facility strictly dominates interbank lending, such that $m \to \infty$ and $a_j = 0$. At the same time, $\forall(1+r+\xi s) > \frac{(1+r_o)}{1-\epsilon}$ obtaining liquidity through the use of the refinancing facility is relatively cheaper than getting liquidity at wholesale level. This means that financial intermediaries would prefer the refinancing facility to interbank borrowing, leading to $O \to \infty$ and $a_j = 0$. Thus, whenever condition (2.16) is violated, the central bank intermediates to modify the interbank market allocation.
A second case is given for an autarkic equilibrium ($a_j = 0$). From the bank's participation constraint with $a_j = 0$ we get

$$(1-\epsilon)[k_j[(1-p)(1+R)l_j + p(1-\lambda) - (1+r_d)] + (1+r)(e_j)] \\ +m_j[(1-\epsilon)(1+r_m) - (1-\epsilon)(1+r_d)] \\ +O_j[(1-\epsilon)(1+r_d) - (1+r_o)] \geq (1+r_d)e_j. \quad (2.30)$$

Thus, it is clear that any pair (r_m, r_o) that leads to $(1+r_m) \geq (1+r_d)$, and $(1+r_d) \leq \frac{(1+r_o)}{(1-\epsilon)}$ generates arbitrage incentives that can distort the autarkic allocation. Then, the equilibrium with $m_j > 0$ for $\xi = 0$, and $O_j > 0$ for $\xi = 1$ requires $(1+r_m) > [1+r_d(S^H;\epsilon)]$, and $\frac{(1+r_o)}{(1-\epsilon)} < [1+r_d(S^L;\epsilon)]$ respectively when $a_j = 0$.

Proposition 1

The proof for proposition 1 can be explained in different steps. First, from Lemma 1 we know that the central bank changes the market allocation when the conditions (2.16) fails. Thus, any pair (r_m, r_o) that contradicts Lemma 1 satisfies this condition. Second, we need to stablish a condition by which central bank improves the market allocation only when, after its intervention, liquidity is transferred to liquidity shortage regions. An additional condition is that the central bank allocation $[k_H(r_m;r_o), k_L(r_m;r_o)]$ must comply with the market clearing condition.

For a market situation with $a_j > 0$, the pair of policy rates (r_m, r_o) that violates condition (2.16) follows to $\hat{k_H}(\hat{r}; \epsilon) > \hat{k_H}(r_m; \epsilon)$ for $\xi = 0$, and $\hat{k_L}(\hat{r} + s; \epsilon) < \hat{k_L}(r_o; \epsilon)$ for $\xi = 1$. Alternatively, for an autarkic situation with $a_j = 0$, the pair (r_m, r_o) that does not comply with condition (2.16) leads to $\hat{k_H}(r_d; \epsilon) > \hat{k_H}(r_m; \epsilon)$ for $\xi = 0$, and $\hat{k_L}(r_d; \epsilon) < \hat{k_L}(r_o; \epsilon)$ for $\xi = 1$.

Thus, the central bank implements an efficient credit policy for the pair (r_m, r_o) with $r_m > r_o$ that leads to $k_H(r_m; r_o) = k_L(r_m; r_o) = k_j^*(\epsilon)$ and fits with the market's clearing condition. Otherwise, the liquidity allocation is unfeasible for $\pi k_H(r_m; \epsilon) + (1-\pi) k_L(r_o; \epsilon) > \bar{S}$, and misplaced for $\pi k_H(r_m; \epsilon) + (1-\pi) k_L(r_o; \epsilon) < \bar{S}$.

Appendix B.3: Tables

Parameter	Baseline Value
Proportion of cash-rich regions, π	0.5
Liquidity asymmetry, μ	0.6
Capital share, α	0.3
Depreciation rate, success case δ	0.045
Depreciation rate, failure case, λ	0.35
Probability of idiosyncratic firm failure, p	0.03
Capital requirement, ρ	0.08
Technology, A	1

TABLE 2.1: Baseline parameterization

	Counterparty Risk, ϵ					
	0%	1%	2%	3%	4%	5%
Market allocation						
K^H	5.013	5.407	5.798	6.015	6.015	6.015
K^L	5.013	4.616	4.228	4.01	4.01	4.01
Deposit Rates (%)						
r_d^H	4.00	3.43	2.92	2.62	2.54	2.45
r_d^L	4.00	4.47	5.02	5.79	6.81	7.84
Spread (%)						
s	–	1.04	2.10	3.17	4.27	5.39
Money Market Size						
a_H	1.026	0.608	0.217	-	-	-
a_L	-1.026	-0.608	-0.217	-	-	-

TABLE 2.2: Counterparty Risk and Market Allocation

	Counterparty Risk, ϵ					
	0%	1%	2%	3%	4%	5%
Market allocation						
$K^H(r;\epsilon)$	5.013	5.407	5.798	6.015	6.015	6.015
$K^L(r+s;\epsilon)$	5.013	4.616	4.228	4.01	4.01	4.01
Central Bank allocation						
$K^H(r_m;\epsilon)$	5.013	5.013	5.013	5.103	5.103	5.103
$K^L(r_o;\epsilon)$	5.013	5.013	5.013	5.103	5.103	5.103
Size Facilities						
m	–	0.394	0.785	1.002	1.002	1.002
O	–	0.394	0.785	1.002	1.002	1.002
Policy Rates (%)						
r_m	3.00	3.90	3.80	3.70	3.70	3.70
r_o	5.00	3.90	3.80	3.70	3.70	3.70

TABLE 2.3: Counterparty Risk and Central Bank Intervention

Chapter 3

Modern Depository Institutions, Runs, and Liquidity

3.1 Introduction

We study modern runs in a banking system where depository institutions issue nominal demandable claims to facilitate transactions. Failures of financial institutions are a recurrent event in the history of banking. A consistent explanation of the fundamental reasons for banking instability, however, is still an open question. According to recent developments in financial markets, bank runs seem to be provoked by the tightening of constraints on bank creditors rather than triggered exclusively by a classic coordination failure. The collapses of Bearn Stearns and Lehman Brothers on 2007 are explained by their heavy reliance on short-term debt, which made both institutions more vulnerable when creditors and other investment banks lost confidence in their ability to redeem short-term loans after an increase in perceived risk (Lucas et al. (2011)). The run of the UK bank Northern Rock on 2007 was caused by its high leverage coupled with reliance on institutional investors for short-term funding, and it did not seem to be related to a coordination failure (Shin (2009)).

In a modern economy, deposit contracts are repayable in terms of money and withdrawals usually take the form of electronic transfers. Banks create the commitment to implement a payment system by which transactions are cleared. This vision contrasts with traditional banking models based on the seminal work of Diamond and Dybvig (1983), which has been widely accepted as the cornerstone to study the roots of bank runs. Diamond and Dybvig (1983) showed that, with no aggregate uncertainty, depositors can coordinate and lead to a self-fulfilling equilibrium wherein uninsured depositors rush to withdraw their savings from the banking system. When it happens, banks are unable to honour their repayment obligations. The withdrawal decision of each depositor depends on her preferences and beliefs about the behavior of the rest of the population. The role of banks is the design of contingent debt arrangements by which individuals with different time preferences choose the bundle of deposits designed to them. Most of the posterior literature has focused on the mechanism design approach and the incentives of depositors to coordinate to a panic.[1] Assuming that banks use real contracts, traditional banking models share two features. First, the essentiality of banking is the superior liquidity insurance achieved through the intermediation process. Second, the vulnerability of banks to runs is explained by the maturity transformation of long-maturity, illiquid assets into short-maturity, liquid liabilities.

We incorporate endogenous money creation into the standard liquidity problem of Diamond and Dybvig (1983), wherein risk-adverse households face uncertainty about their specific consumption needs. The aim is to evaluate the implications of introducing inside money over the withdrawal incentives of depositors and the optimality of the risk-sharing deposit contracts. Several features must be remarked. First, instead of considering the traditional description of banking as financial vehicles that take assets from savers and lend them to ultimate borrowers, we consider that when banks originate a new loan they are creating inside money and purchasing power rather than intermediating pre-existing money.[2] Second, this intermediation process starts on the asset side of the bank's balance sheet. The liquidity risk faced by the banking institution is due to the transfer of funds between banks, which is solved by managing a demand for outside money. Third, the maturity mismatch between bank assets and liabilities arises automatically when a loan is originated. The counterpart of the longer maturity associated to the asset the loan creates is the overnight disposable nature of the means of payment of the liability linked with it.

Under this nominal setting, we show that the real value of deposit contracts is contingent on the mass of withdrawals, which adjusts the demand for consumption

[1] See Jacklin (1987), Wallace (1988), Green and Lin (2000), Peck and Shell (2003), and Ennis and Keister (2009).

[2] This approach is close to the “new view" of banking mentioned by Tobin (1963).

at each date. This mechanism leads to the uniqueness of equilibrium. That is, in an economy where consumers withdraw money to make transactions, the real value of the deposit contract is contingent on the beliefs of patient households, and the withdrawal game depends on the price of goods at each period. We also provide some insights about the inefficiency of nominal deposit contracts. A distinctive feature of modern monetary financial institutions is the way in which their liabilities are used as means of payment. In a world with no record-keeping, this specialized financial vehicles are essential since they make a commitment to facilitate transactions among agents, clearing payments at the end of the trading day. A key feature of the present work, however, is the lack of commitment of depository institutions to ensure future consumption. With nominal deposit contracts repayable in cash, banks cannot set credible promises of repayment in the present because of their inability to set prices.

The present paper is related to models that have introduced money to explore bank runs in a setting with nominal deposit contracts. In sort, this strand of the literature states that nominal contracts can improve risk-sharing through the commitment's ability of a third party. In most cases, the literature focuses on the commitment provided by central bank intervention by issuing fiat money. Banks are able to meet their commitments since the monetary authority, by regulating the price level, ensures the real value of deposits at each date. The adjustments in the price level guarantee that depositors receive the optimal allocation of consumption at each date according with their type.

Allen and Gale (1998) introduce fiat money in a model of banking and show that variations in the price level allow nominal debt to become effectively state contingent so that risk-sharing is improved. In a similar paper, Allen et al. (2014) also focus in the role of fiat money to improve risk-sharing in the economy. They state that the combination of nominal contracts and a central bank policy of accommodating commercial banks demand for money leads to first best efficiency. This result holds when there are aggregate liquidity and asset return shocks and also when there are idiosyncratic liquidity shocks. The closest paper to us is Skeie (2008), who states that with nominal deposit contracts payable in money (e.g. currency) bank runs are not explained by liquidity shocks so additional frictions are required to explain a bank turmoil. The no-bank run equilibrium is also explained by price adjustments on the goods' market. However, he states that banks allocate liquidity optimally in the economy, so nominal contracts are a Pareto improvement with respect to real contracts, which are susceptible to multiple equilibria. Diamond and Rajan (2006), in contrast, find that nominal contracts cannot prevent bank runs when there are idiosyncratic risk on the bank's asset side caused by delays in assets returns.

Contrary to this strand of literature, we find that nominal contracts do not provide optimal risk-sharing in an economy exposed to pure liquidity shocks. Previous studies are based on the assumption that the quantity theory of money holds in equilibrium: the price level at each date is proportional to the supply of money extended to the commercial banks by the central bank. Doing so, the monetary authority creates a commitment about the future value of real deposits providing the proper level of contingency to the nominal debt contract designed by the depository institution. In a nominal setting with endogeneous inside money, however, we state that banks cannot commit that prices will reflect the optimal allocation of goods to achieve the optimal risk-sharing.

The paper is structured as follows. Section 3.2 briefly reviews the empirical discussion whether bank runs are driven by self-fulfilling panics or fundamentals. Section 3.3 describes the real economy. Money is introduced in section 3.4, where we study the existence of panics in a nominal setup. Finally, section 3.5 concludes.

3.2 Causes of bank runs

A crucial debate about financial fragility is whether bank runs are explained by self-fulfilling panics or whether they reflect a deterioration in bank specific variables or fundamentals. In a self-fulfilling panic, depositors, anticipating liquidity shortages, coordinate in a run, causing the bank to actually fail even though the depository institution would otherwise remain solvent. Fundamental-based runs, on the contrary, are caused by a perceived worsening of the balance sheet of the bank.

In this respect, the empirical literature has found a strong link between bank crises and fundamentals. Although bank failures that have occurred in the United States up to the 1930s were initially used as case studies of self-fulfilling runs (Friedman and Schwartz (1963)), nowadays it is not clear, however, to what extent illiquidity itself was the cause of those bank closures. For example, Gorton (1988) shows how bank crises during the National Banking Era in the US between 1863 and 1914 could be linked to an increased perception of risk on the part of depositors. Another important episode for bank failures is the Great Depression. Calomiris and Mason (2003) found that deterioration in bank-specific variables as well as in the economic conditions of the geographical area these banks were operating in, affected the probability of failure during the Great Depression for banks within the Federal Reserve System. These authors also found evidence indicating the importance of fundamental components in the Chicago banking panic of June 1932 (Calomiris et al. (1997)). Another example is the collapse of the Bank of the United States in late 1930. According to Werner et al. (1992), at the time of its failure, the bank was insolvent, not just illiquid. Furthermore, the fragmented banking industry during the 1920s is an important characteristic to support the role of fundamentals. At that time, banks in the US were small and they operated regionally, so the bank failures in 1930 and 1931 might also have been originated by large regional specific shocks (Wicker (1980)).

Similar evidence can be found for other countries and time periods. For instance, Demirguc-Kunt and Detragiache (1998) estimate the probability of a banking crisis with a multinomial logit model using data for 65 countries over the period 1980-1994. They find that the likelihood of a crisis is affected by aggregate variables like low GDP growth, high real interest rates or high inflation. Similarly, Schumacher (2000) tested these two hypotheses of bank runs by studying the bank run that took place in Argentina following the currency run triggered by the Mexican devaluation of December 20, 1994. Her analysis supports the idea that the failures and mergers that were commonly viewed as a consequence of the runs were actually rooted in some pre-existing conditions, such as solvency weakness and poor loan portfolio quality that made them more vulnerable to the currency shock. Finally, Martinez Peria and Schmukler (2001) use data from Argentina, Chile and Mexico between the 1980s and 1990s to show that depositors tend to withdraw their funds and require higher interest rates from banks pursuing riskier strategies.

Whether individual or system-wide runs are explained exclusively by a self-fulfilling component is still an open question. One possible problem with the empirical literature on bank crises is that, as Gorton (1988) recognizes, the panic hypothesis of bank runs does not produce a set of testable implications while the fundamental approach does. Therefore, it is difficult to empirically confront one hypothesis with the other. One answer to this debate is to theoretically show under which conditions banks are fragile and susceptible to self-fulfilling runs. The demostration that panic events are inconsistent in a nominal economy is a contribution to this literaure.

3.3 The real setup

3.3.1 The environment

The model is basically the one described in Diamond and Dybvig (1983) but introducing labor in the production technology. As it will be clear below, this modification does not alter the production possibility frontier in any respect.

The economy is characterized by a circle with measure 1. On each point of the circle there is a continuum of identical risk averse households with measure 1. These households are composed of a worker and an entrepreneur. There are three dates indexed by $t = 0, 1, 2$. At $t = 0$, each worker is endowed with a unit of time, whereas entrepreneurs have access to a risk-free, constant return to scale productive technology. A unit of labor employed in this technology at $t = 0$ produces $r > 1$ units of the good at $t = 2$. If a fraction x of the production is interrupted at $t = 1$ it will produce a scrap value equal to x. The remaining fraction $1 - x$ left until maturity of the production process will yield $r(1 - x)$ at $t = 2$. In addition to the productive technology, households have also access to storage without any cost. Obviously, nobody will store anything from $t = 0$ to $t = 1$ because at $t = 0$ storing is dominated by the production technology. However, it may be the case that storage could be used between $t = 1$ and $t = 2$.

At period $t = 0$, households face uncertainty in the form of the timing of consumption. With probability $\lambda \in [0, 1]$ the household becomes of type 1 (impatient) and likes to consume only at $t = 1$, whereas with probability $1 - \lambda$ the household becomes of type 2 (patient) and would prefer to wait until $t = 2$ to consume. Notice that, because of the Law of Large Numbers, λ is also the fraction of households consuming at $t = 1$, while $1 - \lambda$ is the fraction of households consuming at $t = 2$, both in each location and also along the circle. Finally, suppose the household has a period utility function $u(c)$ with

$$u'(c) > 0, u''(c) < 0, \lim_{c \to 0} u'(c) = \infty, \text{ and } \lim_{c \to \infty} u'(c) = 0.$$

Assume further that the coefficient of relative risk aversion satisfies

$$-\frac{cu'(c)}{u''(c)} > 1 \tag{3.1}$$

everywhere.

3.3.2 The efficient allocation

Let c_t^h be the consumption of a household of type $h \in \{1, 2\}$ at period $t = 1, 2$. A household of type $h \in \{1, 2\}$ faces the problem of choosing the fraction $x^h \in [0, 1]$ of the productive technology to liquidate at $t = 1$ in response to the realized type they become, either patient ($h = 1$) or impatient ($h = 2$) together with the sequence of consumptions c_t^h.

If types were publicly observable, it is easy to see that a planner who treats each household identically would choose $c_1^{2*} = c_2^{1*} = 0$, while determining c_1^1, and c_2^2, together with the aggregate fraction of the productive technology to be liquidated at $t = 1$, $0 \leq x \leq 1$, to maximize

$$\lambda u(c_1^1) + (1 - \lambda)u(c_2^2) \tag{3.2}$$

subject to the feasibility constraints

$$\lambda c_1^1 \leq x, \tag{3.3}$$

and

$$(1 - \lambda)c_2^2 \leq r(1 - x). \tag{3.4}$$

Substituting (3.3) and (3.4) in (3.2), the first order condition of this problem is

$$u'(c_1^{1*}) = ru'(c_2^{2*}),$$

which denotes the efficient risk-sharing condition, as in Diamond and Dybvig (1983). Because $r > 1$ and because of the assumed degree of risk aversion in (3.1), it turns out that $1 < c_1^{1*} < c_2^{2*} < r$, which provides some insurance to households.

3.3.3 Non-contingent labor and goods markets

Assume now types are privately observable only. We decentralize this economy by introducing labor and asset markets. In the labor market entrepreneurs hire workers at $t = 0$ and put them to work in the productive technology. These workers are all paid at $t = 1$ the competitive real rate w. Additionally, at $t = 1$ a goods market opens in which $t = 1$ consumption goods exchange for $t = 2$ consumption goods at the price q. In this case, both, patient and impatient households face the budget constraint

$$c_1^h + qc_2^h \leq w + \left[x^h + qr(1 - x^h) - w\right].$$

The left hand side is the present value of consumption while the right hand side is the total revenue of the household in period $t = 1$ coming either from wage payment, w, or from profits by the entrepreneur $\left[x^h + qr(1 - x^h) - w\right]$.

For the goods market to clear it must be the case that

$$q = \frac{1}{r},$$

which implies $c_1^{1e} = 1$ and $c_2^{2e} = r$ together with $c_1^{2e} = c_2^{1e} = 0$ where the e superscript denotes the market equilibrium allocation. Furthermore, with perfect competition in the goods and labor markets, the zero profits condition will imply that entrepreneurs determine the fraction of the production technology to be liquidated, x^h, so as to fulfill

$$x^h + q(1 - x^h)r = w,$$

so that $w^e = 1$.

Because there are λ households consuming at $t = 1$, market clearing in the $t = 1$ goods market means

$$\lambda c_1^{1e} = \lambda x^1 + (1 - \lambda)x^2,$$

which implies aggregate liquidation at $t = 1$ equals $\lambda x^1 + (1 - \lambda)x^2 = \lambda$. If we compare this allocation with that of the planner we observe markets do not provide enough insurance.

3.3.4 A contingent time bank

A possibility to decentralize the first best allocation is to set a contingent time bank. Imagine a time depository institution appears in which workers can deposit their time at $t = 0$. Those workers are put to work by the bank in the productive technology. The bank then promises the households to give c_1 to anyone withdrawing deposits at $t = 1$, or c_2 if the withdrawal is done at $t = 2$. Notice the bank does not know types and the return on deposits can only depend on the timing of withdrawals. To find the equilibrium allocation, the bank then solves for the choice of the aggregate liquidation rate, x, to maximize the expected utility of households

$$\lambda u(c_1) + (1-\lambda)u(c_2),$$

subject to the budget constraints faced by the bank

$$\lambda c_1 \leq x, \tag{3.5}$$

and

$$(1-\lambda)c_2 \leq (1-x)r. \tag{3.6}$$

Obviously this time bank is able to attain the same solution as the planner as in the bank problem in Diamond and Dybvig (1983).

This time deposit contract is efficient because it determines implicit contingent wages to be paid to households at $t = 1$ depending on their realized types. Looking at (3.5) and (3.6), for one unit of labor, impatient households obtain an equivalent wage of

$$w_1 = \frac{x}{\lambda} = c_1,$$

while for patient households the $t = 1$ equivalent wage is

$$w_2 = \frac{1-x}{1-\lambda} = \frac{c_2}{r}.$$

Because of the assumed degree of risk aversion (3.1), it must be the case that

$$w_1 = \frac{x}{\lambda} > w = 1 > \frac{1-x}{1-\lambda} = w_2,$$

where w is the non contingent labor market wage of the previous section.

As in Diamond and Dybvig (1983), the promise to pay (c_1, c_2) supports a suboptimal equilibria in which all patient households run the bank. In such scenario, the bank is required to liquidate its long term investment to service deposit withdrawals at $t = 1$. The liquidation value of the bank at $t = 1$ is 1. Because $c_1 > 1$, all the bank's assets will be used up at date 1 in the attempt to meet the demands of the early withdrawers. Anyone who waits until the last period will get nothing. Thus, it will be optimal for a late consumer to withdraw at date 1 and store the proceeds until $t = 2$.

3.4 The nominal economy

3.4.1 The environment

In this section we introduce nominal deposit contracts into the economy. To do so, we incorporate the idea that banks create endogenous money in the form of deposits when providing loans. We then explore the extent to which these nominal contracts achieve optimal risk-sharing and study whether self-fulfilling panics do occur.

Production technologies and preferences remain equal as described in Section 3.3. That is, entrepreneurs use labor hired at $t = 0$ in the productive technologies whose proceeds will be collected at either $t = 1$ or $t = 2$, respectively. To introduce a role for banks, assume entrepreneurs cannot hire the workers living with them in the same household. This means entrepreneurs need to hire workers in a competitive labor market. Furthermore, when workers are hired, at $t = 0$, these entrepreneurs lack the credibility to convince workers they will get paid in the future, when production takes place either at $t = 1$ or $t = 2$.

The function of banks under this setting is to intermediate between households in this payment process as follows. Assume each location is served only by one bank. At $t = 0$, entrepreneurs borrow inside money, W, from the bank located in the same location they live in. This loan produces a double entry in the bank's balance sheet. On the asset side, the bank annotates the right associated with the loan taken by the entrepreneur. On the other hand, means of payments are created, and the liability side reflects the right of the entrepreneur to dispose of those funds to make payments. In particular, the loan will be used by entrepreneurs to pay workers. The interest rate of these loans is i^l to be paid at the end of period $t = 2$. Notice the introduction of banks solves the commitment problem of the entrepreneurs as wages are paid in advance. Furthermore, it also solves any commitment problem on the part of workers as the receipt from these transfers is proof of the wage payments and, therefore, can be used by entrepreneurs to claim the workers' labor services. Additionally, deposits are homogeneous units of account that can be used by depositors to buy goods from entrepreneurs at either $t = 1$ or $t = 2$. When a depositor (worker) pays for consumption goods, he transfers these deposits to an entrepreneur. A nominal price for consumption goods will be formed as deposits are exchanged for goods. Entrepreneurs then use these revenues from selling the goods they produce to pay back the loan they asked for at period 0. That is the reason these deposits are accepted back by entrepreneurs in exchange for consumption goods. Thus, with the introduction of depository institutions, loan and deposit creation by banks are used to bridge the intertemporal gap between the wage and goods payments in this economy.

The balance sheet of the bank at the time loans are granted on period 0 is:

Balance sheet of bank when loans are made at period $t = 0$

Assets			Liabilities
Loans (entrep.)	W	Deposits (entrep.)	W

Still at time $t = 0$, the loan is used by entrepreneurs to pay workers in advance for their labor services so that the nominal wage bill is W. Thus, after the wage payments are done, banks just rename deposits who are now owned by workers, that is,

Balance sheet of bank when wages are paid at period $t = 0$

Assets			Liabilities
Loans (entrep.)	W	Deposits (workers)	W

At the beginning of the interim period, $t = 1$, depositors (workers) receive the remuneration from deposits at the interest rate i_1^d. Then, the liquidity shock realizes, so that a fraction λ of the households decide to consume on that period. This means they will transfer part of their deposits to entrepreneurs in exchange for goods produced at $t = 1$. At the beginning of period $t = 2$, interest i_2^d are paid on deposits carried over from period $t = 1$. Then, the remaining fraction $1 - \lambda$ of households pay for consumption too. Finally, entrepreneurs collect revenues from selling the goods which are then used by the household to pay back the loan they asked for at the beginning of period $t = 0$.

This setup includes several features worth mentioning. First, the intermediation role played by banks starts when a borrower asks for a loan. The loan is produced because the borrower lacks the means of payment to make a purchase. Then, once these means of payment, in the form of deposits, are created, they circulate in the economy as broad money as long as the loan does not mature. Notice this sequence of events is opposite to the one in Diamond and Dybvig (1983) where the intermediation process starts when a saver deposit assets in the bank to be loaned out to a borrower.

Second, this intermediation service implies two obligations to depository institutions. From a liability side perspective, the production of deposits means the bank has to service the payment orders of depositors. Obviously, if the owner of the deposits make payments to other clients of the same bank, this service obligation is very easy to fulfill. The bank just renames the owner of the deposits. However, if the destination of the payment is a client of another bank, then the transfer of deposits must be met by a transfer of liquid assets. This will also happen if the depositor wants to convert the deposit into outside money (cash). Unlike Diamond and Dybvig (1983), these liquid assets are not deposits that are left idle or invested in an inferior short term technology. These liquid assets are borrowed from the central bank either in the form of cash in banks' vaults or in the form of reserves (current accounts in the central bank). Thus, the liquidity risk banks face, and therefore, the need to borrow outside money from the central bank, is not so much related to depositors disposing of their deposits as of the transfer of funds between banks and into outside money. For example, in the model here, under the assumption that all payments are distributed evenly across all banks, depositors will be disposing of their deposits but there would not be any need for banks to hold liquid assets as all net flows between them will be zero.[3]

From an asset side perspective, the other obligation has to do with the possibility that the value of the loans falls below that of the liabilities. This may well happen if a fraction of loans are not repaid in full. Notice the value of deposits, and the corresponding value of the obligations they generate, should not be affected by that event. This obligation is met by a new category of liabilities, capital, which should absorb fluctuations in the value of assets. In the model here, because loans are to be repaid, there are no solvency issues and capital is not needed.

The third point to stress is the maturity mismatch between bank assets and liabilities. In the model, loans take two periods to mature while deposits are available to depositors anytime. Notice this maturity mismatch is an inevitable consequence of loan provision. Of course, the bank can manage its balance sheet to reduce or eliminate that maturity mismatch. However, because loans are provided essentially to produce the means of payments a borrower lacks and, therefore, to be disposable immediately, automatically the asset the loan creates will have a longer maturity than the liability associated with it.

[3]In practice, central banks support a payment system through which transactions can be easily settled. According to the BIS (2003), the pivotal role of central bank money in payment systems *"reflects the layered architecture of financial systems, whereby private individuals and non-financial businesses hold (part of) their liquidity in banks, and banks in turn hold (part of) their liquidity in the central bank"*.

Finally, the loan the bank holds provides a right to a future flow of funds to the bank. This flow of funds originates from the production and selling activities of the borrowers (the entrepreneurs in the model). An important point to make is that forcing the bank to liquidate that asset to respond to a deposit outflow, does not necessarily imply the production activity financed with that loan has to be liquidated too. The bank cannot recall the loan or force the borrower to pay earlier than what is established in the loan contract. What the bank can do is to try to sell the asset in the market, possibly at a discount. This means the bank is only obtaining a fraction of the present discounted value of cash flows produced by the loan. But selling the loan this way, per se, has nothing to do with the ability of the borrower to pay back the loan. Thus, liquidation of bank assets is just a redistribution of future flows between market participants and does not need to imply a real cost for society as a whole.

3.4.2 Only inside money

In the previous section, we have described what the balance sheet of banks would look like at the end of time $t = 0$. In this and the next section, we will evaluate the consequences for this balance sheet and final net worth of the bank derived from the flow of funds between banks at $t = 1$ and $t = 2$. In this sense, we have previously argued that there are two possible uses of deposits. One appears when the transfers of deposits happen between clients of the same bank. The second occurs when there is a net flow of funds between depository institutions. This net flow of funds must be met with outside money in the form of either reserves or cash previously obtained from a central bank loan. In this section, we consider the case in which deposits cannot be converted into cash. This means that withdrawals take the form of electronic transfers among depository institutions. Because these transfers, by assumption, are equal among banks, the net flow of funds is zero and there is no need for outside money. The next section will cover the case where net flows between banks are not zero.

We focus on a symmetric equilibrium in which individuals of the same type follow the same strategy. Without cash convertibility, impatient agents do not have incentives to withdraw. However, patient households may have reasons to rush and use their deposits to buy consumption goods at $t = 1$. We first solve for the no bank run equilibrium and then wonder whether an equilibrium with a bank run exists.

3.4.2.1 No bank run equilibrium

Let P_t be the nominal price level of the consumption good at $t = 1, 2$. Then, any of the impatient households, those of type $h = 1$, faces the following budget constraint at $t = 1$

$$P_1 c_1^1 + S^1 \leq (1 + i_1^d)W + P_1 x^1, \tag{3.7}$$

while at $t = 2$ it must be the case that

$$(1 + i^l)W \leq P_2(1 - x^1)r + (1 + i_2^d)S^1. \tag{3.8}$$

At the beginning of $t = 1$, the household starts with the return on deposits carried over from period $t = 0$, $(1+i_1^d)W$. During the period $t = 1$, the entrepreneur sells, at the current price P_1, the production from the liquidation of the productive technology, $P_1 x^1$, and the household buys consumption goods, $P_1 c_1^1$. Thus, S^1 is their nominal savings accumulated at $t = 1$. At the beginning of period $t = 2$, the household starts with the return on those deposits, $(1 + i_2^d)S^1$. These resources together with the revenue from selling the fraction of the production technology that remains in place, $P_2(1-x^1)r$, should be enough to pay back the loan, $(1+i^l)W$. Notice here we impose that, because the household is impatient, it will consume all goods purchased at $t = 1$ and will not be optimal for the household to buy any consumption goods at $t = 2$, i.e. $c_2^1 = 0$. These budget constraints collapse to

$$c_1^1 \leq x^1 + \frac{(1 - x^1)r}{1 + i_2^d}\left(\frac{P_2}{P_1}\right) + (1 + i_1^d)\frac{W}{P_1} - \frac{1 + i^l}{1 + i_2^d}\left(\frac{W}{P_1}\right). \tag{3.9}$$

On the other hand, any of the patient households, those of type $h = 2$, faces the budget constraint at $t = 1$

$$P_1 c_1^2 + S^2 \leq (1 + i_1^d)W + P_1 x^2,$$

while at $t = 2$ the budget constraint is

$$P_2 c_2^2 + (1 + i^l)W \leq P_2(1 - x^2)r + P_2 c_1^2 + (1 + i_2^d)S^2,$$

where c_2^2 is consumption done at $t = 2$ and S^2 is the nominal savings of patient households. Notice, we include the possibility of patient households buying consumption goods at $t = 1$, $c_1^2 > 0$, and storing them to be consumed at $t = 2$.

Similarly, these constraints collapse to

$$\begin{aligned} c_2^2 \;\leq\; & \left[1-(1+i_2^d)\left(\frac{P_1}{P_2}\right)\right]c_1^2+(1+i_2^d)\left(\frac{P_1}{P_2}\right)x^2+(1-x^2)r \\ & +(1+i_1^d)(1+i_2^d)\left(\frac{W}{P_2}\right)-(1+i^l)\frac{W}{P_2}. \end{aligned}$$

In this problem it is important to notice that the decision to liquidate the productive technology, that is, the choice of x^h, $h=\{1,2\}$, is taken by the households, not by the bank, as in Diamond and Dybvig (1983). At this point, the decision to run the bank has to do with the possibility of using deposits at $t=1$ to buy goods and carry them to $t=2$ instead of holding the deposits themselves. Of course, the change in demand for goods, and possibly prices, may affect the liquidation choice in general equilibrium. But this is different than assuming that the bank run automatically forces productive investment to be liquidated as done in Diamond and Dybvig (1983).

Notice that for an equilibrium to exist at $t=1$, households have to liquidate part of the productive technology, $x^h>0$. Otherwise impatient households will not have anything to consume. For that to happen, it must be the case that

$$(1+i_2^d)\left(\frac{P_1}{P_2}\right)\geq r.$$

However, because $r>1$, this necessarily means that the optimal choice for patient households is to set $c_1^2=0$. In other words, deposit holding dominates storage between $t=1$ and $t=2$. Then the intertemporal budget constraint for patient households becomes

$$c_2^2\leq(1+i_2^d)\left(\frac{P_1}{P_2}\right)x^2+(1-x^2)r+(1+i_1^d)(1+i_2^d)\left(\frac{W}{P_2}\right)-(1+i^l)\frac{W}{P_2}. \quad (3.10)$$

Thus, the choice of x^h, $h=\{1,2\}$, is such that

$$x^h=\begin{cases} 1 & \text{if } (1+i_2^d)\left(\frac{P_1}{P_2}\right)>r \\ \in(0,1) & \text{if } (1+i_2^d)\left(\frac{P_1}{P_2}\right)=r. \end{cases} \quad (3.11)$$

In either case, substituting this expression back in (3.9) we have

$$c_1^1=1+\left(1+i_1^d-\frac{1+i^l}{1+i_2^d}\right)\left(\frac{W}{P_1}\right) \quad (3.12)$$

so that

$$\begin{aligned} S^1 &= (1+i_1^d)W + P_1x^1 - P_1c_1^1 \\ &= W + P_1x^1 - P_1 - \left(1 + i_1^d - \frac{1+i^l}{1+i_2^d}\right)W \\ &= \frac{1+i^l}{1+i_2^d}W - (1-x^1)P_1. \end{aligned} \tag{3.13}$$

On the other hand,

$$S^2 = (1+i_1^d)W + P_1x^2. \tag{3.14}$$

In addition, the net worth of banks at the end of $t = 2$ is

$$NW = (1+i^l)W - \lambda(1+i_2^d)S^1 - (1-\lambda)(1+i_2^d)S^2.$$

That is, all households return the loan W at the rate i^l while the bank has to pay a return i_2^d to the S^1 savings of the λ impatient households as well as the savings S^2 of the $1-\lambda$ patient households. Substituting for S^1 and S^2 from (3.13) and (3.14), respectively, and imposing the zero profit condition implies that

$$\left(1 + i_1^d - \frac{1+i^l}{1+i_2^d}\right)\left(\frac{W}{P_1}\right) = \frac{\lambda(1-x^1) - (1-\lambda)x^2}{1-\lambda}. \tag{3.15}$$

As mentioned above, there are two possibilities regarding the liquidation choice, given by expression (3.11). If

$$(1+i_2^d)\left(\frac{P_1}{P_2}\right) = r,$$

then $x^h \in (0,1)$ so that from (3.12) c_1^1 becomes

$$c_1^1 = 1 + \frac{\lambda(1-x^1) - (1-\lambda)x^2}{1-\lambda}.$$

Provided that the supply of goods at $t = 1$ is $\lambda x^1 + (1-\lambda)x^2$, market clearing for goods

$$\lambda c_1^1 = \lambda x^1 + (1-\lambda)x^2,$$

implies

$$c_1^1 = 1,$$

so that

$$c_2^2 = r,$$

and

$$\lambda = \lambda x^1 + (1-\lambda)x^2.$$

This means

$$(1+i_1^d)(1+i_2^d) = 1 + i^l.$$

On the other hand, it may be the case that

$$(1+i_2^d)\left(\frac{P_1}{P_2}\right) > r,$$

so that $x^h = 1$ for both types of households. In such a case, combining expressions (3.12) and (3.15) can be observed that the consumption of the impatient household is $c_1^1 = 0$. However, the market clearing condition for goods is $\lambda c_1^1 = 1$, which implies $c_1^1 = \frac{1}{\lambda} \in (0, 1)$. So, this cannot be an equilibrium.

Thus, the banking solution implies that deposits between $t = 1$ and $t = 2$ must produce a real return equal to the productive technology

$$(1+i_2^d)\left(\frac{P_1}{P_2}\right) = r, \tag{3.16}$$

so that the consumption allocation ($c_1^1 = 1$, $c_2^2 = r$) coincides with the suboptimal equilibrium associated with the noncontingent labor and asset market. The reason for this inefficient allocation is the same both in the market as well as in this banking solution. With its nominal deposit contract the bank cannot promise real returns which are contingent on household types.

Finally, given that everyone is following this policy and keeping their deposits in the bank, we have seen that there are no incentives for any patient household to accumulate goods in period $t = 1$ and store them until $t = 2$ since deposits dominate storage in rate of return, $c_1^2 = 0$. Therefore, it does not pay to deviate in this case and the bank equilibrium is stable.

3.4.2.2 Is there a bank run equilibrium?

In the previous section we have found out that it is not in the interest of an individual patient household to dispose of their deposits at $t = 1$ and transfer goods to $t = 2$. The reason is that deposits pay a gross real return of $r > 1$, whereas storing goods implies a gross real return of 1. Notice that if it does not pay for an individual household to run, for the very same reason it seems that it will also not pay for all households of a single bank to run. With a run in only one bank, prices will still be the same as there is a continuum of banks and, again, maintaining deposits dominates carrying goods from one period to the next. This logic, however, only applies if all payments at $t = 1$ are done among the clients of the bank that is run. It therefore misses the point that if there is a run in a single bank, funds, most likely, will be transferred to another depository institution. Thus, the bank may be facing liquidity risks associated with the run. For that reason, the analysis of this case is delayed to the next section where we allow for cash convertibility.

A second possibility has to do with all patient households coordinating into buying goods at $t = 1$ and running all banks. In a system-wide run, prices will change both at $t = 1$ and $t = 2$. To see whether this is an equilibrium, we need to check the incentives for a patient agent to run the bank, given that all other patient agents are deviating and buying goods at $t = 1$. Because all these payments cancel out between banks, deposits of impatient agents at the end of period $t = 1$, will be, respectively

$$S^{1R} = (1 + i_1^d)W + P_1^R x^{1R} - P_1^R c_1^{1R},$$

and

$$S^{2R} = (1 + i_1^d)W + P_1^R x^{2R} - P_1^R c_1^{2R},$$

where the superscript R in aggregate prices denotes the solution when the aggregate bank run takes place and the superscript R in the individual choices denotes the household is also running the bank.[4]

In this case, because the total measure of households buying goods at $t = 1$ is equal to 1 and the aggregate supply of goods is only $\lambda x^{1R} + (1 - \lambda)x^{2R} \equiv x^R < 1$, each agent, independently of being patient or impatient, will buy $c_1^{hR} = x^R < 1$ goods with their $t = 1$ deposits. Impatient agents consume it, clearly making them worse off with respect to the equilibrium with no run. Patient households store it for consumption at $t = 2$. Substituting these purchases in the deposit holdings implies

$$\begin{aligned} S^{1R} &= (1 + i_1^d)W + P_1^R x^{1R} - P_1^R x^R \\ &= (1 + i_1^d)W + P_1^R (1 - \lambda) \left(x^{1R} - x^{2R}\right), \end{aligned}$$

[4]Notice interest rates on deposits from $t = 0$ to $t = 1$, i_1^d, are fixed at $t = 0$ and, therefore, do not include the possibility that there is a run at $t = 1$. The same thing happens with nominal deposits, W, and the loan rate, i^l.

and

$$\begin{aligned} S^{2R} &= (1+i_1^d)W + P_1^R x^{2R} - P_1^R x^R \\ &= (1+i_1^d)W - P_1^R \lambda \left(x^{1R} - x^{2R}\right). \end{aligned}$$

As mentioned above, although everyone is running on their bank, because there are no flows outside the banking system, the transfer of deposits just cancel out among depository institutions and households still maintain deposits from $t = 1$ until $t = 2$.

The net worth of the bank at $t = 2$ when there is a run, would be

$$\begin{aligned} NW^R &= (1+i^l)W - \lambda(1+i_2^{dR})S^{1R} - (1-\lambda)(1+i_2^{dR})S^{2R} \\ &= (1+i^l)W - \lambda(1+i_2^{dR})\left[(1+i_1^d)W + P_1^R(1-\lambda)\left(x^{1R} - x^{2R}\right)\right] \\ &\quad -(1-\lambda)(1+i_2^{dR})\left[(1+i_1^d)W - P_1^R\lambda\left(x^{1R} - x^{2R}\right)\right] \\ &= (1+i^l)W - (1+i_2^{dR})(1+i_1^d)W. \end{aligned}$$

Again, the zero profit condition implies

$$(1+i_1^d)(1+i_2^{dR}) = 1 + i^l,$$

which means that $i_2^{dR} = i_2^d$ and the bank still is solvent even with the run. Obviously this is because no bank looses funding if deposits are just reshuffled between them.

In this situation, consumption of any patient agent will be

$$\begin{aligned} c_2^{2R} &= \left[1 - (1+i_2^{dR})\left(\frac{P_1^R}{P_2^R}\right)\right] c_1^{2R} + (1+i_2^d)\left(\frac{P_1^R}{P_2^R}\right) x^{2R} + (1 - x^{2R})r \\ &\quad +(1+i_1^d)(1+i_2^{dR})\left(\frac{W}{P_2^R}\right) - (1+i^l)\frac{W}{P_2^R} \\ &= \left[1 - (1+i_2^{dR})\left(\frac{P_1^R}{P_2^R}\right)\right] x^R + (1+i_2^{dR})\left(\frac{P_1^R}{P_2^R}\right) x^{2R} + (1 - x^{2R})r. \end{aligned}$$

Notice that for patient households to run the bank and spend all their accumulate deposits buying goods so as to make $c_1^{2R} > 0$, it must be the case that

$$(1+i_2^{dR})\left(\frac{P_1^R}{P_2^R}\right) \leq 1.$$

However, at the same time, for both patient and impatient households to liquidate some of the productive technology (so that $x^{hR} > 0$, $h = \{1, 2\}$) and have goods to be purchased at $t = 1$, it still have to be the case that

$$(1 + i_2^{dR}) \left(\frac{P_1^R}{P_2^R} \right) \geq r > 1.$$

Thus, without cash convertibility it is impossible to have both a run on banks and liquidation of the productive technology, so there is no equilibrium with a bank run in this case.

3.4.3 Cash convertibility

We analyze now the possibility of bank runs with cash convertibility. Two points must be remarked. First, with this option, apart from deposits, patient households could use also either goods or cash to transfer purchasing power from $t = 1$ until $t = 2$. However, in the event of a run, we have already shown that it is not worth for patient households to buy goods at $t = 1$ and store them until $t = 2$. The existence of cash does not change that result. Thus, a run is now associated with cash withdrawals at $t = 1$. Below we analyze whether this is indeed an equilibrium. Second, allowing for cash convertibility forces banks to demand outside money. Banks gather this liquidity from an open market operation conducted by a central bank at $t = 1$ at the interest rate i^o. This interest rate is set exogenously by the monetary authority.

3.4.3.1 No bank run equilibrium

In section 3.2.1 we have shown the stability of the nominal deposit equilibrium as patient households do not have any incentive to buy goods at $t = 1$ and store them until $t = 2$ given that nobody is running the bank. Here we show whether that is the case when the patient household which is deviating hoards cash instead.

Again, because this is a single household, prices remain at their equilibrium values. Let M^2 be the cash accumulated at the end of period $t = 1$ by this household. It must be the case that

$$M^2 = (1 + i_1^d)W + P_1 x^2.$$

Then, their budget constraint at $t = 2$ must read

$$P_2 c_2^{2D} + (1 + i^l)W = P_2(1 - x^2)r + M^2,$$

where, again, the superscript D means a household deviating, so that

$$c_2^{2D} = (1 - x^2)r + \frac{P_1}{P_2}x^2 - (i^l - i_1^d)\frac{W}{P_2}.$$

Using the equilibrium prices

$$r = \frac{1 + i_2^d}{P_2/P_1},$$

and

$$(1 + i_1^d)(1 + i_2^d) = 1 + i^l,$$

it turns out that

$$c_2^{2D} = (1 - x^2)r + \frac{x^2}{1 + i_2^d}r - (i^l - i_1^d)\frac{W}{P_2} < r = c_2^2.$$

Thus, still it does not pay to deviate and hoard cash instead of deposits. The reason is that since $i_2^d \geq 0$, deposits dominate cash as store of value between $t = 1$ and $t = 2$. Consequently, the nominal deposit equilibrium still is stable under cash convertibility.

3.4.3.2 Is there a bank run equilibrium?

We turn now to the case where all households of a single bank are worried about a possible run. The difference with respect to the case in section 3.2.2. is that now all depositors, independently of their type, will convert nominal deposits into cash. Thus, the demands for cash by both impatient, call it M^1, and patient, call it M^2, households at $t = 1$ are given by

$$P_1 c_1^{1R} + M^1 = (1 + i_1^d)W + P_1 x^{1R},$$

and

$$M^2 = (1 + i_1^d)W + P_1 x^{2R},$$

respectively. At $t = 2$, the budget constraint for impatient households is

$$(1 + i^l)W = P_2(1 - x^{1R})r + M^1,$$

while the constraint for patient househods reads

$$(1 + i^l)W + P_2 c_2^{2R} = P_2(1 - x^{2R})r + M^2,$$

where the superscrit R, again represents the fact that households are running the bank. Notice since there is a run on only a single bank, prices remain at their equilibrium levels

$$r = \frac{1+i_2^d}{P_2/P_1} \tag{3.17}$$

and

$$(1+i_1^d)(1+i_2^d) = 1+i^l. \tag{3.18}$$

Substituting for M^1, the consumption level of impatient households is

$$c_1^{1R} = (1+i_1^d)\frac{W}{P_1} + x^{1R} - \frac{M^1}{P_1} = (i_1^d - i^l)\frac{W}{P_1} + x^{1R} + \frac{P_2}{P_1}(1-x^{1R})r.$$

On the other hand, substituting for M^2 implies that consumption for patient households is

$$c_2^{2R} = (1-x^{2R})r - (1+i^l)\frac{W}{P_2} + \frac{M^2}{P_2} = (i_1^d - i^l)\frac{W}{P_2} + \frac{P_1}{P_2}x^{2R} + (1-x^{2R})r.$$

The allocation (c_1^{1R}, c_2^{2R}) will not be an equilibrium if two conditions hold simultaneously. First, given that everyone is running the bank, (c_1^{1R}, c_2^{2R}) will not be an equilibrium if both impatient and patient households have an incentive not to withdraw. Second, given that everyone is running the bank, for (c_1^{1R}, c_2^{2R}) not to be an equilibrium we also need not withdrawing to be feasible for a household, that is, the bank to be still solvent. To check the first condition, notice that for the aggregate prices (3.17) and (3.18) and using that $M^h > 0$, it can be shown that

$$c_1^{1R} = 1 + (1-x^{1R})i_2^d - (1+i_1^d)\frac{W}{P_1}i_2^d < 1 = c_1^1,$$

and

$$c_2^{2R} = r - \left(1 - \frac{1}{1+i_2^d}\right)x^{2R}r - (i^l - i_1^d)\frac{W}{P_2} < r = c_2^2.$$

Thus, neither impatient nor patient households have an incentive to join the run. They may still do it, however, if they foresee the bank to be insolvent on period $t = 2$. To check that, the net worth of the bank in the event of a run is,

$$NW^R = (1+i^l)W - \lambda(1+i^o)M^1 - (1-\lambda)(1+i^o)M^2$$

since the bank needs to borrow from the central bank, at the rate i^o, M^1 units of cash to be delivered to impatient households and M^2 units of cash for patient households. Using the expressions for c_1^{1R} and c_2^{2R} in the budget constraints, the bank's net worth is

$$\begin{aligned} NW^R &= \left[1 + i^l - \lambda(1+i^o)(1+i^l) - (1-\lambda)(1+i^o)(1+i_1^d)\right] W \\ &\quad + P_1 \left[\lambda(1 - x^{1R}) - (1-\lambda)x^{2R}\right]. \end{aligned}$$

Because there are λ impatient households and patient households do not demand goods at $t = 1$, for an equilibrium to exist it must be the case that

$$\lambda = \lambda x^{1R} + (1-\lambda)x^{2R}.$$

Then, the net worth of the bank will be positive as long as the central bank's refinancing rate satisifies

$$1 + i^o < \frac{1 + i_2^d}{1 + \lambda i_2^d} \equiv 1 + \overline{i^o}.$$

Thus, as long as the refinancing rate of the central bank is low enough, i.e. $0 \leq i^o \leq \overline{i^o}$, there will be no equilibrium with a bank run.

3.5 Conclusions

Banking failures are a complex phenomena. The large variety of factors that foster the difficulties of the banking system, and the inherent characteristics of each financial institution make the evaluation of bank runs a hard task. In this sense, a relevant discussion about financial instability is whether runs of banking institutions are driven by self-fulfilling panics that force solvent banks to fail, or whether they reflect a fundamental deterioration of bank specific variables.

In this paper we show that it is hard to consider self-fulfilling panics as the only cause that explain bank runs in a modern economy where depository institutions issue nominal demandable claims to facilitate transactions. Based on the traditional liquidity problem of Diamond and Dybvig (1983), our framework incorporates three additional elements into the theoretical literature of bank runs. First, the chain of intermediation starts when borrowers need money to make payments. Once a loan is originated, the bank creates deposits that borrowers use as means of payments that circulate through the economy as broad money. Second, depositors withdraw money making electronic transfers to other banking institutions or when they decide to hoard cash. To offset this liquidity risk, banks manage a demand for reserves from the central bank. Third, the maturity mismatch between banks assets and liabilities is inherent to the creation of new loans, and the liquidation of bank assets implies the redistribution of future flows these loans produce between market participants.

In such nominal setting, the existence of a unique equilibria is fundamented by the uncontingent nature of nominal deposit contracts. In addition, we show that depositors have no incentives to withdraw their funds independently of whether cash convertibility is allowed or not. Although coordination failures might contribute to bank instability, these results do not support the critical role played by the self-fulfilling hypothesis as a significant force of bank runs.

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