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General Introduction

Systemic risk, defined as the probability that an event threatens the financial stability of the financial system as a whole and consequently triggers the collapse of the economy (Bernanke, 2009), has become a major concern of governments and regulators around the word since the great financial crisis of 2008. Financial crises are associated with damage not only to the financial system but also to the real economy, triggering, inter alia, a decline on aggregate output and employment that can persist over an extended period of time. These economic downturns required the intervention of governments through public policy solution including macroeconomic and prudential policies.

The literature has identified three sources of systemic risk. First, one of the determinants of the systemic dimension of a financial institution is the common exposure to major risk factors resulting from the same diversification strategies of different agents (commonality phenomenon). For instance, Wagner (2010) shows that even though diversification reduces each institution's individual probability of failure, it makes systemic crises more likely since more diversification makes banks' risks more similar to each other since banks hold identical portfolios. Second, the financial system is characterised by an inherent procyclicality that generates financial imbalances reflecting macroeconomic cycles. For example, through a study of the US financial institutions, Adrian and Shin (2010) highlight that leverage is strongly procyclical for these institutions and that this procyclical leverage affects aggregate volatility and particularly the price of risk. Finally, interconnections between financial institutions (e.g. through interbank lending) produce contagion effects and even cascading defaults. In particular, if one of these financial institutions experiences difficulties, this stress can be transmitted to its counterparty as well as to its counterparty's counterparty, thus weakening the whole financial system. Specific examples include the spillover effects of the Lehman bankruptcy and the exposure of European banks to the risk of sovereign default in some European countries.

The 2008 crisis has relaunched the debate on how to regulate financial institutions to address this systemic risk. At the heart of this debate is the recognition of the need to shift from regulation focusing solely on the individual financial institution risks to regulation

considering the financial system as a whole. The debate also considers how to design and implement new macroprudential regulation and how to integrate it with other policies, in particular monetary policy.

Transition to a new prudential framework

Macroprudential policy, as opposed to microprudential policy, involves adding a macroeconomic perspective to the supervision and regulation of the financial system by considering an institution's links to other institutions, the market and the real economy. Microprudential policy focuses only on the soundness of an individual financial institution.[1] Before the crisis the regulation put in place was only microprudential and this regulation was largely criticized in the aftermath of the crisis.

There are some reasons explaining why micro rules for supervision and regulation are not sufficient. Brunnermeier, Crockett, Goodhart, Persaud, and Shin (2009) argue that the system as a whole behaves differently from its individual components.[2] According to this belief, making individual banks safer would not necessarily make the whole financial system safe. In fact, in trying to become healthier, financial institutions may react similarly and hence make the financial system more fragile. For instance, a bank, that simply wants to respond to capital regulation and increases its capital adequacy ratio, may be forced to sell particular assets. This might be seen as a prudent response from the perspective of an individual institution. However, if many institutions act in this way, these sales lower the general price of the assets in the market, inducing more stress to other institutions. Hence, the first sale can set off a cascade of fire sales that inflicts losses on many institutions, reducing the financial system's capacity to bear risk (French, Baily, Campbell, et al., 2010). Another illustration is that at the peak of the credit cycle, individual financial institutions appear healthy because the measured risk is low, while the whole financial system is increasingly fragile as imbalances accumulate (Minsky, 1986). This absence of a macroprudential perspective on banking risks constituted the major weakness of microprudential regulation set in place before the crisis.

The traditional microprudential regulatory framework also failed by allowing banks to operate at very low levels of capital, and by overlooking the weak banking supervision at the time and the almost non-existent framework for resolving failing financial institu-

[1] See Freixas, Laeven, and Peydró (2015) for a comparison of macroprudential and microprudential regulation.

[2] Indeed, the main tool used by the former regulation was the capital adequacy requirements, which is the capital that financial institutions must hold in relation to the regulatory requirement, defined by the Basel Committee, to ensure their businesses remain stable.

tions. Some aspects of systemic risk can thus be overcome only through macroprudential regulation (e.g. procyclicality of financial regulation). Others can be reduced through adequate microprudential regulation, for example by putting in place a clear and precise bank resolution framework. To meet these objectives, a new regulatory framework has been developed through the Basel III regulation as well as the US financial reform under the Dodd Frank Act (DFA) and the European financial reform under the Bank Recovery and Resolution Directive (BRRD). On the one hand, Basel III takes on a macroprudential dimension and allows, inter alia, to address the problem of the procyclicality of financial regulation. Indeed, this new regulation requires procyclical capital requirements, i.e. banks have to hold higher requirements in good times and lower ones in bad times. Hence, once a crisis hits, banks will have higher buffers than required by regulators, thus have a countercyclical capital buffer (Freixas, Laeven, and Peydró, 2015). On the other hand, both the DFA and the BBRD represent an improved and harmonised tool for orderly resolution of failing banks with minimal costs to taxpayers.[3] A novelty imported by these two frameworks is the increased involvement of the private sector in bank resolution and in particular via bail-ins. In this alternative scheme, the failed bank shareholders and creditors bear the financial consequences of the bank's default. The most common resolution plan in the aftermath of the last crisis was the bailout, which is the action by a government of giving financial assistance to an institution in order to prevent it from collapse.[4] This resolution plan represents a considerable cost to the taxpayers and creates moral hazard.[5] And so, through the bail-ins, the new regulation tries to overcome these bailout drawbacks.

The lessons of the 2008 crisis have let to important institutional changes and the organisation of macroprudential policy.[6] For instance, at the European level, this crisis and the subsequent sovereign debt crisis have revealed the need for a banking union. Indeed, it became clear that difficulties in national banking sectors could easily spill over national borders and cause financial disruption in other Member States. Therefore, the aim of this banking union was to create a unified and coherent framework to ensure better and stronger supervision of European banks. The European Banking Union is

[3]The US and EU frameworks have much in common but also present significant differences. See Philippon and Salord (2017) for a presentation and comparison of the two frameworks.

[4]Laeven and Valencia (2012) provide a detailed report on the interventions that took place during the great financial crisis.

[5]By expecting that they would always be saved by the government (e.g., due to the too-big-to-fail issue, and the too many to fail issue), banks are taking more risks, which further weakens the financial system.

[6]See Freixas, Laeven, and Peydró (2015) for a detailed presentation of institutional changes in prudential regulation in the European Union, United Kingdom and United States.

often presented as based on 3 pillars: the Single Resolution Mechanism (SRM), the Single Supervision Mechanism (SSM) and the European Deposit Insurance Scheme (EDIS).[7]

The macroprudential and microprudenial regulation are not an objective per se but they can complement each other to meet the ultimate objective of prudential regulation, which is to ensure the stability of the financial system.

Monetary policy and systemic risk

The recent global financial crisis has also reopened the discussion on the role of monetary policies. Indeed, before the crisis, the common view was that monetary policy should respond to asset price movements only as far as they impact inflation or the output gap (e.g. Bernanke and Gertler (2000) and Bernanke and Gertler (2001)). This prevailing wisdom has evolved into a broader role for monetary policy that would take into consideration the need to include it in containing global risk since it showed its relevance in reducing systemic risk ex post in the recent crisis (Freixas, Laeven, and Peydró, 2015).[8] By the way, this role for central banks is not new and the idea that they should provide liquidity to support the financial system goes back to the 19th century work of Bagehot (1873).[9] Hence, central banks, during the crisis, via conducting their monetary policies (interest rate policy, open market operations and nonstandard measures) and as a lender of last resort, played a key role in reducing financial crisis externalities by providing liquidity support to the financial sector. Nevertheless, if we go back to the management and prevention of the last crisis, the central banks were criticized for the fact that they could and should have acted differently, partly because of the insufficiency of their preventive action and lack of consideration for the financial stability component. In particular, the predominant belief before the crisis was in favour of a separation of the authorities that set monetary and prudential policy. Yet Peek, Rosengren, and Tootell (1999) showed that confidential bank supervisory information allows monetary policy to be pursued more effectively. Blanchard, Dell'Ariccia, and Mauro (2013) explained that splitting the monetary policy authority and the macroprudential policy authority will generally not lead to the first-best solution since there easily can be conflicts between price stability and financial stability. A consensus therefore emerged since the last crisis to entrust the management of these two

[7]The SRM ensures an orderly resolution of failing banks with minimal costs to taxpayers and to the real economy. The SSM makes the European Central Bank responsible for banking supervision in the euro area, with the mandate to directly supervise the most significant banking groups. The EDIS provides stronger and more uniform insurance cover for all retail depositors in the European Banking Union.

[8]The literature showed that systemic crises tend to follow strong credit booms (e.g. Kindleberger (1978)). As monetary policy affects the credit demand and supply, it is reasonable to think that it constitutes a tool to reduce systemic risk, both before and after the crises occur.

[9]The latter prescribed that the central banks should lend freely against a good collateral.

policies to the central bank. Incidentally, the European Central Bank (ECB), following the creation of the European Banking Union, is also currently responsible for banking supervision. This allows the ECB to directly supervise the soundness of the most significant banking groups, to carry out prudential reviews, on-site inspections and investigations. For instance, the ECB conducts stress tests which are exercises that simulate extreme but plausible economic and financial conditions in order to study the consequences for banks and measure their resilience to such situations.

While monetary policy has been successful in fighting systemic risk and avoiding another Great Depression, its use has raised the problem of moral hazard and the expectations of future bailouts by financial institutions. This role of monetary policy will be reduced once effective macroprudential policies are implemented and operational (Maddaloni and Peydró, 2013). However the effectiveness of this macroprudential policy remains to be determined, as understanding of how best to implement it is still in its infancy. The use of monetary policy is therefore always necessary to prevent and manage crises and the relative roles of monetary policy, and macroprudential policy are still evolving. In this regard, the objective of financial stability and the objective of price stability are complementary in the sense that price stability is a necessary condition for financial stability (Freixas, Laeven, and Peydró, 2015).

Challenges for Regulatory Policy

Lessons from the crisis have been learned since the global financial crisis and governments around the world have put in place new regulatory measures to ensure the financial stability of the system and to avoid the outbreak of new crises.

The new regulatory framework addresses some of the weaknesses of pre-crisis prudential regulation. For instance, as mentioned earlier, Basel III, by requiring a countercyclical capital charge, makes it possible to protect the financial sector from periods of excess aggregate credit growth, often associated with increased systemic risk. However, it remains some regulatory challenges that have the potential to destabilize the international financial sector. To mitigate these shortfalls, the new regulation has to consider, inter alia, the following elements.

First, it is important to pay attention to the direct cost that the regulation could represent to the real economy. Indeed, while a tight supervision and excessive rules may prevent from the build-up of systemic risk, they can have an impact on the real economy through a potential reduction in growth and the eventual misallocation of funds to firms and households. For instance, a new literature including Beck, Da-Rocha-Lopes, and

Silva (2021) has shown that the ultimate new resolution tool proposed by regulators, bail-in, significantly restricts credit supply, reducing investment and employment which is detrimental to the economy. And the current regulation does not give any importance to this issue yet.

Second, endogenous consideration of cross-border spillovers is essential due to the important feedback and amplification effects in contagion phenomena. In fact, systemic risk is an endogenous concept, since in addition to fire-sale spillovers previously explained, financial institutions finance themselves from other institutions via short term loans. This leads to denser and more fragile networks. Although there is now a broad consensus among policymakers that network theory is the appropriate framework for studying systemic risk, most existing financial regulatory rules are still "atomistic" in that they do not take into account the fact that each individual institution is part of a larger network (Enriques, Romano, and Wetzer, 2019). For instance, the systemic-risk scoring methodology currently implemented in the European Union to identify and regulate Systemically Important Financial Institutions takes into account interconnectedness of institutions to capture the expected impact of the failure of a bank on its business partners. However, this is done exogenously without any particular identification of the partners and their degree of connectedness.[10] Another relevant example is the current micro bank resolution framework. New rules for resolution of failing banks are overly focused on the resolution of individual banks, with only a minor exemption for systemic risk (Schoenmaker, 2019). Indeed, the new rules propose bail-in as a resolution tool for failing banks by focusing on the soundness of an individual financial institution without propetly considering the impact of such a measure applied to one bank on other banks. It is as if the same errors of the pre-2008 crisis (micro-supervision) are being repeated.

Third, the institution in charge of macroprudential policy has to set up a communication policy. It is clear that designing such a policy is a complex task. Indeed, one could think that full transparency is the key to financial stability but this is not always the case. For instance, once the likelihood of a systemic crisis is announced, people updates their belief and behave accordingly in the same way, which can create more panic in the market and even turn into a self-fulfilling prophecy. Another relevant example involving the disclosure of stress test results can be mentioned. Indeed, if the stress tests are not suitably conceived, rather than ensuring market discipline, the disclosure of their results may actually generates more fear, thereby weakening confidence in the banking sector.

[10] Another distortion in this new regulation was identified by Benoit, Hurlin, and Pérignon (2019). They showed that the systemic-risk scoring methodology severely distorts the allocation of regulatory capital among banks.

Such a decline in confidence in the banking sector can have additional negative impacts on the real sector.[11] Moreover optimal disclosure strategy may be different in calm time from crisis time. Goldstein and Leitner (2018) show that disclosure is desirable in some circumstances but not in others. This was clearly illustrated by policymakers' behaviour during the crisis. While the Federal Reserve was keen to keep its lending programs anonymous during the crisis to avoid revealing the identities of weak banks, it did reveal the results of its stress tests to restore confidence in the market (Gorton, 2015). The challenge would therefore be to determine the optimal disclosure strategy, for a particular issue and timing, that ensures the financial stability.

Fourth, monetary policy cannot be considered separately from prudential policy as I argued earlier. The introduction of the macroprudential tool is not sufficient to mitigate systemic risk. This policy needs to be supported by macroeconomic policies to avoid economic depressions. Although a step in this direction has been taken, governments still have work to do to set the right balance between these two policies and how best to manage them.

These are some of the challenges that the regulator must overcome. This task is still an ongoing work and depends on the effectiveness of macroprudential policy in participating in managing financial imbalances. The main goal of this dissertation is to contribute to this abundant and stimulating literature by proposing how to address some of the challenges faced by the regulator to better mitigate systemic risk.

Objectives and outline of the thesis

Each chapter of the thesis illustrates how governments policies and tools could better strengthen financial stability, thereby preventing the emergence of new crises. The objective is twofold. As stated above, the role of monetary policies has evolved to target only inflation, the first aim of this dissertation is hence to verify whether policies inspired by unconventional central bank policies can address macroprudential objectives and to propose an optimal way to implement them for minimising systemic risk. Then, I contribute to the literature on the role of information for containing systemic risk. Indeed, I examine the optimal information to be disclosed by the regulator on banks' health in order to limit the cost of its intervention during banks resolution operations (by proposing bail-ins and bailouts). I also study the impact of the financial network structure on the decisions of banks involved in bail-ins as well as on the decisions of the regulator regarding

[11] Goldstein and Sapra (2014) show that while stress tests disclosure can enhance market discipline since they allow supervisors and markets participants to control banks' behavior, it can also create problems.

information disclosure when it intervenes in resolution mechanisms.

Chapter 1: Reshaping monetary policies to reach financial stability

This chapter proposes a new approach to assess central banks interventions by introducing a central bank in the contagion model proposed by Greenwood, Landier, and Thesmar (2015). In this model, contagion is due to fire sales. By taking into account this contagion channel, I study how the central bank can optimally reduce systemic risk by using redesigned unconventional policies.

In a theoretical study, I show that the optimal asset purchase policy depends, inter alia, on the banks' portfolio composition: for two banks having the same portfolio composition, the total budget of the central bank goes to the bank with the highest leverage ratio as this would reduce the impact of fire sales. I show also that, for an optimal Refinancing Operation, the bank with the highest *connectedness*-to-leverage ratio benefits from the most important loan. The connectedness, in this context, expresses the extent to which the bank holds illiquid assets and/or assets that are widely held by other banks in the financial system. These findings show that such policies can create moral hazard (for instance, banks will hold a high leverage ratio to ensure that they are rescued in a crisis), which has been widely criticised in the aftermath of the Great Financial crisis. This analysis is in line with recent literature that suggests that macroprudential policy should be used primarily to ensure the stability of the financial system, but may also be supported by monetary policy if necessary.

My framework is then applied to European banks during the sovereign debt crisis, which allows me to verify the effectiveness of this two reshaped unconventional monetary policies. For instance, the optimal asset purchase policy reduces the aggregate vulnerability of the financial system by 44%. Finally, I find that an optimal asset purchase as a monetary policy is beneficial, especially when the central bank buys specific sovereign debts.

Chapter 2: Bail-in vs. Bailout: A Persuasion Game

This chapter proposes to transpose the mechanism set up by the Single Resolution Mechanism into a theoretical framework, more precisely a Bayesian persuasion game, by considering different variants of the real sphere. The aim of this paper is to study how the regulator should use information at its disposal to ensure the financial stability when it

faces resolution issue through proposing bail-ins and bailouts. We hence propose a model with incomplete information where a distressed bank asks its creditor, a healthy bank, to reduce its debt. Given the information disclosed by the regulator about the asset quality of the distressed bank and its possible bailout by the government, the healthy bank can accept or not the bail-in proposal. The role of the regulator is to select the optimal disclosure rule that reduces its ex-ante expected loss function.

The findings of this chapter suggest that the optimal disclosure strategy depends, inter alia, on the period through which the bank is passing and on the different costs introduced in the model (bankruptcy cost, liquidation cost, bailout cost and bail-in cost). For instance, when bailouts are costly and bail-ins are not, the regulator does not want to bailout banks and thus wants to convince the healthy bank to make bail-ins. Thereafter, in crisis time, it is fully transparent, which discourage the healthy bank from bailing-in the distressed one. However, in normal time, the best way for the regulator to achieve its goal is when it chooses to not disclose information about the distressed bank asset quality. This would encourage the healthy bank to rescue the distressed one.

Chapter 3: Preventing cascade defaults through information disclosure

This chapter proposes a new approach to limit cascades of failures in financial networks, when a crisis occurs by using the disclosure policy of the regulator. Thereafter, I propose to extend the model developed Chapter 2 to a financial network. I consider an endogenous interaction between regulator and financial institutions and see which network architecture (complete network vs. ring network) promotes these interventions.[12] In my model, a group of fundamentally defaulting banks (banks that default even if they are fully reimbursed by their partners) asks their creditors (other banks of the network in my framework) to reduce their debts. The healthy banks can accept or not this bail-in proposal based on information disclosed by the regulator about banks' assets quality.

When I look at the regulator disclosure rule in the case of a single fundamentally defaulting bank linked to several healthy banks, I find that optimal disclosure strategy depends not only on different costs introduced in the model but it is also driven by network structure and density. For instance, when bail-in cost is low and when the distressed bank has dense connections, the regulator wants to encourage bail-ins. To this end, in normal time, the regulator's disclosure rule must be non-informative.

[12] A ring network is a network where each bank i connects to exactly two other nodes, a creditor $i+1$ and a borrower $i-1$. However, a complete network is a fully connected network where all the liabilities of a bank i are held by all other banks.

In networks of three banks (composed of a fundamentally defaulting bank, a distressed bank, i.e. a bank that could default if it is not reimbursed by the fundamentally defaulting bank, and a surviving one), I show that when bail-in is not costly and in the case of shocks of low intensity, there is more gain for the regulator to disclose information promoting bail-ins in ring networks compared to complete networks. In particular, in some cases when on average the fundamentally defaulting bank is suspected of having a poor asset quality and the distressed one is presumed to have good asset quality, while partial disclosure is an optimal strategy in ring networks, no disclosure minimizes the regulator expected losses in complete networks.

Less central results show that the more intense the cascade of defaults, the more a surviving bank is likely to agree to rescue fundamentally defaulting banks even if they are not directly linked.[13] Indeed, the default of distressed banks leads to the collapse of other banks and these cascading defaults become all the more costly for the surviving banks especially when the failure cost is high. I show then that the incentive to bail-in is stronger in less densely connected networks in case of negative small shocks and when there is no possible bailout. In fact, losses are lower in complete networks since this structure allows shocks absorption's when these shocks are of low intensity as shown by Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015).

[13] I mean by intensity the number of defaulting banks and the amount of losses triggered by these defaults.

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Chapter 1

Reshaping monetary policies to reach financial stability

Abstract

I propose a new approach to assess central banks interventions by introducing a central bank in the contagion model proposed by Greenwood, Landier, and Thesmar (2015). I study how, using reshaped unconventional policies, the central bank can safeguard financial stability. In a theoretical study, I show that an optimal asset purchase policy depends, inter alia, on the banks' portfolio composition: for two banks having the same portfolio composition, the total budget of the central bank goes to the bank with the highest leverage ratio. However, with different portfolios, the amount allocated to buy assets from each bank depends on banks characteristics'. I show also that, for a Refinancing Operation, the bank with the highest *connectedness*-to-leverage ratio benefits from the most important loan. My framework is then applied to European banks during the sovereign debt crisis, which allows me to verify the effectiveness of these reshaped unconventional monetary policies. I find also that an asset purchase as a monetary policy is beneficial, especially when the central bank buys specific sovereign debts.

Keywords: Asset Purchase Policy; Fire sales; Refinancing Operation; Systemic risk; Unconventional monetary policy

1.1 Introduction

The financial crisis of 2007 had consequences which spilled over the global economy. Its repercussions have elicited unprecedented responses from major central banks in order to influence monetary and financial conditions. These central banks had therefore recourse to a set of new measures, the so called "unconventional policies".[1] This choice is justified by several factors. Indeed, during that period, central banks lowered their policy interest rate and for some of them almost to the zero lower bond. It was therefore no longer possible for them to further reduce it. Moreover, the transmission mechanism of monetary policy was unable to operate due to the paralysis on the interbank market and the illiquidity of some assets. To all of this one must add an unanticipated systemic magnitude of Lehman Brothers defaults and the fear of a global deflationary spiral (Clerc and Raymond, 2014) .

Nevertheless, by using these unconventional measures, central banks have been entrusted with responsibilities that go beyond their price stability mandate.[2] Hence, the mandates of some of them have evolved to include macroprudential functions. By the way, the European Central Bank (ECB) is now the sole supervisor of euro area banks. Moreover, as the objective of price stability is no longer sufficient to ensure macroeconomic and financial stability, a consensus has emerged among a large number of academics and policy makers according to which the task of financial stability should be carried out by the central bank.[3] The complexity of the financial system and the numerous interconnections between financial institutions is certainly an argument in favour of centralizing all these functions within a single institution. The question now is how do we achieve this goal?

One option is the coordination of macroprudential and monetary policies. This is notably the option proposed by Betbèze, Couppey-Soubeyran, and Plihon (2011). To this end, monetary policies need to reinvent themselves to meet these new challenges for the central bank and this is what I propose in this paper. Indeed, I draw from the unconven-

[1] The conventional (traditional) instrument of monetary policy in most major industrial economies is the very short term nominal interest rate (Bernanke, Reinhart, and Sack, 2004). Unlike conventional monetary policy, unconventional measures targeted something other than short-term interest rates. In fact, they can affect term spreads, influence liquidity and credit spreads or restore liquidity conditions and asset valuations in the financial system as a means of supporting the monetary policy transmission mechanism (Bindseil, 2016).

[2] Goodhart (2014) argue that, after the crisis, central banks have found themselves saddled with two responsibilities and objectives: financial stability as well as price stability.

[3] According to Schnabel (2016), the central bank should take into account financial stability because the banking system plays an important role in the transmission of monetary policy and severe banking crises are most often accompanied by macroeconomic recessions that require the intervention of the central bank.

tional policies adopted by the central bank in the aftermath of the crisis, in particular an asset purchase policy and a refinancing operation, to design policies that meet macroprudential objective, specifically financial stability objective.

However the issue during the financial crises is not only to intervene, but also to choose the appropriate way to do so. Indeed, Taylor (2009) argues that, in the middle of the subprime crisis, one reason that caused, prolonged, and worsened it, is the support provided by the government for certain financial institutions and their creditors but not for others in an ad hoc fashion without a clear and understandable framework. From that, it is clear that well-targeted interventions should be pursued actively to attenuate the buildup of financial risks and that is why I am interested in the optimal way in which these policies can be implemented.

This article proposes a new and simple way to study the role of central banks to mitigate systemic risk. Based on this setup, I am also able to assess the accuracy of these reshaped unconventional policies during the sovereign debt crisis. My model, similar to the contagion model proposed by Greenwood, Landier, and Thesmar (2015), takes as given banks' leverage ratio, assets holding, assets liquidity and equity capitals. It considers then a negative return shock experienced by one or many assets. This shock moves away banks from their initial leverage. Banks respond to this by selling assets to keep their leverage ratio constant. These sales generate a decline in the general price level which depends on the liquidity of the assets sold and their amount. Hence, banks holding the fire-sold assets suffer, in the next period, from a decrease in their assets holdings value. Greenwood, Landier, and Thesmar (2015) introduce also a new systemic risk measure, the *aggregate vulnerability*, which assesses the value of losses in the next period due to the contagion episode. I intervene at this level, by modeling a central bank, which acts, from a certain threshold of vulnerability, by adopting an unconventional monetary policy. I propose a simple modelling of the central bank in this framework: the objective of the latter is to reduce systemic risk, it so minimizes the *aggregate vulnerability* of the system (in absolute terms) given a budget constraint.[4]

I, first, exploit this framework theoretically. I consider an asset purchase policy reshaped to support the asset prices and thus prevent fire sale spirals. I show that, for a financial system composed of two banks holding their assets in the same proportion, the central bank will allot all its budget to the bank with the highest leverage ratio. However, for a system made of two banks having different portfolio composition, the amount allo-

[4]One of the reasons I have a budget constraint in my modeling is to reduce the risk taken by the central bank. By the way, empirical studies of central banks' financial risks are rare mainly because the required data are almost always confidential (Schnabel, 2016).

cated to a bank depends on its characteristics and it is larger when its total assets value is higher. In the second part of the theoretical framework, I consider a modified version of Greenwood, Landier, and Thesmar (2015) model to study a Refinancing Operation. This time, following a severe debt shock, the central bank intervenes by granting loans to banks in order to minimize systemic risk as much as possible. I show, in this case, that the bank with a low leverage ratio and/or a high *connectedness* coefficient (banks that owns large or illiquid asset classes) benefits from the most important amount of loans.

The model used is simple. Nevertheless, its great advantage is that it allows me to have testable implications to apply to European banks. Hence, in the empirical part of the paper, I assess the efficiency of these two unconventional monetary policies. I apply my framework to European banks during the last Eurozone crisis. I mainly use 2011 stress tests inputs published by the European Banking Authority. My simulations lead to several key findings: I show that both policies are effective and succeed in reducing the aggregate vulnerability of the system thus the central bank can safeguard the financial stability using unconventional monetary policies. This is obviously in accordance with the results announced in the theoretical analysis. For the assets purchase policy, my results suggest also that this policy is more efficient when the central bank buys the sovereign debts. The resulting optimal asset purchase policy, highlights that the amount dedicated to Greek banks should be the most important, due to the high exposure of these banks to Hellenic sovereign debt.

What is new with regard to the framework used by Greenwood, Landier, and Thesmar (2015) is the policies studied and the approach used to conduct this study. In fact, I propose to investigate the impact of redesigned monetary policies whereas they focus on rather prudential policies such as leverage cap, size cap, forced mergers... My approach also allows me to intervene in such a way to reduce the impact of fire sales, the main source of contagion and so of systemic risk in this model.

The rest of the paper is organized as follows. Section 1.2 presents a brief review of the related literature. The model is described in Section 1.3. In Section 1.4, I introduce a central bank in this model and study theoretically an asset purchase policy and a Refinancing Operation. Section 1.5 is dedicated to the assessment of this two reshaped unconventional policies using stress tests data of 2011. Section 1.6 concludes the paper. Proofs of technical results are deferred to the Appendices.

1.2 Related literature

My paper is related to several strands of the literature. First, I rely on the rich literature on contagion in financial market. Second, I contribute to the literature on central banks interventions specially after the 2008 crisis. Finally, I add to the literature that study the interaction between monetary and macroprudential policies as well as their effectiveness on macroeconomic and financial stability.

Contagion in financial market. An increasingly growing literature highlights the contagion in financial market due to fire sale or counterparty risk or both. The pioneers who were interested by financial contagion was Allen and Gale (2000) followed by Freixas, Parigi, and Rochet (2000). They worked on financial networks to show that a complete banks network is more resilient to shocks because the proportion of losses of a specific bank is apportioned between other banks via the interbank contracts.[5] Most important results related to this literature (Gai and Kapadia, 2010; Acemoglu, Ozdaglar, and Tahbaz-Salehi, 2015) announced that networks where financial institutions are connected (even indirectly) better resist to shocks because they share the risk. However, beyond a certain level of connection, an extreme shock spreads rapidly which can lead to the collapse of the whole financial system. In addition, the recent literature proposes more sophisticated models. Choi (2014) and Caballero and Simsek (2013) propose a model based on a strategic approach in the financial institutions behavior. However these models are completely theoretical and cannot be used in an empirical framework in contrast to the model proposed by Greenwood, Landier, and Thesmar (2015). The latter suggest a simple and easily calibratable model using available data and which fit with my objective. Duarte and Eisenbach (2015) used this framework by adapting it to a panel setting to estimate vulnerability in U.S market whereas Capponi and Larsson (2015) explicitly extend it in a network model. What is new in my work is the fact that I have built in contagion, and more specifically contagion due to fire sales , to assess unconventional central bank policies.

Central banks interventions. Many papers argue on how effective were the governments and central banks actions. Lenza, Pill, and Reichlin (2010) and Hesse and Frank (2009) show that non-standard measures have played a significant role in stabilizing the financial sector and economy after the collapse of Lehman Brothers. This is also in line with the results of Allen, Carletti, and Gale (2009) as well as Freixas, Martin, and Skeie

[5] See Allen, Carletti, and Gale (2009) for a survey.

(2011) who argue that the central bank action increases the effectiveness of the inter-bank markets and reduces the risk of liquidity.[6] Morrison and Walther (2018) find also theoretically, through an analysis of a general equilibrium model, that a well designed government asset purchase programs can combat systemic risk.[7] My paper adds to this literature by affirming that policies inspired by macroprudential policies can meet financial stability objective and by providing a different theoretical and empirical framework for the evaluation of such policies in a contagion context.

Interaction between monetary and macroprudential policies. A recent growing literature explores the interaction between monetary and macroprudential policies as well as their effectiveness on macroeconomic and financial stability.[8] Smets (2014) argues that various non-standard monetary policy and instruments, used in the recent crisis, fulfill the same objective as macroprudential tools and they are even transmitted through the same transmission channels. Hence, he suggests that this makes financial stability an explicit objective of monetary policy, to be used when macroprudential policies fail. In this line of thought, studying the Chinese case, Klingelhöfer and Sun (2017) show that many monetary policy tools, such as the reserve requirement, window guidance, supervisory pressure and housing market policies, can be used for macroprudential purposes. My research is in line with this findings. Moreover, I can go more in the analysis of the results and suggest that even if these unconventional policies address macroprudential policy objective, their use should be limited. This is because, in addition to the cost that they represent to the taxpayers, they create moral hazard as argued by Freixas, Laeven, and Peydró (2015). In this regard, one of my results suggests that for two banks having the same portfolio composition, the total budget of the central bank, allocated to purchase assets, should go to the bank with the highest leverage ratio. This is likely to encourage banks to become heavily indebted and hold a high leverage ratio to ensure that they are rescued in a crisis. This analysis suggests that macroprudential policy should be used primarily to ensure the stability of the financial system, but may also be supported by monetary policy if necessary, which is in line with Smets (2014) point above.

[6] Freixas, Parigi, and Rochet (2000) clearly show that when a bank occupying a key position in a banks network becomes insolvent, the central bank must intervene by injecting liquidity in the banking system to prevent the waves of bankruptcies. Indeed, the idea that a central bank should provide liquidity to support the financial system goes back to the 19th century work of Bagehot (1873). The latter prescribed that the central bank should lend freely against a good collateral.

[7] Acharya, Pierret, and Steffen (2017) also document channels of monetary policy transmission to banks following two interventions of the European Central Bank (ECB), namely the Outright Monetary Transaction (OMT) program and the long-term refinancing operation.

[8] See Ampudia, Beck, Beyer, Colliard, Leonello, Maddaloni, and Marques-Ibanez (2019) for a survey on the interaction between monetary policy prudential policy.

Central bank in a contagion model. Conceptually my paper is close to Georg and Poschmann (2010) since they introduce a central bank in a contagion model and show that its activity enhances financial stability. In their network model of interbank markets, banks optimize a portfolio of risky investments and riskless excess reserves according to their risk and liquidity preferences. I have used a different approach, based on a simple model where contagion is triggered by fire sales. This model allows me to better study an asset purchase policy and to simulate the unconventional policies by mapping them to a real setting, the European sovereign debt crisis in this chapter.

1.3 Model description

Before describing the model in detail, it is useful to briefly describe the sectors and the agents that characterize the environment. On the one hand, there is a private sector, composed of N banks. On the other hand, There is a public sector, composed of a central bank that wants to minimize systemic risk.

1.3.1 Environment

As in Greenwood, Landier, and Thesmar (2015), I consider an economy composed of N risk-neutral banks and holding K assets. The economy lasts for three periods $t = 0, 1, 2$.

Banks. Each bank is endowed with q_i units of capital which can be invested in K assets. At date t, the total assets of bank i is represented by $a_{it} \in \mathbb{R}_+$ and $m_{ik} \in [0, 1]$ represents the weight of an asset k in the portfolio of this bank i.

Assets of each bank are financed by both debt, $d_{it} \in \mathbb{R}_+$, and equity, $e_{it} \in \mathbb{R}_+$. The equity equals the two sides of the balance sheet i.e. $a_{it} = d_{it} + e_{it}$. The leverage ratio of each bank i, b_i, is equal to d_{it}/e_{it}.

Now, considering the whole banking system, A_t will represent a $N \times N$ diagonal matrix of assets, such that each diagonal element, a_{it}, represents the total assets of bank i. B is a $N \times N$ diagonal matrix of leverage, such that each diagonal element, b_i, represents the leverage ratio of bank i. Similarly, E and D are respectively the equity matrix and the debt matrix and are also diagonals. Finally M, a $N \times K$ matrix, represents the portfolio weights matrix composed of different weights m_{ik}.

Shocks and banks deleveraging. At date t, An initial exogenous shock, F_t, on one or several assets return is transmitted to the banks return R_t following this equation:[9]

$$R_t = MF_t \tag{1.1}$$

This shock R_t in the banks return moves away some banks (those affected by the shock) from their initial leverage ratio. At this stage, the first assumption of the model states that banks want to keep their leverage constant. To do so, they sell (or buy if the shock is positive) some of their assets in the next period.[10] The behavior of targeting leverage ratio is supported empirically by Adrian and Shin (2010) who use individual bank data to show that commercial banks engage in leverage targeting. Although in this framework there is no explicit optimization of an objective function for banks, we can consider the targeting of the leverage ratio as a reduced form for the result of an optimization or simply a constraint as stated by Duarte and Eisenbach (2015). [11]

The amount of assets sold is equal to A_tBR_t.[12] To see the intuition, I consider a bank i which has in the first period a total asset a_t, an equity e_t and a debt d_t and experiences a negative shock r_t. Its balance sheet in t and $t+1$ is represented in Table 1 .

Table 1.1: Bank i balance sheet

t

Assets	Liabilities
a_t	e_t
	d_t

end of the first period

Assets	Liabilities
$a'_t = a_t + a_t.r_t$	$e'_t = e_t + a_t.r_t$
	$d'_t = d_t$

t+1

Assets	Liabilities
$a_{t+1} = a'_t + sales$	$e_{t+1} = e'_t$
	$d_{t+1} = d_t + sales$

As explained above, the bank i sells a part of its assets to maintain a fixed leverage ratio

[9] F_t is a vector such that each element of this vector represents the shock to the corresponding asset.

[10] In period of crisis, it's difficult to raise capital. So, to return to their target leverage, it's easier for banks to sell some assets (Shleifer and Vishny, 1992).

[11] See Duarte and Eisenbach (2015) for a detailed discussion of all the model assumptions.

[12] In case of large shocks, some elements of the vector A_tBR_t can be negative, and some banks can not return to their target leverage. For that, in the empirical implementation, we consider the $max(A_tBR_t, -A_t(1 + R_t))$.

as follows:

$$\begin{aligned}\frac{d_t}{e_t} &= \frac{d_{t+1}}{e_{t+1}} \\ &= \frac{d_t + sales}{e_t + a_t.r_t}\end{aligned}$$

The value of the sold assets for this bank i is then equal to $a_t \times \frac{d_t}{e_t} \times r_t$.[13]
In matrix terms, namely if the whole financial system is considered, the total value of the sold assets, following a shock R_t on banks' portfolio returns, is $A_t B R_t$.
Now I need to describe the mechanism of sales followed in this framework. At this level, Greenwood, Landier, and Thesmar (2015) assume that banks sell their assets such that the weight of each asset in their portfolio remains unchanged between t and *t+1,* i.e. the weight matrix M stays constant over time.[14] This assumption has been applied extensively in the literature on mutual funds. For instance, Coval and Stafford (2007) show empirically that mutual funds are not very selective and behave indistinctly when fire selling assets.

When selling proportionally to their holdings, The vector of net asset purchases of banks, Φ_{t+1}, in the period following the shock, is then expressed as follows:

$$\Phi_{t+1} = M' A_t B R_t \tag{1.2}$$

Φ_{t+1} is a $K \times 1$ vector where each element represents the total amount of sales of asset k by all banks. These assets sales have a price impact in the next period which depends on different assets liquidity. The return of assets, in $t+1$, is then:

$$F_{t+1} = L\Phi_{t+1} \tag{1.3}$$

where L is a $K \times K$ matrix of price impact expressed in terms of Amihud ratio for each assets class. For simplicity, this matrix is diagonal, so that the sale of asset k has no effect on asset k'. However, having a non-diagonal matrix L does not change the equations and the theoretical results.[15]

Finally, price impact cause spillovers to all banks holding the assets affected by the fire sale in $t+1$. By combining the three equations above, we obtain the effect of a shock

[13] I recall that this amount is negative (due to the negative shock r_t) and so refers to a sale of assets.
[14] Yet, one of the simulation carried out in the empirical part consists in selling assets without considering a constant matrix M.
[15] As explained in Greenwood, Landier, and Thesmar (2015), equation 1.3 can be microfounded if we consider assets with uncorrelated payoffs.

in t on banks return in $t+1$:

$$R_{t+1} = MF_{t+1} = ML\Phi_t = MLM'A_tBR_t \tag{1.4}$$

1.3.2 Aggregate Vulnerability

An initial negative shock to assets returns F_t has repercussion on the global financial system via a direct and an indirect effect.[16]

The direct effect. The shock F_t leads to direct losses on banks assets which will be reduced in total by $1'A_tMF_t$.[17] These losses occur in the first period t when the shock happens.

The indirect effect. This effect appears only in the period following the shock. In fact, fire sales, by reducing the value of assets returns, induce new losses in the whole financial system given by $1'A_tMF_{t+1}$. Greenwood, Landier, and Thesmar (2015) introduce thus a new systemic risk measure, the *aggregate vulnerability*, expressed by:

$$AV = \frac{1'A_tMLM'A_tBMF_t}{\sum_i e_{it}} \tag{1.5}$$

This *aggregate vulnerability* represents the fraction of system equity capital lost due to spillovers effect if there was a shock F_t to asset returns, in t.

1.4 Introduction of the central bank

I propose, in this section, to introduce a central bank in the contagion model already described and to study an optimal asset purchase policy and an optimal refinancing operation.

1.4.1 Asset purchase policy

The new purpose considered by the central bank is financial stability and so, in this context, minimizing the systemic risk under some constraints. To this end, the central bank controls the vulnerability of the financial system and intervenes when the vulnerability level is lower than a given threshold at time t, by buying assets from different banks. I assume that the amounts collected by banks is used to pay a portion of their debt.

[16] In this paper, I restrict myself to the case where $R_t = MF_t < 0$ since I am concerned by policies aiming at promoting systemic stability.

[17] 1 is a $N \times 1$ vector of ones.

Nevertheless, the amount devoted to assets purchase is not unlimited. Indeed, I assume the central bank cannot exceed a certain amount P. [18]

This policy of assets purchase reduces fire sale impact by reducing the quantity of assets that banks should sell in the next period to maintain it's leverage ratio constant. As a consequence, the vulnerability level diminish in $t+1$ and thus the systemic risk. The central bank problem, at this stage, is to allocate optimally the amount P between banks to minimize *the aggregate vulnerability.*

To see the intuition, let's consider a financial system composed of a bank i. In t, the vulnerability threshold is reached and the central bank should then intervene by buying assets from this bank, in the end of period, assuming always that this is done in a way which keeps our matrix weight constant over time. Let's c be the value of the assets purchased. The balance sheet of bank i, in t and *t+1*, explaining this operation, is represented in Table 2.[19]

Table 1.2: Bank *i* balance sheet after an Asset Purchase Policy

In t

Assets	Liabilities		Assets	Liabilities
a_t	e_t	*central bank*	$a'_t = a_t - c$	$e'_t = e_t$
	d_t	$\Longrightarrow$ *intervention*		$d'_t = d_t - c$

In t+1

Assets	Liabilities
$a_{t+1} = a'_t + a'_t r_t + sales$	$e_{t+1} = e'_t + a'_t r_t$
	$d_{t+1} = d'_t + sales$

In *t+1*, to reach its target leverage, the bank i sells a quantity of assets of a value equal

[18] Tirole (2012) announces that the government reduces adverse selection enough to let the market rebound, but not too much, so as to limit the cost of intervention. That's why I suggest in this framework to introduce a budget constraint. Thereafter, one of the goals of the paper is to asses empirically the efficiency of reshaped unconventional policies. Hence, in the empirical part, this amount P represents the cost of interventions of central bank following the sovereign debt crisis in order to see how the policies deployed could have reduced systemic risk if they had been used differently.

[19] This way of modelling the central bank's intervention is more interesting than a model where the latter would intervene directly after the shock r_i. Indeed, in this contagion model, banks have no constraints to liquidate their assets on the market and therefore the second choice of modeling is not very interesting to study, especially since, according to the model, if we know the shock in t, we know the magnitude of the shock in t+1 (equation 4), which means that my choice of modeling will not distort the conclusions I can draw.

to $a_t br_t + (1 - br_t)c$ since we have

$$\begin{aligned}\frac{d_t}{e_t} &= \frac{d_{t+1}}{e_{t+1}} \\ &= \frac{d'_t + sales}{e'_t + a'_t r_t}\end{aligned}$$

and so,

$$\begin{aligned}sales &= \frac{d_t}{e_t} \times (e_t + (a_t - c) \times r_t) - d_t + c_i \\ &= a_t br_t + (1 - br_t)c.\end{aligned}$$

To better understand how this model works, let's take an example. Consider a bank i with a leverage ratio equal to 1 and a total assets value of 10 units and the central bank should intervenes in t by buying 1 unit of assets. If, at the end of the period, the value of the assets decline of 30% ($r_t = -0.3$), in the absence of the central bank intervention, the bank should sell 3 units of its assets ($a_t br_t$). However, following the central bank intervention, it only sells 1.7 units ($a_t br_t + (1 - br_t)c$) to return to the target leverage ratio.

Now, if I consider the whole financial system composed of N banks and following the same methodology described in the second section, the banks return vector is such that:

$$R_{t+1} = MLM' \times [A_t BR_t + (I_N - diag(BR_t)) \times C] \tag{1.6}$$

where :

- I_N is the identity matrix
- $diag(BR_t)$ is a diagonal matrix composed of elements of vector BR_t
- $C = \begin{pmatrix} c_1 \\ \vdots \\ c_N \end{pmatrix}$ is the vector of amounts allocated to each bank for assets purchase

The *aggregate vulnerability* is then equal to:

$$AV \times \sum_n e_n = 1'(A_t - diag(C))MLM' \times [A_t BR_t + (I_N - diag(BR_t))C] \tag{1.7}$$

By rearranging the terms of this equation, I obtain:

$$AV \times \sum_n e_n = \sum_n \gamma_n [a_n b_n r_n + (1 - b_n r_n) c_n] \tag{1.8}$$

with $\gamma_n = \sum_k (\sum_m (a_m - c_m) m_{mk}) l_k m_{nk}$ measures the new *connectedness* of bank n as in Greenwood, Landier, and Thesmar (2015). This coefficient reflects the fact that systemic risk is all the more important when banks have large ($\sum_m (a_m - c_m) m_{mk}$ large) or illiquid (l_k large) asset classes.

The central bank's problem, at this stage, is to choose the optimal allocation C to minimize the systemic risk, i.e. the absolute value of the *aggregate vulnerability*. The amount P allocated by the central bank to buy assets from different banks is assumed to be smaller than a certain quantity κ, such that $\kappa = min\{-\frac{a_n b_n r_n}{1-b_n r_n}\}_{n \in [|1,N|]}$. This assumption allows to have a *sales* variable that is always negative.[20] Hence, when the shock is negative, the value of the *aggregate vulnerability* is also negative.[21] The problem is then :

$$\begin{aligned} \underset{C}{\text{minimize}} \quad & |AV| \\ \text{subject to} \quad & \sum_n 1'C = P \quad and \quad C \geq 0 \end{aligned}$$

In the following, for simplicity reasons, I study two cases: the case of two banks holding the same asset and the case of two banks holding two assets.

Two banks holding one asset

In this case, both banks experience the same shock $r_1 = r_2 = r$ and the *aggregate vulnerability* is equal to:

$$AV = \gamma[\pi_1 + \Sigma_1 c_1 + \pi_2 + \Sigma_2 c_2]$$

with: $\gamma = (a_1 - c_1)l + (a_2 - c_2)l$

$\pi_n = a_n b_n r$

$\Sigma_n = 1 - b_n r$

Lemma 1 *The central bank's problem reduces to choosing an allocation* $C = (c_1, c_2)'$ *to*

maximise $\quad (\Sigma_1 - \Sigma_2)c_1$

subject to $\quad c_1 + c_2 = P$

[20] If $P < min\{-\frac{a_n b_n r_n}{(1-b_n r_n)}\}_{n \in [|1,N|]}$ then $c_n < -\frac{a_n b_n r_n}{(1-b_n r_n)}$, $\forall n$

[21] Using a proof by contradiction we can easily show that $c_n < a_n$ (and so $\gamma_n > 0$), $\forall n$ when $P < min\{-\frac{a_n b_n r_n}{(1-b_n r_n)}\}_{n \in [|1,N|]}$.

From Lemma 1, it's clear that the budget P should go to the bank with the greatest Σ_n, since Σ_n is positive. The following proposition summarizes the optimal allocation.

Proposition 1 *If two banks hold only one asset, the total amount P is allocated to the bank with the highest leverage ratio.*

The following proposition states that it is always in the central bank's interest to increase its budget P to minimize systemic risk.

Proposition 2 *The central bank always improves financial stability by increasing the budget P since* $\frac{\partial AV}{\partial P} > 0$.

Two banks holding two assets

In this case, the weight of the two assets in the portfolio of banks, m_{ik}, reappears in our results as it is suggested in the following proposition.[22]

Proposition 3 *The resolution of the central bank's problem reveals 3 possible cases such that:*

- *If* $(t_{12} - 2t_{11})\pi_1 + ((t_{12} - 2t_{11})P + a_2 t_{12})\Sigma_1 + a_1 t_{11} < (t_{12} - 2t_{22})\pi_2 + (a_1 t_{12} - t_{12}P + a_2 t_{22})\Sigma_2$, *then the total amount P goes to the bank 1.*
- *If* $(t_{12} - 2t_{22})\pi_2 + ((t_{12} - 2t_{22})P + a_1 t_{12})\Sigma_2 + a_2 t_{22} < (t_{12} - 2t_{11})\pi_1 + (a_2 t_{12} - t_{12}P + a_1 t_{11})\Sigma_1$, *then the total amount P goes to the bank 2.*
- *If* $(t_{11} - t_{12})\Sigma_1 + (t_{22} - t_{12})\Sigma_2 \neq 0$ *and* $4t_{11}t_{22}\Sigma_1\Sigma_2 \geq t_{12}^2(\Sigma_1 + \Sigma_2)^2$, *the total amount P is divided between the 2 banks such that:*

$$c_1 = \frac{(t_{12} - t_{11})\pi_1 + (t_{22} - t_{12})\pi_2 + ((2t_{22} - t_{12})\Sigma_2 - t_{12}\Sigma_1)P + (a_1 t_{11} + a_2 t_{12})\Sigma_1 - (a_1 t_{12} + a_2 t_{22})\Sigma_2}{2[(t_{11} - t_{12})\Sigma_1 + (t_{22} - t_{12})\Sigma_2]} > 0$$

$$c_2 = \frac{(t_{11} - t_{12})\pi_1 + (t_{12} - t_{22})\pi_2 + ((2t_{11} - t_{12})\Sigma_1 - t_{12}\Sigma_2)P + (a_1 t_{12} + a_2 t_{22})\Sigma_2 - (a_1 t_{11} + a_2 t_{12})\Sigma_1}{2 \times [(t_{11} - t_{12}) * \Sigma_1 + (t_{22} - t_{12}) * \Sigma_2]} > 0$$

with $t_{ij} = \frac{\partial \gamma_i}{\partial c_j} = -\sum_{k=1}^{2} m_{ik} l_k m_{jk}$

All proofs of technical results are deferred to Appendix A. The idea behind this proposition is that the amounts allocated by the central bank depends on banks' characteristics, inter alia, the size, the leverage ratio and the amplitude of the shocks received by

[22] In the first case, the weight matrix is equal to 1, since I have only one asset in the portfolio of the two banks.

the latters. Some conclusions derived from this proposition are presented in the following corollaries.

Corollary 1 *If the two banks hold the two assets in the same proportions, i.e* $m_{11} = m_{21}$*, then* $(t_{11} - t_{12})\Sigma_1 + (t_{22} - t_{12})\Sigma_2 = 0$*. In this situation, the total amount P will be allocated to the bank with the highest leverage ratio (case 1 or 2).*

Indeed, the result found with two banks holding one asset is a particular case of this proposition. A more general result with k assets is expanded in Appendix A.

Corollary 2 *If* $t_{11} = t_{12} = t_{22}$*, then the total amount P goes to the bank with the highest product of the leverage ratio and the shock to the bank's assets (case 1 or 2).*[23]

Corollary 3 *In case 3, the amount that should be allocated to a bank i is all the more important that its size is more significant (i.e* $\frac{\partial c_i}{a_i} > 0$*) when the two banks have the same product of the leverage ratio and the shock to the bank's assets (i.e.* $\Sigma_1 = \Sigma_2$*) and when the weight of the asset held in majority by the bank i is higher than the weight of this same asset in the portfolio of bank j .*

1.4.2 Refinancing Operation

In this section, I examine a modified version of Greenwood, Landier, and Thesmar (2015) model to study the impact of a Refinancing Operation in financial stability. In fact, I consider that the financial system is now affected by a negative debt shock. Indeed, the role of such a policy is to remedy a situation, characterized by funding problems in the banking sector, by trying to allow banks to keep lending despite a rather serious crisis of confidence (Cahn, Matheron, and Sahuc, 2017).
I first start by presenting the model before the central bank intervention. I then present the modifications introduced by the intervention of the latter.

Model without central bank intervention. An exogenous negative debt shock, $S_t = (s_{1t}, s_{2t}, ..., s_{Nt})$, at t, not only forces banks to recover lost fundings by selling their assets but also moves them away from their initial leverage ratio. Always concerned with targeting their leverage ratio, banks decrease their equity and sell for that a part of their

[23] I consider the absolute value of the product, since the shock r_i is negative.

assets.[24] Such operation of buying back assets are set up by banks to increase their return on equity.[25]

Following the negative debt shock and targeting their leverage ratio, the amount of sales by banks is represented by the vector E_tS_t. To explain this result, I use an example; let's consider a bank i, in Table 3, which has in the first period a total asset a_t, an equity e_t and a debt d_t and experiences a negative debt shock s_t.

Table 1.3: Bank i balance sheet in the modified model

t

Assets	Liabilities
a_t	e_t
	d_t

Assets	Liabilities
$a'_t = a_t + d_t \times s_t$	$e'_t = e_t$
	$d'_t = d_t + d_t \times s_t$

t+1

Assets	Liabilities
$a_{t+1} = a'_t + sales$	$e_{t+1} = e'_t + sales$
	$d_{t+1} = d'_t$

As mentioned above, to maintain a fixed leverage ratio, the bank i sells some of its asset as follows:

$$\begin{aligned}\frac{d_t}{e_t} &= \frac{d_{t+1}}{e_{t+1}} \\ &= \frac{d_t + d_t \times s_t}{e_t + sales}\end{aligned}$$

The value of the sold assets for this bank i is then equal to $e_t \times s_t$.
Based in the same hypothesis specified in the model with an asset shock, I determine the impact of an initial debt shock S_t on banks' return in $t+1$ due to spillover effect, following the beyond equation:

$$R_{t+1} = MF_{t+1} = ML\Phi_t = MLM'E_tS_t$$

[24]Since I deal with a debt shock, the value of the leverage ratio value becomes lower after the shock. In a stress periods in the interbank market, acquiring more debt does not appear evident, that's why I propose to decrease equity.

[25]Focusing on the US market, TrimTabs confirms that assets buybacks activity has become increasingly concentrated in the banking sector. Most notably, the firm said that Bank of America Corp, Citigroup Inc, Goldman, Sachs Group Inc, J.P. Morgan Chase & Co, Morgan Stanley, and Wells Fargo & Co have accounted for a combined 20% of stock buyback volume in 2017 (for more details, see http://www.marketwatch.com/story/stock-buyback-enthusiasm-has-waned-but-not-at-the-big-banks-2017-08-14).

In this case also, a negative debt shock S_t has repercussion on all financial system via a direct and an indirect effect.

- The direct effect: the shock S_t leads to direct losses, in period t, on banks assets which will be reduced in total by $1'D_tS_t$.

- The indirect effect: once the debt shock happens and reduces access to credit, banks by buying back shares, they need to sell assets and so induce new losses in the whole financial system. This losses continue to be evaluated using the *aggregate vulnerability*, such that:

$$AV \times \sum_n e_n = 1'A_tMLM'E_tS_t \tag{1.9}$$

Model with central bank intervention Starting from the model explained above, I propose in this section to introduce a central bank and study a Refinancing Operation. The aim of financial stability maintained, the central bank intervenes, following a severe debt shock, by granting loans to the banks of the financial system. As one purpose of these loans was to avoid credit crunch and to support ongoing growth, I assume, in our model, that banks use them to buy different assets. I take into consideration, in this section too, the budget constraint announced in the analysis of the asset purchase policy.

As before, to explain the framework, I first consider a financial system composed of a bank i and assume that, in t, the central bank should intervene by adopting a Refinancing operation. Let c be the value of the loan attributed to the bank i. Its balance sheet, in t and *t+1*, explaining this kind of central bank refinancing operation, is represented in Table 4.

Table 1.4: Bank *i* balance sheet after a Refinancing Operation

In t

Assets	Liabilities	Assets	Liabilities	*central bank*	Assets	Liabilities
a_t	e_t	$a'_t = a_t + d_t.s_t$	$e'_t = e_t$	$\Longrightarrow$	$a''_t = a'_t + c$	$e''_t = e'_t$
	d_t		$d'_t = d_t + d_t.s_1$	*intervention*		$d''_t = d'_t + c$

In t+1

Assets	Liabilities
$a_{t+1} = a''_t + sales$	$e_{t+1} = e'_t + sales$
	$d_{t+1} = d''_t$

Always to keep its leverage ratio constant, the bank sells in *t+1* a part of its assets.

The amount of these sales is equal to $(e_t s_t + \frac{1}{b_t} c)$ since I have:

$$\begin{aligned} \frac{d_t}{e_t} &= \frac{d_{t+1}}{e_{t+1}} \\ &= \frac{d_t + d_t.s_t + c}{e_t + sales} \end{aligned}$$

and so $$sales = e_t.s_t + \frac{e_t}{d_t}.c$$

From here, it's clear that this policy is efficient since it reduces the amount of sold assets in the second period. For instance, if I consider a bank i which has an equity equal to 10 units, a total assets value of 100 units and it is subject to a 30% decline in the value of its debt, then, in the absence of the central bank intervention, it should sell 3 units of its assets to offset the losses on the liability side. Now, let's consider that the central bank intervenes following this shock and provides this bank with a loan of 9 units, then the bank i only sells 2 units instead of 3.

The next step is to determine the impact of this intervention on the whole financial system. At this stage, I assume that the Refinancing operation does not modify the composition of the initial weight matrix. That means that, with the credit accorded by the central bank, banks sell assets in a way to maintain the same proportions of assets in their portfolio. In fact, modifying the composition of banks' portfolios does not change my results since I consider a debt shock and not an asset shock. Then following the same steps described above, I determine the new value of the aggregate vulnerability.

$$AV \times \sum_n e_n = \frac{1' A_t M L M' (E_t S_t + B^{-1} C)}{E q_t} \tag{1.10}$$

such that $C = \begin{pmatrix} c_1 \\ \vdots \\ c_N \end{pmatrix}$ is the vector of loans allocated to each bank.

The terms of this equation can be rearranged and I then obtain the following expression:

$$AV \times \sum_n e_n = \sum_n \gamma_n [e_n s_n + \frac{c_n}{b_n}] \tag{1.11}$$

with $\gamma_n = \sum_k (\sum_m a_m m_{mk}) l_k m_{nk}$ the connectedness of the bank n.

In addition to the budget constraint, I consider a borrowing constraint. In fact, I assume that the bank can benefit from these refinancing operations against a collateral of the same value. I translate this in this model by the fact that after the fire sale, in $t+1$,

the value of the reminded assets should exceed the collateral value i.e. $a_{t+1} \geq c$.[26] This means that:

$$a_t'' + sales \geq c$$

$$=> \ a_t + d_t s_t + c + e_t s_t + \frac{e_t}{d_t} c \geq c$$

$$=> \ a_t(1 + s_t) + \frac{e_t}{d_t} c \geq 0$$

Hence this constraint is verified for all $-1 \leq s_t \leq 0$ and $c \geq 0$.

Once the *aggregate vulnerability* expression and the constraints are established, I propose to allocate the total amount P, as appropriately as possible, between banks to minimize the absolute value of the *aggregate vulnerability* and so the systemic risk. Here again, we assume that the amount P is smaller than a certain quantity ξ, such that $\xi = min\{-s_n d_n\}_{n \in [|1,N|]}$.[27] The problem is then represented as follows:

$$\begin{aligned} &\underset{(c_1,c_2,...,c_n)}{\text{minimize}} \quad |\sum_n \gamma_n (e_n s_n + \frac{c_n}{b_n})| \\ &\text{subject to} \quad \sum_n c_i = P \quad and \quad c_1, c_2, .., c_N \geq 0 \end{aligned}$$

Lemma 2 *The central bank's problem reduces to choosing an allocation* $C = (c_1, c_2, ..., c_n)'$ *to*

$$\begin{aligned} &\underset{(c_1,c_2)}{maximise} \quad \sum_n \frac{\gamma_n}{b_n} c_n \\ &subject\ to \quad \sum_n c_i = P \quad and \quad c_1, c_2, .., c_N \geq 0 \end{aligned}$$

The resolution of this problem is exposed in the following proposition.

Proposition 4 *The total amount P is allocated to the bank i if*

$$\frac{\gamma_i}{b_i} > \frac{\gamma_j}{b_j}, \quad \forall j \in \{1, 2, .., N\} \ and \ j \neq i.$$

The Proposition 4 shows therefore that the bank with the highest connectedness-to-leverage ratio, i.e. bank that has a low leverage ratio and/or is highly connected, benefits from the most important amount of loan.

[26] I was inspired from Kocherlakota (2009) model for this representation. Indeed, he considered that collateral is an asset that cannot be used to produce consumption.

[27] This assumption allows to have $AV < 0$. It allows also to have an amount granted to each bank, c_i, that does not exceed the value of losses on the liability side (i.e. the amount $s_i d_i$).

1.5 Policies simulation

As an extension of 2008 financial crisis, the sovereign crisis of Eurozone was unleashed in late 2009, by the new Greek government announcement reporting a huge deficit. This deficit was twice as much as announced previously (Jeanneret and Chouaib, 2015). The crisis was then extended to two others European country: Ireland then Portugal. These shocks have also threaten larger economies that could have jeopardized the Eurozone survival, namely Spain and Italy. This situation created a collective panic among investors, for whom a default of a Eurozone country was not conceivable due to the common market and the unique currency, which presupposes a substantial support from European partners. This uncertainty in financial market and the subsequent consequences of the crisis on the economy required an unprecedented intervention from the European Central Bank (ECB), which resorted to a battery of non-conventional policies. Moreover, by using these new measures, it has gone beyond the scope of its price stability mandate to integrate financial stability to its objective.[28] This suggest that price stability is no longer sufficient to ensure economic stability and hence monetary policy should take into account financial stability. In this context, I propose in this section an empirical implementation of the two reshaped unconventional policies described in the theoretical framework, namely the asset purchase policy and the refinancing operation, based on 2011 Stress tests data.

1.5.1 Data description

I gather 3 types of data: the EU 2011 stress test inputs, shocks on PIIGS (Portugal, Ireland, Italy, Greece and Spain) sovereign debt and assets liquidity.

Stress Test data. Since 2011, the European Banking Authority (EBA) has conducted three stress tests. The first ones was in 2011, the second ones in 2014 and the last ones in 2016. I propose, in this framework, to use those of 2011 because they represent the real situation of banks during the sovereign crisis. Therefore, I can evaluate the effectiveness of various policies used by the ECB at this moment. In fact, the EBA published in July 2011 EU wide stress test of 90 banks in 21 countries (Appendix B), representing 65% of total assets of the European banking sector.[29] These stress tests exposed detailed balance sheets of stressed banks. Table 1.5 gives the summary statistics for our sample of balance sheets data.

[28] The Bank for International Settlements (BIS) suggests that the central bank is also able to assume macroprudential responsibilities.

[29] See http://www.eba.europa.eu/risk-analysis-and-data/eu-wide-stress-testing/2011/results.

Table 1.5: Summary statistics for 2011 Stress Tests.

	System	Min.	Max.	Mean.
Assets (€ billions)	23156	0.339	1444	257
Equity (€ billions)	952	0.020	87	11
Leverage	-	3.6	540.8	33.6

Note : System denotes the sum for all banks assets and equities, Min denotes the minimum value in the sample and Max refer to the maximum value.

The assets Matrix A is directly derived from EBA data by considering the sum of all exposures. These exposures are divided in different blocks reflecting the main risks in banks' balance sheets. This allow us to obtain the weight matrix M. I consider thus that M is composed of 10 asset classes: retail loans, corporate loans, commercial real estate, PIIGS sovereign debt (5 classes), other European country sovereign debts and a final class regrouping the remained exposures.

For the matrix B, I do not have values of leverage ratios in stress tests, I then calculate them using equities and assets values, such as, for each bank i, b_i is equal to $\frac{a_i - e_i}{e_i}$. However, I impose a leverage cap of 50 in my sample to avoid results greatly influenced by extreme values. Furthermore, targeting a very high leverage is not realistic. This threshold is applied for 6 banks (Appendix B).[30]

Shocks calibration. Data used to calibrate assets shock, which represents a reduction in PIIGS sovereign debt value, are from Bloomberg. In fact, I extract PIIGS yield of Government Bond 10Y from 31 December 2010 to 31 December 2011 and I then calculate, for each bond, the variation between its value in 31 December 2010 and the maximum value reached in 2011.[31] Thus I apply shocks of 65% in Greece sovereign debt, 53% in Portugal sovereign debt, 34% in Ireland sovereign debt, 33% in Italy sovereign debt and 19% in Spain sovereign debt.

For the debt shock, I consider a 20% reduction in the debt value applied to all banks.

[30] I consider that imposing a leverage cap of 30 as in Greenwood, Landier, and Thesmar (2015) is too strict in such a period. I choose then 50 to only remove outlier values.

[31] Bonds issued by national governments in foreign currencies are normally referred to as sovereign bonds. The yield required by investors to loan funds to governments reflects inflation expectations and the likelihood that the debt will be repaid (Bloomberg).

Assets liquidity. As in Greenwood, Landier, and Thesmar (2015), I consider the same liquidity value for all assets classes, such as $L = 10^{-13}I$.[32] It corresponds to 10 basis points price change per 10 billion euros of trading imbalances. This value is close to recent empirical estimates of the price impact in the bond market. However, it is probably an underestimate for some other asset classes.

Central bank budget. In this section, I relax the assumption on P introduced in the previous sections. Hence, I consider that the budget allocated by the central bank for each of the asset purchase policy and the refinancing operation is P= €1 trillion. The choice is motivated by the amount spent by the European central bank in some unconventional policies following the sovereign debt crisis. Further details are provided in the next two sub-sections.

1.5.2 Asset purchase policy

During the last crisis, many central banks have engaged in multiple rounds of large scale asset purchase programs. The aim of these programs was to revitalize the economy properly since the traditional instruments are not available due to the zero bound constraint (Chen, Cúrdia, and Ferrero, 2012). These central banks decided then to increase the size of their balance sheets, namely the ECB, which launched many assets purchase programs as the Outright Monetary Transactions, the Securities Market Program or whether the Quantitative Easing program in 2015 to fulfill price stability mandate.[33] The last one combined monthly asset purchases to amount to €60 billion, which was carried out until at least September 2016 (ECB, 2015). The total amount of these assets purchase program exceeded thus €1 trillion.

So I propose in this section to allocate the €1 trillion optimally among the banking system. I remind that the *aggregate vulnerability* expression, in this case, was determined in Equation 1.7 by assuming that assets are purchased in the same proportions presented in the matrix M.

The asset purchase policy has beneficial effect on banks vulnerability. In fact, using this framework, I find that such a policy reduces the absolute value of the *aggregate vulnerability* by 44%. Table 1.6 reports the optimal asset purchase policy.[34] I only represent the 10 largest banks, ranked by the size of the amount allocated by the central bank to

[32] I is a 10×10 identity matrix.
[33] See ECB (2011) for more details about those programs.
[34] I add in the empirical part, a new constraint, such that the amount allocate to buy assets from each bank i is lower than the value of its total assets.

buy assets from each. The banks taking the leading positions in this ranking are in most Greek, Italian, Portuguese and Spanish.

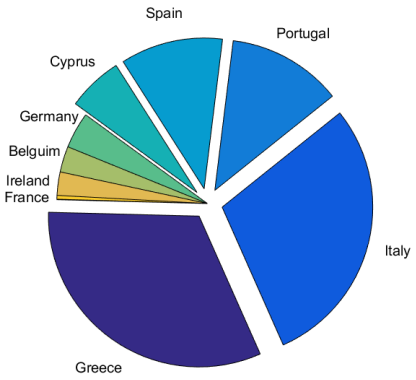
Table 1.6: Optimal Asset Purchase Policy.

Bank	c_i (bn euros)	shock	Leverage	Size(a/E)
BANCA MONTE DEI PASCHI DI SIENA (Italy)	200	-0.052	46	0.22
NATIONAL BANK OF GREECE (Greece)	92	-0.078	13	0.11
EFG EUROBANK ERGASIAS (Greece)	80	0,071	23	0.08
BANCO COMERCIAL PORTUGUES (Portugal)	67	-0,036	27	0.10
BANCO BPI (Portugal)	49	-0.055	22	0.05
PIRAEUS BANK GROUP (Greece)	47	-0.111	17	0.05
MARFIN POPULAR BANK PUBLIC (Cyprus)	43	-0.052	20	0.05
INTESA SANPAOLO (Italy)	42	-0.033	21	0.62
BANCO POPOLARE - S.C. (Italy)	36	-0.030	31	0.13
CAJA ESPANA DE INVERSIONES (Spain)	35	-0.033	27	0.05

Note : I simulate the framework for an asset purchase policy to find an optimal repartition of the €1000 billion. I report the top 10 banks ranked in order, from highest amount allocated by the central bank to the lowest one.

Furthermore, from Figure 1.1, I can notice that the amount that should be dedicated to the Greece is the most important, which may be expected given the high shock that affected the Greek banks. In addition, these banks have a high exposure to Hellenic sovereign debt. Italy, Portugal and Spain are followed by Cyprus. Indeed, although the weight of the Cypriot economy is negligible in the euro area (0.2% of total GDP), the size of the financial sector is considerable in relation to the country's economy and is equivalent to eight times its GDP. Moreover, the two largest Cypriot banks (ranked in top 15 of our banks classification) had major operations in Greece, so the Greek part of the operation and the bond holdings caused them a lot of damage (Economist, 2015). Germany and Belgium are also among the countries that should benefit from the asset purchase program. Indeed, Germany has a significant banking system with some banks which are highly leveraged and at the same time affected by shocks to sovereign debts. However, Dexia, which is a Belgian bank with an important size and a high leverage ratio, has first been weakened by the subprime crisis and the euro crisis then makes its situation worse due to its high exposure to PIIGS debt.

Figure 1.1: Repartition of assets purchase among countries.



There are several potential approaches to this unconventional monetary policy depending, inter alia, on which kind of assets are purchased. That's why I propose, to take as input the optimal amounts granted to Eurozone banks, as calculated above, and determine which assets the central bank should buy to further minimize the *aggregate vulnerability*. The result suggests that central bank should buy more PIIGS debt (Table 1.7) which will reduce further the *aggregate vulnerability* by 53%. In fact, purchasing sovereign debt, if it is possible, reduces in the next period the amount of the sold assets and so the fire sale impact which, in turn, reduces the systemic risk.

Table 1.7: Difference in assets weights after and before the new optimal Asset Purchase Policy.

Bank	Greece S.D	Ireland S.D	Italy S.D	Portugal S.D	Spain S.D	Other assets
BANCA MONTE ..	0	0	-0,16	-0,001	-0,001	0,16
NATIONAL BANK..	-0,18	0	0	0	0	0,18
EFG EUROBANK..	-0,09	0	-0,001	0	0	0,09
BANCO COMERCIAL..	-0,007	-0,002	-0,0005	-0,07	0	0,08
BANCO BPI..	-0,007	-0,006	-0,02	-0,08	0	0,11

Note : I report the new values of the weight matrix after the second optimal asset purchase policy for the five top ranked banks: I consider as input the optimal amounts exposed in Table 1.6 and propose to determine the asset classes that the central bank should buy to further reduce the *aggregate vulnerability*. To see the intuition, if I consider that the initial weight of Greece sovereign debt in the portfolio of a bank i is equal to 0.5 and that after the optimal asset purchase policy this weight becomes equal to 0.2, I report in the table a value equal to -0.3, i.e. the central bank will purchase an amount α of Greece sovereign debt. S.V denotes the sovereign debt. Other assets denotes the aggregate weights of the remained assets composing the banks' portfolio.

1.5.3 Refinancing Operations

By the Long Term Refinancing Operation (LTRO), the European Central Bank provided liquidity to Euro zone banks which were suffering from a lack of access to the interbank market. The aim of these loans was to avoid credit crunch and to support ongoing growth.

The ECB's LTROs, on December 2011 and February 2012, accounted for more than €1 trillion (Enrich and Forelle, 2012).

Therefore I propose, in this section, to implement a Refinancing Operation of €1 trillion, using the framework extended in the theoretical part. However, this time, I propose to add a new constraint. In fact, to have a more realistic analysis, I assume that the loan granted to bank i should be lower than the losses caused by the debt shock (i.e. $c_i < s_i d_i$) because I don't want to over-indebt banks. The simulation of this policy shows that it is efficient. In fact, according to the model, by granting loans to banks, the central bank, reduces the value of losses in t due to the debt shock. This diminishes the volume of sold assets, in the next period, minimizing thus the fire sale impact. This results in a decrease in the absolute value of the *Aggregate vulnerability* by 13%. This decrease of the *aggregate vulnerability* is less important than that recorded in the case of an asset purchase policy. By the way, Angeloni and Wolff (2012) confirmed that the December LTRO had no significant effect on banks' stock market values.

Table 8 reports the optimal refinancing operation. I represent the top 10 banks benefiting from the highest loan amounts. Banks occupying leading positions, in this case, are in majority German banks. In fact, the latter are too connected but also very levered and are therefore included in my ranking because of the last constraint I have added.

Table 1.8: Optimal Refinancing Operation.

Bank	c_i (bn euros)	Leverage	*Connectedness*
DEUTSCHE BANK (Germany)	213	35	0,63
COMMERZBANK (Germany)	122	50	0,55
ING BANK NV (Netherlands)	110	31	0,58
DANSKE BANK (Denmark)	81	37	0,58
LANDESBANK BADEN-WURTTEMBERG (Germany)	70	36	0,61
DZ BANK (Germany)	61	42	0,60
NORDDEUTSCHE LANDESBANK (Germany)	48	50	0,54
HYPO REAL ESTATE HOLDING (Germany)	41	43	0,54
BANCA MONTE DEI PASCHI .. (Italy)	40	46	0,49
WESTLB (Germany)	34	50	0,56

Note : I simulate the framework for a refinancing operation to find an optimal repartition of the €1 trillion. I report in this table the top 10 banks ranked in order, from highest loan granted by the central bank to the lowest one.

Deutsche Bank, the first bank in the ranking, is the third largest bank in Europe and was considered by the International Monetary Fund, even before the bank's last crisis, as "the largest net contributor to systemic risks". It actually benefited from a significant proportion of the of ECB liquidity scheme of 2012, according to Reuters. This was the case also of Commerzbank, the second bank of my ranking.

Noteworthy is the fact that during the financial crisis, the main source of HRE difficulties (the eighth bank in our ranking) was its inability of financing long-term wholesale investments by short-term interbank financing. This has put the bank on the verge of insolvency which required liquidity support from the German government on several occasions before injecting capital (Buder, Lienemeyer, Magnus, Smits, and Soukup, 2011).

1.6 Conclusion and discussion

Since the outbreak of the financial crisis of 2007 in the United States, regulators are increasingly concerned about the emergence of new systemic crises, which would affect the whole financial system through contagion phenomena. These fears are shared by central banks since these crises affect the economic sphere.

This paper has extended the modelling framework of Greenwood, Landier, and Thesmar (2015) to allow for assessing the efficiency of reshaped unconventional monetary policies in terms of financial stability. A first theoretical framework, based on an asset purchase policy, shows that for two banks having the same portfolio composition, the central bank should allocate all its budget to purchase assets from the bank with the highest leverage ratio. I show also, that for two banks holding two assets, the amount allocated to each bank depends on the leverage ratio, the value of the shock and the bank's size. The second theoretical part, studying a refinancing operation, reveals that the total budget of the central bank should be allocated to the bank with the highest *connectedness*-to-leverage ratio.

Furthermore, by simulating these reshaped unconventional monetary policies, I confirm their efficiency, since they considerably lower systemic risk. My results affirm also that an asset purchase policy is more effective when the central bank buys specific sovereign debts.

The model best attribute is its simplicity and adaptability which allow me to use it in an empirical work using real data. Nevertheless, the model is more adapted to study an asset purchase policy, since it is based on a contagion due to fire sales. A future work, enriching this model by exploiting interbank liabilities and counterparty risk, can better explain the refinancing operation impact.

In addition to the cost of such policies to the taxpayer, they create moral hazard, which has been widely criticised in the aftermath of the Great Financial crisis. For instance, my results suggest that in the case of an asset purchase policy, the highest amount should be allocated to purchasing assets from banks with the highest leverage ratio (if they have the same portfolio composition). This is likely to encourage banks to become heavily indebted and hold a high leverage ratio to ensure that they are rescued in a crisis. This supports the argument that macroprudential policy is necessary to ensure financial stability and complements monetary policy.

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Appendices

Appendix A

Technical results

1. Asset purchase policy

1.1. Two banks and one asset: variation of the budget depending in model parameters

Proof of proposition 2. By proposition 1, $c_1 = 0$ or $c_1 = P$ and so:

- When $c_1 = 0$, $AV(P) = (a_1 + a_2 - P)l(\pi_1 + \pi_2 + \Sigma_2 P)$
  $\frac{\partial AV}{\partial P} = (a_1 + a_2 - P)l\Sigma_2 - l(\pi_1 + \pi_2 + \Sigma_2 P) > 0$
  since by assumption P$< min\{-\frac{a_n b_n r_n}{(1-b_n r_n)}\}_{n\in[|1,N|]}$ and so $\pi_2 + \Sigma_2 P < 0$ and $(a_1 + a_2 - P > 0)$.
- When $c_1 = P$, similarly, we show that $\frac{\partial AV}{\partial P} > 0$.

1.2. Two banks with two assets

Proof of proposition 3. AV is a continuous function on a closed bounded interval and so the maximum exists.

Application of Karush–Kuhn–Tucker (KKT) theorem:

Let $h(c_1, c_2) = c_1 + c_2 - P$ (the equality constraint function) and $g_i(c_1, c_2) = c_i$, $\forall i = 1, 2$ (the inequality constraint functions).

- AV, h and g are C^1. So if there is $\bar{x} = (\bar{c_1}, \bar{c_2})$ verifying the above optimization program and if $\nabla h(\bar{x})$ and $\nabla g_k(\bar{x})$ for $k \in J(\bar{x})$ (constraints qualification), then it exist $\lambda,\ \mu_1,\ \mu_2 \in \mathbb{R}$ such as: [1]

$$\begin{cases} \nabla AV(\bar{x}) + \lambda \nabla h(\bar{x}) + \mu_1 \nabla g_1(\bar{x}) + \mu_2 \nabla g_2(\bar{x}) = 0 \\ g_1(\bar{x}),\ g_2(\bar{x}) \geq 0 \\ h(\bar{x}) = 0 \\ \mu_1 g_1(\bar{x}) = 0 \\ \mu_2 g_2(\bar{x}) = 0 \\ \mu_1,\ \mu_2 \geq 0 \end{cases}$$

[1] $J(x) = \{j = 1, 2;\ g_j(x) = 0\}$

- Verification of constraints qualification:
$\nabla h(\bar{x}) = (1,1)$, $\nabla g_1(\bar{x}) = (1,0)$, $\nabla g_2(\bar{x}) = (0,1)$.
$J(\bar{x})$ can not be the set $\{1,2\}$, else we will have $\bar{c_1} = \bar{c_2} = 0$ (however according to our budget constraint $\bar{c_1} + \bar{c_2} = P > 0$). As a result, the vectors family to consider is $\{(1,1), e^i\}$[2] with $i = 1, 2$.
Clearly this family of vectors is always linearly independent. So the constraints are qualified.

Once the KKT conditions are satisfied, I resolve the system exposed above.

The resolution of our system results in 4 cases:

- **Case 1:** $\mu_1 \neq 0$ and $\mu_2 \neq 0$. This implies that $\bar{c_1} = \bar{c_2} = 0$ which is impossible for the reason mentioned above.
- **Case 2:** $\mu_1 = 0$ and $\mu_2 \neq 0$. This implies that $\bar{c_2} = 0$ and $\bar{c_1} = P$.
  At this stage, we should verify that $\mu_2 > 0$. This condition implies that:

  $$(t_{12} - t_{11})\pi_1 + (t_{22} - t_{12})\pi_2 + (t_{12} - t_{11})\Sigma_1 P + \gamma_2\Sigma_2 - \gamma_1\Sigma_1 = -\mu_2 < 0$$

  $\Rightarrow$

  $$(t_{12}-2t_{11})\pi_1+((t_{12}-2t_{11})P+a_2t_{12})\Sigma_1+a_1t_{11} < (t_{12}-2t_{22})\pi_2+(a_1t_{12}-t_{12}P+a_2t_{22})\Sigma_2$$

- **Case 3:** $\mu_1 \neq 0$ and $\mu_2 = 0$. This implies that $\bar{c_1} = 0$ and $\bar{c_2} = P$.
  At this stage, I should verify that $\mu_1 > 0$. This condition implies that:

  $$(t_{11} - t_{12})\pi_1 + (t_{12} - t_{22})\pi_2 + (t_{12} - t_{22})\Sigma_2 P + \gamma_1\Sigma_1 - \gamma_2\Sigma_2 = -\mu_1 < 0$$

  $\Rightarrow$

  $$(t_{12}-2t_{22})\pi_2+((t_{12}-2t_{22})P+a_1t_{12})\Sigma_2+a_2t_{22} < (t_{12}-2t_{11})\pi_1+(a_2t_{12}-t_{12}P+a_1t_{11})\Sigma_1$$

- **Case 4:** $\mu_1 = 0$ and $\mu_2 = 0$. This implies that :

  $$\begin{cases} t_{11}\pi_1 + t_{12}\pi_2 + t_{11}\Sigma_1 c_1 + t_{12}\Sigma_2 c_2 + \gamma_1\Sigma_1 + \lambda = 0 \\ t_{12}\pi_1 + t_{22}\pi_2 + t_{12}\Sigma_1 c_1 + t_{22}\Sigma_2 c_2 + \gamma_2\Sigma_2 + \lambda = 0 \\ c_1 + c_2 = P \\ c_1, c_2 \geq 0 \end{cases}$$

  The resolution of this system gives the expression of c_1 and c_2:

  $$c_1 = \frac{(t_{12} - t_{11})\pi_1 + (t_{22} - t_{12})\pi_2 + ((2t_{22} - t_{12})\Sigma_2 - t_{12}\Sigma_1)P + (a_1t_{11} + a_2t_{12})\Sigma_1 - (a_1t_{12} + a_2t_{22})\Sigma_2}{2 \times [(t_{11} - t_{12})\Sigma_1 + (t_{22} - t_{12})\Sigma_2]}$$

  $$c_2 = \frac{(t_{11} - t_{12})\pi_1 + (t_{12} - t_{22})\pi_2 + ((2t_{11} - t_{12})\Sigma_1 - t_{12}\Sigma_2)P + (a_1t_{12} + a_2t_{22})\Sigma_2 - (a_1t_{11} + a_2t_{12})\Sigma_1}{2 \times [(t_{11} - t_{12})\Sigma_1 + (t_{22} - t_{12})\Sigma_2]}$$

  with c_1 and c_2 are positive and $t_{ij} = \frac{\partial\gamma_i}{\partial c_j} = -\sum_{k=1}^{2} m_{ik}l_k m_{jk}$

[2] e^i denotes the vector with a 1 in the ith coordinate and 0's elsewhere.

Function concavity: AV is a twice-differentiable function of 2 variables. Its Hessian at (c_1, c_2) is then:

$$H(c_1, c_2) = \begin{pmatrix} 2t_{11}\Sigma_1 & t_{12}(\Sigma_1 + \Sigma_2) \\ t_{12}(\Sigma_1 + \Sigma_2) & 2t_{22}\Sigma_2 \end{pmatrix}$$

The determinant of the matrix is equal to : $4t_{11}t_{22}\Sigma_1\Sigma_2 - t_{12}^2(\Sigma_1 + \Sigma_2)^2$. Consequently, AV is concave only if $4t_{11}t_{22}\Sigma_1\Sigma_2 \geq t_{12}^2(\Sigma_1 + \Sigma_2)^2$, because we have already the trace of H which is negative ($2t_{11}\Sigma_1 + 2t_{22}\Sigma_2 \leq 0$ since $t_{ij} \leq 0$, $\forall i, j = 1, 2$).

Proof of corollary 2. Generalization. I can demonstrate proposition 3 for two banks holding K assets. In this case, the modifications concern the value of γ_n which is equal to $\sum_{k=1}^{K}(\sum_m^2(a_m - c_m)m_{mk})l_k m_{nk}$ and the value of t_{ij} such that $t_{ij} = \frac{\partial \gamma_i}{\partial c_j} = -\sum_{k=1}^{K} m_{ik}l_k m_{jk}$.

I resolve the same system exposed above and I only focus in the second and third case. If the K assets are held by banks in the same proportions, we have $\gamma_1 = \gamma_2$ and $t_{11} = t_{12} = t_{22}$. Then by replacing this, in case 2, we find that $\bar{c_2} = 0$ and $\bar{c_1} = P$, if $b_1 > b_2$.[3]

Proof of corollary 3. Without loss of generality, I focus on the impact of a change in the size of bank 1 on the amount that must be allocated to buy some of its assets.

$\frac{\partial c_1}{\partial a_1} = \frac{(t_{12}-t_{11})b_1 r_1 + t_{11}\Sigma_1 - t_{12}\Sigma_2}{2[(t_{11}-t_{12})\Sigma_1 + (t_{22}-t_{12})\Sigma_2]}$
If $\Sigma_1 = \Sigma_2 = \Sigma$ then, $\frac{\partial c_1}{\partial a_1} = \frac{(t_{11}-t_{12})(1-2b_1 r_1)}{2[(t_{11}+t_{22}-2t_{12})\Sigma]}$
Now let $\bar{m} = (\bar{m_1}, \bar{m_2}) = (\frac{m_{11}+m_{21}}{2}, \frac{m_{12}+m_{22}}{2})$.
Hence the weight matrix M is equal to : $M = \begin{pmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{pmatrix} = \begin{pmatrix} \bar{m_1} + \Delta & \bar{m_2} - \Delta \\ \bar{m_1} - \Delta & \bar{m_2} + \Delta \end{pmatrix}$ and so

$$\frac{\partial c_1}{\partial a_1} = \frac{((\bar{m_1} + \Delta)l_1 - (\bar{m_2} - \Delta)l_2)(1 - 2b_1 r_1)}{4\Delta(l_1 + l_2)(1 - b_1 r_1)}$$

For $l_1 = l_2 = l$ (i.e. the two assets have the same liquidity), we have

$$\begin{aligned} \frac{\partial c_1}{\partial a_1} &= \frac{(\bar{m_1} - \bar{m_2} + 2\Delta)(1 - 2b_1 r_1)}{4\Delta(1 - b_1 r_1)} \\ &= \frac{(m_{11} - m_{12})(1 - 2b_1 r_1)}{2(m_{11} - m_{21})(1 - b_1 r_1)} > 0 \; for \; all \; m_{11} < \frac{1}{2} \; and \; m_{11} < m_{21} \\ &\qquad\qquad (or \; m_{11} > \frac{1}{2} \; and \; m_{11} > m_{21}) \end{aligned}$$

[3] The same exercise is straightforward with the third case.

Appendix B

2011 Stress Tests

Table B.1: List of European banks involved in 2011 Stress Tests.

Erste Bank Group	Credit Agricole
Raiffeisen Bank International	BPCE
Oesterreichische Volksbank AG *	Societe Generale
Dexia	Royal Bank Of Scotland Group
KBC Bank	HSBC Holdings
Marfin Popular Bank Public	Barclays
Bank Of Cyprus Public	Lloyds Banking Group
Deutsche Bank AG	EFG Eurobank Ergasias
Commerz Bank AG *	National Bank Of Greece
Landesbank Baden-Württemberg	Alpha Bank
Dz BanK AG Dt. Zentral-Genossenschafts bank	Piraeus Bank Group
Bayerische Landesbank	Agricultural Bank Of Greece *
Norddeutsche Landesbank GZ *	Tt Hellenic Postbank
Hypo Real Estate Holding AG, München	Otp Bank Nyrt
WestLB AG, Düsseldorf *	Allied Irish Banks *
HSH Nordbank AG, Hamburg	Bank OF Ireland
Landesbank Berlin AG	Irish Life And Permanent
Deka Bank Deutsche Girozentrale, Frankfurt	Intesa Sanpaolo
WGZ Bank AG Westdt. Geno. Zentralbk	Unicredit
Danske Bank	Banca Monte Dei Paschi Di Siena
Jyske Bank	Banco popolare
Sydbank	Unione di Banche Italiane Scpa
Nykredit	Banque Et Caisse D'epargne De L'etat
Banco Santander	Bank Of Valletta
Banco Bilbao Vizcaya Argentaria	Ing Bank
BFA Bankia	Rabobank Nederland
Caja De Ahorros Y Pensiones De Barcelona	Abn Amro Bank
Effibank	SNS Bank
Banco Popular Espagnol	Dnb Nor Bank
Banco De Sabadell	Powszechna Kasa Oszczednosci Bank
Caixa D'estalvis De Catalunya Tarragona I Manresa	Caixa Geral De Depósitos
Caixa De Aforros De Galicia, Vigo	Banco Comercial Português
Grupo BMN	Espírito Santo Financial Group
Bankinter	Banco BPI
Caja Espana De Inversiones, Salamanca	Nordea Bank
Grupo Banca Civica	Skandinaviska Enskilda Banken
Caja De Ahorros Y M.P. De Zaragoza	Svenska Handelsbanken
Monte De Piedad Y Caja De Ahorros	Swedbank
Banco Pastor	Nova Ljubljanska Banka
Grupo BBK	Nova Kreditna Banka Maribor
Caixa D'estalvis Unio De Caixes De Manlleu	
Caja De Ahorros Y M.P. De Gipuzkua Y San Seb	
Grupo Caja	
Banca March	
Caja De Ahorros De Victoria Y Alava	
Caja De Ahorros Y M.P. De Ontinyent	
Colonya - Caixa D'estalavis De Pollensa	
Caja De Ahorros Del Mediterraneo	
OP-Pohjola Group	
Bnp Paribas	

Note : (*) Banks with leverage ratio higher than 50.

Chapter 2

Bail-in vs. Bailout: a Persuasion Game

Co-authored with Sylvain Benoit

Abstract

We propose a model with incomplete information where a distressed bank asks its creditor, a healthy bank, to reduce its debt. Given the information disclosed by the regulator about the asset quality of the distressed bank and its possible bailout by the government, the healthy bank can accept or not the bail-in proposal. When the regulator has the option to bail out the distressed bank, the healthy bank may refuse to save the distressed bank that it could have saved if the regulator cannot bail out. The role of the regulator is to select the optimal disclosure rule that reduces its ex-ante expected loss function. We find that full disclosure is desirable in some circumstances (extreme times) but not in others. For instance, when the bail-in cost is large and bailout cost is not, the optimal loss is reached thanks to a partial disclosure in normal times.

Keywords: Bank resolution, bail-in, bailout, disclosure policy, moral hazard.

2.1 Introduction

The consequences of the Great Financial Crisis (GFC) have led to unprecedented responses from major governments around the world in order to restore financial stability. At the time, the most common bank resolution plan was the bailout of failing banks, which is the action by a government of giving financial assistance to an institution in order to prevent it from collapse. However, this resolution procedure has been largely criticized since it represents a considerable cost for taxpayers and creates moral hazard (Lee and Shin, 2008). By expecting that they would always be saved by the government (e.g., due to the too-big-to-fail issue, and the too many to fail issue), banks are taking more risks, which further weakens the financial system.[1] To limit these negative externalities, a new worldwide banking regulation (Basel III) has been put in place as well as the European Banking Union following the Eurozone crisis.

The first pillar of the European Banking Union, the Single Supervision Mechanism (SSM), proposes a uniform approach for bank supervision and makes the European Central Bank (ECB) responsible for banking supervision in the euro area, with the mandate to directly supervise the most significant banking groups, to carry out prudential reviews, on-site inspections and investigations (e.g., the AQR for Asset Quality Review).[2] This provides the regulator with more information giving it a better ability to safeguard the financial stability. The purpose of the second pillar of the European Banking Union, the Single Resolution Mechanism (SRM), is to ensure an orderly resolution of failing banks with minimal costs to taxpayers and to the real economy.[3] This new regulation first proposes to bail-in debt before a possible bailout (or liquidation) of a failing bank. In such an alternative resolution plan, creditors bear the losses: they only recover a part of their investment but the distressed bank is saved in return.[4]

The SRM, proposed by the European Commission in 2013, entered into force in August 2014 and became fully operational on January 1, 2016. It implements the Bank

[1] Dam and Koetter (2012) show that the marginal effect of an increase of bailout expectations on risk taking is equal to 7.2 basis points. This significant positive impact on the likelihood of distress is due to moral hazard.

[2] The AQR is a review of the asset quality of the 130 leading banks in the European Union implemented by the European Central Bank since November 2013 (see ECB, 2013, for more details). Results form the AQR and stress tests are factored into the assessment of banks' risks, governance, capital and liquidity as part of the Supervisory Review and Evaluation Process (SREP).

[3] The third pillar of the European Banking Union is the European Deposit Insurance Scheme (EDIS). It should provide stronger and more uniform insurance cover for all retail depositors in the European Banking Union.

[4] In the United States, the resolution mechanism for financial institutions is set in the Orderly Liquidation Authority of Title II of the Dodd-Frank Wall Street Reform and Consumer Protection Act of 2010 (Reform, Dodd-Frank Wall Street and Act, Consumer Protection, 2010). See Philippon and Salord (2017) for a comparison of the two resolution mechanisms.

Recovery and Resolution Directive (BRRD). This legal framework aiming at eliminating the possibility of bailing-out institutions by presenting bail-ins as substitute for bailout. However, as stated by Schoenmaker (2019), bail-ins and bailouts are complementary in practice. Indeed, while bail-in is appropriate for idiosyncratic individual failures, bailing large banks could exacerbate - rather than alleviate - the financial panic (Avgouleas and Goodhart, 2015). Incidentally, in the post-BBRD world there have been exceptions and governments have resorted to bailouts of some banks such as the Italian case of June 2017 (Famfollet and Sankotová, 2020) where the European Commission and Italy agreed on a state bailout for Monte dei Paschi di Siena, but also Banca Popolare di Vicenza and Veneto Banca. Resolution occurs when the ECB determines that a bank is failing or likely to fail (FOLTF) and that there is no other supervisory or private sector intervention that can restore the viability of the bank.[5] Once on the FOLTF list, like Banco Popular in June 2017, the Single Resolution Board (SRB) decides to adopt or not a resolution plan by evaluating whether the bank's failure could cause financial instability or disruptions in the market. If a resolution decision is taken, several resolution tools are available to the SRB: (i) parts of the bank can be sold, (ii) parts of the bank can be transferred to a "bridge bank", (iii) certain assets and liabilities can be transferred to a "bad" bank, (iv) the bank's liabilities can be cancelled or reduced through a bail-in procedure.

In this paper, we propose to transpose the mechanism set up by the SRM into a Bayesian persuasion game by studying how the regulator (the ECB in cooperation with the SRB) should use information at its disposal to ensure the financial stability when confronted to resolution issues. In our theoretical framework, decisions are based on a set of costs: a bankruptcy cost, a liquidation cost, a bailout cost and a bail-in cost. The latter is largely neglected in the theoretical literature. Recently, Beck, Da-Rocha-Lopes, and Silva (2021) show that bail-ins significantly restrict credit supply, reducing investment and employment which is detrimental to the economy.

We consider a model à la Eisenberg and Noe (2001) where liquidation and bankruptcy costs are considered as in Rogers and Veraart (2013), whereas seniority in debt repayment is considered as in Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015). In our setting, a distressed bank asks its creditors, which is a healthy bank, to reduce its debt. The healthy bank can accept or not this bail-in operation based on information disclosed by the regulator about the asset quality of the stressed bank. Indeed, there is an asymmetric information in our model since the regulator has more information on the distressed bank than its creditor and chooses a disclosure rule, as in Goldstein and Leitner (2018), in order to minimize its expected total loss function rather than maximize banks' profits.

[5] Usual recovery plan designed by the bank are not sufficient for restoring it profitability.

This total loss function is a weighted function considering bankruptcy costs, liquidation losses, the cost of the bail-ins to the economy as well as the cost of bailouts to taxpayers.

Based on reputation concerns, we design a framework in which the regulator has to make (ex-ante) decisions about which information to gather before observing the asset quality. This information, inter alia, reveals the degree of the regulator's transparency. Furthermore, information disclosures is key for promoting financial stability (Goldstein and Sapra, 2014). The resolution of Long Term Capital Management (LTCM) in 1999 illustrates such a design of information disclosure: the President of the Federal Bank of New York at the time brought together the representatives of the LTCM's creditors (wall street investment banks and some European banks) and agreed with them to put in place an emergency plan to bail-in the fund, in order to avoid what he perceived as the risk of a breakdown of the international financial system (Financial Times, 25 september 1998). Most LTCM's creditors agreed with the notable exception of Bear Stearns. The information disclosed by the regulator would have played a major role in the creditors' decision.

In our setting, the regulator gives information about banks asset quality based on a given chronology. First, the regulator ties its hands by choosing a disclosure rule and announcing it publicly. Hereafter, the asset quality of each bank is realized and observed by the bank itself and the regulator. Then the regulator assigns a score to the distressed bank based on its disclosure rule, and publicly announces it to the healthy bank. Simultaneously, the distressed bank (who also observes its own asset quality's type), knows if the regulator triggers a resolution plan. If it is the case, it then asks the healthy bank to write-down its debt. The latter accepts or not to proceed to the bail-in.[6] If the healthy bank refuses, the government can intervene and bail-out the distressed bank if and only if the bailout is less costly than the no-intervention (bank liquidation). Finally, payments between banks are made simultaneously in the spirit of Eisenberg and Noe (2001) and the total loss of the regulator is determined.

First, we study a benchmark model where we assume that the healthy bank can rescue the distressed bank. The regulator can just influence the healthy bank by disclosing information about the asset quality of the defaulting bank. We find that the healthy bank accepts to bail-in the distressed bank when the expected investment return of the

[6]In practice, since the resolution scheme of Banco Popular, we have seen that is quite difficult for investors to refuse a bail-in. The need to maintain the protection of the public interest and depositors by ensuring the financial stability (without using public fund) could explain the quick execution of a resolution plan without determining properly whether creditors would have received a better treatment under normal insolvency proceeding (such as liquidation). Based on this "no creditor worse off" condition, dozen of lawsuits have been filed against the SRB and the European Commission at the EU general court for contesting the resolution plan of Banco Populare, especially the use of the bail-in tool.

distressed bank observed by the healthy bank is above a given threshold. The value of this threshold decreases when we have high liquidation and bankruptcy costs. It means that the healthy bank becomes less demanding and accepts even to rescue banks with bad asset quality when liquidation and bankruptcy costs are large.

Second, the government can partake in the resolution plan and may bail-out the failing bank if the healthy bank refuses the bail-in proposal. Considering a potential intervention of the government creates moral hazard. Indeed, given the information at its disposal, the healthy bank calculates the probability of the distressed bank to be bailed-out by the government and takes it into account in its bail-in decision. We show that the bail-in threshold, considered by the healthy bank, depends on the disclosure rule, contrary to the benchmark model. In this case, the healthy bank can refuse to save banks that it could have saved if there were no government intervention.

Third, since the information disclosure influences the cost of bank resolution, we look at the optimal disclosure rule that minimises the government losses.[7] Our results suggest that the full disclosure is not systematically optimal. The regulator is particularly keen to be completely transparent in the extreme states of the economy. It is especially true when we are in crisis, and that the bail-in cost is high and/or the bankruptcy cost is low. In contrast, when both bail-in and bailout costs are low in crises period, then the partial disclosure is an optimal strategy. The reverse disclosure policies are optimal in good time. The no disclosure policy should be chosen in normal time, when bailouts are costly and bail-ins are not. In fact, since bailout cost is high, government does not want to bail out banks and thus regulator wants to convince the healthy bank to make bail-ins. Such a policy of undisclosed information about the distressed bank asset quality is also efficient in bad time when the bail-in cost is large, while the partial disclosure is optimal if bail-in cost is low. To see how results evolve according to different sets of parameters, we propose an online web applications.

The rest of the paper is organised as follows. Section 1.2 presents a brief review of the related literature. Our model is presented in Section 1.3. In Section 1.4, we introduce our benchmark case where we define a resolution plan without government intervention and determine the optimal disclosure rule. In Section 1.5, we consider a possible intervention of the government, i.e., a possible bailout, which creates moral hazard and we resolve our model accordingly. Section 1.6 concludes. Proofs of technical results are deferred to the Appendices.

[7] Granja (2013) shows empirically that disclosure regulation policy influences the cost of resolution of a bank and, as a result, could be an important factor in the definition of the optimal resolution strategy during a banking crisis event.

2.2 Literature review

Our paper is related to several strands of the literature. First, we contribute to the recent and rich literature on bail-in, bailout and bank resolution. Second, we rely on the literature on Bayesian persuasion for studying determinants in the use of information disclosure as a regulatory instrument to improve financial stability.

Bail-in and bailout. Seminal works on bail-ins and bailouts have emphasized their potential advantages and drawbacks (Dewatripont, 2014; Avgouleas and Goodhart, 2015). While bailout mainly shifts the burden of losses due to a bankruptcy from claim holders to taxpayers, Dam and Koetter (2012) and Bianchi (2016) point out the moral hazard generated by such a resolution since banks are taking more risks thanks to this implicit government guarantees.[8] This effect is particularly evident for global systematically important banks that are too-big-to-fail (Afonso, Santos, and Traina, 2014), but also for many small banks exposed to the same risk factors that are too-many-to-fail (Acharya and Yorulmazer, 2007).[9] To overcome bailout issues, bail-in has been suggested as an alternative to bailout by policy makers both in Europe and in the United-States. However, Philippon and Salord (2017), through a review of the EU resolution framework, argue that transferring the losses to the private creditors can create short-term financial instability especially if banks do not have sufficient long-term loss absorbency capacity to reassure short-term claim holders (Dewatripont, 2014). Avgouleas and Goodhart (2015) discuss also the weaknesses of bail-ins compared to bailouts, as they could be more contagious and pro-cyclical for example, and they argue that bailouts would continue to be needed in the wake of some extreme situations (e.g., systemic crisis, simultaneous failure of multiple banks...). Pandolfi (2018) explores theoretically how bail-ins affects banks' funding costs and incentives to monitor loans. He shows that in some cases bailouts may be more efficient than bail-ins since they avoid credit market collapse and induce better monitoring incentives. Beck, Da-Rocha-Lopes, and Silva (2021) show that banks more exposed to a bail-in significantly reduce their credit supply after a shock which lower investment and employment to firms more exposed to an intervention.

Bank resolution. A more recent literature studies how to trigger bail-ins when bailouts are possible. By using a game-theoretic network model with complete information, Bernard, Capponi, and Stiglitz (2017) find that bail-in is possible only when the reg-

[8] See Benoit, Colliard, Hurlin, and Pérignon (2017), for a review on systemic risk.

[9] These banks involved in herding behavior are prompt to fail or survive together. Acharya and Yorulmazer (2008) show that regulation itself generates a herding behavior.

ulator's threat to not bailout insolvent banks is credible. They also show that incentives to join a rescue consortium are stronger in networks where banks have a high exposure to default contagion, and weaker if banks realize that a large fraction of the benefits resulting from their contributions accrue to others. Rogers and Veraart (2013) deal with a network with complete information and suggest that a consortium of banks can rescue distressed banks when it has the incentive to do so.[10] Our model is different from these two papers since our game is based on incomplete information. In our setting, the regulator gives information about the failing bank's asset quality according to a disclosure rule that it chooses ex-ante by minimizing its expected loss function. Walther and White (2020) have also a setting where the regulator has more information than a bank's creditors (the healthy bank in our model) about the value of its assets, and they analyze how to reach efficient bail-ins by signalling or not private information. Indeed, signalling bad news would create a bank run. In Keister and Mitkov (2020), the threat of a run disciplines the distressed bank to impose losses on its creditors and helps the regulator to improve financial stability.[11] In their model, some investors (creditors) have private information about the size of their banks' losses and can withdraw funds before this information becomes public. Banks with such a fraction of worthless goods pay them less than in normal times. The size of the bail-in is measured as the percentage haircut from the allocation in normal times. This notion of bail-in is not very different from ours, in the sense that in our model the size of the bail-in is represented by the amount of the debt write down. Colliard and Gromb (2018) investigate how resolution frameworks affect the private restructuring of distressed banks by modelling a distressed bank that asks an external creditor for a bail-in through a signaling game with incomplete information. The time is used to signal the asset quality to the creditor. They show that strict bail-in rules increase delays by worsening informational frictions and reducing bargaining surplus. They find also that, when the government partakes in negotiations, the delays may be shorter or longer. We extend their initial model to a financial network of two banks, where the creditor is the healthy bank of the network. Our setting captures the negative externalities, due to fire sales and domino effects, endogenously through banks' losses induced by bankruptcy and liquidation costs.[12]

[10] Indeed, solvent banks should avoid distressed banks to fail in succession. Incentive to rescue is introduced by default costs. Leitner (2005) motivates also private sector bailout in his network model by the fear of collapse due to contagion.

[11] We do not based our analysis on an extended version of the Diamond and Dybvig (1983) model as in Keister (2016) and Keister and Mitkov (2020) since bank runs are not central in our setting.

[12] Colliard and Gromb (2018) capture these externalities by applying a negative externality factor to the proportion of the debt which is not bailed out by the government.

Information disclosures and persuasion. We are also related to the literature on regulatory disclosures in the financial system, see Goldstein and Sapra (2014) for a literature review. In addition, information design and Bayesian persuasion are two key literature for our work, see Bergemann and Morris (2019) for a review of the latter. Indeed, our methodology is similar to the one proposed by Goldstein and Leitner (2018) where they study the design of stress tests by a regulator (the sender) facing a competitive market (the receiver). Theoretically, they map their setting into a Bayesian persuasion problem with one sender and one receiver (Kamenica and Gentzkow, 2011).[13] The sender discloses information to persuade the receiver to make a sufficiently high price offer to the bank so that the bank's capital does not fall below the critical level. Instead of selling an asset, we introduce a framework where the informed party offers to exchange existing financial claims (e.g., debt) against new financial claims (e.g., lower debt). More precisely, our regulator (the sender) faces a financial system where a distressed bank requires a resolution plan and asks a healthy bank (the receiver) to proceed to its bail-in thanks to a debt write down. The decision of the healthy bank is based on the information disclosed by the regulator about the asset quality of the distressed bank and its bailout probability. As in Goldstein and Leitner (2018), we assume that the regulator and banks hold homogeneous beliefs about their own balance sheet and we consider that the regulator allows for flexible information structures (full disclosure, partial disclosure, no disclosure).[14] However, our regulator minimizes an ex-ante expected loss function which is different from banks' objective function, which is to maximize their ex-ante expected payoff. Thus, the regulator and banks may have uncommon interests, and this is based on the different costs that we take into account in our model.

2.3 Model description

Before describing our model in detail, it is useful to briefly describe the sectors and the agents that characterize the environment. On the one hand, there is a private sector, composed of two banks with interbank exposures, both banks want to maximize their own profit. On the other hand, we have a public sector, composed of a regulator and a government (with the fiscal authority), both entities have the same objective function.

[13] A recent growing literature studies persuasion with multiple receivers (Wang, 2013; Inostroza and Pavan, 2018; Goldstein and Huang, 2016) or multiple senders (Gentzkow and Kamenica, 2017).

[14] Inostroza and Pavan (2018) study the design of stress tests by a policy maker facing a continuum of investors with heterogeneous private beliefs. Flexible information structures are allowed as opposed to Bouvard, Chaigneau, and Motta (2015). Their policy maker has to make a choice between transparency (full disclosure) and opacity (no disclosure) but cannot commit to a disclosure policy.

2.3.1 The environment

We consider an economy composed of two risk-neutral banks: a healthy bank, labelled bank $\mathcal{H}$, and a distressed one, labelled bank $\mathcal{D}$. The economy lasts for three periods $t = 0, 1, 2$, and the resolution plan of bank $\mathcal{D}$ is triggered by the regulator at $t = 1$ since bank $\mathcal{D}$ is too indebted to bank $\mathcal{H}$ (due to its interbank debt).

Banks. Initially, the two banks spend their capital on (i) lending to the other bank; and/or on (ii) investing an amount a_i in an illiquid asset (a project) yielding a random return in the intermediate period, $\tilde{\theta}_i$, and a fixed return in the final period, e_i. However, if the bank is unable to fully repay its liabilities, at time $t = 1$, its asset can be liquidated partially or totally. We assume that the liquidation is costly since the bank can only recover a fraction α (with $\alpha < 1$) of the asset's full value.

We also assume that the healthy bank is a creditor of the distressed one. The face value of the debt of bank $\mathcal{D}$ to bank $\mathcal{H}$ is denoted L. Assets of each bank i are financed by both interbank credits (if they exist) and deposits, d_i. Then the equity equals the two sides of the balance sheet (see Table 2.1).

Table 2.1: Stylized banks balance sheet.

Stylized bank $\mathcal{H}$ balance sheet

Assets	Liabilities
L Debt of bank $\mathcal{D}$ to bank $\mathcal{H}$	$d_{\mathcal{H}}$ Deposits
$a_{\mathcal{H}}$ Return on bank $\mathcal{H}$ project	$E_{\mathcal{H}}$ Equity

Stylized bank $\mathcal{D}$ balance sheet

Assets	Liabilities
	L Debt of bank $\mathcal{D}$ to bank $\mathcal{H}$
$a_{\mathcal{D}}$ Return on bank $\mathcal{D}$ project	$d_{\mathcal{D}}$ Deposits
	$E_{\mathcal{D}}$ Equity

Failure, liquidation and payments. As it is standard in financial literature, we consider that the distressed bank defaults when its equity is negative, i.e. when $L + d_{\mathcal{D}} > a_{\mathcal{D}}$. When this happens, the latter bears a bankruptcy cost. We assume, as in Rogers and Veraart (2013), that the bank only recovers a fraction β (with $\beta < 1$) of the face value of its assets realized in liquidation.

When the bank i does not have the necessary cash flow to repay its creditors, it liquidates, l_i, a part (or all) of its investment. More precisely, if bank $\mathcal{D}$ cannot repay totally its liability, $L + d_{\mathcal{D}}$, it does liquidate the entire $e_{\mathcal{D}}$ and it repays $p_{\mathcal{D}\mathcal{H}}$ to bank $\mathcal{H}$. Since we consider seniority in payments: depositors are reimbursed first and the healthy

bank is repaid second, the payment of bank $\mathcal{D}$ to bank $\mathcal{H}$ is equal to:

$$p_{\mathcal{DH}} = \beta\left(\tilde{\theta}_{\mathcal{D}} + \alpha e_{\mathcal{D}}\right) - d_{\mathcal{D}}. \tag{2.1}$$

Moving to bank $\mathcal{H}$, we assume that the maximum value it can obtain from liquidation is always sufficient to repay its depositors (i.e. equity remains positive). Thus, the amount liquidated by bank $\mathcal{H}$ is given by:

$$l_{\mathcal{H}} = \frac{1}{\alpha}\left(d_{\mathcal{H}} - p_{\mathcal{DH}} - \theta_{\mathcal{H}}\right). \tag{2.2}$$

Regulator. At $t = 1$, the regulator provides banks with information about the asset quality of the distressed bank $\tilde{\theta} = \tilde{\theta}_{\mathcal{D}}$. The asset quality is drawn from a finite set $\Theta \subset \mathbb{R}$ according to a probability function $p(\theta) = \Pr(\tilde{\theta} = \theta)$. This probability distribution is common knowledge across all agents. The types in Θ are denoted $\theta_{max} = \theta^1 > \theta^2 > ... > \theta^k = \theta_{min} > 0$.

The regulator discloses information about banks' asset quality according to a disclosure rule chosen before observing the realization of $\tilde{\theta}$. The choice of the disclosure rule minimises its expected loss function. A disclosure rule, as in Goldstein and Leitner (2018), is defined by a set of scores, S, and a function, g, that maps each asset quality to a distribution over scores. To better understand this, let us imagine that the regulator conducts an investigation and reports its outcome to banks. This outcome is represented by g. Let $g(s \mid \theta) = \Pr\left(\tilde{s} = s \mid \tilde{\theta} = \theta\right)$ be the probability, according to the disclosure rule, that the regulator assigns a score $s \in S$ when it observes asset quality θ. Then $\sum_{s\in S} g(s \mid \theta) = 1$, for every $\theta \in \Theta$.

For instance, if there is only two assets quality, a high quality (θ_H) and a low quality (θ_L), and that the regulator assigns only two scores s_H and s_L, then the full disclosure (perfectly informative) can be obtained when the following signal is sent:

$$g(s_H \mid \theta_H) = 1 \ , \ g(s_L \mid \theta_H) = 0;$$
$$g(s_H \mid \theta_L) = 0 \ , \ g(s_L \mid \theta_L) = 1.$$

However, no disclosure (non informative) can be realized when the regulator sends the following signal:

$$g(s_H \mid \theta_H) = 1/2 \ , \ g(s_L \mid \theta_H) = 1/2;$$
$$g(s_H \mid \theta_L) = 1/2 \ , \ g(s_L \mid \theta_L) = 1/2.$$

In this setting, like it is standard in mechanism design problem, we assume that the regulator commits to assigning scores according to the disclosure rule previously announced.

2.3.2 Expected outcomes

Banks. Based on Section 2.3.1, we can explicit the expected value of the investment return of bank $\mathcal{D}$, conditional on the bank obtaining score s, $R(s)$. We obtain, from Bayes rule, that:

$$R(s) = \mathbb{E}\left[\tilde{\theta} \mid s\right] = \sum_{\theta \in \Theta} \theta \Pr\left(\tilde{\theta} = \theta \mid \tilde{s} = s\right) = \frac{\sum_{\theta \in \Theta} \theta p(\theta) g\left(s \mid \theta\right)}{\sum_{\theta \in \Theta} p(\theta) g\left(s \mid \theta\right)}. \tag{2.3}$$

We define the profit of bank $\mathcal{H}$ given the information s by:

$$\pi = \left[p_{\mathcal{D}\mathcal{H}} + \theta_{\mathcal{H}} + e_{\mathcal{H}} - (1-\alpha) l_{\mathcal{H}} - d_{\mathcal{H}}\right]. \tag{2.4}$$

This profit represents the value of bank equity.[15] Our profit formula is similar to the one proposed by Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015). This quantity is also analogous to the notion of *the value of bank equity* established by Bernard, Capponi, and Stiglitz (2017).

Regulator. The regulator welfare function, defined as a weighted sum of different losses, is the following:

$$w(\theta) = (1-\alpha) \sum_i l_i + (1-\beta)[\theta_{\mathcal{D}} + \alpha e_{\mathcal{D}}]. \tag{2.5}$$

The first term represents losses due to inefficient asset liquidation whereas the second term is the sum of losses due to bankruptcy cost.

2.4 Model solution without government intervention

In this section, we resolve our model by assuming that the government does not partake in the resolution plan, i.e., there is no possible bailout. The more general case, where the government intervenes is presented in the next section. As the intuition for solving both

[15] The quantity "$\theta_{\mathcal{H}} + e_{\mathcal{H}} - (1-\alpha) l_{\mathcal{H}}$" comes from the return on illiquid asset at $t = 1$ and $t = 2$. In fact, at $t = 1$, this asset yields $\theta_{\mathcal{H}}$ and the bank liquidates a part of it, $l_{\mathcal{H}}$, to meet its obligation. However, since liquidation is costly, the income obtained from the liquidation is $\alpha l_{\mathcal{H}}$. At $t = 2$, the bank recovers only an amount of $e_{\mathcal{H}} - l_{\mathcal{H}}$.

cases is largely the same, we decide to present a benchmark model in this section without adding any mathematical complexity, to better introduce our framework.

2.4.1 Model equilibrium

The resolution plan consists of a bail-in which is defined as a write down in the debt value.[16] The healthy bank accepts or not the regulator's bail-in proposal. The purpose is to save the distressed bank.[17]

The bail-in game. The model is outlined in Figure 2.1. We have a sequence of events similar to Goldstein and Leitner (2018). First, the regulator chooses a disclosure rule (S, g), and publicly announces it. Hereafter, the asset quality of type θ of each bank is drawn and observed by the bank itself and by the regulator. It then assigns a score s to banks according to its disclosure rule and lets everyone know s. Simultaneously, the distressed bank, who also observes its own asset quality's type, knows if it needs a rescue plan. If it is the case (and we assume that it is always the case to run our model), this failing bank asks the healthy bank to write-down its debt. The latter accepts or not to proceed to the bail-in. And finally, payments between banks are made simultaneously in the spirit of Eisenberg and Noe (2001) and the total losses for the regulator are determined. In our framework, we assume that the distressed bank can always repay its depositors.[18] This assumption is translated by the fact that $\theta_{min} \geq d_{\mathcal{D}} - \alpha e_{\mathcal{D}}$. We assume also that the distressed bank (bank $\mathcal{D}$) cannot lie to the healthy bank (bank $\mathcal{H}$). In particular, the distressed bank does not ask the healthy bank to write down its debt, if a resolution plan is not necessary to rescue it. Hence $\theta_{max} < d_{\mathcal{D}} + L - \alpha e_{\mathcal{D}}$.

Let $b_{\mathcal{H}}(\theta)$ denotes the amount required of the debt write down. When bank $\mathcal{H}$ accepts to renegotiate the debt of bank $\mathcal{D}$, it sets a new face value $L - \mathbb{E}(b_{\mathcal{H}}(\theta) \mid s)$ instead of $E(p_{\mathcal{HD}}|s)$. Our solution concept corresponds to perfect Bayesian equilibria models. Concretely, the healthy bank chooses whether or not to accept the bail-in in order to maximize its expected profit based on its information.

[16] There are several forms of bail-ins. The most direct way to achieve bail-in is to write down the value of a claim (and this is what we use in our framework). An alternative is to offer creditors debt-equity swap that allows them to held a certain number of shares in a bank in exchange for debt cancellation (Wihlborg, 2017).

[17] This modeling approach is standard in the literature (e.g. Bernard, Capponi, and Stiglitz (2017), and Colliard and Gromb (2018)). In fact, what we model in our framework is the SRM scheme, i.e. a bail-in proposal before a possible bailout.

[18] If it is not the case, the surviving bank has no motivation to accept the bail-in since the bail-in amount, $b_{\mathcal{H}}(\theta)$, as defined by condition (II), will be systematically greater than the amount due to the healthy bank, L.

We assume that the healthy bank always liquidates a part of its investment to meet its obligations. Henceforth, in the case where there is no bail-in, the expected profit of the surviving bank is:

$$\begin{aligned} \Pi_{no-inter}(s) &= \mathbb{E}(p_{\mathcal{DH}} \mid s) + \theta_{\mathcal{H}} + e_{\mathcal{H}} - (1-\alpha)\,\mathbb{E}(l_{\mathcal{H}} \mid s) - d_{\mathcal{H}}, \\ \text{with } \mathbb{E}(p_{\mathcal{DH}} \mid s) &= \beta\left(\alpha e_{\mathcal{D}} + \mathbb{E}\left(\theta \mid s\right)\right) - d_{\mathcal{D}}, \\ \text{and } \mathbb{E}(l_{\mathcal{H}} \mid s) &= \frac{1}{\alpha}\left[d_{\mathcal{H}} - \mathbb{E}(p_{\mathcal{DH}} \mid s) - \theta_{\mathcal{H}}\right]. \end{aligned} \tag{2.6}$$

However, when bank $\mathcal{H}$ accepts the bail-in proposal, its expected profit is equal to:

$$\begin{aligned} \Pi_{bail-in}(s) &= L - \mathbb{E}(b_{\mathcal{H}}(\theta) \mid s) + \theta_{\mathcal{H}} + e_{\mathcal{H}} - (1-\alpha)\,\mathbb{E}(l'_{\mathcal{H}} \mid s) - d_{\mathcal{H}}, \\ \text{with } \mathbb{E}(l'_{\mathcal{H}} \mid s) &= \frac{1}{\alpha}\left[d_{\mathcal{H}} - (L - \mathbb{E}(b_{\mathcal{H}}(\theta) \mid s)) - \theta_{\mathcal{H}}\right]. \end{aligned} \tag{2.7}$$

The goal of the surviving bank is to maximize its expected profit. As a consequence, bank $\mathcal{H}$ accepts the bail-in proposal if and only if,

$$\begin{aligned} &\Pi_{bail-in}(s) \geq \Pi_{no-inter}(s), \\ i.e., \quad &L - \mathbb{E}(b_{\mathcal{H}}(\theta) \mid s) \geq \mathbb{E}(p_{\mathcal{DH}} \mid s) \quad \text{since} \quad \alpha \in (0,1]. \end{aligned} \tag{I}$$

This condition is similar to the bail-in condition exposed by Bernard, Capponi, and Stiglitz (2017). It states that the healthy bank is willing to make a net contribution up to the sum of its expected exposure.

Amount of debt write-down. As in Bernard, Capponi, and Stiglitz (2017), we assume that the amount of the debt write-down is determined by the regulator.[19] This hypothesis allows us to rule out any strategic game between the failing bank and the healthy bank. Hence, the information available to the healthy bank is only provided by the regulator.

To survive, the value of the total equity (or profit, to be coherent with the previous notation) of bank $\mathcal{D}$ must be positive:[20]

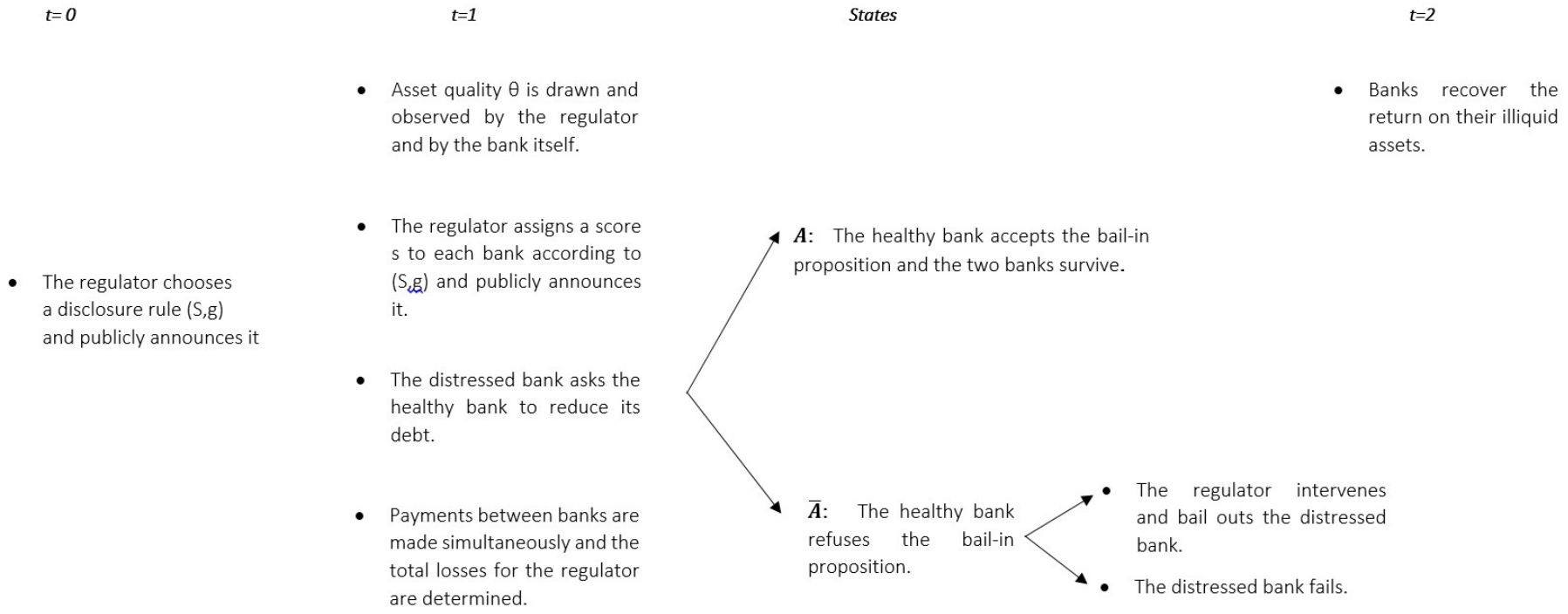
$$\tilde{\theta} + \alpha e_{\mathcal{D}} - (L - b_{\mathcal{H}}(\theta)) - d_{\mathcal{D}} > 0. \tag{2.8}$$

The amount of debt write-down that bank $\mathcal{H}$ is able to make is such that its total equity

[19] In their setting, Bernard, Capponi, and Stiglitz (2017) characterize the optimal amount of this debt write-down.

[20] We assume the strict positivity to let the bank operate in the next period, because with equity equal to 0 (in case of large inequality), it can reimburse all its creditors but should liquidate all its projects for doing it.

Figure 2.1: Timeline of the model



Note: We present the complete timeline of our model. In section 2.4, we consider that the regulator does not take part in the resolution plan. In other words, in state $\bar{A}$, the healthy bank refuses the bail-in proposal and so the distressed bank fails since there is no possibility of bailout. In the most complete version of our model (Section 2.5, the regulator has the choice between bailing out the distressed bank or letting it fail.

after the bail-in operation remains positive, i.e.,

$$(L - b_{\mathcal{H}}(\theta)) + \theta_{\mathcal{H}} + \alpha e_{\mathcal{H}} - d_{\mathcal{H}} > 0. \tag{2.9}$$

Following this inequalities, it is obvious that the amount of the debt write down, that bank $\mathcal{D}$ can ask for, is such that:

$$L + d_{\mathcal{D}} - \tilde{\theta} - \alpha e_{\mathcal{D}} < b_{\mathcal{H}}(\theta) < L + \theta_{\mathcal{H}} + \alpha e_{\mathcal{H}} - d_{\mathcal{H}}. \tag{II}$$

We distinguish between two different conditions. This condition reflects the fact that bank $\mathcal{H}$ can rescue bank $\mathcal{D}$ by writing down its debt (ability to rescue). But this does not necessarily mean that it accepts to proceed to this resolution plan. For doing it, condition (I) must be verified (incentive to rescue). We assume in our framework that bank $\mathcal{H}$ has still sufficient resources to save bank $\mathcal{D}$. and the condition established by equation 2.9 is always verified. Hence, the amount of the debt write-down, $b_{\mathcal{H}}(\theta)$, requested by the defaulting bank is a decreasing function of the expected value of bank $\mathcal{D}$ asset quality, i.e.,

$$b_{\mathcal{H}}(\theta) = -\theta + C, \tag{2.10}$$

with C a positive constant satisfying condition (II), that is $C > L + d_{\mathcal{D}} - \alpha e_{\mathcal{D}}$.[21]

Lemma 1 *In equilibrium, bank $\mathcal{H}$ accepts the bail-in proposal if and only if, bank $\mathcal{D}$ obtains a score s such that $R(s) \geq R^*$ with $R^* = \frac{\beta}{1-\beta}\alpha e_{\mathcal{D}} - \frac{1}{1-\beta}(d_{\mathcal{D}} + L - C)$.*

Lemma 1 underlines the fact that better the condition of the distressed bank (bank $\mathcal{D}$) is, the more likely the creditor bank (bank $\mathcal{H}$) is apt to accept the bail-in offer. Indeed, bank $\mathcal{H}$ will accept to save bank $\mathcal{D}$ with an asset quality above a certain threshold R^*. The value of this threshold is larger when we have low liquidation and bankruptcy costs since the first derivatives of this threshold with respect to these costs are positive:

1. $\frac{\partial R^*}{\partial \alpha} = \frac{\beta}{1-\beta} e_{\mathcal{D}} > 0.$
2. $\frac{\partial R^*}{\partial \beta} = \frac{1}{(1-\beta)^2}\left[\alpha e_{\mathcal{D}} + C - d_{\mathcal{D}} - L\right] > 0.$

The following corollary summarizes this point:

Corollary 1 *For important liquidation and bankruptcy costs (low α and β, respectively), the surviving bank is less demanding and accepts to rescue the distressed bank even if its asset quality is worsening (it becomes more costly for bank $\mathcal{H}$ to let bank $\mathcal{D}$ default).*

[21] C is positive because $b_{\mathcal{H}}(\theta) > 0$.

Regulator's welfare function. We assume that the regulator has the welfare function $w(\theta)$, reported in Equation 2.5. This function is a weighted sum of different losses (Table 2.2). Our welfare function considered in the following extends the corresponding notion introduced by Bernard, Capponi, and Stiglitz (2017), by attributing a weight, γ, to the amount of bail-in granted by the healthy banks. This choice is motivated by the papers of Beck, Da-Rocha-Lopes, and Silva (2021) and Philippon and Salord (2017). Thus, a higher γ considers the significant negative impact of this bail-in to the economy. Conversely, bail-ins have no impact on the economy and only represents a transfer of wealth from the healthy bank to the distressed one when γ is set to 0.

Table 2.2: Different losses due to a cascade default.

Losses	Calculation in the welfare function
Liquidation losses $(1-\alpha)\sum_i \mathbb{E}(l_i \mid s)$	If there is no liquidation the investment value is: e_i After liquidation at t its value is: $\alpha\,\mathbb{E}(l_i \mid s) + (e_i - \mathbb{E}(l_i \mid s))$
Default cost $(1-\beta)[\mathbb{E}(\theta_{\mathcal{D}} \mid s) + \alpha e_{\mathcal{D}} + c_{\mathcal{D}}]$	if there is no default cost the payment is: $\mathbb{E}(\theta_{\mathcal{D}} \mid s) + \alpha e_{\mathcal{D}} + c_{\mathcal{D}} - d_{\mathcal{D}}$ In presence of default cost the payment is: $\beta[\mathbb{E}(\theta_{\mathcal{D}} \mid s) + \alpha e_{\mathcal{D}} - c_{\mathcal{D}}] - d_{\mathcal{D}}$
Bail-in losses $\gamma b_{\mathcal{H}}(\theta)$	If there is no bail-in: $\gamma b_{\mathcal{H}}(\theta) = 0$ else: $\gamma b_{\mathcal{H}}(\theta) > 0$

Note : This table reports different type of losses considered by the regulator in the calculation of its welfare function.

To make the notation less cluttered, we note $w_1(\theta)$ the welfare losses in the case where bank $\mathcal{H}$ accepts to bail-in bank $\mathcal{D}$ such that:[22]

$$\begin{aligned} w_1(\theta) &= (1-\alpha)[l'_{\mathcal{H}} + l'_{\mathcal{D}}] + \gamma b_{\mathcal{H}}(\theta), \\ &= \frac{(1-\alpha)}{\alpha}[d_{\mathcal{H}} - \theta_{\mathcal{H}} + d_{\mathcal{D}}] - \frac{1-\alpha}{\alpha}\theta - \gamma\theta + \gamma C. \end{aligned} \tag{2.11}$$

Again, for simplicity reasons, we note $w_0(\theta)$ the welfare losses in the case where there is

[22] When the healthy bank accepts the bail-in proposal, a distressed bank with an asset quality θ, liquidates the amount $l'_{\mathcal{D}} = \frac{1}{\alpha}[d_{\mathcal{D}} + L - \theta - b_{\mathcal{H}}(\theta)]$.

no intervention from bank $\mathcal{H}$:[23]

$$\begin{aligned} w_0(\theta) &= (1-\alpha)l_{\mathcal{H}} + (1-\alpha)e_{\mathcal{D}} + (1-\beta)[\theta + \alpha e_{\mathcal{D}}], \\ &= (\frac{1-\alpha}{\alpha})\left[d_{\mathcal{H}} - \theta_{\mathcal{H}} + d_{\mathcal{D}}\right] + (1-\beta)e_{\mathcal{D}} + (\frac{1-\beta}{\beta} - \frac{1-\alpha}{\alpha})\beta\theta. \end{aligned} \tag{2.12}$$

Hence the expected welfare losses for the regulator, when bank $\mathcal{D}$ has an asset quality θ, given a disclosure rule (S, g) is:

$$\mathcal{L}(\theta) = \sum_{s:R(s)\geq R^*} w_1(\theta)g(s \mid \theta) + \sum_{s:R(s)<R^*} w_0(\theta)g(s \mid \theta). \tag{2.13}$$

The first term represents cases in which bank $\mathcal{H}$ accepts the bail-in proposal whereas the second term represents cases in which the restructuring plan is refused.

The regulator's problem at this stage is to choose a disclosure rule (S, g) which minimizes its ex-ante expected losses $\sum_{\theta\in\Theta} p(\theta)\mathcal{L}(\theta)$. The function to minimize is:[24]

$$\begin{aligned} &\sum_{\theta\in\Theta} p(\theta) \sum_{s:R(s)\geq R^*} \Big[\frac{1-\alpha}{\alpha}(d_{\mathcal{H}} + d_{\mathcal{D}} - \theta_{\mathcal{H}}) - (\gamma + \frac{1-\alpha}{\alpha})\theta + \gamma C\Big]\, g(s \mid \theta) \\ &+ \sum_{\theta\in\Theta} p(\theta) \sum_{s:R(s)<R^*} \Big[\frac{1-\alpha}{\alpha}(d_{\mathcal{H}} + d_{\mathcal{D}} - \theta_{\mathcal{H}}) + (1-\beta)e_{\mathcal{D}} + (\frac{1-\beta}{\beta} - \frac{1-\alpha}{\alpha})\beta\theta\Big]\, g(s \mid \theta). \end{aligned} \tag{2.14}$$

Lemma 2 *The regulator's problem reduces to choose a disclosure rule (S, g) for maximizing:*

$$\sum_{\theta\in\Theta} p(\theta)A(\theta) \sum_{s:R(s)\geq R^*} g(s \mid \theta),$$

with $A(\theta) = \frac{1-\beta}{\alpha}\theta - \gamma(C-\theta) + (1-\beta)e_{\mathcal{D}}$, the potential gains and losses for the regulator.

In Lemma 2, the term $\sum_{s:R(s)\geq R^*} g(s \mid \theta)$ represents the probability that bank $\mathcal{D}$ with asset quality θ benefits from a bail-in. The term $A(\theta)$ represents the potential gains and losses (since $A(\theta)$ can be both positive or negative) for the regulator when bank $\mathcal{D}$ is subject to a bail-in operation. All other things being equal, this term is usually positive when liquidation cost is high ($\alpha \to 0$) and/or bail-in cost is low ($\gamma \to 0$). In

[23] When the distressed bank has an asset quality θ, the healthy bank liquidates an amount $l_{\mathcal{H}}$ if it refuses the bail-in proposal, such that $l_{\mathcal{H}} = \frac{1}{\alpha}[d_{\mathcal{H}} - \theta_{\mathcal{H}} - p_{\mathcal{D}\mathcal{H}}]$ with $p_{\mathcal{D}\mathcal{H}}$ the executed payment of bank $\mathcal{D}$, when it defaults, to bank $\mathcal{H}$.

[24] The regulator payoff, for an asset quality θ, is then equal to $\mathbb{1}_{BI=1}w_1(\theta) + \mathbb{1}_{BI=0}w_0(\theta)$, where $\mathbb{1}_{BI=1}$ is an indicator variable taking value 1 when the bail-in takes place and 0 otherwise and $\mathbb{1}_{BI=0}$ an indicator variable taking value 1 when the bail-in is refused.

contrast, it is negative when bail-in cost is high ($\gamma \to +\infty$) and/or bankruptcy cost is very low ($\beta \to 1$).[25] The marginal effects of these three costs on $A(\theta)$ are negatives, leading to additional losses. In the following lemma, we show that we can focus, without loss of generality, on disclosure rules assigning at most 2 scores, under certain conditions explained in Lemma 3.

Lemma 3 *Considering a disclosure rule (S, g) and a disclosure rule $(\hat{S}, \hat{g})$ defined by $\hat{S} = \{s_L, s_H\}$, such that $\hat{g}(s_H \mid \theta) = \sum_{s:R(s)\geq R^*} g(s \mid \theta)$ and $\hat{g}(s_L \mid \theta) = 1 - \sum_{s:R(s)\geq R^*} g(s \mid \theta)$. Then, the probability that bank $\mathcal{H}$ accepts the bail-in operation is the same under the two rules. The value of the regulator's objective function is also the same under both rules.*

Let s_H represents the high type and s_L the low type. We define also $h(\theta) := \hat{g}(s_H \mid \theta)$ the probability that a bank with an asset quality θ obtains the high score.

Lemma 4 *The regulator problem reduces to find a function $h : \Theta \longrightarrow [0, 1]$ to maximize:*

$$\sum_{\theta\in\theta} A(\theta)p(\theta)h(\theta),$$

subject to:

$$\sum_{\theta\in\Theta} p(\theta)(\theta - R^*)h(\theta) \geq 0,$$

$$\sum_{\theta\in\Theta} p(\theta)(\theta - R^*)(1 - h(\theta)) < 0.$$

The objective function follows from Lemma 2. Constraints follows from $R(s_H) \geq R^*$ and $R(s_L) < R^*$. Moreover, the objective function is continuous on a compact space (the feasible region is closed and bounded since $h : \Theta \longrightarrow [0, 1]$) and so the maximum exists.

We distinguish for the resolution several cases:

Case 1: $\mathbb{E}(\tilde{\theta}) < R^*$

In this case, the problem exposed in Lemma 4 is reduced to find a function $h : \Theta \longrightarrow [0, 1]$ to

$$\begin{aligned} \text{maximize} \quad & \sum_{\theta\in\theta} A(\theta)p(\theta)h(\theta), \\ \text{subject to} \quad & \sum_{\theta\in\Theta} p(\theta)(\theta - R^*)h(\theta) \geq 0. \end{aligned} \tag{III}$$

- *When $A(\theta) < 0$ for every $\theta \in \Theta$.*

Setting $h(\theta) = 0$ for every $\theta \in \Theta$ is optimal. In fact, since $A(\theta) < 0$, the gain of saving

[25] This is due to the fact that $(C - \theta) \geq 0$ since $b_{\mathcal{H}}(\theta) > 0$.

a bank with an asset quality θ is negative. Hence, it is obvious that it's better for the regulator that the bail-in does not take place, thus the lowest score s_L is attributed for every asset quality. This solution respects constraint (III).

- *When* $A(\theta) > 0$ *for every* $\theta \in \Theta$.

It is not possible here to attribute the high score for every asset quality θ, otherwise the constraint (III) will be violated. We then look at the optimal disclosure rule and determine the probability with which each asset quality θ gets the highest score. For that we construct a gain-to-cost ratio according to which we attribute the probability of the highest score to each type. In fact, the gain for having asset quality θ is $A(\theta)p(\theta)$ (we can see this from the objective function reported in (III)). However, the cost for having this is equal to $(R^* - \theta)p(\theta)$. The gain-to-cost ratio is then defined such that:

$$G(\theta) = \frac{A(\theta)}{R^* - \theta}. \tag{2.15}$$

The cost (the denominator) is negative for banks with asset quality $\theta \geq R^*$. It's obvious, in this case, that setting $h(\theta) = 1$ for all θ satisfying this condition is optimal. However the cost is positive for banks with asset quality $\theta < R^*$. Since the gain-to-cost ratio is increasing in θ, we attribute, in this case, a probability 1 of having the highest score ($h(\theta) = 1$), for all asset quality with a gain-to-cost ratio above a certain threshold G^*.[26] When $G(\theta) = G^*, h(\theta)$ is set such that (III) is equal to 0. Needless to mention that for all the other asset quality, the regulator assigns the low score.

Case 2: $\mathbb{E}(\tilde{\theta}) \geq R^*$

In this case, the problem exposed in Lemma 4 is reduced to find a function $h : \Theta \longrightarrow [0, 1]$ to

$$\begin{aligned} \text{maximize} \quad & \sum_{\theta \in \theta} A(\theta)p(\theta)h(\theta), \\ \text{subject to} \quad & \sum_{\theta \in \Theta} p(\theta)(\theta - R^*)(1 - h(\theta)) \leq 0. \end{aligned} \tag{IV}$$

- *When* $A(\theta) > 0$, *for every* $\theta \in \Theta$.

Setting $h(\theta) = 1$, for every asset quality $\theta \in \Theta$, satisfies constraint (IV) and is optimal. This means that in this case, the regulator attributes the highest score s_H for bank $\mathcal{D}$ asset quality since this action increases the value of its objective function.

[26] $\frac{\partial G}{\partial \theta} = \frac{\left(\frac{1-\beta}{\alpha} + \gamma\right)R^* + (1-\beta)e_{\mathcal{D}} - \gamma C}{(R^* - \theta)^2} > \frac{A(\theta)}{(R^* - \theta)^2} > 0$, since $\theta < R^*$ and $A(\theta) > 0$.

- *When* $A(\theta) < 0$, *for every* $\theta \in \Theta$.

By a symmetrical reasoning to the previous case, it is clear that, when $\theta < R^*$, setting $h(\theta) = 0$, for every asset quality $\theta \in \Theta$, satisfies constraint (IV) and is optimal. This means that in this case, the regulator attributes the lowest score s_H for bank $\mathcal{D}$ asset's quality that are under the threshold R^*. For $\theta \geq R^*$, the gain-to-cost ratio defined above is also used here. We hence attribute a probability 1 of having the highest score ($h(\theta) = 1$), for all asset quality with a gain-to-cost ratio under a certain threshold G^{**} and the lowest score for all asset quality above this threshold. When $G(\theta) = G^{**}, h(\theta)$ is set such that (IV) is equal to 0.

The following proposition summarizes the solution for the regulator problem. Since $A(\theta)$ can be negative, some additional results appeared compared to Goldstein and Leitner (2018) framework.

Proposition 1 *The optimal disclosure rule for the regulator is the following:*

- *When* $A(\theta) > 0$ *for all* $\theta \in \Theta$.

  1. *If* $\mathbb{E}(\tilde{\theta}) \geq R^*$, *then* $h(\theta) = 1 \ \forall \theta \in \Theta$.
  2. *If* $\mathbb{E}(\tilde{\theta}) < R^*$ *then:*

  $$h(\theta) = \begin{cases} 1 \text{ if, for all } \theta \in \Theta,\ \theta \geq R^* \text{ or } \theta < R^* \text{ and } G(\theta) > G^*, \\ 0 \text{ if, for all } \theta \in \Theta,\ \theta < R^* \text{ and } G(\theta) < G^*, \end{cases}$$

  where G^* *is the lowest* $G \in G(\Theta)$ *that satisfies:*

  $$\sum_{\theta \geq R^*} p(\theta)(\theta - R^*) + \sum_{\theta < R^* : G(\theta) > G} p(\theta)(\theta - R^*) \geq 0,$$

  if such G *exists; otherwise,* $G^* \equiv \max_{\theta < R^*} G(\theta)$. *If* $G(\theta) = G^*$, *then* $h(\theta) \in [0, 1)$ *is set such that (III) is equal to zero.*

- *When* $A(\theta) < 0$ *for all* $\theta \in \Theta$.

  1. *If* $\mathbb{E}(\tilde{\theta}) < R^*$, *then* $h(\theta) = 0 \ \forall \theta \in \Theta$.
  2. *If* $\mathbb{E}(\tilde{\theta}) \geq R^*$ *then:*

  $$h(\theta) = \begin{cases} 0 \text{ if, for all } \theta \in \Theta,\ \theta < R^* \text{ or } \theta \geq R^* \text{ and } G(\theta) > G^{**}, \\ 1 \text{ if, for all } \theta \in \Theta,\ \theta \geq R^* \text{ and } G(\theta) < G^{**}, \end{cases}$$

  where G^{**} *is the highest* $G \in G(\Theta)$ *that satisfies:*

  $$\sum_{\theta \in \Theta} p(\theta)(\theta - R^*) + \sum_{\theta \geq R^* : G(\theta) < G} p(\theta)(\theta - R^*) \leq 0,$$

if such G exists; otherwise, $G^{**} \equiv \min_{\theta \geq R^*} G(\theta)$. If $G(\theta) = G^{**}$, then $h(\theta) \in [0, 1)$ is set such that (IV) is equal to zero.

Policy implications. We can easily distinguish four states of the economy, (i) a "good state" occurring when $\theta_{min} \geq R^*$; (ii) a "normal state" qualified by $\mathbb{E}(\tilde{\theta}) \geq R^*$; (iii) a "bad state" arising when $\mathbb{E}(\tilde{\theta}) < R^*$; and (iv) a "crisis state" taking place when $\theta_{max} < R^*$. Some simple conclusions can be drawn, about the optimal regulator's behavior (full disclosure, no disclosure or partial disclosure), from the previous proposition. These conclusions depend on the state of the economy and on the cost parameters introduced by the model. First, when the bail-in cost is important and/or the bankruptcy cost is low (i.e., $A(\theta) < 0$), the regulator sends signals to discourage the healthy bank from bailing-in the distressed bank, because its rescue would be very costly to the economy. More precisely, the healthy bank, thinking that the distressed bank has a high chance of having a poor asset quality will not save it, and this action is less costly for the regulator. To reach this regulatory optimum, no disclosure has to be made in bad times whereas full disclosure is required during crisis. Second, when bail-in cost is not important (i.e., $A(\theta) > 0$), the regulator should be completely transparent in good times, which happens when the smallest value of the possible asset quality is greater than R^* (i.e., $\theta_{min} > R^*$). Indeed, in this case, bank $\mathcal{H}$ will always accept to save bank $\mathcal{D}$, since its asset quality θ will be always greater than the threshold R^*. This minimizes the regulator expected losses. These conclusions are summarized in Corollary 2.

Corollary 2

- *If $A(\theta) > 0$ for all $\theta \in \Theta$.*
  1. *Full disclosure is optimal if and only if $\theta_{min} \geq R^*$.*
  2. *No disclosure is optimal if and only if $\mathbb{E}(\tilde{\theta}) \geq R^*$.*
  3. *If $\mathbb{E}(\tilde{\theta}) < R^*$, then partial disclosure is the only way to maximize the regulator's objective function.*
- *If $A(\theta) < 0$ for all $\theta \in \Theta$.*
  1. *Full disclosure is optimal if and only if $\theta_{max} < R^*$.*
  2. *No disclosure is optimal if and only if $\mathbb{E}(\tilde{\theta}) < R^*$.*
  3. *If $\mathbb{E}(\tilde{\theta}) \geq R^*$, then partial disclosure is the only way to maximize the regulator's objective function.*

	$A(\theta) > 0, \forall \theta \in \Theta$	$A(\theta) < 0, \forall \theta \in \Theta$
Good time ($\theta_{min} \geq R^*$)	Full disclosure	Partial disclosure
Normal time ($\mathbb{E}(\tilde{\theta}) \geq R^*$)	No disclosure	Partial disclosure
Bad time ($\mathbb{E}(\tilde{\theta}) < R^*$)	Partial disclosure	No disclosure
Crisis time ($\theta_{max} < R^*$)	Partial disclosure	Full disclosure

Based on Corollary 2, we observe that when the bail-in cost has a large impact on the economy (transition from $A(\theta)$ positive to $A(\theta)$ negative) and that we are in a normal time (i.e. $\mathbb{E}(\tilde{\theta}) \geq R^*$), then the optimal regulator's disclosure strategy moves from non-disclosure to partial disclosure. Indeed, under no disclosure, the surviving bank accepts always the resolution operation (because in this case $R(s) = \mathbb{E}(\tilde{\theta}) \geq R^*$) and it is exactly what the regulator want to encourage when bail-in cost is low. However, when bail-in cost becomes large, the regulator wants to dissuade the healthy bank to accept the bail-in proposal and the use of a partial disclosure rule is therefore an optimal strategy in this case. An interesting result is also the fact that the full disclosure rule is optimal in some cases, but not in others. Actually, in good time, full disclosure is optimal when the bail-in cost are low, because the regulator wants to promote bail-ins. By being completely transparent, the healthy bank accepts always to rescue the distressed bank because in this case, $R(s) = \theta \geq R^*$, but as soon as the bail-in cost becomes significant this strategy is no longer optimal for the regulator. However, in crisis, full disclosure constitutes an optimal choice, when the bail-in cost is high. Indeed, in this case, the regulator wants to discourage banks from making bail-ins. By revealing the true asset quality of the distressed bank, no rescue operation will take place by the surviving bank since $R(s) = \theta < R^*$.

2.4.2 Example

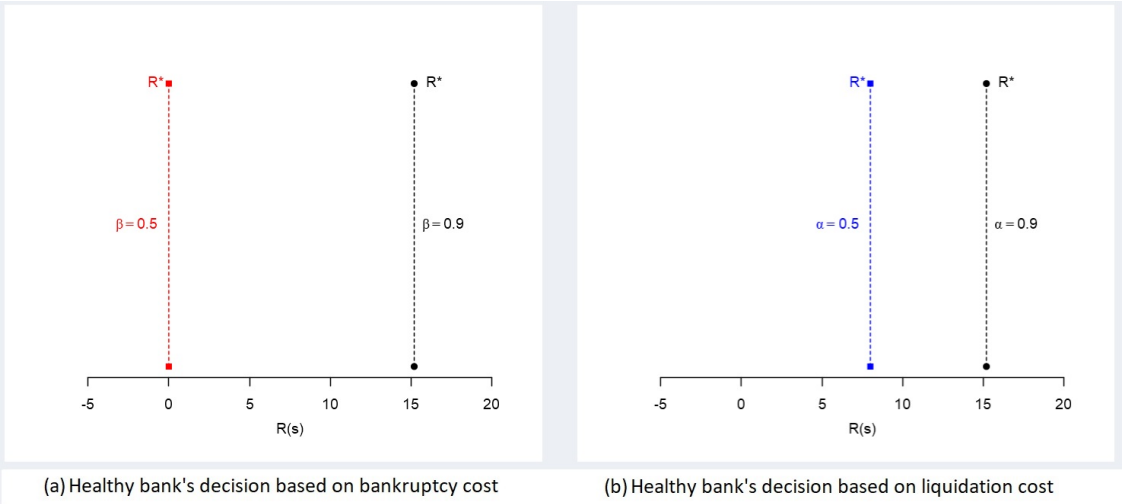
In this section, we illustrate on a simple example some of the results established by the previous sections.[27] We consider, as in the theoretical framework, two banks: a healthy bank (bank $\mathcal{H}$) and a distressed bank (bank $\mathcal{D}$). The net deposits are given by $d_{\mathcal{H}} = 2$ and $d_{\mathcal{D}} = 1.5$ and the nominal values of the outside investments are equal to $e_{\mathcal{H}} = 2$ and $e_{\mathcal{D}} = 1$. We set the interbank liabilities to $L = 1$. The constant C is set to 2.6.

In Figure 2.2, we show how the threshold, R^*, below which the healthy bank refuses the bail-in operation varies according to the liquidation and bankruptcy costs. As found in the theoretical part, this threshold is lower when these costs are important. However,

[27] To play with this benchmark model, please go to https://dataformer.shinyapps.io/BailinVsBailout_BenchmarkModel/.

we notice that the bankruptcy cost has a higher impact on the threshold's position. The healthy bank is more sensitive to the negative externality produced by the bankruptcy of the distressed bank than by the liquidation costs.

Figure 2.2: Healthy bank's decision.



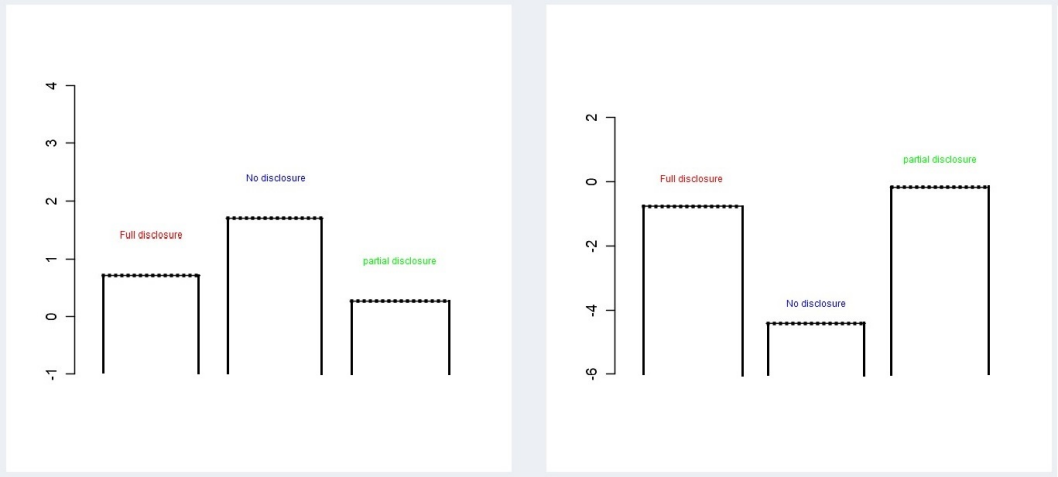
(a) Healthy bank's decision based on bankruptcy cost

(b) Healthy bank's decision based on liquidation cost

Note: We present the decision of the healthy bank with respect to bankruptcy and liquidation costs: for any value of the expected investment return, $R(s)$, in the region to the right of the threshold R^*, the healthy bank accepts to make the bail-in, otherwise it does not intervene and lets the distressed bank default. In (a), we set β to 0.9 (low bankruptcy cost) and show to what extent the threshold becomes lower when bankruptcy cost increases (smaller β). In (b), we set α to 0.9 (low liquidation cost) and show to what extent the threshold becomes lower when liquidation cost increases (smaller α).

Figure 2.3 displays how the regulator's disclosure rule varies according to the bail-in cost. We use the same calibration as before and we set the recovery rates to $\alpha = 0.5$ and $\beta = 0.7$ for the liquidation and bankruptcy cost, respectively. The set of asset qualities is given by $\Theta = \{\frac{1}{2}, 1, \frac{3}{2}\}$ and the corresponding probability vector is such that $p = \{\frac{2}{3}, \frac{1}{6}, \frac{1}{6}\}$. Hence, we have $\mathbb{E}(\tilde{\theta}) \geq R^*$ which corresponds to a normal time. As determined in the theoretical part, in this case when bail-in costs are low, the expected optimal losses are achieved when there is no disclosure. However, when bail-in losses are important, the regulator minimises its expected losses when it chooses to partially disclose information about the asset quality of the distressed bank.

Figure 2.3: Regulator's disclosure rule.



(a) Regulator's disclosure rule when bail-in cost is low

(b) Regulator's disclosure rule when bail-in cost is high

Note: We present the regulator's disclosure rule based on bail-in cost. The vertical axis represent the reduced form of the objective function (function in Lemma 4) that the regulator would maximize. In (a), we set the bail-in cost γ to 0.5 and show that *no disclosure* is the best solution to minimise the expected losses of the regulator. In (b), we set γ to 3.6 and we show that its expected losses are optimal when the regulator chooses a *partial disclosure*.

2.5 Model solution with government intervention

In this section, we transpose the mechanism proposed by the SRM. In other words, the government can intervene and bail out the failing bank if the healthy bank refuses the bail-in proposal.[28] One of the major reforms ushered in by the Great Financial Crisis is the requirement to bail-in debt before a possible bailout of a failing bank can take place. The aim of this resolution plan is to reduce moral hazard (Philippon and Salord, 2017) and the costs of bank bailouts for taxpayers as well.

2.5.1 Model resolution

We consider the same sequence of events defined as in Section 2.4, except for the penultimate step. Indeed, at this level, in the eventuality that bank $\mathcal{H}$ does not agree to proceed to the bail-in, the government can intervene and bail-out the distressed bank. However, the government does it only if the bailout is less costly than the absence of intervention (bank liquidation).

To take its decision, bank $\mathcal{H}$ considers the eventuality of a possible bailout of bank $\mathcal{D}$

[28] Avgouleas and Goodhart (2015) discuss the weaknesses of the bail-in and argue that a bailout would continue to be needed in the wake of some extreme situations (e.g., systemic crisis, simultaneous failure of multiple banks...) even if there is a consensus in the bank resolution literature that it is neither desirable nor feasible to provide full, unconditional support to failing banks (Walther and White, 2020).

by the government if it refuses the bail-in. Let $\mu(s)$ be the probability that bank $\mathcal{D}$ will be bailed out by the government. This probability is determined by *bank* $\mathcal{H}$ conditional on the information available to it. We assume that this probability increases with the expected losses in payment suffered by banks. Hence $\mu(s)$ is decreasing in $\mathbb{E}(\theta \mid s)$. For instance, we can have the following expression for the bailout probability:

$$\mu(s) = exp\left(-\lambda \frac{E(p_{\mathcal{DH}} \mid s)}{L}\right), \tag{2.16}$$

where λ is a positive constant. Hence, when the expected payment tends to 0, the expected payment losses are maximal and the probability of bailout is close to 1. However, when the expected payment is close to the due debt, L, we assume that this probability is equal to 0.[29]

We denote by $\pi_{bailout}$ the profit of bank $\mathcal{H}$ in the case where the regulator proceeds to bank $\mathcal{D}$ bailout, such that:

$$\pi_{bailout} = L + \theta_{\mathcal{H}} + e_{\mathcal{H}} - (1-\alpha) l''_{\mathcal{H}} - d_{\mathcal{H}}, \tag{2.17}$$

with $l''_{\mathcal{H}} = \frac{1}{\alpha}[d_{\mathcal{H}} - L - \theta_{\mathcal{H}}]$. In this case, the healthy bank accepts to bail-in the distressed bank, if and only if its expected profit, when accepting the bail in, is greater than its expected profit if it does not accept it. This condition is given by:

$$\begin{aligned} & \pi_{bail-in}(s) \;\geq\; \mu(s)\pi_{bailout} + (1-\mu(s))\,\pi_{no-inter}(s), \\ i.e., \quad & L - \mathbb{E}(b_{\mathcal{H}}(\theta) \mid s) \;\geq\; \mu(s)L + (1-\mu(s))\,\mathbb{E}(p_{\mathcal{DH}} \mid s). \end{aligned} \tag{2.18}$$

Lemma 5 *In equilibrium, bank $\mathcal{H}$ accepts the bail-in proposal if, and only if, bank $\mathcal{D}$, obtains a score s such that $R(s) \geq R^*(s)$ with $R^*(s) = \frac{(1-\mu(s))(1-\beta)R^*}{1-\beta(1-\mu(s))} + \frac{\mu(s)C}{1-\beta(1-\mu(s))}$.*

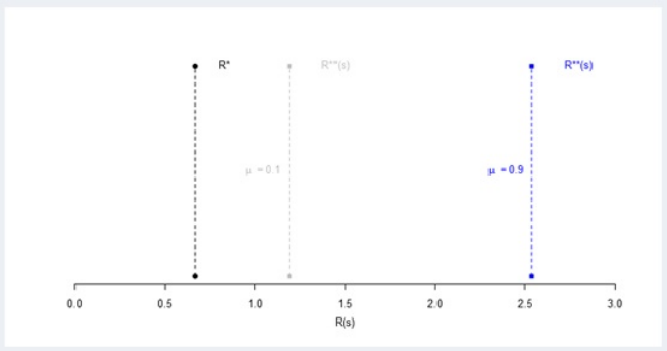
The threshold below which the surviving bank is no longer willing to accept the bail-in proposal depends now on the disclosure rule. It was not the case in the benchmark model. Then, the healthy bank can refuse to save the distressed bank that it could have saved if there were no potential government intervention ($R^*(s) - R^* = \frac{\mu(s)}{1-\beta(1-\mu(s))}(C - R^*) > 0$).[30]

We also find that higher the probability of a bailout, the more demanding the healthy bank is, because its threshold value becomes higher ($\frac{\partial R^*(s)}{\partial \mu(s)} = \frac{(1-\beta)}{1-\beta(1-\mu(s))}(C - R^*) > 0$) as illustrated in Figure 2.4.

[29] Our result remains consistent for any bailout probability chosen such that $\mu(s)$ is strictly increasing in $\mathbb{E}(\theta \mid s)$. We also show that the regulator can still focus on disclosure rules that assign at most 2 scores when we consider an endogenous bailout probability linked to its welfare function.

[30] $C - R^*$ is positive since $b_{\mathcal{H}}(\theta) = -\theta + C > 0$.

Figure 2.4: Healthy bank's decision based on the probability of bailout.



Note: We present the decision of the healthy bank depending on the bailout probability. R^* represents the healthy bank threshold where there is no government intervention (i.e., no possible bailout). $R^*(s)$ represents the bank threshold where there is a possible government intervention. We use the same data as in the example in Section 2.4 and set the bailout probability, $\mu(s)$, to 0.1, and then we set it to 0.9 and show that the higher the probability of bailout, the higher the threshold is.

The condition established in Lemma 5 can be rewritten as follows $f(R(s)) \geq R^*$ with $f : R(s) \mapsto R(s) + \frac{\mu(s)}{1-\beta}[\beta(\alpha e_{\mathcal{D}} + R(s)) - L - d_{\mathcal{D}}]$. f is continuous and strictly increasing on $\mathbb{R}$ and hence according to the intermediate value theorem and its corollary, it has an inverse function f^{-1}. The condition $f(R(s)) \geq R^*$ is equivalent to $R(s) \geq R^{**}$ with $R^{**} = f^{-1}(R^*)$ since f^{-1} is strictly increasing.[31]

Regulator's welfare function. In this section, we define three different losses depending on both bank $\mathcal{H}$ and government decisions. The losses in the eventuality that bank $\mathcal{H}$ does not accept the bail-in and the losses in the eventuality of non-intervention remain unchanged (as defined in Section 2.4). However, a new type of loss must be defined. Indeed, since the government can intervene and save the distressed bank, the loss due to the bailout has to be considered in the computation of the regulator's total losses function. This welfare losses in the case where the government proceeds to a bailout is then expressed as follow:[32]

$$\begin{aligned} w_2(\theta) &= (1-\alpha)\left[l''_{\mathcal{H}} + l''_{\mathcal{D}}\right] + \delta b_2 \\ &= \left(\frac{1-\alpha}{\alpha}\right)\left[d_{\mathcal{H}} - \theta_{\mathcal{H}} + d_{\mathcal{D}}\right] - \left(\frac{1-\alpha}{\alpha} - \delta\right) C - \delta\theta. \end{aligned} \tag{2.19}$$

[31] $\frac{\partial f}{\partial R(s)} = 1 + \mu(s)\frac{\beta}{1-\beta} + \frac{\lambda}{L}\frac{\mu(s)}{1-\beta}[\beta(\alpha e_{\mathcal{D}} + R(s)) - L - d_{\mathcal{D}}] > 0$ because $\beta(\alpha e_{\mathcal{D}} + R(s)) - L - d_{\mathcal{D}} < 0$ (since $\theta_{max} < d_{\mathcal{D}} + L - \alpha e_{\mathcal{D}}$).

[32] When the healthy bank refuses the bail-in proposal and the government bail out the distressed bank, then bank $\mathcal{H}$ liquidates $l''_{\mathcal{H}} = \frac{1}{\alpha}[d_{\mathcal{H}} - L - \theta_{\mathcal{H}}]$ and bank $\mathcal{D}$ liquidates $l''_{\mathcal{D}} = \frac{1}{\alpha}[d_{\mathcal{D}} + L - b_{\mathcal{D}} - \theta]$.

where b_2 is the bailout amount required to save bank $\mathcal{D}$. Since the regulator knows the value of θ after its realisation, we assume that $b_2 = -\theta + C$.

We assume that the government accepts to bail-out a bank if the welfare losses in case of bailout are lower than the welfare losses in case of a no intervention, i.e., $w_0 \geq w_2$.[33]

Lemma 6 *The regulator accepts to bail-out the distressed bank if and only if, bank $\mathcal{D}$ has an asset quality θ such that $\theta \geq \theta^*$ with $\theta^* = \frac{[\alpha(\delta+1)-1]C-(1-\beta)\alpha e_{\mathcal{D}}}{\alpha(1+\delta)-\beta}$.*[34]

This threshold is of utmost importance as the cost of bailout increases.[35] It means that the government is less likely to save a distressed bank when the bailout cost is significant.

At this stage, the regulator's problem is to select a disclosure rule (S, g) minimizing the ex-ante expected losses $\sum_{\theta\in\Theta} p(\theta)\mathcal{L}(\theta)$ such that:

$$\begin{aligned}\mathcal{L}(\theta) = &\sum_{s:R(s)\geq R^{**}} w_1(\theta)\ g(s \mid \theta) + \sum_{s:R(s)<R^{**}} w_2(\theta).\mathbb{1}_{\theta\geq\theta^*}\ g(s \mid \theta)\\ &+ \sum_{s:R(s)<R^{**}} w_0(\theta).\mathbb{1}_{\theta<\theta^*}\ g(s \mid \theta),\end{aligned} \tag{2.20}$$

where $\mathbb{1}_{\theta\geq\theta^*}$ is an indicator variable taking value 1 if $\theta \geq \theta^*$ and 0 otherwise. The first term of the previous expression represents the cases where bank 1 accepts to proceed to a bail-in. The second term represents the cases where the government proceeds to a bailout. The third term represents the cases where there is no intervention.

Lemma 7 *The regulator's problem reduces to the selection of a disclosure rule (S, g) maximizing:*

$$\sum_{\substack{\theta<\theta^*\\ \theta\in\Theta}} A(\theta)p(\theta) \sum_{s:R(s)\geq R^{**}} g(s \mid \theta) + \sum_{\substack{\theta\geq\theta^*\\ \theta\in\Theta}} B(\theta)p(\theta) \sum_{s:R(s)\geq R^{**}} g(s \mid \theta),$$

with $B(\theta) = (\delta - \frac{1-\alpha}{\alpha} - \gamma)(C - \theta)$.

The term $\sum_{s:R(s)\geq R^{**}} g(s \mid \theta)$ represents the probability that bank $\mathcal{D}$ with asset quality θ benefits from a bail-in. The term $A(\theta)$ represents the potential gain (or loss since $A(\theta)$ can be negative) for the regulator if bank $\mathcal{D}$ is subject to a bail-in when the regulator would have refused the bailout if the healthy bank had refused the bail-in. The term $B(\theta)$ represents the potential gain (or loss since $B(\theta)$ can be negative) for the regulator if bank

[33] We assume that in case where the two losses are equal, the government decides to proceed to a bailout to enhance financial stability.

[34] We assume that we always have $\alpha(1+\delta) \neq \beta$.

[35] $\frac{\partial\theta^*}{\partial\delta} = \frac{\alpha(1-\beta)C+\alpha^2(1-\beta)e_{\mathcal{D}}+\alpha^2(1+\delta)(C-1)}{(\alpha(1+\delta)-\beta)^2>0}$, since it is consistent to assume that $C > 1$.

$\mathcal{D}$ is subject to a bail-in when the regulator would have agreed to a bailout if the healthy bank had refused the bail-in. This term $B(\theta)$ is positive when the bailout cost is high (i.e., $\delta \to +\infty$). However, it is negative when bail-in and/or liquidation costs are high (i.e., $\gamma \to +\infty$ and/or $\alpha \to 0$).

Alternatively, we show that we can focus only on disclosure rules that assign at most 2 scores, under certain conditions as explained in the Lemma 8.

Lemma 8 *Considering a disclosure rule (S, g) and a disclosure rule $(\hat{S}, \hat{g})$ defined by $\hat{S} = \{s_L, s_H\}$, such that $\hat{g}(s_H \mid \theta) = \sum_{s:R(s)\geq R^{**}} g(s \mid \theta)$ and $\hat{g}(s_L \mid \theta) = 1 - \sum_{s:R(s)\geq R^{**}} g(s \mid \theta)$. Then the probability that bank $\mathcal{H}$ accepts the bail-in operation is the same under the two rules. The value of the regulator's objective function is also the same under both rules.*

Let here also assume that s_H represents the high type and s_L the low type. We define again $h(\theta) := \hat{g}(s_H \mid \theta)$ the probability that a bank with an asset quality θ obtains the high score.

Lemma 9 *The regulator problem simplifies since it has to find a function $h : \Theta \longrightarrow [0, 1]$ to maximize:*

$$\sum_{\substack{\theta<\theta^* \\ \theta\in\Theta}} A(\theta)p(\theta)h(\theta) + \sum_{\substack{\theta\geq\theta^* \\ \theta\in\Theta}} B(\theta)p(\theta)h(\theta),$$

subject to:

$$\sum_{\theta\in\Theta} [\theta - R^{**}]p(\theta)h(\theta) \geq 0,$$

$$\sum_{\theta\in\Theta} [\theta - R^{**}]p(\theta)(1 - h(\theta)) < 0.$$

The objective function follows from Lemma 6. Constraints follows from $R(s_H) \geq R^{**}$ and $R(s_L) < R^{**}$. Moreover, the objective function is continuous on a compact space (the feasible region is closed and bounded since $h : \theta \longrightarrow [0, 1]$) and so the maximum exists.

We distinguish many cases for the resolution of the regulator problem.

Case 1: $\mathbb{E}(\tilde{\theta}) < R^*$

In this case, the problem exposed in Lemma 7 is reduced to find a function $h : \Theta \longrightarrow [0, 1]$ to

$$\begin{aligned} \text{maximize} \quad & \sum_{\substack{\theta<\theta^* \\ \theta\in\Theta}} A(\theta)p(\theta)h(\theta) + \sum_{\substack{\theta\geq\theta^* \\ \theta\in\Theta}} B(\theta)p(\theta)h(\theta) \\ \text{subject to} \quad & \sum_{\theta\in\Theta} [\theta - R^{**}]p(\theta)h(\theta) \geq 0 \end{aligned} \tag{V}$$

Case 2: $\mathbb{E}(\tilde{\theta}) \geq R^*$.

In this case, the problem exposed in Lemma **??** is reduced to find a function $h : \Theta \longrightarrow [0,1]$ to

$$\begin{aligned} \text{maximize} \quad & \sum_{\substack{\theta<\theta^* \\ \theta\in\Theta}} A(\theta)p(\theta)h(\theta) + \sum_{\substack{\theta\geq\theta^* \\ \theta\in\Theta}} B(\theta)p(\theta)h(\theta) \\ \text{subject to} \quad & \sum_{\theta\in\Theta} [\theta - R^{**}]p(\theta)(1-h(\theta)) < 0 \end{aligned} \tag{VI}$$

For solving these different cases, we proceed as in Proposition **??** but our gain-to-cost ratio is now different, since it sometimes depends on $B(\theta)$. The new expression of the gain-to-cost ratio such that for every $\theta \in \Theta$, is given by:

$$G(\theta) = \begin{cases} G_1(\theta) = \frac{A(\theta)}{R^{**}-\theta} & if\ \theta < \theta^*, \\ G_2(\theta) = \frac{B(\theta)}{R^{**}-\theta} & if\ \theta \geq \theta^*. \end{cases}$$

To lighten the body of the paper, we have deferred detailed explanations of the model solution of this regulator problem to D.

Policy implications. Some conclusions regarding regulator transparency can be drawn from this model solution. Once again we define four states through which banks go through: (i) a "good state" occurring when $\theta_{min} \geq R^{**}$; (ii) a "normal state" qualified by $\mathbb{E}(\tilde{\theta}) \geq R^{**}$; (iii) a "bad state" arising when $\mathbb{E}(\tilde{\theta}) < R^{**}$; and (iv) a "crisis state" taking place when $\theta_{max} < R^{**}$. What is new with respect to Corollary **??** is that our threshold changes (from R^* to R^{**}) and more interestingly, we interpret our results not only in relation to bail-in cost (in addition to liquidation and bankruptcy costs), but also in relation to the bailout cost.

One way to get $A(\theta)$ and $B(\theta)$ both negative is still to set significant bail-in cost. However, when the bailout cost is large, we are in a situation in which $B(\theta)$ is positive. The following corollary summarizes some of these conclusions.

Corollary 3

- *If* $A(\theta) < 0$ *for all* $\theta < \theta^*$ *and* $B(\theta) < 0$ *for all* $\theta \geq \theta^*$.
  1. *Full disclosure is optimal if and only if* $\theta_{max} < R^{**}$.
  2. *No disclosure is optimal if and only if* $\mathbb{E}(\tilde{\theta}) < R^{**}$.
  3. *If* $\mathbb{E}(\tilde{\theta}) \geq R^{**}$ *then partial disclosure is optimal.*
- *If* $A(\theta) > 0$ *for all* $\theta < \theta^*$ *and* $B(\theta) > 0$ *for all* $\theta \geq \theta^*$.

1. *Full disclosure is optimal if and only if* $\theta_{min} \geq R^{**}$.
2. *No disclosure is optimal if and only if* $\mathbb{E}(\tilde{\theta}) \geq R^{**}$.
3. *If* $\mathbb{E}(\tilde{\theta}) < R^{**}$ *then partial disclosure is optimal.*

	$A(\theta) > 0$, $\forall \theta < \theta^*$, and $B(\theta) > 0$, $\forall \theta \geq \theta^*$	$A(\theta) < 0$, $\forall \theta < \theta^*$, and $B(\theta) < 0$, $\forall \theta \geq \theta^*$
Good time ($\theta_{min} \geq R^{**}$)	Full disclosure	Partial disclosure
Normal time ($\mathbb{E}(\tilde{\theta}) \geq R^{**}$)	No disclosure	Partial disclosure
Bad time ($\mathbb{E}(\tilde{\theta}) < R^{**}$)	Partial disclosure	No disclosure
Crisis time ($\theta_{max} < R^{**}$)	Partial disclosure	Full disclosure

As in the previous corollary, the full disclosure is not always the optimal rule and some results are similar. For instance, when the bail-in costs are important ($A(\theta) < 0$ for all $\theta \geq \theta^*$ and $B(\theta) < 0$ for all $\theta < \theta^*$) and in bad times ($\mathbb{E}(\tilde{\theta}) < R^{**}$), no disclosure is optimal. Indeed, in this case, the regulator wants to dissuade the healthy bank from bailing-in the distressed bank (because it accepts to do it since $\theta > R^{**}$). It would like to proceed to the bailout of the distressed bank if the bailout is less costly than the no intervention (i.e., $\theta \geq \theta^*$). However, new findings show that, when the bailouts are costly and the bail-ins are not ($A(\theta) > 0$ for all $\theta \geq \theta^*$ and $B(\theta) > 0$ for all $\theta < \theta^*$), then the regulator does not want to bailout banks and thus would like to convince the healthy bank to make bail-ins. Hence, in normal times (i.e., $\mathbb{E}(\tilde{\theta}) \geq R^{**}$), the best way to achieve its goal is when it chooses to not disclose information about the distressed bank asset quality and so the healthy bank will for sure save it (since $R(s) = \mathbb{E}(\tilde{\theta}) \geq R^{**}$). In the special case where $\theta_{min} \geq R^{**}$ (i.e., in good times), the regulator minimizes its expected welfare losses by being perfectly transparent.

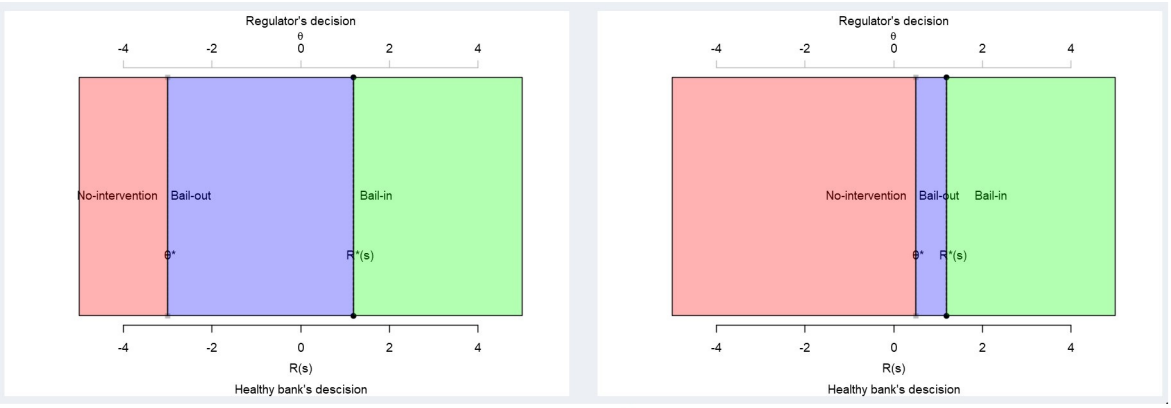
2.5.2 Example

In this section, we illustrate some of the results provided in Section 2.5.1. We use the same parameters as in Section 2.4.2 and set the bailout probability, $\mu(s)$, to 10%.[36]

In Figure 2.5, we show how the threshold, θ^*, above which the regulator's accepts to bail-out the distressed bank becomes higher when the bailout cost is important. This threshold varies also according to liquidation and bankruptcy costs.

[36]To play with this general model, please go to https://dataformer.shinyapps.io/BailinVsBailout_CompleteModel/.

Figure 2.5: Regulator's and healthy bank's decisions.



(a) Regulator's and healthy bank's decisions when bailout cost is low

(b) Regulator's and healthy bank's decisions when bailout cost is high

Note: This Figure displays the decisions of the regulator and the healthy bank when the bailout cost is considered. For any value of the expected investment return, $R(s)$, in the region to the right of the threshold $R^*(s)$, the healthy bank accepts to make the bail-in. For any value of the investment return, θ, in the region to the right of the threshold θ^*, the regulator accepts to bail-out the distressed bank if the healthy bank did not proceed to a bail-in. Otherwise, no one intervenes and the distressed bank defaults. In (a), we set the bailout cost δ to 1 and draw two vertical lines reporting thresholds for the intervention of the regulator and of the healthy bank, respectively. In (b), we set δ to 2 and show that the bailout region becomes smaller when bailout cost is high.

In Figure 2.6, we show how the regulator's disclosure rule varies depending in bail-in and bailout costs. We use the same parameters as before and set the probability of bailout to 1%. Since we are in normal times ($\mathbb{E}(\tilde{\theta}) \geq R^*(s)$), it is optimal for the regulator to not disclose information about distressed bank asset quality when the bailout cost is high. However, when bail-in cost is high, the regulator should use a partial disclosure of the information.

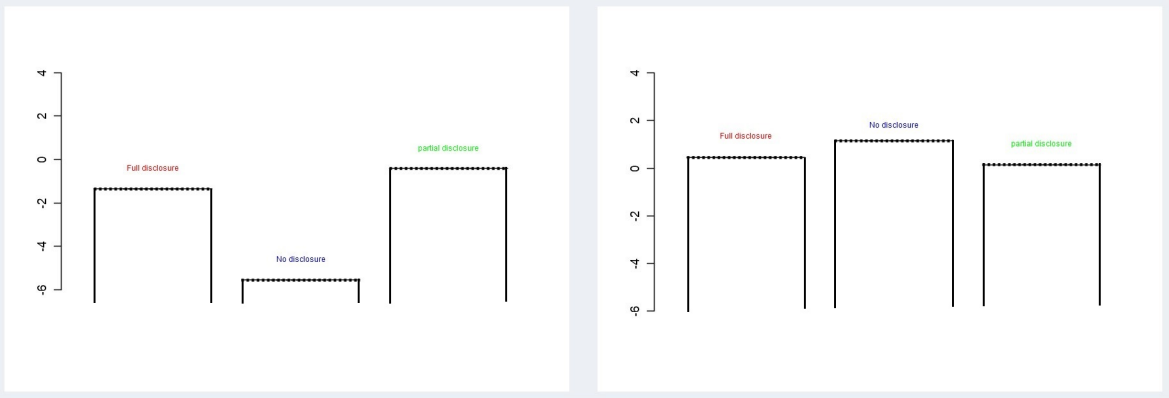
2.5.3 Discussion

The bailout probability can be endogenized by taking into account the government welfare functions. Indeed, if the healthy bank considers that the government accepts to bail-out a bank if its welfare losses in case of bailout are lower than its welfare losses in case of a no intervention (i.e., $w_0 \geq w_2$), then it determines the following bailout probability:

$$\mu(s) = \sum_{\theta:\ \theta \geq \theta^*} Pr(\tilde{\theta} = \theta \mid \tilde{s} = s) = \frac{\sum_{\theta:\ \theta \geq \theta^*} p(\theta) g\left(s \mid \theta\right)}{\sum_{\theta \in \Theta} p(\theta) g\left(s \mid \theta\right)}$$

However, such a consideration for the bailout probability introduce some changes in the calculation of the expected profit of the healthy bank. The equation 2.18 is then

Figure 2.6: Regulator's disclosure rule



(a) Regulator's disclosure rule when bail-in cost is high

(b) Regulator's disclosure rule when bailout cost is high

Note: This Figure reports the regulator optimal disclosure rule depending in bail-in and bailout costs. The vertical axis represent the reduced form of the objective function (function provided in Lemma 5) that the regulator would maximize. In (a), we set the bailout cost δ to 0.5 and the bail-in cost γ to 2.5 and show that *partial disclosure* is optimal. In (b), we set δ to 2.5 and γ to 0.5 and show that *no disclosure* is optimal.

modified as follow:

$$\pi_{bail-in}(\theta) \quad \geq \quad \mu(s)\pi_{bailout} + \sum_{\theta<\theta^*} Pr(\tilde{\theta} = \theta \mid \tilde{s} = s)\pi_{no-inter}(\theta),$$

The resolution in this case is more complicated but we can show here too that the regulator can focus only on disclosure rules that assign at most 2 scores.

2.6 Conclusion

In this paper, we transpose the mechanism introduced by the SRM into a theoretical framework for showing how the regulator should use the information at its disposal to minimize its expected losses and ensure financial stability.

We design a model with two banks where the trigger of a resolution plan by the regulator enforces the failing bank to ask the healthy bank (its creditor) to write down its debt by a given amount determined by the regulator for insuring the existence of the failing bank over the next periods. The healthy bank faces a choice between bailing-in or not the distressed bank. Its decision is based on its ability to maximize its profit with respect to bankruptcy and liquidation costs, but also on the likelihood of a potential bailout by the government. We find that the healthy bank becomes less stringent and even agreeing to bail-in banks with poor asset quality when the liquidation and bankruptcy costs are too high. We show also that when the bailout probability is high, the healthy

bank has little incentive to accept the bail-in proposal. Hence, it can refuse to save banks that it could have saved if there were no government intervention.

The regulator in our model plays the role of a social planner and gives information (a set of scores) about the failing bank asset's quality to the healthy bank. Due to reputation concerns, we assume that the disclosure rule is publicly announced before observing banks' asset quality. To select its optimal disclosure, the regulator minimizes its ex-ante expected losses, which depends on a set of costs: a bankruptcy cost, a liquidation cost, a bailout cost and a bail-in cost. Depending on the state of the economy, the regulator would like to favor one of the three following situations: bail-in, bailout, or no intervention and thus let the distressed bank defaults. We find that the full disclosure is not systematically preferred to the other forms of disclosure. For instance, in crisis time and when the bail-in cost for the economy is low, then partial disclosure is optimal. Indeed, a complete disclosure cannot be optimal since with such a perfect information, the healthy bank would never want to bail-in the distressed bank.

Policy implications of our paper are twofold. First, we show that the optimal disclosure rule of the regulator for ensuring financial stability (in case of banking resolution) is linked to the state of the economy but also to set of costs. We confirm previous findings showing that a full disclosure policy is not always optimal. In most of our cases, the partial disclosure is optimal due to its higher flexibility. Second, by allowing creditors to accept or not the bail-in, we deal with the "no creditor worse off" condition since creditors evaluate themselves whether they may get a higher profit in case of liquidation or bailout of the failing bank.

Finally, one possible extension of our model is to consider a complete financial network of N banks and to study the role of the network structure (e.g., ring network versus complete network) in: (i) the choice of the optimal disclosure rule used by the regulator, and (ii) the decision taken by the healthy banks.

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Appendices

Appendix C

Resolution without government intervention

The proofs in these appendices are mainly an adaptation of Goldstein and Leitner (2018) proofs to our setting.

Lemma 2 (proof).
The regulator problem is minimizing the following program:

$$\sum_{\theta\in\Theta} p(\theta)\Big[\sum_{s:R(s)\geq R^*}\Big[\frac{1-\alpha}{\alpha}(d_{\mathcal{H}}+d_{\mathcal{D}}-\theta_{\mathcal{H}})-(\gamma+\frac{1-\alpha}{\alpha})\theta+\gamma C\Big]\ g(s\mid\theta)$$
$$+\sum_{s:R(s)<R^*}\Big[\frac{1-\alpha}{\alpha}(d_{\mathcal{H}}+d_{\mathcal{D}}-\theta_{\mathcal{H}})+(1-\beta)e_{\mathcal{D}}+(\frac{1-\beta}{\beta}-\frac{1-\alpha}{\alpha})\beta\theta\Big]\ g(s\mid\theta)\Big]$$

$$=-\sum_{\theta\in\Theta} p(\theta)\sum_{s:R(s)\geq R^*}\Big[(\frac{1-\beta}{\alpha}+\gamma)\theta+(1-\beta)e_{\mathcal{D}}-\gamma C\Big]\ g(s\mid\theta)$$
$$+\sum_{\theta\in\Theta} p(\theta)\Big[\frac{1-\alpha}{\alpha}(d_{\mathcal{H}}+d_{\mathcal{D}}-\theta_{\mathcal{H}})+(1-\beta)e_{\mathcal{D}}+(\frac{1-\beta}{\beta}-\frac{1-\alpha}{\alpha})\beta\theta\Big]. \tag{C.1}$$

Since the last term is constant with respect to the disclosure rule, the regulator problem becomes maximizing:

$$\sum_{\theta\in\Theta} p(\theta)\Big[(\frac{1-\beta}{\alpha}+\gamma)\theta+(1-\beta)e_{\mathcal{D}}-\gamma C\Big]\sum_{s:R(s)\geq R^*} g(s\mid\theta). \tag{C.2}$$

□

Lemma 3 (proof). We consider a disclosure rule $(\hat{S},\hat{g})$ such that $\hat{S}=\{s_L,s_H\}$ and where the expectations are calculated under $\hat{g}$ (i.e., $\hat{R}(s)=\mathbb{E}(\theta\mid s),\forall s\in\hat{S}$). We start by the case where $\sum_{\theta\in\Theta} p(\theta)\hat{g}(s_H\mid\theta)\neq 0$ and first proof that the expected value of the

investment return of a bank $\mathcal{D}$, when it obtains the score s_H, is greater than R^*:

$$\begin{aligned}\hat{R}(s_H) &= \frac{\sum_{\theta\in\Theta}\theta p(\theta)\hat{g}(s_H \mid \theta)}{\sum_{\theta\in\Theta} p(\theta)\hat{g}(s_H \mid \theta)},\\ &= \frac{\sum_{\theta\in\Theta}\theta p(\theta)\sum_{s:R(s)\geq R^*} g(s \mid \theta)}{\sum_{\theta\in\Theta} p(\theta)\sum_{s:R(s)\geq R^*} g(s \mid \theta)},\\ &= \frac{\sum_{\theta\in\Theta} p(\theta)\sum_{s:R(s)\geq R^*} R(s)g(s \mid \theta)}{\sum_{\theta\in\Theta} p(\theta)\sum_{s:R(s)\geq R^*} g(s \mid \theta)} \geq R^*, \end{aligned} \tag{C.3}$$

and so under this disclosure rule bank $\mathcal{H}$ accepts to bail-in bank $\mathcal{D}$ with probability $\hat{g}(s_H \mid \theta)$. The same reasoning is used to proof that $\hat{R}(s_L) < R^*$.

We are now looking at the special case where $\sum_{\theta\in\Theta} p(\theta)\hat{g}(s_H \mid \theta) = 0$. In this case, we have $\hat{g}(s_H \mid \theta) = 0, \forall\theta \in \Theta$. We have then:

- under $(\hat{S}, \hat{g})$, $Pr(\tilde{s} = s_H) = 0$ and $Pr(\tilde{s} = s_L) = 1$ and so from the law of iterated expectations, we have $E(\tilde{\theta}) = E(\hat{R}(s)) = \hat{R}(s_H)Pr(\tilde{s} = s_H) + \hat{R}(s_L)Pr(\tilde{s} = s_L) = \hat{R}(s_L)$.
- under (S, g), bank $\mathcal{D}$ obtain a score s, such that $R(s) < R^*$, with probability 1 and so always under the law of iterated expectations, $E(\tilde{\theta}) = \sum_{s\in S} R(s)Pr(\tilde{s} = s) = \sum_{s:R(s)\geq R^*} R(s)Pr(\tilde{s} = s) + \sum_{s:R(s)<R^*} R(s)Pr(\tilde{s} = s)$. Hence $E(\tilde{\theta}) < R^*$.

Hence, $\hat{R}(s_L) > R^*$ and so under both disclosure rules, bank $\mathcal{H}$ refuses to bail-in the distressed bank.

□

Lemma 4 (proof). We first notice that:

$$\begin{aligned} R(s) \geq R^* &\iff \frac{\sum_{\theta\in\Theta}\theta p(\theta)g\left(s \mid \theta\right)}{\sum_{\theta\in\Theta} p(\theta)g\left(s \mid \theta\right)} \geq R^*,\\ &\iff \sum_{\theta\in\Theta}(\theta - R^*)p(\theta)g\left(s \mid \theta\right) \geq 0. \end{aligned} \tag{C.4}$$

$$R(s) < R^* \iff \sum_{\theta\in\Theta}(\theta - R^*)p(\theta)g\left(s \mid \theta\right) < 0. \tag{C.5}$$

We showed in the previous lemma that to resolve the regulator problem, we can restrict ourselves to disclosure rules $(\hat{S}, \hat{g})$ that assign at most two scores $\hat{s}_L$ and $\hat{s}_H$, such that $\hat{R}(\hat{s}_H) \geq R^*$ and $\hat{R}(\hat{s}_L) < R^*$.

Case 1: $\mathbb{E}(\theta) < R^*$
As a first step, we show that if this disclosure rule $(\hat{S}, \hat{g})$ solves the problem in Lemma 2, then $h(\theta) = \hat{g}(\hat{s}_H \mid \theta)$ solves the problem in Lemma 4. We first note that since $\hat{R}(\hat{s}_H) \geq R^*$, h satisfies constraint (III). Then to proof this implication, we proceed to a

proof by contradiction: suppose that there exists a probability $\tilde{h} : \Theta \to [0,1]$ that satisfies (III) and gives higher value for the objective function, that is:

$$\sum_{\theta\in\theta} A(\theta)p(\theta)\tilde{h}(\theta) > \sum_{\theta\in\theta} A(\theta)p(\theta)h(\theta). \tag{C.6}$$

To this probability $\tilde{h}$, we can match any disclosure rule (S', g') such as $S' = \{s'_L, s'_H\}$, $g'(s'_H \mid \theta) = \tilde{h}(\theta)$ and $g'(s'_L, \theta) = 1 - \tilde{h}(\theta)$. Since $\tilde{h}$ satisfies (III), then $R'(.) \geq R^*$ at least for score s'_H (i.e the expected value of the investment return of a bank $\mathcal{D}$ under the disclosure rule (S', g') is greater than the Threshold R^* at least for s'_H).[1] So, the value of the objective function in Lemma 2 is at least $\sum_{\theta\in\theta} A(\theta)p(\theta)g'(s'_H \mid \theta) = \sum_{\theta\in\theta} A(\theta)p(\theta)\tilde{h}(\theta)$. And under $(\hat{S}, \hat{g})$, the value of the objective function in Lemma 2 is only equal to:

$$\sum_{\theta\in\theta} A(\theta)p(\theta)\hat{g}(\hat{s}_H \mid \theta) = \sum_{\theta\in\theta} A(\theta)p(\theta)h(\theta). \tag{C.7}$$

However, according to C.6:

$$\begin{aligned} \sum_{\theta\in\theta} A(\theta)p(\theta)h(\theta) &< \sum_{\theta\in\theta} A(\theta)p(\theta)\tilde{h}(\theta), \\ i.e., \quad \sum_{\theta\in\theta} A(\theta)p(\theta)\hat{g}(\hat{s}_H \mid \theta) &< \sum_{\theta\in\theta} A(\theta)p(\theta)\hat{g'}(s'_H \mid \theta), \end{aligned} \tag{C.8}$$

which contradicts the optimality of $(\hat{S}, \hat{g})$.

In a second step, we show that if h solves the problem in Lemma 4, then (S, g) defined by $S = \{s_L, s_H\}$, $g(s_H \mid \theta) = h(\theta)$ and $g(s_L \mid \theta) = 1 - h(\theta)$, solves the problem in Lemma 2. We proceed here also to a proof by contradiction: suppose that there exists a disclosure rule $(\check{S}, \check{g})$ that gives higher value for the objective function in Lemma 2. This disclosure rule can be defined by, without loss of generality, $\check{S} = \{\check{s}_L, \check{s}_H\}$. Also, we consider that the expected value of the investment return of the distressed bank when calculated under this rule is such that $\check{R}(s_H) \geq R^*$ and $\check{R}(s_L) < R^*$. Since $(\check{S}, \check{g})$ gives higher value for the objective function in Lemma 2, then:

$$\sum_{\theta\in\theta} A(\theta)p(\theta)\check{g}(\check{s}_H \mid \theta) > \sum_{\theta\in\theta} A(\theta)p(\theta)g(s_H \mid \theta) \tag{C.9}$$

Now let $\check{h}(\theta) = \check{g}(\check{s_H} \mid \theta)$, we have then $\check{h}$ satisfies (III) (since $\check{R}(s_H) \geq R^*$) and $\sum_{\theta\in\theta} A(\theta)p(\theta)\check{h}(\theta) > \sum_{\theta\in\theta} A(\theta)p(\theta)h(\theta)$ which contradicts the optimality of h.

Case 2: $\mathbb{E}(\theta) \geq R^*$
The demonstration is done in a similar way. Just remember in the first part of the proof that since $\tilde{h}$ satisfies (IV), it satisfies (IV) (since $\mathbb{E}(\theta) \geq R^*$), then $R'(.) \geq R^*$ at least for score s'_H.

□

[1] We don't know how is $R'(s_L)$ compared to R^*.

Proposition 1 (proof).

Case 1: $A(\theta) > 0$, *for every* $\theta \in \Theta$.

Part 1: If $\mathbb{E}(\theta) \geq R^*$, for every types $\theta \in \Theta$, setting $h(\theta) = 1$ satisfies constraint (IV) and, hence is optimal, since any other value of $h(\theta)$ reduces the value of the objective function in Lemma 4.

Part 2: If $\mathbb{E}(\theta) < R^*$, for every types $\theta \in \Theta$, setting $h(\theta) = 1$ maximises the objective function in Lemma 4 but it it is binding constraint (III). However, setting $h(\theta) = 1$ for every $\theta \geq R^*$, increases the value of the objective function and weakly relaxes the constraint (III).

We prove in the following that if $h(\theta') > 0$ for a certain $\theta' < R^*$, then $h(\theta) = 1$ for every $\theta \in \Theta$, such that $G(\theta) > G(\theta')$. To do this, we proceed to a proof by contradiction: suppose that there exists an asset quality $\theta'' < R^*$, such that $G(\theta'') > G(\theta')$, but $h(\theta'') < 1$. Constructing an other solution $\tilde{h}$, such that:

$$\tilde{h}(\theta) = \begin{cases} h(\theta) & if\ \theta \notin \{\theta', \theta"\}, \\ h(\theta) + \epsilon & if\ \theta = \theta'', \\ h(\theta) - \frac{(R^* - \theta'')p(\theta'')}{(R^* - \theta')p(\theta')}\epsilon & if\ \theta = \theta'. \end{cases}$$

Hereafter, $\tilde{h}$ is a function from Θ to [0,1], for every $\epsilon > 0$ and sufficiently small. Since h verifies constraint (III), $\tilde{h}$ verifies also constraint (III):

$$\sum_{\theta \in \Theta} p(\theta)(\theta - R^*)\tilde{h}(\theta) = \sum_{\theta \in \Theta} p(\theta)(\theta - R^*)h(\theta) + p(\theta'')(\theta'' - R^*)\epsilon - p(\theta')(\theta' - R^*)\frac{(R^* - \theta'')p(\theta'')}{(R^* - \theta')p(\theta')}\epsilon \geq 0 \tag{C.10}$$

The sum of the last two terms being equal to 0. We show then that with the new solution $\tilde{h}$ we have a higher value of the objective function. In fact, the latter is increased by $A(\theta'')p(\theta'')\epsilon - A(\theta')p(\theta')\frac{(R^* - \theta'')p(\theta'')}{(R^* - \theta')p(\theta')}\epsilon = (R^* - \theta'')p(\theta'')\epsilon[G(\theta'') - G(\theta')] > 0$. We can then conclude that there exists θ^* , such that for every $\theta < R^*$, $h(\theta) = 1$ if $G(\theta) > G(\theta^*)$ and $h(\theta) = 0$ if $G(\theta) < G(\theta^*)$. Note $G^* = G(\theta)$. To satisfy constraint (III), we should have $\sum_{\theta \geq R^*} p(\theta)(\theta - R^*) + \sum_{\theta < R^*: G(\theta) > G^*} p(\theta)(\theta - R^*) + \sum_{\theta < R^*: G(\theta) = G^*} p(\theta)(\theta - R^*)h(\theta) = 0$

Case 2: $A(\theta) < 0$, *for every* $\theta \in \Theta$.

Part 1: If $\mathbb{E}(\theta) < R^*$, for every types $\theta \in \Theta$, setting $h(\theta)$ equal to zero, for every asset quality θ satisfies the constraint (III) and gives the objective function a value of zero, which is optimal since $A(\theta) < 0, \forall \theta \in \Theta$.

Part 2: If $\mathbb{E}(\theta) \geq R^*$, for every types $\theta \in \Theta$, the proof is similar to the previous case.

□

Proof corollary 2:

A) If $A(\theta) > 0$ for every $\theta \in \Theta$.

1. Under full disclosure, scores assigned to asset quality θ of the distressed bank are such that $R(s) = \theta$. Hence, for an asset quality $\theta \geq R^*$ (*i.e.*, $R(s) \geq R^*$), the surviving bank accepts to bail-in the distressed bank with probability 1, which is optimal since $A(\theta) > 0$.

2. Under no disclosure, $R(s) = \mathbb{E}(\tilde{\theta})$, $\forall s \in S$ (scores become non-informative in this case). Hence, if $\mathbb{E}(\tilde{\theta}) \geq R^*$ (i.e., $R(s) \geq R^*$), then bailing-in the distressed bank with probability 1 is optimal, since $A(\theta) > 0$.

3. On the one hand, under no disclosure, $R(s) = \mathbb{E}(\tilde{\theta})$, $\forall s \in S$. Hence, if $\mathbb{E}(\tilde{\theta}) < R^*$ (i.e., $R(s) < R^*$), then bailing-in the distressed bank with probability 0 is not optimal. On the other hand, if $\mathbb{E}(\tilde{\theta}) < R^*$, then $\theta_{min} < R^*$, Hence according to 1, Full disclosure is not optimal. The only way to achieve the optimal loss is partial disclosure.

4. On the one hand, under no disclosure, $R(s) = \mathbb{E}(\tilde{\theta})$, $\forall s \in S$. Hence, if $\theta_{max}) < R^*$, then $\mathbb{E}(\tilde{\theta}) < R^*$ (i.e., $R(s) < R^*$), and so bailing-in the distressed bank with probability 0 is not optimal. On the other hand, if $\theta_{max} < R^*$, then $\theta_{min} < R^*$, Hence according to 1, Full disclosure is not optimal. The only way to achieve the optimal loss is partial disclosure.

B) If $A(\theta) < 0$ for every $\theta \in \Theta$.

1. Under full disclosure, $R(s) = \theta$. Hence, for an asset quality $\theta < R^*$, the surviving bank refuses to bail-in the distressed bank with probability one, which is optimal since $A(\theta) < 0$ (otherwise, the value of the objective function in Lemma 4 is negative).

2. Under no disclosure, $R(s) = \mathbb{E}(\tilde{\theta})$, $\forall s \in S$. Hence, if $\mathbb{E}(\tilde{\theta}) < R^*$ (i.e., $R(s) < R^*$), then bailing-in the distressed bank with probability 0 is optimal according to Proposition 1.

3. On the one hand, under no disclosure, if $\mathbb{E}(\tilde{\theta}) \geq R^*$, then bailing-in the distressed bank with probability 1 is sub-optimal. On the other hand, if $\mathbb{E}(\tilde{\theta}) \geq R^*$, then $\theta_{max} \geq R^*$, Hence, according to 1, full disclosure is not optimal. The only way to achieve the optimal loss is partial disclosure.

4. On the one hand, under no disclosure, if $\theta_{min} \geq R^*$ (and so $\mathbb{E}(\tilde{\theta}) \geq R^*$), then bailing-in the distressed bank with probability 1 is sub-optimal. On the other hand, if $\theta_{min} \geq R^*$, then $\theta_{max} \geq R^*$, Hence, according to 1, full disclosure is not optimal. The only way to achieve the optimal loss is partial disclosure.

□

Appendix D

Resolution with government intervention

Lemma 7 (proof). The regulator's problem is to choose a disclosure rule (S, g) that minimizes $\mathcal{P} = \sum_{\theta\in\Theta} p(\theta)\mathcal{L}(\theta)$, i.e., minimizing:

$$\begin{aligned}
\mathcal{P} &= \sum_{\theta\in\Theta} p(\theta) \sum_{s:R(s)\geq R^{**}} w_1(\theta, s)\ g(s \mid \theta) + \sum_{\substack{\theta\geq\theta^* \\ \theta\in\Theta}} p(\theta) w_2(\theta) \sum_{s:R(s)<R^{**}} g(s \mid \theta) \\
&+ \sum_{\substack{\theta<\theta^* \\ \theta\in\Theta}} p(\theta) w_0(\theta) \sum_{s:R(s)<R^{*}} g(s \mid \theta) \\
&= \sum_{\substack{\theta\geq\theta^* \\ \theta\in\Theta}} \Big[\sum_{s:R(s)\geq R^{**}} w_1\ g(s \mid \theta) + \sum_{s:R(s)<R^{**}} w_2\ g(s \mid \theta)\Big] p(\theta) \\
&+ \sum_{\substack{\theta<\theta^* \\ \theta\in\Theta}} \Big[\sum_{s:R(s)\geq R^{**}} w_1\ g(s \mid \theta) + \sum_{s:R(s)<R^{**}} w_0\ g(s \mid \theta)\Big] p(\theta)
\end{aligned} \tag{D.1}$$

Hence

$$\begin{aligned}
\mathcal{P} = &- \sum_{\substack{\theta\geq\theta^* \\ \theta\in\Theta}} p(\theta) \sum_{s:R(s)\geq R^{**}} \Big[(\delta - \frac{1-\alpha}{\alpha} - \gamma)(C-\theta)\Big]\ g(s \mid \theta) \\
&- \sum_{\substack{\theta\in\Theta \\ \theta<\theta^*}} p(\theta) \sum_{s:R(s)\geq R^{**}} \Big[(1-\beta)e_{\mathcal{D}} + (\frac{1-\beta}{\alpha} + \gamma)\theta - \gamma C\Big]\ g(s \mid \theta) \\
&+ \sum_{\substack{\theta\geq\theta^* \\ \theta\in\Theta}} p(\theta)\Big[\frac{1-\alpha}{\alpha}(d_{\mathcal{H}} + d_{\mathcal{D}} - \theta_1) + (\delta + \frac{1-\alpha}{\alpha})C - \delta\theta)\Big] \\
&+ \sum_{\substack{\theta<\theta^* \\ \theta\in\Theta}} p(\theta)\Big[\frac{1-\alpha}{\alpha}(d_{\mathcal{H}} + d_{\mathcal{D}} - \theta_{\mathcal{H}}) + (1-\beta)e_{\mathcal{D}} + (\frac{1-\beta}{\beta} - \frac{1-\alpha}{\alpha})\beta\theta\Big]
\end{aligned} \tag{D.2}$$

Since the last two terms are constant with respect to the disclosure rule, the regulator problem becomes maximizing:

$$\sum_{\substack{\theta<\theta^* \\ \theta\in\Theta}} A(\theta)p(\theta) \sum_{s:R(s)\geq R^{**}} g(s \mid \theta) + \sum_{\substack{\theta\geq\theta^* \\ \theta\in\Theta}} B(\theta)p(\theta) \sum_{s:R(s)\geq R^{**}} g(s \mid \theta)$$

$$\text{with } A(\theta) = \frac{1-\beta}{\alpha}\theta + (1-\beta)e_{\mathcal{D}} - \gamma(C-\theta)$$

$$\text{and } B(\theta) = (\delta - \frac{1-\alpha}{\alpha} - \gamma)(C-\theta) \tag{D.3}$$

□

Lemma 8 (proof). We proceed as in Lemma 2 and consider a disclosure rule $(\hat{S}, \hat{g})$ such that $\hat{S} = \{s_L, s_H\}$ and where the expectations are calculated under $\hat{g}$ (i.e., $\hat{R}(s) = \mathbb{E}(\theta \mid s), \forall s \in \hat{S}$). Let $\hat{g}(s_H \mid \theta) = \sum_{s:R(s)\geq R^{**}} g(s \mid \theta)$.

- We first assume that $\sum_{\theta\in\Theta} p(\theta)\hat{g}(s_H \mid \theta) > 0$, and show that $\hat{R}(s_H) \geq R^{**}$.

$$\begin{aligned}
\hat{R}(s_H) &= \frac{\sum_{\theta\in\Theta} \theta p(\theta)\hat{g}(s_H \mid \theta)}{\sum_{\theta\in\Theta} p(\theta)\hat{g}(s_H \mid \theta)}, \\
&= \frac{\sum_{\theta\in\Theta} \theta p(\theta) \sum_{s:R(s)\geq R^{**}} g(s \mid \theta)}{\sum_{\theta\in\Theta} p(\theta) \sum_{s:R(s)\geq R^{**}} g(s \mid \theta)}, \\
&= \frac{\sum_{\theta\in\Theta} p(\theta) \sum_{s:R(s)\geq R^{**}} R(s) g(s \mid \theta)}{\sum_{\theta\in\Theta} p(\theta) \sum_{s:R(s)\geq R^{**}} g(s \mid \theta)} \\
&\geq \frac{\sum_{\theta\in\Theta} p(\theta) \sum_{s:R(s)\geq R^{**}} f^{-1}(R^*) g(s \mid \theta)}{\sum_{\theta\in\Theta} p(\theta) \sum_{s:R(s)\geq R^{**}} g(s \mid \theta)} \\
&\geq R^{**},
\end{aligned} \tag{D.4}$$

  and so under this disclosure rule bank $\mathcal{H}$ accepts to bail-in bank $\mathcal{D}$ with probability $\hat{g}(s_H \mid \theta)$. The same reasoning is used to proof that $\hat{R}(s_L) < R^{**}$.

- For the special case where $\sum_{\theta\in\Theta} p(\theta)\hat{g}(s_H \mid \theta) = 0$, we proceed in the same way as for the Lemma 3.

□

Explication of the regulator problem solutions:

Case 1: $\mathbb{E}(\tilde{\theta}) < R^{**}$

- *When $B(\theta)$ is negative and $A(\theta)$ for every asset quality $\theta < \theta^*$ is negative.*

In this case, the optimal solution consists in assigning a $h(\theta)$ equal to 0 for every asset quality θ and this solution satisfies constraint (V). For instance, this situation arises when the cost of the lease-in is significant (large γ). In this case, the regulator wants to dissuade the surviving bank from bailing-in the distressed bank and will proceed to a bailout if $\theta \geq \theta^*$ (i.e., if the bailout is less costly than the no intervention), or will do nothing otherwise.

- *When* $B(\theta) > 0$ *and* $A(\theta) < 0$ *for every asset quality* $\theta < \theta^*$.

We first define the set Θ_2, such that $\Theta_2 = \{\theta \in \Theta | \theta \geq \theta^*\}$, which allows us to present the following solutions of the regulator problem:

- For asset quality $\theta < \theta^*$, it's obvious that assigning 0 for every $h(\theta)$ is optimal, since setting positive values of $h(\theta)$ reduces the value of the objective function.

- For asset quality $\theta \geq \theta^*$:
  - If $\mathbb{E}(\theta \mid \theta \in \Theta_2) \geq R^{**}$, then setting $h(\theta)$ equal to 1 is optimal and verifies constraint (V).
  - If $\mathbb{E}(\theta \mid \theta \in \Theta_2) < R^{**}$, setting $h(\theta)$ equal to 1 certainly maximizes the objective function but it violates the constraint (V). Thus, to determine the probability of the high score for each asset quality θ, we construct, as in the first part, a gain-to-cost ratio. This ratio is defined as follow:

$$G_2(\theta) = \frac{B(\theta)}{R^{**} - \theta}$$

  when the asset quality θ is such $\theta \geq R^{**}$, it's optimal to assign it the high score s_H with probability 1, since the gain-to-cost ratio is negative. However, when the asset quality θ is such $\theta < R^{**}$, we attribute a probability 1 of having the highest score, for all asset quality with a gain-to-cost ratio above a certain threshold G_2^*.[1]

- *When* $B(\theta) < 0$ *and* $A(\theta) > 0$ *for every asset quality* $\theta < \theta^*$.[2]

- For every asset quality θ such that $\theta \geq \theta^*$, assigning 0 for every $h(\theta)$ is optimal.

- For every asset quality θ such that $\theta < \theta^*$,
  - if $\mathbb{E}(\theta \mid \theta \in \bar{\Theta}_2) \geq R^{**}$, then assigning the high score with probability 1 for every asset quality is optimal and the constraint (V) is respected.
  - if $\mathbb{E}(\theta \mid \theta \in \bar{\Theta}_2) < R^{**}$, it is no longer possible to assign a probability of 1 for each $h(\theta)$ otherwise the constraint would be violated. Thus, as previously, we construct a new gain-to-cost ratio that allows us to judge to which asset quality the regulator should assign the high score. In fact, the gain from increasing $h(\theta)$ is $B(\theta)p(\theta)$. However, the cost of doing so is, $(\theta - R^{**})p(\theta)$. The gain-to-cost ratio is then the following:

$$G_1(\theta) = \frac{A(\theta)}{R^{**} - \theta}$$

  For every asset quality $\theta > R^{**}$, the gain gain-to-cost ratio is negative. Hence, it's optimal to assign the high score s_H with probability 1 for every asset quality θ that meets this condition. Nevertheless, for every asset quality $\theta < R^{**}$, the regulator should only do so for those that have a gain-to-cost ratio greater than a certain threshold G_1^*.

[1] Since the gain-to-cost ratio is increasing in θ, this will consist in ordering the θ and trying to find the smallest θ which verifies the condition (V), and attribute to all asset quality θ above it, the score s_H.

[2] Note that $B(\theta)$ is negative only when $\delta < \gamma + \frac{1-\alpha}{\alpha}$, it does not depend in θ values

- *When $A(\theta)$ and $B(\theta)$ are both positive for every asset quality θ.*

It is not optimal to attribute the highest score with probability 1 to all asset quality, else the condition (V) is binding. To resolve the regulator problem, we construct as previously a gain-to-cost ratio but this time our ratio is defined by interval as follows:

$$G(\theta) = \begin{cases} \frac{A(\theta)}{R^{**}-\theta} & if\ \theta \geq \theta^*, \\ \frac{B(\theta)}{R^{**}-\theta} & if\ \theta < \theta^*. \end{cases} \tag{D.5}$$

So the regulator attributes the high score with probability 1, if the distressed bank has an asset quality $\theta \geq R^{**}$. Indeed, this increases the value of the objective function of Lemma 6 on the one hand and allows to relax the constraint (V) on the other hand (since we obtain a negative gain-to-cost ratio in this case). However, if the realised return θ of the distressed bank is below R^{**}, for the realisations of θ such that, $G(\theta) > G^*$, the regulator attributes the highest score with probability 1.

Case 2: $\mathbb{E}(\theta \geq R^{**})$

The resolution is symmetrical to case 1.

- *When $A(\theta)$ and $B(\theta)$ are both positive for every asset quality θ.*

Setting $h(\theta)$ equal to 1 for every asset quality θ satisfies constraint (VI) and is optimal. Hence, the regulator assign the high score s_H to the asset quality of the distressed bank, with probability 1, to encourage the healthy bank to rescue the latter.

- *When $B(\theta)$ is negative and $A(\theta)$ for every asset quality $\theta < \theta^*$ is negative.*

When $\theta < R^*$, setting $h(\theta) = 0$, for every asset quality $\theta \in \Theta$, satisfies constraint (VI) and is optimal. For $\theta \geq R^*$, we attribute a probability 1 of having the highest score ($h(\theta) = 1$), for all asset quality with a gain-to-cost ratio under a certain threshold G^{**} and the lowest score for all asset quality above this threshold. When $G(\theta) = G^{**}, h(\theta)$ is set such that (VI) is equal to 0.

- *When $B(\theta) > 0$ and $A(\theta) < 0$ for every asset quality $\theta < \theta^*$.*

- For asset quality $\theta \geq \theta^*$, it's obvious that assigning 1 for every $h(\theta)$ is optimal.
- For asset quality $\theta < \theta^*$:
  - If $\mathbb{E}(\theta \mid \theta \in \Theta_2) < R^{**}$, then setting $h(\theta)$ equal to 0 is optimal and verifies constraint (VI).
  - If $\mathbb{E}(\theta \mid \theta \in \Theta_2) \geq R^{**}$, setting $h(\theta)$ equal to 0 certainly maximizes the objective function but it violates the constraint (VI). We attribute the lowest score to every asset quality $\theta < R^{**}$. Then for $\theta \geq R^{**}$, We attribute a probability 1 of having the highest score ($h(\theta) = 1$), for all asset quality with a gain-to-cost ratio under a certain threshold G_2^{**} and the lowest score for all asset quality above this threshold. When $G(\theta) = G_2^{**}, h(\theta)$ is set such that (VI) is equal to 0.

- *When $B(\theta) < 0$ and $A(\theta) > 0$ for every asset quality $\theta < \theta^*$.*

- For asset quality θ such that $\theta < \theta^*$, assigning 1 for every $h(\theta)$ is optimal.

- For asset quality θ such that $\theta \geq \theta^*$,
  - if $\mathbb{E}(\theta \mid \theta \in \bar{\Theta}_2) < R^{**}$, then assigning the high score with probability 0 for every asset quality is optimal and the constraint (VI) is respected.
  - if $\mathbb{E}(\theta \mid \theta \in \bar{\Theta}_2) \geq R^{**}$, it is no longer possible to assign a probability of 0 for each $h(\theta)$ otherwise the constraint would be violated. Thus, as previously, we set $h(\theta)$ equal to 0 for every asset quality $\theta < R^{**}$ since it maximizes the objective function and verifies the constraint (VI). Then for $\theta \geq R^{**}$, We attribute a probability 1 of having the highest score ($h(\theta) = 1$), for all asset quality with a gain-to-cost ratio under a certain threshold G_1^{**} and the lowest score for all asset quality above this threshold. When $G(\theta) = G_1^{**}, h(\theta)$ is set such that (VI) is equal to 0.

Proofs of these results and Corollary 3 are similar to those of Proposition 1 and Corollary 3.

Chapter 3

Preventing cascade defaults through information disclosure

Abstract

I consider a financial system composed of N banks connected through interbank claims. This network is made up of different types of banks, some of them are in a situation of bankruptcy, so the regulator must act to minimise its ex-ante expected loss function by disclosing information about the asset quality of the distressed banks. I show that the incentive to bail-in is stronger in less densely connected networks in case of negative small shocks and when there is no possible bailout. The regulator threat of not rescuing the defaulting banks is also less credible in ring networks facing shocks of low intensity. When I look at the regulator's disclosure rule in the case of a single defaulting bank linked to several healthy banks, I find that optimal disclosure strategy depends not only on different costs introduced in the model (bail-in, bailout, liquidation and bankruptcy costs) but it is also driven by network structure and density. Finally, I show for a network of 3 banks and in case of shocks of low intensity, when the more distressed bank is suspected to have bad asset quality, more disclosure is needed in ring networks.

Keywords: Financial network, default cascade, bank resolution, bail-in, bailout, optimal disclosure.

3.1 Introduction

The European banking system can be modelled by a network where the links between different banks are represented by interbank credits.[1] The study of the financial system architecture has raised the interest of researchers specially since the global financial crisis of 2008. Indeed, the interconnectedness of the financial system contributes to the financial fragility: an initial negative shock hitting a financial institution can be amplified and transmitted to its creditors, others banks of the networks, through interbank credits, triggering afterward a cascade of failures. Most of the existing studies focus on how the network architecture amplifies or absorbs initial shocks.[2] Only a few recent articles have looked at the endogenous interaction between regulator and financial institutions to stop these cascades of failures and at the architecture that promotes these interventions.[3] The goal of my paper is not only to endogenize the intervention mechanism but also to find how the information disclosed by the regulator can intervene to minimize cascade of defaults and so systemic risk. I show that information disclosed affects the socially desirable network structure and can prevent from cascade of defaults in financial networks.

The financial crisis in 2008 results in failures of large banks and many other banking recapitalizations. During this period, governments followed a recurring strategy of using public resources to bail out banks. Therefore, taxpayers essentially bear the cost of resolving the financial institutions.[4] To limit these negative externalities, the new regulation, through the creation of the Single Resolution Mechanism (SRM), proposes first to bail-in debt before a possible bailout. In this alternative resolution plan, the creditors bear the losses since they only recover some of their initial investment. Nonetheless, a new recent literature shows that these bail-ins also have their drawbacks. For instance, Beck, Da-Rocha-Lopes, and Silva (2021) show that bail-ins significantly restrict credit supply, reducing investment and employment which is detrimental to the economy. Therefore, I suggest in this paper to transpose the mechanism set by the SRM into a theoretical framework, more precisely a Bayesian persuasion game, by considering different costs: a

[1] Gabrieli and Georg (2017) use in their study the fact that the euro area overnight interbank market is best described as a network. In fact, the 2008 annual report of the ECB shows that, on average, interbank lending accounts for over 25% and interbank borrowing for roughly 21% of total asset size in the euro area in 2008 (see ECB, 2009). Upper (2011) has also shown that interbank loans represent a significant fraction of bank balance sheets in several European countries.

[2] A non-exhaustive list of papers includes Allen and Gale (2000), Freixas, Parigi, and Rochet (2000), Stiglitz and Greenwald (2003), Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015), Elliott, Golub, and Jackson (2014)...

[3] Most notably Bernard, Capponi, and Stiglitz (2017).

[4] Philippon and Salord (2017) estimate that the amount spent by the American government to save the banks approximate 6% of 2008 GDP. The one injected in Europe represented about 4.6% of their aggregate annual GDP up to 2012.

bankruptcy cost, a liquidation cost, a bailout cost and a bail-in cost and study how the regulator should disclose information at its disposal when it is confronted to resolution issues.

Recent literature highlights two main channels through which contagion is created between financial institutions. The first comes from fire-sale spillovers: when confronted to a liquidity shortage, banks are forced to sell their assets in order to remain solvent. These sales lower the price in the market, thus inducing more stress on other institutions. The second operates through credit loans: when distressed banks can not honor their obligations, they transmit losses to their creditors, which can in turn transmit to their own creditors and hence a cascade of defaults can occur. In this paper, I exploit this second channel. I hence consider a financial system composed of N banks in the spirit of Eisenberg and Noe (2001). Banks are connected through interbank claims. Liquidation and bankruptcy costs are considered as in Rogers and Veraart (2013), whereas seniority in debt repayment is considered as in Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015). In this model, a group of fundamentally defaulting banks asks their creditors (other banks of the network), to reduce their debts. The latter can accept or not this bail-in operation based on information disclosed by the regulator about banks' assets quality. Indeed, I account for asymmetric information in my framework since the regulator has more information on the distressed banks than the other banks of the network. This assumption is justified by the new regulation and the creation of the Single Supervision Mechanism (SSM) which proposes a uniform approach for bank supervision and makes the European Central Bank (ECB) responsible for banking supervision in the euro area. The ECB can hence carry out prudential reviews, on-site inspections and investigations (e.g., the AQR for Asset Quality Review). A relevant example of the importance of information in these situations can be found in the failed rescue of Lehman Brothers. Indeed, the U.S. Government apparently did not manage to convince other investment banks to organize a rescue. Hence, designing a better information structure would have possibly made this rescue possible.

In the model, the regulator chooses a disclosure rule before the realisation of the distressed banks' asset quality, as in Goldstein and Leitner (2018), in order to minimize its expected total loss function. This total loss function is a weighted function considering bankruptcy costs, liquidation losses, the cost of the bail-ins to the economy as well as the cost of bailouts to taxpayers.

The disclosure of information by the government follows a certain chronological order. First, the regulator chooses a disclosure rule and publicly announces it. Hereafter, the asset quality of each bank is realized and observed by the bank itself and the regulator. Then the regulator assigns a score to the distressed banks based on its disclosure rule,

and publicly announces it to the consortium of healthy banks. Simultaneously, the fundamentally defaulting banks (who also observe their own asset quality), know if they need a rescue plan. If it is the case, they ask the other banks of the network to write-down their debts. The latters accept or not to proceed to the bail-in. If the bail-in proposal is refused, the government can intervene and bail out the fundamentally defaulting banks if and only if the bailout strategy is less costly than the no-intervention. Finally, payments between banks are made simultaneously in the spirit of Eisenberg and Noe (2001) and the total losses for the regulator are determined.

My first results show that the more intense the cascade of defaults, the more a surviving bank is likely to agree to rescue fundamentally defaulting banks even if they are not directly linked, when the bailout probability is not significant.[5] Indeed, the default of distressed banks leads to the collapse of other banks and these cascading defaults become all the more costly for the surviving banks especially when the failure cost is high.

I show also, in case of small negative shocks, for a network formed of 3 banks (a fundamentally defaulting bank, a distressed bank and a surviving one) that the incentive to bail-in is stronger in a less densely connected network (a ring network) when there is no possible bailout. The incentive to bailout the defaulting banks from the government is more credible in complete networks, in the case of shocks of low intensity. However, this threat becomes less credible as the intensity of shocks become higher. In fact, losses are lower in complete networks since this structure allows shocks absorption's when these shocks are of low intensity as shown by Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015).

When I look at the regulator's disclosure rule in the case of a single defaulting bank linked to several healthy banks, I find that full disclosure may be desirable in some cases but not in others. These results not only depend on different costs (bail-in, bailout, liquidation an bankruptcy costs) but also they are driven by network structure and density. For instance, when bail-in cost is low and when the distressed bank has dense connections, the regulator wants to encourage bail-ins. To this end, in normal time, the regulator's disclosure rule must be non-informative. In the special case, where the possible realisations of the asset quality are greater than a certain threshold, the regulator may convince the consortium rescue to proceed to the bail-in by being completely transparent.

Full disclosure may be an optimal strategy in some cases but not in others when studying networks formed by 3 banks (a fundamentally defaulting bank, a distressed bank and a surviving one). Indeed, when the bail-in is costly to the regulator, it sends signals to discourage the surviving bank from bailing-in the fundamentally defaulting bank, because

[5] I mean by intensity the number of defaulting banks and the amount of losses triggered by these defaults.

its rescue would be very costly to the economy. Hence, when the surviving bank, thinks that in average the fundamentally defaulting bank has a high chance of having a poor asset quality and that the distressed bank has a high chance to have a good one, it will not accept the bail-in proposal whenever the regulator adopt a strategy of no disclosure since the healthy bank expects to recover more by refusing the bail-in in this case.

I show also that the regulator is more likely to reveal information that promotes bail-ins in ring networks, in case of shocks of low intensity, since complete networks allows shocks absorption. It adopts hence different strategies of disclosure depending on the network structure. Indeed, in some cases when on average the fundamentally defaulting bank is suspected of having a poor asset quality and the distressed one is presumed to have good asset quality, more disclosure is needed in ring networks since it encourages the healthy bank for bailing the fundamentally distressed bank.

The rest of the paper is organised as follows. Section 3.2 presents a brief review of the related literature. The existence and characterisation of clearing vectors is addressed in Section 3.3. The model is presented in Section 3.4. In Section 3.5, I study the incentive of a consortium of healthy banks to bail-in a single distressed bank. In Section 3.6, I study a more complete model where healthy banks accept or not to save fundamentally defaulting banks in order to avoid the collapse of the financial system. In Section 3.7, I analyse the impact of the network structure through a comparison of the ring network and the complete network. Section 3.8 concludes. Proofs of technical results are deferred to the Appendices.

3.2 Related literature

My paper is related to several strands of the literature. First, I rely on the literature on contagion and financial networks. Second, I contribute to the recent and rich literature on bail-in, bailout and bank resolution. Finally, I built on the literature on information disclosures and persuasion.

Contagion and financial networks. Seminal work on financial contagion in interbank networks have studied the amplification of the impact of an initial shock through the network. The pioneers were Allen and Gale (2000) followed by Freixas, Parigi, and Rochet (2000). They worked on financial networks to show that a complete banks network is more resilient to shocks because the losses are divided among more creditors via the interbank contracts, reducing the impact of initial negative shocks to the rest of the system. Most important results related to this literature (Gai and Kapadia, 2010; Acemoglu,

Ozdaglar, and Tahbaz-Salehi, 2015) announced that networks where financial institutions are connected better resist to shocks because they share the risk. However, beyond a certain level of connection, an extreme shock spreads rapidly and likelihood of a systemic collapse increases.[6] Nonetheless, a more recent literature has introduced into this framework a regulator that can intervene strategically (proposing bail-ins and bailouts) to limit the impact of the initial negative shocks.[7] Rogers and Veraart (2013) show that when a consortium of banks can rescue distressed banks then it has the incentive to do so.[8] Bernard, Capponi, and Stiglitz (2017), using a game-theoretic model with complete information, find that bail-in is possible only when the regulator's threat to not bailout insolvent banks is credible. They also show that incentives to join a rescue consortium are stronger in networks where banks have a high exposure to default contagion, and weaker if banks realize that a large fraction of the benefits resulting from their contributions accrue to others. My model is different from these papers since my game is based on incomplete information. In my setting, the regulator gives information about the distressed banks' asset quality, before proposing bail-ins and bailouts, according to a disclosure rule that it chooses ex-ante by minimizing an expected loss function.

Bail-in, Bailout and Bank resolution. A more recent literature studies how to trigger bail-ins when bailouts are possible. In addition to Bernard, Capponi, and Stiglitz (2017) and Rogers and Veraart (2013), a branch of the literature has addressed this issue based on models that take into consideration the information revealed to the different actors rather than the structure of the network formed by the financial institutions. Walther and White (2020) have also a setting where the regulator has more information than a bank's creditors (the healthy bank in my model) about the value of its assets, and they analyze how to reach efficient bail-ins by signalling or not private information. Indeed, signalling bad news would create a bank run. In Keister and Mitkov (2020), the threat of a run disciplines the distressed bank to impose losses on its creditors and helps the regulator to improve financial stability. In their model, some investors (creditors) have private information about the size of their banks' losses and can withdraw funds before this information becomes public. Banks with such a fraction of worthless goods pay them less than in normal times. The size of the bail-in is measured as the percentage haircut

[6] I refer to Glasserman and Young (2016) for a thorough survey on financial contagion.

[7] Different works (Erol and Ordoñez, 2017; Erol, 2019) have studied the issue of bank resolution based on endogenous networks. However, the framework and the interest are different from mine.

[8] Indeed, solvent banks should avoid distressed banks to fail in succession. Incentive to rescue is introduced by default costs. Leitner (2005) motivates also private sector bailout in his network model by the fear of collapse due to contagion.

from the allocation in normal times. This notion of bail-in is not very different from mine, in the sense that in my model the size of the bail-in is represented by the amount of the debt write down. Colliard and Gromb (2018) investigate how resolution frameworks affect the private restructuring of distressed banks by modelling a distressed bank that asks an external creditor for a bail-in through a signaling game with incomplete information. The time is used to signal the asset quality to the creditor. They show that strict bail-in rules increase delays by worsening informational frictions and reducing bargaining surplus. They find also that, when the government partakes in negotiations, the delays may be shorter or longer. I extend their initial model to a financial network. My setting captures the negative externalities, due to fire sales and domino effects, endogenously through the network effect and banks' losses induced by liquidation cost.[9]

Information disclosures and persuasion. My work is also related to the literature on regulatory disclosures in the financial system, see Goldstein and Sapra (2014) for a literature review. In addition, information design and Bayesian persuasion are two key literature for my work, see Bergemann and Morris (2019) for a review of the latter. Closest to my work, the methodology proposed by Goldstein and Leitner (2018) where they study the design of stress tests by a regulator (the sender) facing a competitive market (the receiver). Theoretically, they map their setting into a Bayesian persuasion problem with one sender and one receiver (Kamenica and Gentzkow, 2011).[10] The sender discloses information to persuade the receiver to make a sufficiently high price offer to the bank so that the bank's capital does not fall below the critical level. Instead of selling an asset, I introduce a framework where the informed party offers to exchange existing financial claims (e.g., debt) against new financial claims (e.g., lower debt). More precisely, the regulator (the sender) in my model faces a financial network composed of fundamentally defaulting banks, distressed banks and healthy banks. Fundamentally defaulting banks are hitted by a shock and require a resolution plan to avoid triggering a cascade of defaults. Hence, these fundamentally defaulting banks ask healthy banks (the receiver) to proceed to their bail-in thanks to a debt write down. The decision of the healthy banks is based on the information disclosed by the regulator about the asset quality of all the distressed banks in the network and its bailout probability. As in Goldstein and Leitner (2018), I assume that the regulator and banks hold homogeneous beliefs about their own balance sheet and I consider that the regulator allows for flexible information structures

[9] Colliard and Gromb (2018) capture these externalities by applying a negative externality factor to the proportion of the debt which is not bailed out by the government.

[10] A recent growing literature studies persuasion with multiple receivers (Wang, 2013; Inostroza and Pavan, 2018; Goldstein and Huang, 2016) or multiple senders (Gentzkow and Kamenica, 2017).

(full disclosure, partial disclosure, no disclosure). However, the regulator minimizes an ex-ante expected loss function which is different from banks' objective function, which is to maximize their ex-ante expected payoff. Thus, the regulator and banks may have uncommon interests, and this is based on the different costs that I take into account in my model. What is also different in my model is the fact that the regulator discloses information on the asset quality of several banks and not only of one, which makes the resolution more complex. Similar in this spirit to my work Huang (2021) who studies the optimal disclosure in banking networks with potential spillovers and contagion among banks. In her model, the regulator discloses information on banks' asset quality to maximizes the weighted number of banks that are solvent, by influencing the market beliefs about banks. This influences the amount that a bank could raise if it exchanges its risky asset side. However, Huang (2021) studies a different framework. While, information in my model allows the rescue consortium to accept or not to bail-in fundamentally defaulting banks, the signals in her model influence a bank's refinancing opportunity. Moreover, she considers only two possible signals per bank, whereas in my model, even for a network of three banks (a fundamentally defaulting bank, a distressed bank and a surviving one, two signals are not sufficient to characterise the optimal rule.

3.3 Model

Before describing the model in detail, it is useful to briefly describe the sectors and the agents that characterize the environment. On the one hand, there is a private sector, composed of a network of banks with interbank exposures. All banks want to maximize their own profit and survive. On the other hand, I have a public sector, composed of a regulator and a government (with the fiscal authority), both entities have the same objective of ensuring financial stability with minimal cost to the economy and to the taxpayer.

3.3.1 The environment

I consider an economy composed of a regulator and a network of N banks. The economy lasts for three periods $t = 0, 1, 2$.

Financial network. The financial system is composed of a network of N banks in the spirit of Eisenberg and Noe (2001). Banks are connected through interbank claims such that the nominal liability of bank i toward bank j is denoted by L_{ij}. The total nominal

obligations of bank i to all other banks in the system are denoted L_i such that $L_i = \sum_j L_{ij}$. The network structure is represented by the relative liabilities matrix $\Pi \in \mathbb{R}^{n \times n}$, defined as follows:

$$\pi_{ij} = \begin{cases} \frac{L_{ij}}{L_i} & \text{if } L_i > 0 \\ 0 & \text{otherwise} \end{cases}$$

Hence, when $L_i > 0$, $\sum_j \pi_{ij} = 1$.

Each bank i of the network is endowed with k_i units of capital which can be (i) invested in a liquid asset (cash), c_i; (ii) lent to another bank; and/or (iii) invested in an illiquid asset (a project) yielding a random return at date t=1, $\tilde{\theta}_i$, and a fixed return in the final period, e_i, if it is held until maturity.[11] However, if the bank is unable to fully repay its liabilities, at time $t = 1$, its asset can be liquidated partially or totally. I assume that the liquidation is costly since the bank can only recover a fraction $\alpha < 1$ of the asset's full value.

Assets of each bank i are financed, in addition to interbank credits, L_{ij}, by deposits, d_i. Then the equity sets the two sides of the balance sheet equal (see Table 3.1).

Table 3.1: Stylized bank balance sheet

Assets	Liabilities
$L'_i = \sum_j L_{ji}$ In-network assets	$L_i = \sum_j L_{ij}$ In-network liability
A_i Return on banks outside assets	d_i Deposits: outside liabilities
	E_i Equity

To simplify the computation, I assume in the following that $c_i = 0$. This will not change our conclusions.

Failure, liquidation and payments. As it is standard in financial literature, a bank is said to be insolvent or in default when its equity is negative. Banks in this situation bear a bankruptcy cost. I assume, as in Rogers and Veraart (2013), that they only recover a fraction $\beta < 1$ of the face value of their assets realized in liquidation.

If a shock on the asset value cannot be absorbed by bank's equity, bank i becomes unable to fully repay its liabilities: it first repays its senior creditors, i.e. depositors, then

[11] $\tilde{\theta}_i$ reflects the asset quality of bank i. A bank has a good asset quality if its investment has proven to be profitable ex-post.

it repays its junior creditors, i.e. other banks of the network. I assume that the latter have the same seniority and are reimbursed in proportion to the face value of their contracts.

To maximize their profit, banks consider the payment received by other banks. Hence, the payment of bank i is equal to: [12]

$$p_i = \begin{cases} L_i & \text{if } \sum_j p_{ji} + \tilde{\theta}_i + \alpha e_i - d_i \geq L_{ij} \\ \left[\beta \left(\sum_j p_{ji} + \tilde{\theta}_i + \alpha e_i\right) - d_i\right]^+ & \text{otherwise} \end{cases} \tag{3.1}$$

The payment of bank i to bank j is $p_{ij} = \pi_{ij} p_i$. $p = \{p_i\}_{i \in [|1,n|]}$ denotes the payment vector.

If a bank does not have the necessary cash flow to repay its creditors, it liquidates its investment (partially or totally). Indeed, for the bank i, if $L_i + d_i > \sum_j p_{ji} + \theta_i + c_i$, it starts to liquidate its project until recovering its shortfall, since liquidation is costly. The amount liquidated is thus given by:

$$l_i = \left[\min\left(\frac{1}{\alpha}\left(L_i + d_i - \sum_j p_{ji} - \theta_i\right), e_i\right)\right]^+ \tag{3.2}$$

I denote by $(L, \Pi, \theta, e, d, \alpha, \beta)$ the financial system where $L, \theta, e,$ and d are vectors whose entries are the corresponding balance sheet quantities of each bank.

Contagion and defaults. A relatively small shock hitting a bank can have large effects on the financial system by triggering a cascade of failures. In this model the channel of contagion is credit contagion. In fact, fundamentally defaulting banks, $\mathcal{F}$, i.e. banks that can not reimburse their liabilities even when all other banks fully repay them, are hit by a shock.[13] This shock is then transmitted to distressed banks, $\mathcal{D}$.[14] This category of bank can honor its engagements if it is fully paid by its counterparties. But since, banks in $\mathcal{F}$ can not reimburse them, banks in $\mathcal{D}$ fail in turn, which creates a cascade of defaults if there is no external intervention to save the financial system. The set of surviving banks $\mathcal{S}$ consists of banks that are holding well and survive after shocks.[15]

[12] I show later that the healthy banks of the network consider the expected payment of other banks given the information available to them. This assumption is new and was not considered in Bernard, Capponi, and Stiglitz (2017) and Rogers and Veraart (2013) who have assumed that banks have complete information about other banks assets and so payments. I show later how this hypothesis leads to more realistic behaviours and provides interesting results.

[13] $\mathcal{F} = \{i \in [\![1, N]\!] \text{ such that } \sum_j \pi_{ji} L_j + \theta_i + \alpha e_i < L_i + d_i\}$.

[14] $\mathcal{D} = \{i \in [\![1, N]\!] \setminus \mathcal{F} \text{ such that } L_i > p_i(s)\}$.

[15] $\mathcal{S} = \{i \in [\![1, N]\!] \text{ such that } \sum_j \pi_{ji} p_j(s) + \theta_i + \alpha e_i > L_i + d_i\}$.

Information structure. The regulator provides banks with information about the asset quality $\tilde{\theta}_i$ of each bank i, at t=1. I assume that each bank knows its asset quality type but not the asset quality of the other banks. The asset quality of bank i is drawn from a finite set $\Theta_i \subset \mathbb{R}$ according to a probability function $q_i(\theta_i) = \Pr(\tilde{\theta}_i = \theta_i)$. This probability distribution is common knowledge across all agents. The assets quality in Θ_i are denoted $\theta_i^{max} = \theta_i^1 > \theta_i^2 > ... > \theta_i^{k_i} = \theta_i^{min}$. $\Theta = (\Theta_1, \Theta_2, ..., \Theta_n)$ represents the vector of the set of assets quality.

The regulator, in my framework, discloses information about banks' asset quality according to a disclosure rule that it chooses before observing $\tilde{\theta}$=$(\tilde{\theta}_1, \tilde{\theta}_2, ..., \tilde{\theta}_n)$. Its choice of the disclosure rule minimises its expected loss function.

A disclosure rule is defined by a vector of the sets of scores, $S = (S_1, S_2, ..., S_n)$, and a function, g, that maps each asset quality to a distribution over scores. Each S_i represents a set of finite scores that can be assigned to bank i. Let $g(s_i \mid \theta_i) = \Pr\left(\tilde{s}_i = s_i \mid \tilde{\theta}_i = \theta_i\right)$ be the probability, according to the disclosure rule, that the regulator assigns a score $s_i \in S_i$ when it observes asset quality θ_i. Then $\sum_{s_i \in S_i} g(s_i \mid \theta_i) = 1$, for every $\theta_i \in \Theta_i$. $s = (s_1, s_2, ..., s_n) \in S$ denotes the vector of scores assigned by the regulator to the banks of the financial network.

3.3.2 Expected outcomes

Financial network. Following the description above, the expected value of the investment return of bank i, conditional on the bank obtaining score s_i, $R_i(s_i)$ is the following:

$$R_i(s_i) = \mathbb{E}\left[\tilde{\theta}_i \mid s_i\right] = \sum_{\theta_i \in \Theta_i} \theta_i \Pr\left(\tilde{\theta}_i = \theta_i \mid \tilde{s}_i = s_i\right) = \frac{\sum_{\theta_i \in \Theta_i} \theta_i q_i(\theta_i) g\left(s_i \mid \theta_i\right)}{\sum_{\theta_i \in \Theta_i} q_i(\theta_i) g\left(s_i \mid \theta_i\right)}. \tag{3.3}$$

I define the profit of a bank i corresponding to a clearing vector p in the financial network $(L, \Pi, \theta, e, d, \alpha, \beta)$ by:

$$\Pi_i(p) = \left[\sum_j p_{ji} + \theta_i + e_i - (1-\alpha) l_i - L_i - d_i\right]^+ \tag{3.4}$$

This profit represents the value of the bank equity after clearing and by definition it is assumed to be equal to zero when a bank defaults. A similar function is considered in Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015) and Bernard, Capponi, and Stiglitz (2017).

Senior creditors. When a bank i is unable to fully repay its senior creditors, the losses

beared by the latters is :

$$\eta_i = \left[d_i - \beta(\theta_i + \alpha e_i + \sum_j p_{ji}) \right]^+ \tag{3.5}$$

Regulator. The regulator welfare losses function defined as a weighted sum of different losses is the following:

$$w(\theta) = (1-\alpha)\sum_i l_i + (1-\beta)\sum_{i \notin \mathcal{S}} \left[\sum_j p_{ji} + \theta_i + \alpha e_i \right] + \delta \sum_{i \notin \mathcal{S}} \eta_i, \tag{3.6}$$

The first term represents losses due to inefficient asset liquidation. The second term is the sum of losses due to bankruptcy cost whereas the third term reflects the cost of senior creditors losses to the economy.

3.4 Existence and characterisation of clearing vectors

In this section, I show the existence of a clearing vector for all $0 < \alpha, \beta \leq 1$. I also extend the algorithm proposed by Rogers and Veraart (2013) by including seniority in debt repayment and allowing for a partial liquidation of the project value.[16]

3.4.1 Existence

In analogy with Rogers and Veraart (2013), there always exist a clearing vector of payment and even there can exist multiple solutions to the Equation 3.1 due to the bankruptcy cost introduced in the model. The following lemma exposes this point.

Lemma 1 *For any financial network $(L, \Pi, \theta, e, d, \alpha, \beta)$, an payment equilibrium always exists. Moreover, there exist a greatest and a lowest clearing payment vector $\bar{p}$ and $\underline{p}$, respectively, with $\bar{p}^i \geq p^i \geq \underline{p}^i$ for any clearing payment vector p and any bank i. Moreover, $\bar{p}$ is Pareto dominant, i.e., $\pi_i(\bar{p}) \geq \pi_i(p)$ for every bank i.*

3.4.2 Algorithm

In what follow, I set up an iterative algorithm that determine the greatest expected clearing vector. This algorithm is an extension of the Greatest Clearing Vector Algorithm

[16]The algorithm of Rogers and Veraart (2013) is an extension of Eisenberg and Noe (2001) algorithm which does not account for bankruptcy and liquidation costs.

developed by Rogers and Veraart (2013). In addition to them, I take into account seniority in debt repayment, possibility of partial liquidation and expected return investment.

For a financial system $(L, \Pi, \theta, e, d, \alpha, \beta)$, I determine a sequence of expected payment vectors $(p^{(k)})_{k\in\mathbb{N}}$. This sequence converges in at most n iterations to the greatest clearing vector.

1. k considered as the number of iterations, $p^{(k)}$ the expected vector payment at the iteration k and $\mathcal{I}_k$ and $\mathcal{J}_k$ respectively the set of insolvent banks defaulting on their junior and senior debt at the iteration k. I first start by initializing $k = 0$, $p^{(0)} = L$, $\mathcal{I}_{-1} = \emptyset$ and $\mathcal{J}_{-1} = \emptyset$.

2. For each iteration k, I define respectively the expected total asset and equity of each bank as follow:
$$A_i^{(k)} = \sum_j \pi_{ji} p_j^{(k)} + \theta_i + \alpha e_i$$
$$E_i^{(k)} = A_i^{(k)} - L_i - d_i$$

3. I define 3 different sets:
- $\mathcal{J}_k = \{i \in [\![1, N]\!] \text{ such that } E_i^{(k)} < 0 \text{ and } \beta A_i^{(k)} < d_i\}$. The set of banks that default on their senior debt.
- $\mathcal{I}_k = \{i \in [\![1, N]\!] \text{ such that } E_i^{(k)} < 0 \text{ and } \beta A_i^{(k)} > d_i\}$. The set of insolvent banks that can pay their senior debt.
- $\mathcal{S}_k = \{i \in [\![1, N]\!] \text{ such that } E_i^{(k)} > 0\}$. The set of surviving banks.

4. If $\mathcal{J}_k = \mathcal{J}_{k-1}$ and $\mathcal{I}_k = \mathcal{I}_{k-1}$, the algorithm ends.

5. Else if $\mathcal{J}_k \neq \mathcal{J}_{k-1}$ (or $\mathcal{I}_k \neq \mathcal{I}_{k-1}$),
- $p_i^{(k+1)} = L_i$ for all $i \in \mathcal{S}_k$
- $p_i^{(k+1)} = 0$ for all $i \in \mathcal{J}_k$
- $p_i^{(k+1)} = x_i$ for $i \in \mathcal{I}_k$, such that the $(x_i)_{i\in\mathcal{I}_k}$ are determined by finding the maximal solution to the system of the following linear equations:
$$x_i = \beta \left(\tilde{\theta}_i + \alpha e_i + \sum_{j\in\mathcal{S}_k} \pi_{ji} L_j + \sum_{j\in\mathcal{I}_k} \pi_{ji} x_j \right) - d_i$$

6. I increment by 1 the iteration k, i.e. k = k +1. Then, I go back to steps 2 to 5 to update the different sets and the expected payment vector until the convergence to fixed sets $\mathcal{J}$ and $\mathcal{I}$. When the algorithm terminates, I determine the greatest expected payment vector defined in 3.1.

3.5 A consortium of banks saving one bank

As explained in section 2, the failure of a fundamentally defaulting bank can trigger a cascade of defaults. In this section, I propose to start by presenting a simple case without a cascade of defaults in order to better introduce my framework without adding any mathematical complexity. I consider hence a network formed by a fundamentally defaulting bank, bank $\mathcal{F}$, and a set of surviving banks. bank $\mathcal{F}$ asks its creditors to save it from collapse. These banks form a consortium $\mathcal{R}$, i.e. $\mathcal{R}= \{i \in [\![1, N]\!] \ \textit{such that} \ L_{\mathcal{F}i} \neq 0\}$ and can accept or not the resolution proposal.

The resolution plan consists of a bail-in which is defined as a write down in the debt value.[17] The amount of this haircut is determined by the regulator as in Bernard, Capponi, and Stiglitz (2017).

3.5.1 Bail-in proposal

I consider a sequence of events similar to Goldstein and Huang (2016) extended to a network of banks. This sequence is described as follows:

1. The regulator chooses a disclosure rule (S, g) and publicly announces it ;
2. The asset quality of each bank i, θ_i, is drawn and observed by the regulator and by the bank i itself;
3. The regulator assigns a score s_i to each bank i according to the disclosure rule and publicly announces $s = (s_1, s_2, ..., s_n)$;
4. The fundamentally defaulting bank asks the consortium of surviving banks, $\mathcal{R}$, to accept to write-down its debt;
5. The consortium $\mathcal{R}$ accepts or not to proceed to the bail-in;
6. If surviving banks refuses the bail-in proposal, the government intervenes and proceeds to a bailout but only when the bailout strategy is less costly than the absence of intervention;
7. The payment between banks is made simultaneously in the spirit of Eisenberg and Noe (2001) and the total losses for the regulator are determined.

[17] There are several forms of bail-ins. The most direct way to achieve bail-in is to write down the value of a claim and this is what I consider in this framework. See Wihlborg (2017) for alternative bail-in forms.

In this framework, I assume that the fundamentally defaulting bank can always repay its depositors. This assumption is translated by the fact that $\sum_i \pi_{i\mathcal{F}} L_i + \theta_{\mathcal{F}}^{min} + \alpha e_{\mathcal{F}} \geq d_{\mathcal{F}}$. In addition, the fundamentally defaulting bank cannot lie to the consortium of surviving banks. In particular, bank $\mathcal{F}$ does not ask $\mathcal{R}$ to write down its debt, if a resolution plan is not necessary to rescue it, since $\sum_i \pi_{i\mathcal{F}} L_i + \theta_{\mathcal{F}}^{max} + \alpha e_{\mathcal{F}} < L_{\mathcal{F}} + d_{\mathcal{F}}$.

The surviving banks choose whether or not to accept the bail-in proposal in order to maximize its expected profit based on its information. To take their decision, these banks consider the eventuality of a possible bailout of bank $\mathcal{F}$ by the government if the bail-in proposal is refused. Let $\mu(s)$ be the probability that bank $\mathcal{F}$ will be bailed out by the government. I assume, as in Chapter 2, that this probability is a belief formed by the bank and depends on expected losses in payment of the distressed bank and hence $\mu(s)$ is decreasing in $\mathbb{E}(\theta_{\mathcal{F}} \mid s)$.[18] We can thus have the following form for the bailout probability:

$$\mu(s) = exp\left(-\lambda \frac{p_{\mathcal{F}}(s)}{L_{\mathcal{F}}}\right), \tag{3.7}$$

where λ is a positive constant and $p_{\mathcal{F}}$ is the expected payment of bank $\mathcal{F}$. Hence, when the expected payment tends to 0, the expected payment losses are maximal and the probability of bailout is close to 1. However, when the expected payment is close to the due debt, $L_{\mathcal{F}}$, I assume that λ is small enough to have this probability equal to 0.

I assume that the surviving banks always liquidate a part of their investment to meet their obligations. To take their decision, the healthy banks calculate their expected profit in different cases. Hence, in the case where there is no bail-in, the expected profit of *bank* $i \in \mathcal{R}$ is:

$$\begin{aligned}
\Pi^i_{no-inter}(s) &= \sum_{j \neq \mathcal{F}} \pi_{ji} L_j + p_{\mathcal{F}i}(s) + \theta_i + e_i - (1-\alpha) l_i(s) - d_i - L_i, \qquad (3.8)\\
\text{with } p_{\mathcal{F}i}(s) &= \pi_{\mathcal{F}i}\left[\beta\left(\sum_i \pi_{i\mathcal{F}} L_i + \mathbb{E}\left(\theta_{\mathcal{F}} \mid s\right) + \alpha e_{\mathcal{F}}\right) - d_{\mathcal{F}}\right],\\
\text{and } l_i(s) &= \frac{1}{\alpha}\left[L_i + d_i - \sum_{j \neq \mathcal{F}} \pi_{ji} L_j - p_{\mathcal{F}i}(s) - \theta_i\right].
\end{aligned}$$

Denoting by b_i the amount of the debt write down asked to the *bank* $i \in \mathcal{R}$, the

[18] This probability can also be endogenised here as discussed in Chapter 2.

expected profit of the latter, in the case of bail-in, is:

$$\begin{aligned} \Pi^i_{bail-in}(s) &= \sum_j \pi_{ji} L_j - \mathbb{E}(b_i \mid s) + \theta_i + e_i - (1-\alpha) l'_i(s) - d_i - L_i, \\ \text{with } l'_i(s) &= \frac{1}{\alpha}\left[L_i + d_i - (\sum_j \pi_{ji} L_j - \mathbb{E}(b_i(\theta) \mid s)) - \theta_i \right]. \end{aligned} \tag{3.9}$$

Finally, the profit of a *bank* $i \in \mathcal{R}$ in the case where the regulator proceeds to the bailout of bank $\mathcal{F}$, is:

$$\begin{aligned} \Pi^i_{bailout} &= \sum_j \pi_{ji} L_j + \theta_i + e_i - (1-\alpha) l''_i - d_i - L_i, \\ \text{with } l''_i &= \frac{1}{\alpha}[L_i + d_i - \sum_j \pi_{ji} L_j - \theta_i]. \end{aligned} \tag{3.10}$$

The purpose of banks i $\in \mathcal{R}$ is the maximization of their expected profit, i.e. they accept the rescue bank $\mathcal{F}$ if and only if their expected profit before the bail-in operation is greater than their expected profit in the case where they refuse the bail-in. This translates into :

$$\begin{aligned} & \Pi_{bail-in}(s) \geq \mu(s) \pi^i_{bailout}(s) + (1-\mu(s)) \Pi^i_{no-inter}(s), \\ i.e., \quad & L_{\mathcal{F}i} - \mathbb{E}(b_i \mid s) \geq \mu(s) L_{\mathcal{F}i} + (1-\mu(s)) p_{\mathcal{F}i}(s). \end{aligned} \tag{I}$$

3.5.2 Amount of debt write down

The bail-in amount needed to save the financial networks is equal to $\sum_{i \in \mathcal{R}} b_i = [L_{\mathcal{F}} + d_{\mathcal{F}} - \sum_j \pi_{j\mathcal{F}} L_j - \theta_{\mathcal{F}} - \alpha e_{\mathcal{F}}] + c$. This choice is motivated by the fact that in order to survive, the equity of bank $\mathcal{F}$ must be positive.[19] $\sum_{i \in \mathcal{R}} b_i$ is thus equal to the bank's $\mathcal{F}$ shortfall, to which I add a positive constant c.[20] For simplicity, $\sum_{i \in \mathcal{R}} b_i$ can be expressed as follows:

$$\sum_{i \in \mathcal{R}} b_i = -\theta_{\mathcal{F}} + C \quad \text{with} \quad C > L_{\mathcal{F}} + d_{\mathcal{F}} - \sum_j \pi_{j\mathcal{F}} L_j - \alpha e_{\mathcal{F}}.$$

In addition, I assume that the government wants to transmit information to banks only through the scores that it assigned to each bank. Henceforth the amount of debt writ down considered by the healthy banks, $\mathbb{E}(b_i \mid s)$, is expressed in function of $E(\theta_{\mathcal{F}} \mid s)$ and not of $\theta_{\mathcal{F}}$, which makes it uninformative. The amount of debt write down asked from bank

[19] We assume the strict positivity to let the bank $\mathcal{F}$ operate in the next period, because with equity equal to 0, it can reimburse all its creditors but should liquidate all its projects for doing it.

[20] I do not look for the optimal amount of b_i which is already done in Bernard, Capponi, and Stiglitz (2017).

$i \in \mathcal{R}$ is proportional to the face value of the contracts i.e. $\mathbb{E}(b_i \mid s) = \pi_{\mathcal{F}i} \sum_{i=1}^{n} \mathbb{E}(b_i \mid s)$. Moreover, it is assumed that the bail-in asked by the fundamentally defaulting banks is always feasible, i.e. $(L_i - b_i) + d_i > \sum_j \pi_{ji} L_j + \theta_i + \alpha e_i$, $\forall i \in \mathcal{R}$.

A bank $i \in \mathcal{R}$ accepts the bail-in proposal if and only if bank $\mathcal{F}$ satisfies a certain condition explained in the following lemma.

Lemma 2 *In equilibrium, bank i belonging to the rescue consortium $\mathcal{R}$ accepts to bail-in the fundamentally defaulting bank, bank $\mathcal{F}$, if and only if, it obtains a score s such that $R_{\mathcal{F}}(s) \geq R^*(s)$ with $R^*(s) = \frac{1-\mu(s)}{1-\beta(1-\mu(s))}\beta(\sum_k L_{k\mathcal{F}} + \alpha e_{\mathcal{F}} - d_{\mathcal{F}} - \sum_k L_{\mathcal{F}k}) + \frac{1}{1-\beta(1-\mu(s))}C$.*

The threshold below which the surviving banks are no longer willing to accept the bail-in proposal depends only on bank $\mathcal{F}$ characteristics and hence is the same for all banks in $i \in \mathcal{R}$; i.e. the incentive to bail-in is the same for all banks in $\mathcal{R}$. The higher is the bailout probability, the higher is the threshold $R^*(s)$, i.e., banks in $\mathcal{R}$ accept to save bank $\mathcal{F}$ only if it has a very good asset quality.[21]

The condition established in Lemma 2 can be rewritten as follows $f(R(s)) \geq R^*$ with $f : R(s) \mapsto R(s) + \frac{\mu(s)}{1-\beta}[\beta(\sum_k L_{k\mathcal{F}} + \alpha e_{\mathcal{F}} - R_{\mathcal{F}}(s)) - d_{\mathcal{F}} - \sum_k L_{\mathcal{F}k}]$ and R^* is the value of $R^*(s)$ when $\mu(s)$ is equal to 0. f is continuous and strictly increasing on $\mathbb{R}$ and hence according to the intermediate value theorem and its corollary, it has an inverse function f^{-1}. The condition $f(R(s)) \geq R^*$ is equivalent to $R(s) \geq R^{**}$ with $R^{**} = f^{-1}(R^*)$ since f^{-1} is strictly increasing.[22]

3.5.3 Regulator's disclosure rule

The regulator goal in this framework is to choose a disclosure rule (S, g) that minimizes its ex-ante expected losses. Depending on both the rescue consortium $\mathcal{R}$ and government decisions, this ex-ante expected losses take into account three different type of losses: the losses in the eventuality that the surviving banks do not accept the bail-in, the losses in the eventuality of a bailout by the government and finally the losses in the eventuality of a non-intervention. The welfare function considered in the following extends the corresponding notion introduced by Bernard, Capponi, and Stiglitz (2017), by attributing a weight, γ, to the amount of bail-in granted by the healthy banks. This choice is motivated by the papers of Beck, Da-Rocha-Lopes, and Silva (2021) and Philippon and Salord (2017).

[21] $\frac{\partial R^*(s)}{\partial \mu(s)} > 0$.

[22] $\frac{\partial f}{\partial R(s)} = 1 + \mu(s)\frac{\beta}{1-\beta} + \frac{\lambda}{L_{\mathcal{F}}}\frac{1}{1-\beta}[\beta(\sum_k L_{k\mathcal{F}} + \alpha e_{\mathcal{F}} - R_{\mathcal{F}}(s)) - d_{\mathcal{F}} - \sum_k L_{\mathcal{F}k}] > 0$

Thus, a higher γ considers the significant negative impact of this bail-in to the economy. Conversely, bail-ins have no impact on the economy when γ is set to 0.

-What if the bail-in proposal is accepted. When banks in $\mathcal{R}$ accept the bail-in proposal, the regulator welfare losses are obtained from 3.6 by additionally accounting for the bail-in cost to the economy, and so equal to:

$$\begin{aligned} w_1(\theta_{\mathcal{F}}) &= (1-\alpha)\sum_i l_i + \gamma \sum_{i\in\mathcal{R}} b_i \\ &= \frac{1-\alpha}{\alpha}(\sum_i d_i - \sum_{i\neq\mathcal{F}} \theta_i) - \frac{1-\alpha}{\alpha}\theta_{\mathcal{F}} - \gamma\theta_{\mathcal{F}} + \gamma C. \end{aligned}$$

- What if the regulator intervenes. In a public bailout, the amount spent by the government to save the financial network is $b' = [L_{\mathcal{F}} + d_{\mathcal{F}} - \sum_j \pi_{j\mathcal{F}} L_j - \theta_{\mathcal{F}} - \alpha e_{\mathcal{F}}] + c$. This choice is motivated by the fact that in order to survive, the equity of bank $\mathcal{F}$ must be positive ($c > 0$).[23] For easy of notation and resolution, I assume as previously that $b' = -\theta_{\mathcal{F}} + C$.

In any complete bailout with subsidies b', the regulator losses are equal to :

$$\begin{aligned} w_2(\theta_{\mathcal{F}}) &= (1-\alpha)\sum_i l_i(s) + \delta \sum_i b' \\ &= \frac{1-\alpha}{\alpha}\left[\sum_i d_i - \sum_{i\neq j}\theta_i\right] - \left(\frac{1-\alpha}{\alpha} - \delta\right) C - \delta\theta_{\mathcal{F}}. \end{aligned}$$

- What if no one intervenes. When the fundamentally defaulting bank creditors reject the bail-in proposal and the regulator welfare losses in case of a bailout are lower than its welfare losses in case of a no intervention (i.e. $w_0(\theta_{\mathcal{F}}) > w_2(\theta_{\mathcal{F}})$), bank $\mathcal{F}$ defaults and the regulator welfare losses are the following:

$$\begin{aligned} w_0(\theta_{\mathcal{F}}) &= (1-\alpha)\sum_{i\in\mathcal{R}} l_i(s) + (1-\alpha)e_{\mathcal{F}} + (1-\beta)[\sum_i \pi_{i\mathcal{F}} L_i + \theta_{\mathcal{F}} + \alpha e_{\mathcal{F}}] \\ &= \frac{1-\alpha}{\alpha}\left[\sum_i d_i - \sum_{i\neq\mathcal{F}}\theta_i\right] + \frac{1-\beta}{\alpha}\sum_i \pi_{i\mathcal{F}} L_i + \\ &+ (1-\beta)e_{\mathcal{F}} + (\frac{1-\beta}{\beta} - \frac{1-\alpha}{\alpha})\beta\theta_{\mathcal{F}}. \end{aligned}$$

The condition of no intervention, $w_0(\theta_{\mathcal{F}}) > w_2(\theta_{\mathcal{F}})$, is translated into $\theta_{\mathcal{F}} < \theta^*$ where $\theta^* = \frac{[\alpha(\delta+1)-1]C-(1-\beta)[\sum_i \pi_{i\mathcal{F}} L_i + \alpha e_{\mathcal{F}}]}{\alpha(1+\delta)-\beta}$ and represents a low threshold below which the gov-

[23] Here also I do not look for the optimal amount of b' which is already done in Bernard, Capponi, and Stiglitz (2017).

ernment refuses to proceed to a bailout. This threshold increases for networks where the distressed bank has dense connections.[24]

I focus now in determining disclosure rules (S, g) minimizing the regulator ex-ante expected losses function $\sum_{\theta_{\mathcal{F}} \in \Theta} q(\theta_{\mathcal{F}}) \mathcal{L}(\theta_{\mathcal{F}})$ such that:

$$\mathcal{L}(\theta_{\mathcal{F}}) = \sum_{s:R(s)\geq R^{**}} w_1(s, \theta_{\mathcal{F}})\ g(s \mid \theta_{\mathcal{F}}) + \sum_{s:R(s)<R^{**}} w_2(\theta_{\mathcal{F}}).\mathbb{1}_{\theta_{\mathcal{F}}\geq\theta^*}\ g(s \mid \theta_{\mathcal{F}}) + \sum_{s:R(s)<R^{**}} w_0(\theta_{\mathcal{F}}).\mathbb{1}_{\theta_{\mathcal{F}}<\theta^*}\ g(s \mid \theta_{\mathcal{F}}),$$

where $\mathbb{1}$ is an indicator function.[25] The first term of the previous expression represents the cases where the rescue consortium accepts to proceed to a bail-in. The second term represents the cases where the government proceeds to a bail out. The third term, represents the cases where there is no intervention.

In the following lemma I show that I can focus, without loss of generality, on disclosure rules assigning at most 2 scores, under certain conditions explained in this lemma.

Lemma 3 *Considering a disclosure rule (S, g) and a disclosure rule $(\hat{S}, \hat{g})$ defined by $\hat{S} = \{s_L, s_H\}$, such that $\hat{g}(s_H \mid \theta_{\mathcal{F}}) = \sum_{s:R(s)\geq R^*} g(s \mid \theta_{\mathcal{F}})$ and $\hat{g}(s_L \mid \theta_{\mathcal{F}}) = 1 - \sum_{s:R(s)\geq R^*} g(s \mid \theta_{\mathcal{F}})$. Then the probability that the rescue consortium $\mathcal{R}$ accepts the bail-in operation is the same under the two rules. The value of the regulator's objective function is also the same under both rules.*

Let s_H represents the high type and s_L the low type. I define also $h(\theta_{\mathcal{F}}) := \hat{g}(s_H \mid \theta_{\mathcal{F}})$ the probability that the fundamentally defaulting bank with an asset quality $\theta_{\mathcal{F}}$ obtains the high score.

Lemma 4 *The simplified regulator problem's is to find a function $h : \Theta \longrightarrow [0, 1]$ to*

[24] $\frac{\partial \theta^*}{\partial(\sum_i \pi_{i\mathcal{F}} L_i)} < 0$.

[25] $\mathbb{1}$ is an indicator function such that $\mathbb{1}_{\theta_{\mathcal{F}}\geq\theta^*} = \begin{cases} 1 & \text{if } \theta \geq \theta^*, \\ 0 & \text{otherwise.} \end{cases}$.

maximize:

$$\sum_{\substack{\theta_{\mathcal{F}} \geq \theta^* \\ \theta \in \Theta}} A(\theta_{\mathcal{F}}) q_{\mathcal{F}}(\theta_{\mathcal{F}}) h(\theta_{\mathcal{F}}) + \sum_{\substack{\theta_{\mathcal{F}} < \theta^* \\ \theta_{\mathcal{F}} \in \Theta}} B(\theta_{\mathcal{F}}) q_{\mathcal{F}}(\theta_{\mathcal{F}}) h(\theta_{\mathcal{F}}),$$

subject to

$$\sum_{\theta_{\mathcal{F}} \in \Theta} [\theta_{\mathcal{F}} - R^{**}] q_{\mathcal{F}}(\theta_{\mathcal{F}}) h(\theta_{\mathcal{F}}) \geq 0$$

$$\sum_{\theta_{\mathcal{F}} \in \Theta} [\theta_{\mathcal{F}} - R^{**}] q_{\mathcal{F}}(\theta_{\mathcal{F}}) h(1 - \theta_{\mathcal{F}}) < 0$$

with $A(\theta_{\mathcal{F}}) = \frac{1-\beta}{\alpha}\theta_{\mathcal{F}} - \gamma(C - \theta_{\mathcal{F}}) + \frac{1-\beta}{\alpha}\sum_i \pi_{i\mathcal{F}} L_i + (1-\beta)e_{\mathcal{F}}$.

$$B(\theta_{\mathcal{F}}) = (\delta - \tfrac{1-\alpha}{\alpha} - \gamma)(C - \theta_{\mathcal{F}})$$

The term $A(\theta_{\mathcal{F}})$ represents the potential gain (or loss since $A(\theta_{\mathcal{F}})$ can be negative) for the regulator if bank $\mathcal{F}$ is subject to a bail-in. The term $B(\theta_{\mathcal{F}})$ represents the potential gain (or loss since $B(\theta_{\mathcal{F}})$ can be negative) for the regulator if bank $\mathcal{F}$ is subject to a bail-in when the regulator would have refused the bailout if the healthy bank had refused the bail-in. One way to have $A(\theta_{\mathcal{F}})$ positive is when the bank $\mathcal{F}$ is very connected more precisely here, it is when the amount of credits that is repaid to it by the other banks, $\sum_i \pi_{i\mathcal{F}} L_i$, is important. This term is also positive when liquidation cost is high ($\alpha \to 0$) and/or bail-in cost is low ($\gamma \to 0$). However, it is negative when bail-in cost is high ($\gamma \to +\infty$) and/or bankruptcy cost is very low ($\beta \to 1$.) The term $B(\theta_{\mathcal{F}})$ is positive when the bailout cost is high (i.e., $\delta \to +\infty$). However, it is negative when bail-in and/or liquidation costs are high (i.e., $\gamma \to +\infty$ and/or $\alpha \to 0$).
From the resolution of the problem exposed in Lemma 4, some conclusions can be drawn regarding regulator's transparency. Corollary 1 resumes some.

Corollary 1

- *If* $A(\theta_{\mathcal{F}}) < 0$ *for all* $\theta_{\mathcal{F}} \geq \theta^*$ *and* $B(\theta_{\mathcal{F}}) < 0$ *for all* $\theta_{\mathcal{F}} < \theta^*$.
  1- Full disclosure is optimal if and only if $\theta_{\mathcal{F}}^{max} < R^{**}$.
  2- No disclosure is optimal if and only if $\mathbb{E}(\tilde{\theta_{\mathcal{F}}}) < R^{**}$.
  3- If $\mathbb{E}(\tilde{\theta_{\mathcal{F}}}) \geq R^{**}$ *then partial disclosure is optimal.*

- *If* $A(\theta_{\mathcal{F}}) > 0$ *for all* $\theta_{\mathcal{F}} \geq \theta^*$ *and* $B(\theta_{\mathcal{F}}) > 0$ *for all* $\theta_{\mathcal{F}} < \theta^*$.
  1- Full disclosure is optimal if and only if $\theta_{\mathcal{F}}^{min} \geq R^{**}$.
  2- No disclosure is optimal if and only if $\mathbb{E}(\tilde{\theta_{\mathcal{F}}}) \geq R^{**}$.
  3- If $\mathbb{E}(\tilde{\theta_{\mathcal{F}}}) < R^{**}$ *then partial disclosure is optimal.*

From this corollary, I can conclude that full disclosure may be desirable in some cases but not in others. These results not only depend on different costs (bail-in, bailout,

liquidation and bankruptcy costs) but also they are driven by the network structure and density. For instance, When the fundamentally defaulting bank has dense connections ($A(\theta_{\mathcal{F}}) > 0 \ \forall \ \theta_{\mathcal{F}} \geq \theta^*$), the regulator wants to encourage bail-ins. To this end, in normal time ($\mathbb{E}(\tilde{\theta_{\mathcal{F}}}) \geq R^{**}$), the regulator's disclosure rule must be non-informative. hence $\mathbb{E}(\tilde{\theta_{\mathcal{F}}} \mid s)$ is equal to $\mathbb{E}(\tilde{\theta_{\mathcal{F}}})$ and banks in $\mathcal{R}$ accept to rescue bank $\mathcal{F}$ since $R_{\mathcal{F}}(s) \geq R^{**}$.

In the special case, where the possible realisations of the asset quality of bank $\mathcal{F}$ are greater then the threshold R^{**} ($\theta_{\mathcal{F}}^{min} \geq R^{**}$), the regulator may convince the consortium rescue to proceed to the bail-in by being completely transparent.

3.6 A consortium of banks saving a group of banks: complete interventions

In this section, I am interested in studying the possible default of more than one bank in the absence of intervention by the surviving banks or the government. Indeed, when fundamentally defaulting banks $\mathcal{F}$ are hit by a shock (a realisation of bad asset qualities in this framework), they can not reimburse their liabilities even when other banks fully repay them. This in turn leads to the default of the banks in distress $\mathcal{D}$.[26] Hence, when banks in $\mathcal{F}$ are saved, the financial system is saved. Otherwise, dropping all the banks in $\mathcal{F}$ (or some of them) can cause a cascade of defaults throughout the financial system. I propose to study complete intervention, i.e. interventions where the rescue consortium or the government save all the fundamentally defaulting banks. I make the hypothesis that we know in advance to which group each bank belongs independently of the realisation of $\tilde{\theta}_i$. Therefore, for every bank i in the set of the fundamentally defaulting banks, $\theta_i^{max} < L_i + d_i - \sum_i \pi_{ji} L_j - \alpha e_i$. However for every bank i in the set of the defaulting banks, $\theta_i^{min} > L_i + d_i - \sum_i \pi_{ji} L_j - \alpha e_i$ and $\theta_i^{max} < L_i + d_i - \sum_{i \in \mathcal{S}} \pi_{ji} L_j - \sum_{i \in \mathcal{I}} \pi_{ji} p_j(\theta_j^{max}) - \alpha e_i$.[27] And finally, for every bank i belonging to the set of the surviving banks, $\theta_i^{min} > L_i + d_i - \alpha e_i$.[28]

3.6.1 Bail-in game

The same sequence of events and the same assumptions of Section 3.5 are maintained except that here the banks concerned by the rescue are all banks in the set $\mathcal{F}$ and the rescue consortium is composed of banks in the set $\mathcal{D} \cup \mathcal{S}$. I assume that every bank

[26] It's important to recall that these banks can honor their engagements if they are fully paid by their counterparties.

[27] θ_i^{max} is expressed so to have banks i that do not belong to the set of surviving banks defaulting even if they receive the maximum possible payments ($\sum_{i \in \mathcal{I}} \pi_{ji} p_j(\theta_j^{max})$).

[28] This means that these banks survive even if they do not receive any money from other banks.

$i \in \mathcal{D}$ accepts a feasible bail-in proposal for fear of failure. Nevertheless a surviving bank $i \in \mathcal{S}$ can accept or not the rescue operation. This decision depends on the information disclosed by the regulator regarding the asset quality of banks $\mathcal{F}$ and $\mathcal{D}$. As previously, only feasible bail-ins are considered, i.e. $(L_i - b_i) + d_i > \sum_j \pi_{ji} L_j + \theta_i + \alpha e_i$, $\forall i \in \mathcal{R}$, where b_i is the amount of debt-write down asked to bank i.

The bailout probability of the financial system is denoted by $\mu(s)$. I assume, as previously, that this probability increases exponentially with the payment losses suffered by the banks. Mathematically, this probability is given by:[29]

$$\mu(s) = exp\left(-\lambda \frac{\sum_{i \notin \mathcal{S}} p_i(s)}{\sum_{i \notin \mathcal{S}} L_i}\right), \tag{3.11}$$

Maximizing its expected profit, a surviving bank i accepts to bail-in fundamentally defaulting banks if and only if:

$$\begin{aligned} &\sum_k L_{ki} - \mathbb{E}(b_i \mid s) \geq \mu(s) \sum_k L_{ki} + (1 - \mu(s)) \sum_k p_{ki}(s) \\ \text{i.e. } &\sum_{k \notin \mathcal{S}} L_{ki} - \mathbb{E}(b_i \mid s) \geq \mu(s) \sum_{k \notin \mathcal{S}} L_{ki} + (1 - \mu(s)) \sum_{k \notin \mathcal{S}} p_{ki}(s) \end{aligned} \tag{I_c}$$

The more intense the cascade of defaults, the more a surviving bank i is likely to agree to rescue fundamentally failing banks even if they are not directly linked. Indeed, the default of banks in $\mathcal{F}$ leads to the collapse of other banks and these cascading defaults become all the more costly for the surviving banks especially when the failure cost is high.[30] For instance, a surviving bank will never agree to rescue a bank in $\mathcal{I}$ if it does not trigger other banks defaults.

The total amount of the bail-in corresponds to the sum of shortfalls of fundamentally defaulting banks, for which I add a positive constant, c, so that these banks can operate in the next period. Hence, $\sum_{i \in \mathcal{R}} b_i = \sum_{i \in \mathcal{F}} [L_i + d_i - \sum_j \pi_{ji} L_j - \theta_i - \alpha e_i] + c = -\sum_{i \in \mathcal{F}} \theta_i + C$ with $C > [L_i + d_i - \sum_j \pi_{ji} L_j - \alpha e_i]$.

3.6.2 Derivation of the regulator's problem

We proceed as previously, to determine the expected losses of the regulator in different scenarios:

- When the bail-in proposal is accepted.

[29] The same assumptions made about μ in the previous section are kept.

[30] In fact, when there is less banks in $\mathcal{I}$, $\sum_{k \notin \mathcal{S}} \mathbb{E}(p_{ki} \mid s)$ decreases. Indeed, A defaulting bank i reduces the payments to its creditors, thereby imposing expected losses $[L_i - E(p_i|s)]^+$ to the rest of the financial system.

When banks in $\mathcal{R}$accept the bail-in proposal, the regulator expected welfare losses, given the assets' quality vector θ are the following:

$$\begin{aligned} w_1(\theta) &= (1-\alpha)\sum_i \text{ł}_i + \gamma \sum_{i\notin\mathcal{F}} b_i \\ &= \frac{1-\alpha}{\alpha}(\sum_i d_i - \sum_i \theta_i) - \gamma \sum_{i\in\mathcal{F}} \theta_i + \gamma C. \end{aligned}$$

- When the regulator bailout banks in $\mathcal{F}$.

Similar to the previous section, I assume that the amount of the subsidies, b', spent by the government to save fundamentally defaulting banks is defined as follow: $b' = -\sum_{i\in\mathcal{F}}\theta_i + C$. In any complete bailout with subsidies b', the regulator welfare losses, given assets' quality vector θ, are the following :

$$\begin{aligned} w_2(\theta) &= (1-\alpha)\sum_i l_i + \delta b' \\ &= \frac{1-\alpha}{\alpha}\left[\sum_i d_i - \sum_{i\notin\mathcal{F}}\theta_i\right] - \delta\sum_{i\in\mathcal{F}}\theta_i - \left(\frac{1-\alpha}{\alpha} - \delta\right)C. \end{aligned}$$

- When there is no intervention.

If no party intervenes in the rescue of the fundamentally defaulting banks and if a cascade of defaults is triggered, the regulator welfare losses, given assets' quality vector θ, are the following:

$$\begin{aligned} w_0(\theta) &= (1-\alpha)\sum_i l_i + (1-\beta)\sum_{i\notin\mathcal{S}}(\sum_j p_{ji} + \theta_i + \alpha e_i) + \delta\sum_{i\notin\mathcal{S}}\eta_i \\ &= \frac{1-\alpha}{\alpha}\sum_{i\in\mathcal{S}}(L_i + d_i - \theta_i) + [(1-\alpha)+(1-\beta)\alpha]\sum_{i\notin\mathcal{S}} e_i - \beta\delta\alpha\sum_{i\in\mathcal{J}} e_i \\ &+ \delta\sum_{i\in\mathcal{J}} d_i + (1-\alpha)\sum_{i\in\mathcal{S}}\sum_j p_{ji} + (1-\beta)\sum_{i\in I}\sum_j p_{ji} - \delta\beta\sum_{i\in\mathcal{J}}\sum_j p_{ji} \\ &+ (1-\beta)\sum_{i\notin\mathcal{S}}\theta_i - \delta\beta\sum_{i\in\mathcal{J}}\theta_i \end{aligned}$$

- Bailout Vs. no intervention.

When the rescue consortium refuses the bail-in proposal, the regulator proceeds to the bailout of the fundamentally defaulting banks if losses in the bailout are smaller that losses in a cascade of defaults, i.e. when $w_0 \geq w_2$. This condition is translated into $\mathcal{N}(\theta) \geq \mathcal{N}^*$.

The regulator's problem, as previously, is to select a disclosure rule (S, g) minimizing

its ex-ante expected losses $\sum_{\theta\in\Theta} P(\theta)\mathcal{L}(\theta)$ such that:

$$\mathcal{L}(\theta) = \sum_{s:\ \forall i\in\mathcal{R};\ X_i(s)\geq X_i^*} w_1(s,\theta)\ m(s\mid\theta) + \sum_{s:\ \exists i\in\mathcal{R};\ X_i(s)<X_i^*} w_2(\theta).\mathbb{1}_{\mathcal{N}(\theta)\geq\mathcal{N}^*}\ m(s\mid\theta)$$
$$+ \sum_{s:\ \exists i\in\mathcal{R};\ X_i(s)<X_i^*} w_0(\theta).\mathbb{1}_{\mathcal{N}(\theta)<\mathcal{N}^*}\ m(s\mid\theta),$$

Where $m(s\mid\theta) = g(s\mid\theta_1)\times...\times g(s\mid\theta_{|\mathcal{F}|+|\mathcal{D}|})$ and $P(\theta) = q_i(\theta_1)\times...\times q_{|\mathcal{F}|+|\mathcal{D}|}(\theta_{|\mathcal{F}|+|\mathcal{D}|})$. The first term of the previous expression represents the cases where all banks in the rescue consortium $\mathcal{R}$accept to proceed to a bail-in. The second term represents the cases where, at least one bank in $\mathcal{R}$does not accept the bail-in and so the government proceeds to a bail out. The third term, represents the cases where there is no intervention by either the government or the banks in $\mathcal{R}$. Lemma 5 states a simplified form of this regulator problem.

Lemma 5 *The regulator's problem reduces to the selection of a disclosure rule* (S,g) *maximizing:*

$$\sum_{\theta:\ \mathcal{N}(\theta)<\mathcal{N}^*} A(\theta)P(\theta) \sum_{s:\forall i\in\mathcal{R};\ X_i(s)\geq X_i^*} m(s\mid\theta) + \sum_{\theta:\ \mathcal{N}(\theta)\geq\mathcal{N}^*} B(\theta)P(\theta) \sum_{s:\forall i\in\mathcal{R};\ X_i(s)\geq X_i^*} m(s\mid\theta),$$

with:

$$\begin{aligned} A(\theta) &= \frac{1-\alpha}{\alpha}\sum_{i\in\mathcal{S}} L_i - \frac{1-\alpha}{\alpha}\sum_{i\in\mathcal{I}} d_i + (\delta - \frac{1-\alpha}{\alpha})\sum_{i\in\mathcal{J}} d_i - \gamma C \\ &+ [(1-\alpha)+(1-\beta)\alpha]\sum_{i\notin\mathcal{S}} e_i - \beta\delta\alpha\sum_{i\in\mathcal{J}} e_i \\ &+ (1-\alpha)\sum_{i\in\mathcal{S}}\sum_j p_{ji} + (1-\beta)\sum_{i\in\mathcal{I}}\sum_j p_{ji} - \delta\beta\sum_{i\in\mathcal{J}}\sum_j p_{ji} \\ &- \delta\beta\sum_{i\in\mathcal{J}}\theta_i + \gamma\sum_{i\in\mathcal{F}}\theta_i + (\frac{1-\alpha}{\alpha}+1-\beta)\sum_{i\notin\mathcal{S}}\theta_i \end{aligned}$$

and $B(\theta) = (\delta - \frac{1-\alpha}{\alpha} - \gamma)(C - \sum_{i\in\mathcal{F}}\theta_i)$.

The term $A(\theta)$ represents the potential gain (or loss) for the regulator if fundamentally defaulting banks are subject to a bail-in. The term $B(\theta)$ represents the potential gain (or loss) for the regulator if fundamentally defaulting banks are subject to a bail-in when the regulator would have refused the bailout if the rescue consortium had refused the bail-in.

Since solving this problem is complicated, I propose in the following section to restrict myself to a simpler framework in order to draw some conclusions.

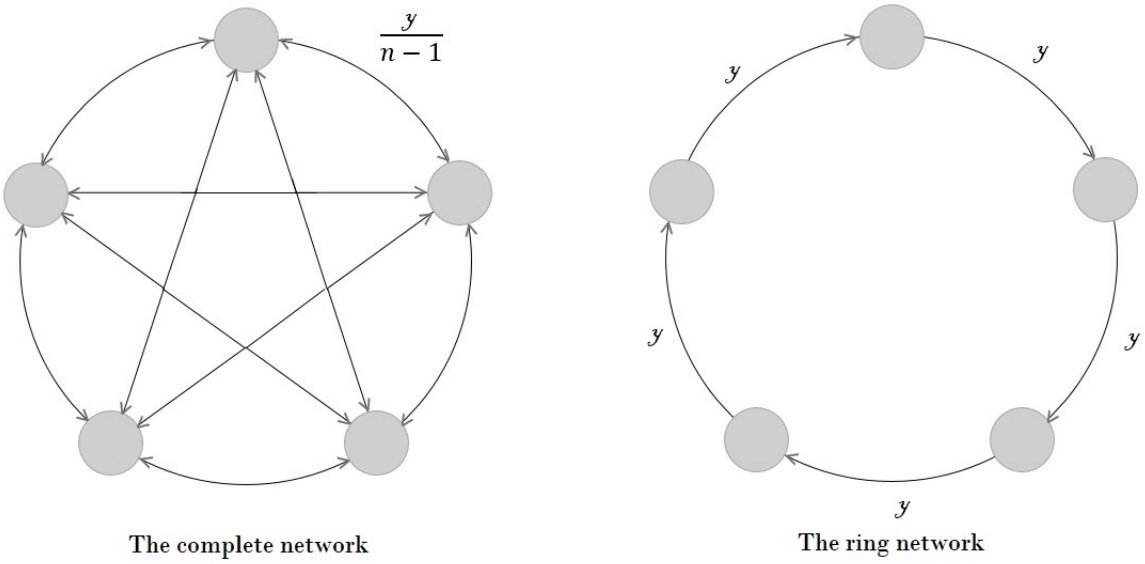
3.7 Results in specific Networks

Regulator's optimal strategy not only depends on the number of fundamentally defaulting banks and on the different costs introduced in the model, but also on the structure of the financial network. To illustrate the relation between the optimal decisions of healthy banks and the regulator and the network structure simply and clearly, I initially assume that there is exactly one fundamentally defaulting bank and one surviving bank, i.e. $|\mathcal{F}| = 1$ and $|\mathcal{S}| = 1$.

In what follows, I consider that banks are identical such that for every bank i, $e_i = e$ and $d_i = d$ and that the fundamentally defaulting bank can fully reimburse its senior creditor.

In this section, I consider only regular networks. Regular networks are networks where banks have identical interbank claims and liabilities, i.e. for all banks i, $\sum_j \pi_{ji} L_j = \sum_j \pi_{ij} L_j = y$. I focus on regular networks in this section to simplify the calculation and have results more related to the network structure. In what follows, I am interested in ring and complete networks as illustrated in figure 3.1. They represent respectively the regular networks with sparsest and more dense connections.

Figure 3.1: The Ring and Complete Networks



3.7.1 Ring Network

A ring regular network $(L, \Pi, \theta, e, d, \alpha, \beta)$ is a network where each bank i connects to exactly two other nodes, a creditor $i + 1$ and a borrower $i - 1$. The liabilities matrix

$L \in \mathbb{R}^{n\times n}$ is defined as following

$$L = \begin{pmatrix} 0 & y & 0 & \dots & & 0 \\ 0 & 0 & y & 0 & \dots & 0 \\ \vdots & & \ddots & \ddots & & \vdots \\ 0 & \dots & & 0 & y & 0 \\ y & 0 & \dots & & & 0 \end{pmatrix}$$

In some specific cases there is no impact of the disclosure rule on surviving banks decisions. The regular ring network with certain specifications represents one such case. In fact, if all the defaulting banks can not reimburse their senior debt and are direct neighbors of surviving banks, there is no incentive to the latter to bail-in these banks, because the bail-in amount is more important than their due liability, i.e: $L < E(b_i \mid s)$ for any disclosure rule announced by the regulator. In fact, in this case, the bail-in amount is equal to $E(b_i \mid s) = L + c(s)$, with $c(s) > 0$ and hence condition (I_c) can never be verified since $y - E(b_i \mid s) < 0$ and $\mu(s)L > 0$.

Moving to a more broader framework and without loss of generality, I assume that bank 1 is a fundamentally defaulting bank but can reimburse its senior creditors (i.e. $p_{12} > 0$). Then, banks in $\mathcal{D}$ trail bank 1 to form together a chain of banks of length $|\mathcal{I}|$. I determine by induction the value of the expected payment of bank $|\mathcal{I}|$, to its creditor, a bank in $\mathcal{S}$, when $|\mathcal{I}| > 1$ as illustrated in Lemma 6.[31]

Lemma 6 *In a regular ring network, the expected payment of the last bank in default, to its sole creditor is equal to:*

$$p_{|\mathcal{I}|,|\mathcal{I}|+1}(s) = \sum_{i=1}^{|\mathcal{I}|} \beta^{|\mathcal{I}|-i+1}\, \mathbb{E}(\theta_i \mid s) + \beta^{|\mathcal{I}|} y + \sum_{i=0}^{|\mathcal{I}|-1} \beta^i(\beta\alpha e - d)$$

The bail-in condition (I_c) becomes then :

$$(1-\mu(s))y + \frac{1}{|\mathcal{I}|}(\mathbb{E}(\theta_1 \mid s) - C) \geq (1-\mu(s))\Big[\sum_{i=1}^{|\mathcal{I}|} \beta^{|\mathcal{I}|-i+1}\, \mathbb{E}(\theta_i \mid s) + \beta^{|\mathcal{I}|} y + \sum_{i=0}^{|\mathcal{I}|-1} \beta^i(\beta\alpha e - d)\Big]$$

[31] $|x|$ represents the cardinal of the set x, i.e. the number of elements of x. I recall that $\mathcal{I}$ represents the set of insolvent banks that can pay their senior debt.

3.7.2 Complete Network

A complete regular network $(L, \Pi, \theta, e, d, \alpha, \beta)$, is a fully connected network where all the liabilities of a bank i are held in the same proportion by all other banks. The liabilities matrix $L \in \mathbb{R}^{n\times n}$ is hence defined as following:

$$L = \begin{pmatrix} 0 & \frac{y}{n-1} & \cdots & \frac{y}{n-1} \\ \frac{y}{n-1} & 0 & \ddots & \vdots \\ \vdots & \ddots & \ddots & \frac{y}{n-1} \\ \frac{y}{n-1} & \cdots & \frac{y}{n-1} & 0 \end{pmatrix}$$

For $|I| = 2$, it is simple to verify that the expected payment of bank $i \in I$ is equal to: $p_i(s) = \frac{1}{1-\frac{\beta^2}{4}}[\beta\,\mathbb{E}(\theta_i \mid s) + \frac{\beta^2}{2}\,\mathbb{E}(\theta_j \mid s)] + \frac{1}{1-\frac{\beta}{2}}[\beta(\alpha e + \frac{y}{2}) - d]$, for $j \neq i$ *and* $j \in I$.
For each bank $i \in I$ such that $|I| > 2$, I determine, by induction, in Appendix F the value of the expected payment vector of a defaulting bank $i \in \mathcal{I}$ to its creditor as stated in the following lemma.

Lemma 7 *In a complete regular network, the expected payment vector of a defaulting bank $i \in \mathcal{I}$ to its creditor, such that $|I| > 2$ and $(1 + \frac{\beta}{n-1})(1 - (|I| - 1)\frac{\beta}{n-1}) \neq 0$, is equal to:*

$p_i(s) = \psi_1 a_i(s) + \psi_2 \sum_{j\in\mathcal{I}} a_j(s)$

with:

- $a_i(s) = \beta(\mathbb{E}(\theta_i \mid s) + \alpha e_i + |\mathcal{S}|\frac{y}{n-1}) - d_i$
- $\psi_1 = \frac{1-(|I|-2)\frac{\beta}{n-1}}{(1+\frac{\beta}{n-1})(1-(|I|-1)\frac{\beta}{n-1})}$
- $\psi_2 = \frac{\frac{\beta}{n-1}}{(1+\frac{\beta}{n-1})(1-(|I|-1)\frac{\beta}{n-1})}$

Without loss of generality, I assume that bank 1 is the fundamentally defaulting bank. Hence, the bail-in condition (I_c) becomes: [32]

$$(1-\mu(s))y + \frac{1}{n-1}(\mathbb{E}(\theta_1 \mid s) - C) \geq \frac{(1-\mu(s))}{n-1-(|\mathcal{I}|-1)\beta}\left[\beta(\sum_{i\in\mathcal{I}}\mathbb{E}(\theta_i \mid s) + |\mathcal{I}|(\alpha e + |\mathcal{S}|\frac{y}{n-1})) - |\mathcal{I}|d\right]$$

3.7.3 Comparison of the two networks formed by three banks

For simplicity, in this section, I look at networks composed of three banks: a fundamentally defaulting bank, bank $\mathcal{F}$, a distressed bank, bank $\mathcal{D}$, and a surviving one, bank $\mathcal{S}$.

[32] Since I consider that it exists only a surviving bank, $n - 1 = |\mathcal{I}|$.

Incentive to bail out. If the regulator or the rescue consortium does not intervene to save the fundamentally defaulting bank, a cascade of defaults is triggered and the regulator welfare losses, given assets quality vector θ, are the following:

$$\begin{aligned} w_0(\theta) &= (1-\beta)(\theta_{\mathcal{F}}+\theta_{\mathcal{D}}) - \frac{1-\alpha}{\alpha}\theta_{\mathcal{S}} + \frac{1-\alpha}{\alpha}d \\ &+ \left[\frac{1-\alpha}{\alpha} - (1-\beta)\right] y + 2\left[(1-\alpha) + (1-\beta)\alpha\right] e \\ &+ (1-\beta)\left[p_{\mathcal{FD}} + p_{\mathcal{DF}}\right] - \frac{1-\alpha}{\alpha}\left[p_{\mathcal{FS}} + p_{\mathcal{DS}}\right]. \end{aligned}$$

The incentive to bail out in the ring network and in the complete network depends on the different parameters of the model. However, I show in Lemma 8 that when the losses in the asset value of the fundamentally defaulting bank due to bankruptcy cost (i.e. $(1-\beta)(\theta_{\mathcal{F}}+\alpha e+y)$) are larger than the surplus of the distressed bank if there were no cascade of defaults (i.e. $\theta_{\mathcal{D}}+\alpha e-d$), the incentive to bailout is stronger in ring networks.

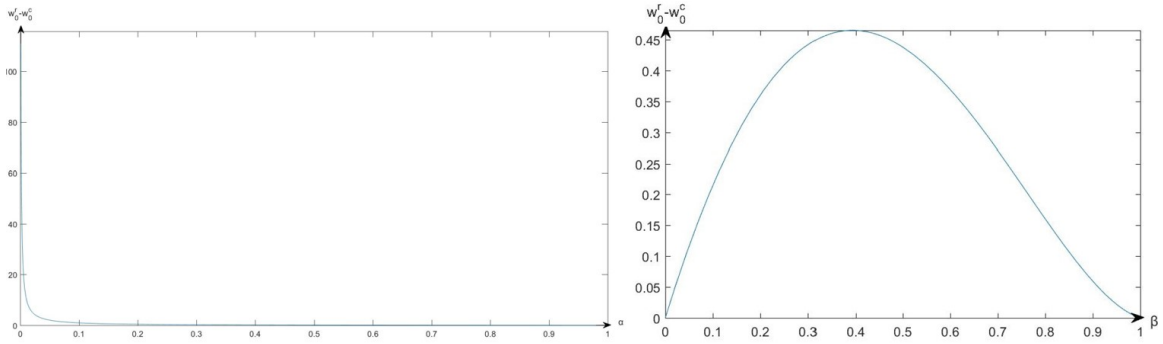
Lemma 8 *When $\theta_{\mathcal{F}} > \theta^*_{\mathcal{F}}$, the incentive to bailout is stronger in ring networks. However when $\theta_{\mathcal{F}} < \theta^*_{\mathcal{F}}$, this incentive to bailout is higher in complete networks.*

The condition $\theta_{\mathcal{F}} > \theta^*_{\mathcal{F}}$ translates the case when the asset value of the fundamentally defaulting bank due to bankruptcy cost are larger than the surplus of the distressed bank if there were no cascade of defaults (i.e. $\theta_{\mathcal{D}}+\alpha e+y < (1-\beta)(\theta_{\mathcal{F}}+\alpha e+y)$). This condition can be verified when the fundamentally defaulting bank is hit by a small shock (i.e. realisation of a good asset quality: $\theta_{\mathcal{F}}$ is high). Hence, in case of shocks of high intensity, the incentive to bailout is stronger in complete networks. Indeed, as shown by Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015), the complete network allows shocks absorption in case of small shocks and amplify them if they are of large intensity. This result is also consistent with the findings of Bernard, Capponi, and Stiglitz (2017); the credibility of the regulator to not bailout improves as the shock grows larger in sparsely connected networks.

It can be also interesting to study the variation of the regulator welfare losses in the ring and complete networks, in a cascade of defaults, as a function of the bankruptcy and liquidation costs. I show in Corollary 2 that in case of shocks of low intensity, the difference between the regulator welfare losses in the ring and the complete networks depends on the value of bankruptcy cost, β. However, this difference is decreasing in the liquidation costs α. This result is also illustrated graphically in Figure 3.2.

Corollary 2 *In the case of a cascade of defaults, when $\theta_{\mathcal{F}} > \theta^*_{\mathcal{F}}$, the difference between the regulator welfare losses in the ring and the complete networks is decreasing in the liquidation costs.*

Figure 3.2: The difference between the welfare losses of the regulator in the ring and the complete networks.



Note: The two charts present the difference between the regulator welfare losses in the ring and the complete networks,$w_0^r - w_0^c$, on α and β, when $\theta_{\mathcal{F}} > \theta^*_{\mathcal{F}}$. This difference is decreasing in α and is nonmonotonic in β. However, it is always positive as states in Lemma 8.

Incentive to bail-in. To simply draw some conclusions, I assume here that the probability of bailout is null. The bail-in condition, respectively for the ring and the complete network, is the following:

$$y + \frac{1}{2}\Big[\,\mathbb{E}(\theta_{\mathcal{F}}|s) - C\Big] \geq \Big[\beta^2\,\mathbb{E}(\theta_{\mathcal{F}}|s) + \beta\,\mathbb{E}(\theta_{\mathcal{D}}|s) + (1+\beta)(\beta\alpha e - d) + \beta^2 y$$

$$y + \frac{1}{2}\Big[\,\mathbb{E}(\theta_{\mathcal{F}}|s) - C\Big] \geq \frac{1}{2-\beta}\Big[\beta\,\mathbb{E}(\theta_{\mathcal{F}}|s) + \beta\,\mathbb{E}(\theta_{\mathcal{D}}|s) + 2(\beta\alpha e - d) + \beta y\Big]$$

The incentive to bail-in is stronger when the fundamentally defaulting bank has a good asset quality (high $\mathbb{E}(\theta_{\mathcal{F}} \mid s)$).[33] However, the regulator is discouraged from making bail-ins when the distressed banks has a good asset quality (high $\mathbb{E}(\theta_{\mathcal{D}} \mid s)$). I show also in Lemma 9 that the incentive to bail-in is stronger in ring networks when the fundamentally defaulting bank is hit by a small shock. In fact, losses are lower in complete networks since this structure allows shocks absorption when these shocks are of low intensity as shown by Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015).

Lemma 9 *When there is no potential bailout and when $\theta_{\mathcal{F}} > \theta^*_{\mathcal{F}}$, the incentive to bail-in is stronger in sparser network. However when $\theta_{\mathcal{F}} < \theta^*_{\mathcal{F}}$, the incentive to bail-in is higher in complete networks.*

[33]This result is verified when $\beta > \frac{2}{3}$.

This result can be generalised for some specific networks, if we consider that each bank can represent a group of banks with the same characteristics and each group has the same specifications.[34]

Without loss of generality, the bail-in condition can be expressed as following: $\rho(\theta, s) = f_1\,\mathbb{E}(\theta_{\mathcal{F}} \mid s) - f_2\,\mathbb{E}(\theta_{\mathcal{D}} \mid s) \geq R^*$ with f_1 and f_2 two positive constants that depend on β, for every $\beta < \frac{2}{3}$. I suppose that this last condition still holds in the following.

Regulator disclosure rule. I show, in this part, that the optimal disclosure of the regulator depends on the different banks characteristics, on the network structure and on different costs introduced in the model. To draw some simple conclusions, I assume here that the probability of bailout is null.

The regulator's problem reduces to the selection of a disclosure rule (S, g) maximizing:

$$\sum_{\theta\in\Theta} A(\theta) q_{\mathcal{F}}(\theta_{\mathcal{F}}) q_{\mathcal{D}}(\theta_{\mathcal{D}}) \sum_{s:\rho(\theta,s)\geq R^*} g(s_{\mathcal{F}} \mid \theta_{\mathcal{F}}) g(s_{\mathcal{D}} \mid \theta_{\mathcal{D}}),$$

with:

$A(\theta) = A^r(\theta) = \frac{1-\beta^2}{\alpha}[\theta_{\mathcal{F}} + y + \alpha e] + \frac{1-\beta}{\alpha}[\theta_{\mathcal{D}} + \alpha e - d] - \gamma(C - \theta_{\mathcal{F}})$, for a ring network.

$A(\theta) = A^c(\theta) = \frac{2(1-\beta)}{\alpha(2-\beta)}[\theta_{\mathcal{F}} + y + \alpha e] + \frac{2(1-\beta)}{\alpha(2-\beta)}[\theta_{\mathcal{D}} + \alpha e - d] - \gamma(C - \theta_{\mathcal{F}})$, for a complete network.

Unlike section 3.5, the regulator may need to assign more than 2 scores for each bank to distinguish among the possible linear combination of the assets quality (of banks $\mathcal{F}$ and $\mathcal{D}$). The following Lemma exposes some conclusions under optimal disclosure rule. These results depend on whether the regulator has some gain when the bail-in takes place ($A(\theta) > 0,\ \forall\theta \in \Theta$) or not ($A(\theta) < 0,\ \forall\theta \in \Theta$).

Lemma 10 *Under an optimal disclosure rule:*

- *when $A(\theta) > 0$ for all $\theta \in \Theta$*

  1. *Let $\theta = (\theta^i_{\mathcal{F}}, \theta^j_{\mathcal{D}})$ such that $f_1\theta^i_{\mathcal{F}} - f_2\theta^j_{\mathcal{D}} \geq R^*$, then the fundamentally defaulting bank is bailed -in with probability 1.*
  2. *Let $\theta = (\theta^i_{\mathcal{F}}, \theta^j_{\mathcal{D}})$ such that $f_1\theta^i_{\mathcal{F}} - f_2\theta^j_{\mathcal{D}} \geq R^*$. If the defaulting banks with the couple of asset quality $\theta = (\theta^i_{\mathcal{F}}, \theta^j_{\mathcal{D}})$ obtain the score $s = (s_{\mathcal{F}}, s_{\mathcal{D}})$, then the bail-in takes place whenever a couple of asset quality receives the score s.*

[34] This means that there are three groups of banks: a group of fundamentally defaulting banks(with positive payments for all banks), $\mathcal{F}$, a group of distressed banks, $\mathcal{D}$, and a group of surviving banks $\mathcal{S}$, such that $\alpha\sum_{i\in\mathcal{F}} e_i = \alpha\sum_{i\in\mathcal{D}} e_i = \alpha\sum_{i\in\mathcal{S}} e_i$ and $\sum_{i\in\mathcal{F}} d_i = \sum_{i\in\mathcal{D}} d_i = \sum_{i\in\mathcal{S}} d_i$.

- *when* $A(\theta) < 0$ *for all* $\theta \in \Theta$

  1. *Let* $\theta = (\theta^i_{\mathcal{F}}, \theta^j_{\mathcal{D}})$ *such that* $f_1\theta^i_{\mathcal{F}} - f_2\theta^j_{\mathcal{D}} < R^*$*, then the bail-in proposal is refused with probability 1.*
  2. *Let* $\theta = (\theta^i_{\mathcal{F}}, \theta^j_{\mathcal{D}})$ *such that* $f_1\theta^i_{\mathcal{F}} - f_2\theta^j_{\mathcal{D}} < R^*$*. If the defaulting banks with the couple of asset quality* $\theta = (\theta^i_{\mathcal{F}}, \theta^j_{\mathcal{D}})$ *obtain the score* $s = (s_{\mathcal{F}}, s_{\mathcal{D}})$*, then a cascade of defaults is triggered whenever a couple of asset quality receives the score* s*.*

Lemma 10 exposes some of the regulator behaviors under optimal disclosure rules. For instance, whenever the couple of defaulting banks has assets quality, $(\theta^i_{\mathcal{F}}, \theta^j_{\mathcal{D}})$, that verify $f_1\theta^i_{\mathcal{F}} - f_2\theta^j_{\mathcal{D}} \geq R^*$, the regulator sends signal that encourage the rescue of fundamentally defaulting banks and this rescue occurs with probability 1, which avoids a cascade of defaults and saves the financial system.

The following lemma exposes when there should be less or more disclosure depending on the different framework characteristics.

Lemma 11

- *when* $A(\theta) > 0$ *for all* $\theta \in \Theta$

  1. *Full disclosure is optimal if and only if* $f_1\theta^{min}_{\mathcal{F}} - f_2\theta^{max}_{\mathcal{D}} \geq R^*$*.*
  2. *No disclosure is optimal if and only if* $f_1\,\mathbb{E}(\tilde{\theta}_{\mathcal{F}}) - f_2\,\mathbb{E}(\tilde{\theta}_{\mathcal{D}}) \geq R^*$*.*
  3. *If* $f_1\,\mathbb{E}(\tilde{\theta}_{\mathcal{F}}) - f_2\,\mathbb{E}(\tilde{\theta}_{\mathcal{D}}) < R^*$ *then partial disclosure is optimal.*

- *when* $A(\theta) < 0$ *for all* $\theta \in \Theta$

  1. *Full disclosure is optimal if and only if* $f_1\theta^{max}_{\mathcal{F}} - f_2\theta^{min}_{\mathcal{D}} < R^*$*.*
  2. *No disclosure is optimal if and only if* $f_1\,\mathbb{E}(\tilde{\theta}_{\mathcal{F}}) - f_2\,\mathbb{E}(\tilde{\theta}_{\mathcal{D}}) < R^*$*.*
  3. *If* $f_1\,\mathbb{E}(\tilde{\theta}_{\mathcal{F}}) - f_2\,\mathbb{E}(\tilde{\theta}_{\mathcal{D}}) \geq R^*$ *then partial disclosure is optimal.*

As shown in Section 3.5, disclosure may be desirable in some cases but not in others. For instance, when the bail-in is costly to the regulator (i.e., $A(\theta) < 0$), it sends signals to discourage the surviving bank from bailing-in the fundamentally defaulting bank, because its rescue would be very costly to the economy. Indeed, the healthy bank, thinking that the fundamentally defaulting bank has a high chance of having a poor asset quality and that the distressed bank has a high chance to have a good one (i.e. $f_1\,\mathbb{E}(\tilde{\theta}_{\mathcal{F}}) - f_2\,\mathbb{E}(\tilde{\theta}_{\mathcal{D}}) < R^*$), will not accept the bail-in proposal. In this case, a strategy of no disclosure minimizes

its ex-ante expected losses whereas full disclosure is required when $f_1\theta_{\mathcal{F}}^{max} - f_2\theta_{\mathcal{D}}^{min} < R^*$.

When comparing $A^r(\theta)$ and $A^c(\theta)$, I find that $A^r(\theta) > A^c(\theta)$ for shocks of low intensity (i.e. $\theta_{\mathcal{F}} > \theta_{\mathcal{F}}^*$). This means that the regulator is more likely to disclose information that promotes bail-ins in ring networks since complete networks allow for shocks absorption and so its losses are lower in this network structure. The fact that $A^r(\theta) > A^c(\theta)$ can lead us to cases where we could have $A^r(\theta) > 0$ and $A^c(\theta) < 0$. As a consequence, the regulator should adopt two different strategies of disclosure depending in the network structure. For instance, in this case and when on average bank $\mathcal{F}$ is suspected of having poor asset quality and bank $\mathcal{D}$ is presumed to have good asset quality, more disclosure is needed in ring networks.[35] In fact, in this case, the regulator may disclose some information when it is faced to a ring network to promote bail-ins according to Lemma 11. However, for complete network, it wants to dissuade the healthy bank from bailing-in the fundamentally defaulting bank by not disclosing information.

3.8 Conclusion

In this paper, I consider a network of N banks that can be hit by a negative shock and study how the regulator should use the information at its disposal to prevent from cascade of defaults in some cases by minimizing its ex-ante expected losses.

In my model, there are three groups of banks: fundamentally defaulting banks, that are hit by a shock and can not reimburse their creditors even if they are fully repaid by all other banks, distressed banks, that can default only because they are not reimbursed by the precedent group of banks, and surviving banks that are holding well. The fundamentally defaulting banks ask their creditors to write down their debt for insuring their ability to survive over the next periods. The distressed banks accept always the bail-in proposal. However, the surviving banks take their decision after maximizing their expected profits, which depend, inter alia, on the information disclosed by the government about the asset quality of other banks and on the network structure. I show that the more intense the cascade of defaults is, the more a surviving bank is likely to agree to rescue fundamentally defaulting banks even if they are not directly linked, when the bailout probability is not significant. I show also that the incentive to bail-in is stronger in less densely connected networks in case of negative small shocks and when there is no possible bailout.

The regulator in this model plays the role of a social planner and gives information (a

[35] More precisely, when $f_1^c\,\mathbb{E}(\tilde{\theta}_{\mathcal{F}}) - f_2^c\,\mathbb{E}(\tilde{\theta}_{\mathcal{D}}) < R_c^*$, since the incentive to bail-in is stronger in ring networks.

set of scores) about the defaulting banks (fundamentally defaulting banks and distressed banks) assets quality to the healthy banks. To select its optimal disclosure rule, the regulator minimizes its ex-ante expected losses,which depends on a set of costs: a bankruptcy cost, a liquidation cost, a bailout cost and a bail-in cost. Depending on the circumstances of the case, the regulator would like to favor one of the three following situations: bail-in, bailout, or no intervention. I show that the regulator threat of not rescuing the defaulting banks is less credible in ring networks when faced to shocks of low intensity. I show also that full disclosure is not always the optimal strategy. For instance, studying a network of three banks (a fundamentally defaulting bank, a distressed bank and a surviving one), I show that when the bail-in is costly to the regulator, it sends signals to discourage the surviving bank from bailing-in the fundamentally defaulting bank. Hence, when the surviving bank, thinks that in average the fundamentally defaulting bank has a high chance of having a poor asset quality and that the distressed bank has a high chance to have a good one, it will not accept the bail-in proposal whenever the regulator adopt a strategy of no disclosure.

I show also that the optimal disclosure rules not only depend on different costs but also they are driven by network structure and density. Indeed, in some cases when on average the fundamentally defaulting bank is suspected of having a poor asset quality and the distressed one is presumed to have good asset quality, more disclosure is needed in ring networks.

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Appendices

Appendix E

Section 3.5 proofs

Lemma A.1. The regulator's problem reduces to the selection of a disclosure rule (S, g) maximizing:

$$\sum_{\substack{\theta_{\mathcal{F}} \geq \theta^* \\ \theta_{\mathcal{F}} \in \Theta_{\mathcal{F}}}} A(\theta_{\mathcal{F}}) q(\theta_{\mathcal{F}}) \sum_{s:R(s) \geq R^{**}} g(s \mid \theta_{\mathcal{F}}) + \sum_{\substack{\theta_{\mathcal{F}} < \theta^* \\ \theta_{\mathcal{F}} \in \Theta_{\mathcal{F}}}} B(\theta_{\mathcal{F}}) q(\theta_{\mathcal{F}}) \sum_{s:R(s) \geq R^{**}} g(s \mid \theta_{\mathcal{F}}),$$

with $A(\theta_{\mathcal{F}}) = \frac{1-\beta}{\alpha}\theta_{\mathcal{F}} - \gamma(C - \theta_{\mathcal{F}}) + \frac{1-\beta}{\alpha}\sum_k L_{k\mathcal{F}} + (1-\beta)e_{\mathcal{F}}$.

$B(\theta_{\mathcal{F}}) = (\delta - \frac{1-\alpha}{\alpha} - \gamma)(C - \theta_{\mathcal{F}})$.

We define also the gain-to-cost ratio such that for every $\theta_{\mathcal{F}} \in \Theta_4 \cup \Theta_5$, we have :

$$G(\theta_{\mathcal{F}}) = \begin{cases} G_1(\theta_{\mathcal{F}}) = \frac{A(\theta_{\mathcal{F}})}{R^* - \theta_{\mathcal{F}}} & if\ \theta_{\mathcal{F}} < \theta^*, \\ G_2(\theta_{\mathcal{F}}) = \frac{B(\theta_{\mathcal{F}})}{R^* - \theta_{\mathcal{F}}} & if\ \theta_{\mathcal{F}} \geq \theta^*. \end{cases}$$

The following proposition summarize the different solutions for the regulator problem.

Proposition A.2. The optimal disclosure rule for the regulator is the following:

- *When* $A(\theta_{\mathcal{F}}) < 0$ *for all* $\theta_{\mathcal{F}} < \theta^*$ *and* $B(\theta_{\mathcal{F}}) < 0$

  1. If $\mathbb{E}(\tilde{\theta_{\mathcal{F}}}) < R^{**}$, then $h(\theta_{\mathcal{F}}) = 0\ \forall \theta_{\mathcal{F}} \in \Theta_{\mathcal{F}}$.
  2. If $\mathbb{E}(\tilde{\theta_{\mathcal{F}}}) \geq R^{**}$ then:
     $h(\theta_{\mathcal{F}}) = \begin{cases} 0 \text{ if, for all } \theta_{\mathcal{F}} \in \Theta_{\mathcal{F}},\ \theta_{\mathcal{F}} < R^{**} \text{ or } \theta_{\mathcal{F}} \geq R^{**} \text{ and } G(\theta_{\mathcal{F}}) > G^{**}, \\ 1 \text{ if, for all } \theta_{\mathcal{F}} \in \Theta_{\mathcal{F}},\ \theta_{\mathcal{F}} \geq R^{**} \text{ and } G(\theta_{\mathcal{F}}) < G^{**}, \end{cases}$

     where G^{**} is the highest $G \in G(\Theta_{\mathcal{F}})$ that satisfies:

     $$\sum_{\theta_{\mathcal{F}} \in \Theta_{\mathcal{F}}} q(\theta_{\mathcal{F}})(\theta_{\mathcal{F}} - R^{**}) + \sum_{\theta_{\mathcal{F}} \geq R^*: G(\theta_{\mathcal{F}}) < G} q(\theta_{\mathcal{F}})(\theta_{\mathcal{F}} - R^{**}) \leq 0,$$

     if such G exists; otherwise, $G^{**} \equiv \min_{\theta_{\mathcal{F}} \geq R^*} G(\theta_{\mathcal{F}})$. If $G(\theta_{\mathcal{F}}) = G^{**}$, then $h(\theta_{\mathcal{F}}) \in [0, 1)$ is set such that the second condition of the regulator problem is equal to zero.

- *When* $A(\theta_{\mathcal{F}}) > 0$ *for all* $\theta_{\mathcal{F}} < \theta^*$ *and* $B(\theta) > 0$

  1. If $\mathbb{E}(\tilde{\theta_{\mathcal{F}}}) \geq R^{**}$, then $h(\theta_{\mathcal{F}}) = 1 \ \forall \theta_{\mathcal{F}} \in \Theta_{\mathcal{F}}$.
  2. If $\mathbb{E}(\tilde{\theta_{\mathcal{F}}}) \geq R^{**}$ then:
     $h(\theta_{\mathcal{F}}) = \begin{cases} 1 \text{ if, for all } \theta_{\mathcal{F}} \in \Theta_{\mathcal{F}},\ \theta_{\mathcal{F}} \geq R^{**} \text{ or } \theta_{\mathcal{F}} < R^{**} \text{ and } G(\theta_{\mathcal{F}}) > G^*, \\ 0 \text{ if, for all } \theta_{\mathcal{F}} \in \Theta_{\mathcal{F}},\ \theta_{\mathcal{F}} < R^{**} \text{ and } G(\theta_{\mathcal{F}}) < G^*, \end{cases}$

     where G^* is the lowest $G \in G(\Theta_{\mathcal{F}})$ that satisfies:

     $$\sum_{\theta_{\mathcal{F}} \geq R^{**}} q(\theta_{\mathcal{F}})(\theta_{\mathcal{F}} - R^{**}) + \sum_{\theta_{\mathcal{F}} < R^{**} : G(\theta_{\mathcal{F}}) > G} q(\theta_{\mathcal{F}})(\theta_{\mathcal{F}} - R^{**}) \leq 0,$$

     if such G exists; otherwise, $G^* \equiv \max_{\theta_{\mathcal{F}} \geq R^{**}} G(\theta_{\mathcal{F}})$. If $G(\theta_{\mathcal{F}}) = G^*$, then $h(\theta_{\mathcal{F}}) \in [0, 1)$ is set such that the first condition of the regulator problem is equal to zero.

The proof of this proposition and other results in Section 3.5 and 3.6 are similar to the proofs in Chapter 2.

□

Appendix F

Section 3.7 proofs

Lemma 7 (proof). The proof is by induction.

Suppose that the statement is true for $|\mathcal{I}| - 1$, and let's proof that it is true for $|\mathcal{I}|$.

According to the algorithm in Section 2, for $|\mathcal{I}|$ banks that have positive payments, we have the following set of equations:

$$(II) \begin{cases} p_1 = a_1(s) + \frac{\beta}{n-1}p_2 + \frac{\beta}{n-1}p_3 + ... + \frac{\beta}{n-1}p_{|\mathcal{I}|} \\ p_2 = a_2(s) + \frac{\beta}{n-1}p_1 + \frac{\beta}{n-1}p_3 + ... + \frac{\beta}{n-1}p_{|\mathcal{I}|} \\ ... \\ p_{|\mathcal{I}|} = a_{|\mathcal{I}|}(s) + \frac{\beta}{n-1}p_1 + \frac{\beta}{n-1}p_2 + ... + \frac{\beta}{n-1}p_{|\mathcal{I}|-1} \end{cases}$$

This system is equivalent to:

$$(II) \begin{cases} p_1(s) = \frac{a_1(s)+\frac{\beta}{n-1}a_{|\mathcal{I}|}(s)}{1-(\frac{\beta}{n-1})^2} + \frac{\frac{\beta}{n-1}}{1-\frac{\beta}{n-1}} \sum_{\substack{i=1 \\ i\neq 1}}^{i=|\mathcal{I}|-1} p_i(s) \\ p_2(s) = \frac{a_2(s)+\frac{\beta}{n-1}a_{|\mathcal{I}|}(s)}{1-(\frac{\beta}{n-1})^2} + \frac{\frac{\beta}{n-1}}{1-\frac{\beta}{n-1}} \sum_{\substack{i=1 \\ i\neq 2}}^{i=|\mathcal{I}|-1} p_i(s) \\ ... \\ p_{|\mathcal{I}|}(s) = a_{|\mathcal{I}|}(s) + \frac{\beta}{n-1} \sum_{\substack{i\in\mathcal{I} \\ i\neq|\mathcal{I}|}} p_i(s) \end{cases}$$

Applying the induction hypothesis for the |I| - 1 payments, we obtain :

$$\begin{cases} p_1(s) = \phi_1 \frac{a_1(s)+\frac{\beta}{n-1}a_{|\mathcal{I}|}(s)}{1-(\frac{\beta}{n-1})^2} + \phi_2 \sum_{\substack{i=1 \\ i\neq 1}}^{i=|\mathcal{I}|-1} \frac{a_i(s)+\frac{\beta}{n-1}a_{|\mathcal{I}|}(s)}{1-(\frac{\beta}{n-1})^2} \\ p_2(s) = \phi_1 \frac{a_2(s)+\frac{\beta}{n-1}a_{|\mathcal{I}|}(s)}{1-(\frac{\beta}{n-1})^2} + \phi_2 \sum_{\substack{i=1 \\ i\neq 2}}^{i=|\mathcal{I}|-1} \frac{a_i(s)+\frac{\beta}{n-1}a_{|\mathcal{I}|}(s)}{1-(\frac{\beta}{n-1})^2} \\ ... \\ p_{|\mathcal{I}|}(s) = a_{|\mathcal{I}|}(s) + \frac{\beta}{n-1} \sum_{\substack{i\in\mathcal{I} \\ i\neq|\mathcal{I}|}} p_i(s) \end{cases}$$

$$\text{with} \begin{cases} \phi_1 = \frac{1-(|I|-3)\frac{\frac{\beta}{n-1}}{1-\frac{\beta}{n-1}}}{(1+\frac{\frac{\beta}{n-1}}{1-\frac{\beta}{n-1}})(1-(|I|-2)\frac{\frac{\beta}{n-1}}{1-\frac{\beta}{n-1}})} \\ \phi_2 = \frac{\frac{\frac{\beta}{n-1}}{1-\frac{\beta}{n-1}}}{(1+\frac{\frac{\beta}{n-1}}{1-\frac{\beta}{n-1}})(1-(|I|-2)\frac{\frac{\beta}{n-1}}{1-\frac{\beta}{n-1}})} \end{cases}$$

and end up with the desired result:

$$(II)\begin{cases} p_1 = \frac{a_1(s)+\frac{\beta}{n-1}a_{|\mathcal{I}|}(s)}{1-(\frac{\beta}{n-1})^2} + \frac{\frac{\beta}{n-1}}{1-\frac{\beta}{n-1}}(p_2+p_3+...+p_{|\mathcal{I}|-1}) \\ p_2 = \frac{a_2(s)+\frac{\beta}{n-1}a_{|\mathcal{I}|}(s)}{1-(\frac{\beta}{n-1})^2} + \frac{\frac{\beta}{n-1}}{1-\frac{\beta}{n-1}}(p_1+p_2+...+p_{|\mathcal{I}|-1}) \\ ... \\ p_{|\mathcal{I}|} = a_{|\mathcal{I}|}(s) + \frac{\beta}{n-1}p_1 + \frac{\beta}{n-1}p_2 + ... + \frac{\beta}{n-1}p_{|\mathcal{I}|-1} \end{cases}$$

□

Lemma 8 and Corollary 2 (proof).
I first show that the difference between the regulator welfare losses in the complete and the ring networks is the following:

$$\begin{aligned} w_0^c(\theta) - w_0^r(\theta) &= (1-\beta)\left[\frac{\beta}{2-\beta}(\theta_{\mathcal{F}}+\theta_{\mathcal{D}}+2\alpha e+y) - \frac{2}{2-\beta}d - \beta(\theta_{\mathcal{D}}+\alpha e+y)+d\right] \\ &+ \frac{1-\alpha}{\alpha}[\beta^2(\theta_{\mathcal{D}}+\alpha e+y)+\beta(\theta_{\mathcal{D}}+\alpha e)-(1+\beta)d \\ &- \frac{\beta}{2-\beta}(\theta_{\mathcal{F}}+\theta_{\mathcal{D}}+2\alpha e+y)+\frac{2}{2-\beta}d] \\ &= \frac{1-\beta}{2-\beta}\frac{\beta}{\alpha}\left[(\theta_{\mathcal{D}}+\alpha e-d)-(1-\beta)(\theta_{\mathcal{F}}+\alpha e+y)\right]. \end{aligned}$$

This difference is negative when $\theta_{\mathcal{F}} > \theta^*_{\mathcal{F}}$ with $\theta^*_{\mathcal{F}} = \frac{\theta_{\mathcal{D}}+\alpha e-d}{1-\beta} - (\alpha e+y)$.

$\frac{\partial(w_0^c(\theta)-w_0^r(\theta))}{\partial\alpha} = \frac{-1}{\alpha}(w_0^c(\theta)-w_0^r(\theta)) + \frac{1-\beta}{2-\beta}\frac{\beta^2}{\alpha}e > 0, \quad \forall \ \ \theta_{\mathcal{F}} > \theta^*_{\mathcal{F}}.$

□

Lemma 9 (proof). Let B_r and B_c be respectively the lower bounds of the bail-in condition for the ring and the complete network

$$B_r = \left[\beta^2\,\mathbb{E}(\theta_{\mathcal{F}}|s) + \beta\,\mathbb{E}(\theta_{\mathcal{D}}|s) + (1+\beta)(\beta\alpha e - d) + \beta^2 y\right.$$

$$B_c = y + \frac{1}{2}\Big[\,\mathbb{E}(\theta_{\mathcal{F}}|s) - C\Big] \geq \frac{1}{2-\beta}\Big[\beta\,\mathbb{E}(\theta_{\mathcal{F}}|s) + \beta\,\mathbb{E}(\theta_{\mathcal{D}}|s) + 2(\beta\alpha e - d) + \beta y\Big]$$

The calculation of the difference between the two lower bounds gives:

$$\begin{aligned} \Delta &= B_r - B_c \\ &= -\frac{\beta(1-\beta)}{(2-\beta)}\Big[(\theta_{\mathcal{D}}+\alpha e-d)-(1-\beta)(\theta_{\mathcal{F}}+\alpha e+y)\Big] \end{aligned}$$

Δ is positive when $\theta_{\mathcal{F}} > \theta^*_{\mathcal{F}}$ with $\theta^*_{\mathcal{F}} = \frac{\theta_{\mathcal{D}}+\alpha e-d}{1-\beta} - (\alpha e+y)$. Hence, under this condition, the incentive to bail-in is stronger in ring networks.

□

Lemma 10 (proof). Let *(S,g)* be an optimal disclosure rule.

Part 1: $A(\theta) > 0$ for all $\theta \in \Theta$.

1. Suppose that it exists a couple of asset quality $\theta' = (\theta'_{\mathcal{F}}, \theta'_{\mathcal{D}})$ such that $f_1\theta'_{\mathcal{F}} - f_2\theta'_{\mathcal{D}} \geq R^*$ and a score $s' = (s'_{\mathcal{F}}, s'_{\mathcal{D}}) \in S$ such that $g(s'_{\mathcal{F}}, \theta'_{\mathcal{F}}) > 0$ and $g(s'_{\mathcal{D}}, \theta'_{\mathcal{D}}) > 0$ and suppose that in this case the fundamentally defaulting bank is not bailed-in when it obtains the score $s'_{\mathcal{F}}$ and the distressed bank obtains the score $s'_{\mathcal{D}}$.
Construct an alternative rule as follow:

   - $S = S \cup \{\tilde{s}\}$ with $\tilde{s} = (\tilde{s}_{\mathcal{F}}, \tilde{s}_{\mathcal{D}})$
   - For $\theta_{\mathcal{F}} \neq \theta'_{\mathcal{F}}$; $\tilde{g}(s_{\mathcal{F}} \mid \theta_{\mathcal{F}}) = \begin{cases} g(s_{\mathcal{F}} \mid \theta_{\mathcal{F}}) & if\ s_{\mathcal{F}} \neq \tilde{s}_{\mathcal{F}}, \\ 0 & if\ s_{\mathcal{F}} = \tilde{s}_{\mathcal{F}}. \end{cases}$

     and $\tilde{g}(s_{\mathcal{F}} \mid \theta'_{\mathcal{F}}) = \begin{cases} g(s'_{\mathcal{F}} \mid \theta'_{\mathcal{F}}) & if\ s_{\mathcal{F}} \neq \tilde{s}_{\mathcal{F}}, \\ 0 & if\ s_{\mathcal{F}} = s'_{\mathcal{F}}, \\ g(s_{\mathcal{F}} \mid \theta'_{\mathcal{F}}) & if\ s_{\mathcal{F}} \notin \{s'_{\mathcal{F}}, \tilde{s}_{\mathcal{F}}\}. \end{cases}$
   - For $\theta_{\mathcal{D}} \neq \theta'_{\mathcal{D}}$; $\tilde{g}(s_{\mathcal{D}} \mid \theta_{\mathcal{D}}) = \begin{cases} g(s_{\mathcal{D}} \mid \theta_{\mathcal{D}}) & if\ s_{\mathcal{D}} \neq \tilde{s}_{\mathcal{D}}, \\ 0 & if\ s_{\mathcal{D}} = \tilde{s}_{\mathcal{D}}. \end{cases}$

     and $\tilde{g}(s_{\mathcal{D}} \mid \theta'_{\mathcal{D}}) = \begin{cases} g(s'_{\mathcal{D}} \mid \theta'_{\mathcal{D}}) & if\ s_{\mathcal{D}} \neq \tilde{s}_{\mathcal{D}}, \\ 0 & if\ s_{\mathcal{D}} = s'_{\mathcal{D}}, \\ g(s_{\mathcal{D}} \mid \theta'_{\mathcal{D}}) & if\ s_{\mathcal{D}} \notin \{s'_{\mathcal{D}}, \tilde{s}_{\mathcal{D}}\}. \end{cases}$

   Under the disclosure rule $(\tilde{S}, \tilde{g})$, only the couple of asset quality $\theta' = (\theta'_{\mathcal{F}}, \theta'_{\mathcal{D}})$ obtains the score $s' = (s'_{\mathcal{F}}, s'_{\mathcal{D}})$. Hence,

$$\tilde{R}_{\mathcal{F}}(\tilde{s}_{\mathcal{F}}) = \frac{\sum_{\theta_{\mathcal{F}} \in \Theta_{\mathcal{F}}} \theta_{\mathcal{F}} q(\theta_{\mathcal{F}}) \tilde{g}\left(\tilde{s}_{\mathcal{F}} \mid \theta_{\mathcal{F}}\right)}{\sum_{\theta_{\mathcal{F}} \in \Theta_{\mathcal{F}}} q(\theta_{\mathcal{F}}) \tilde{g}\left(\tilde{s}_{\mathcal{F}} \mid \theta_{\mathcal{F}}\right)} = \frac{\theta'_{\mathcal{F}} q(\theta'_{\mathcal{F}}) \tilde{g}\left(s'_{\mathcal{F}} \mid \theta'_{\mathcal{F}}\right)}{q(\theta'_{\mathcal{F}}) \tilde{g}\left(s'_{\mathcal{F}} \mid \theta'_{\mathcal{F}}\right)} = \theta'_{\mathcal{F}}.$$

   In the same vein $\tilde{R}_{\mathcal{D}}(\tilde{s}_{\mathcal{D}}) = \theta'_{\mathcal{D}}$. Using the bail-in condition, the fundamentally defaulting bank is saved when banks $\mathcal{F}$ and $\mathcal{D}$ obtains respectively scores $\tilde{s}_{\mathcal{F}}$ and $\tilde{s}_{\mathcal{D}}$ (because in this case, I obtains $f_1\tilde{R}_{\mathcal{F}}(\tilde{s}_{\mathcal{F}}) - f_2\tilde{R}_{\mathcal{D}}(\tilde{s}_{\mathcal{D}}) = f_1\theta'_{\mathcal{F}} - f_2\theta'_{\mathcal{D}} \geq R^*$). As for the other scores, under this disclosure rule $\tilde{R}_i(s_i) = R_i(s_i)$, for all $i \in \{\mathcal{F}, \mathcal{D}\}$, then the behaviour of the surviving bank, when observing these scores, remains unchanged under $(\tilde{S}, \tilde{g})$. It is clear at this stage that under the new disclosure rule $(\tilde{S}, \tilde{g})$, the expected payoff of the regulator increases (since the payoff for the couple of asset quality $\theta' = (\theta'_{\mathcal{F}}, \theta'_{\mathcal{D}})$ is increased), which contradicts the optimality of (S, g).

2. Since $f_1\theta_{\mathcal{F}} - f_2\theta_{\mathcal{D}} \geq R^*$, then from the precedent result, the bail-in takes place when banks $\mathcal{F}$ and $\mathcal{D}$ obtains respectively the scores $s_{\mathcal{F}}$ and $s_{\mathcal{D}}$. Then from the bail-i condition, we have in this case, $f_1R_{\mathcal{F}}(s_{\mathcal{F}}) - f_2R_{\mathcal{D}}(s_{\mathcal{D}}) \geq R^*$). According to this, it is clear that the financial system is saved upon assigning a score s to the defaulting banks.

Part 2: $A(\theta) < 0$ for all $\theta \in \Theta$.
1. I proceed in a similar way to show this part. Suppose that it exists a couple of asset quality $\theta' = (\theta'_{\mathcal{F}}, \theta'_{\mathcal{D}})$ such that $f_1\theta'_{\mathcal{F}} - f_2\theta'_{\mathcal{D}} < R^*$ and a score $s' = (s'_{\mathcal{F}}, s'_{\mathcal{D}}) \in S$ such that $g(s'_{\mathcal{F}}, \theta'_{\mathcal{F}}) > 0$ and $g(s'_{\mathcal{D}}, \theta'_{\mathcal{D}}) > 0$ and suppose that in this case the fundamentally defaulting bank is bailed-in when it obtains the score $s'_{\mathcal{F}}$ and the distressed bank obtains the score $s'_{\mathcal{D}}$.
I consider the same alternative rule $(\tilde{S}, \tilde{g})$, and for the same reasons mentioned previously,

I obtain $f_1\tilde{R}_{\mathcal{F}}(\tilde{s}_{\mathcal{F}}) - f_2\tilde{R}_{\mathcal{D}}(\tilde{s}_{\mathcal{D}}) = f_1\theta'_{\mathcal{F}} - f_2\theta'_{\mathcal{D}} < R^*$. Hence the surviving bank refuses the bail-in proposal for the couple of asset quality θ' when it observes the score $\tilde{s}$, which increases the regulator welfare (since $A(\theta') < 0$) and contradicts the optimality of (S, g).
2. The proof is similar to the first part.

Lemma 11 (proof).
Part 1: $A(\theta) > 0$ for all $\theta \in \Theta$

1. Under full disclosure, scores assigned to the defaulting banks are such $R_{\mathcal{F}}(s_{\mathcal{F}}) = \theta_{\mathcal{F}}$ and $R_{\mathcal{F}}(s_{\mathcal{D}}) = \theta_{\mathcal{D}}$. Hence, $f_1 R_{\mathcal{F}}(s_{\mathcal{F}}) - f_2 R_{\mathcal{D}}(s_{\mathcal{D}}) = f_1\theta_{\mathcal{F}} - f_2\theta_{\mathcal{D}}$ and since $f_1\theta_{\mathcal{F}} - f_2\theta_{\mathcal{D}} > f_1\theta_{\mathcal{F}}^{min} - f_2\theta_{\mathcal{D}}^{max}$, the surviving bank accepts the bail-in proposal with probability 1.

2. Under no disclosure, $R_i(s_i) = \mathbb{E}(\tilde{\theta}_i)$, $\forall \;\; i \in \{\mathcal{F}, \mathcal{D}\}$ and $s \in S$. Hence, $f_1 R_{\mathcal{F}}(s_{\mathcal{F}}) - f_2 R_{\mathcal{D}}(s_{\mathcal{D}}) = f_1\,\mathbb{E}(\tilde{\theta_{\mathcal{F}}}) - f_2\,\mathbb{E}(\tilde{\theta_{\mathcal{D}}}) \geq R^*$, then bailing-in the distressed bank with probability 1 is optimal, since $A(\theta) > 0$.

3. On the one hand, under no disclosure, $R_i(s_i) = \mathbb{E}(\tilde{\theta}_i)$, $\forall \;\; i \in \{\mathcal{F}, \mathcal{D}\}$ and $s \in S$. Hence, if $f_1\,\mathbb{E}(\tilde{\theta_{\mathcal{F}}}) - f_2\,\mathbb{E}(\tilde{\theta_{\mathcal{D}}}) < R^*$, then bailing-in the distressed bank with probability 0 is not optimal. On the other hand, if $f_1\,\mathbb{E}(\tilde{\theta_{\mathcal{F}}}) - f_2\,\mathbb{E}(\tilde{\theta_{\mathcal{D}}}) < R^*$, then $f_1\theta_{\mathcal{F}}^{min} - f_2\theta_{\mathcal{D}}^{max} < R^*$ ($\theta_i^{min} < \mathbb{E}(\tilde{\theta}_i) < \theta_i^{max}$), Hence according to 1, Full disclosure is not optimal. So, the only way to achieve the optimal loss is partial disclosure.

Part 2: The proof here is similar to the first part.

□

General Conclusion

This thesis contributes to the literature on systemic risk by proposing news mechanisms to address some of the current prudential regulation shortcomings, to strengthen the stability of the financial system with minimal cost to taxpayers and to the economy. Indeed, the financial and economic crisis started in summer 2007 highlighted the need to renew the regulatory approach of the financial system by incorporating a macroprudential perspective to go beyond the micro-focus on the risk of individual institution that characterised previous prudential regulation (Brunnermeier, Crockett, Goodhart, Persaud, and Shin, 2009). In this sense, Supervision and regulation should become more macroprudential, focusing on the stability of the financial system as a whole and its relationship with the wider economy (Freixas, Laeven, and Peydró, 2015). Effective arrangements for the authorities to take preventive measures have thus been put in place through the setting of Basel III regulation as well as the US financial reform under the Dodd Frank Act (DFA) and the European financial reform under the Bank Recovery and Resolution Directive (BRRD).

While efforts have been made and there has been a great deal of progress in the prudential regulatory framework since the great financial crisis, there are still challenges that the regulator has to face and shortfalls in the current regulation that need to be filled. In that regard, it needs to continue to work on the design and implementation of macroprudential policy and its interaction with existing macroeconomic policies, in particular monetary policy. This thesis seeks to contribute to filling some of these gaps to better strengthen the stability of the financial system. Its main aims have hence been (i) to verify whether policies inspired by unconventional central bank policies can address macroprudential objectives and to propose an optimal way to implement them to minimise systemic risk, (ii) to examine the optimal information to be disclosed by the regulator on banks health in order to limit the cost of its intervention during banks resolution operations by proposing bail-ins and bailouts, and (iii) to study the impact of the financial network structure and density on the decisions of banks involved in bail-ins as well as on the decisions of the regulator regarding information disclosure when it intervenes in resolu-

tion mechanisms. Each of the three chapters has respectively developed one of these goals.

Chapter 1 offers a new approach to assess theoretically and empirically central banks interventions. Indeed, one of the criticisms levelled at the current regulation is that it does not take sufficient account of the interaction between monetary policy and macroprudential policy. I hence introduce a central bank in the contagion model proposed by Greenwood, Landier, and Thesmar (2015), where contagion is due to fire sales, and study how the central bank, by using redesigned unconventional policies, namely an Asset purchase policy and a Refinancing Operation, can optimally address macroprudential objectives. In a theoretical study, I showed for two banks having the same portfolio composition, the total budget of the central bank should go to the bank with the highest leverage ratio. I find also that, for an optimal Refinancing Operation, the bank with the highest *connectedness*-to-leverage ratio benefits from the most important loan. The connectedness, in this context, expresses the extent to which the bank holds illiquid assets and/or assets that are widely held by other banks in the financial system. Thereafter, applying my framework to European banks during the sovereign debt crisis, I confirm the efficiency of this two reshaped unconventional monetary policies since they considerably lower systemic risk and show that an asset purchase policy is more effective when the central bank buys specific sovereign debts.

The best attribute of the used model is its simplicity and adaptability to simulate these policies with real data. Nevertheless, it would be interesting to enrich the model and account for counterparty risk to study the question raised in this chapter. In fact, such a framework is more suitable for the study of a Refinancing Operation.

Chapter 2 proposes to transpose the mechanism set up by the Single Resolution Mechanism into a theoretical framework, more precisely a Bayesian persuasion game, and studies how the regulator should use information at its disposal to ensure the financial stability when it is confronted to resolution issue (through proposing bail-ins and bailouts). Indeed, another shortfall of the current regulation is the absence of communication policy from the institution in charge of macroprudential regulation. We hence propose a model with incomplete information where a distressed bank asks its creditor, a healthy bank, to reduce its debt. Given the information disclosed by the regulator about the asset quality of the distressed bank and its possible bailout by the government, the healthy bank can accept or not the bail-in proposal. The role of the regulator is to select the optimal disclosure rule that reduces its ex-ante expected loss function. We find that the *full disclosure* is desirable in some circumstances but not in others. There should be more disclosures

in either very good or very bad times, but less disclosure in intermediate regimes. For instance, when the bail-in cost is large and bailout cost is not, the optimal loss is reached thanks to a *partial disclosure* in normal times. In contrast, when the bailout cost is high and bail-in cost is not, *no disclosure* minimizes the regulator's expected welfare losses in normal times.

Studying the optimal information to be disclosed by the regulator in a bank resolution context is an original question and has not yet been studied to our knowledge. What would be interesting is to extend the model to a network of banks to see how the structure of the network can influence our results, which is indeed the question I propose to study in Chapter 3.

Chapter 3 provides an original way to limit cascades of failures in financial networks, when a crisis occurs, by using the information disclosed by the regulator. The current regulations is criticised for not taking sufficiently into account the fact that each individual institution is part of a larger network, even though the recent literature has emphasised the endogenous nature of systemic risk and the impact of a bank's failure on its financial partners depending in the network structure (e.g. Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015), Rogers and Veraart (2013), Allen and Gale (2000)...). I extend hence in this chapter, the model developed in the Chapter 2 by considering a financial network composed of banks connected through interbank claims. In my model, a group of fundamentally defaulting banks (banks that default even if they are fully reimbursed by their partners) asks their creditors (other banks of the network in my framework), to reduce their debts. The healthy banks can accept or not this bail-in proposal based on information disclosed by the regulator about banks' assets quality. My first results show that the more intense the cascade of banks defaults, the more a surviving bank is likely to agree to rescue fundamentally defaulting banks even if they are not directly linked and have a bad asset quality, when the bailout probability is not significant.[1] Then, I show that the incentive to bail-in is stronger in less densely connected networks in case of negative small shocks and when there is no possible bailout. When I look at the regulator disclosure rule in the case of a single defaulting bank linked to several healthy banks, I find that disclosure may be desirable in some cases but not in others. These results not only depend on different costs (bail-in, bailout, liquidation and bankruptcy costs) but also they are driven by network structure and density. I show hence, in networks of three banks that in some cases when on average the fundamentally defaulting bank is

[1] I mean by intensity the number of defaulting banks and the amount of losses triggered by these defaults.

suspected of having a poor asset quality and the distressed one is presumed to have good asset quality, more disclosure is needed in ring networks. I show also that when bail-in is not costly and in the case of shocks of low intensity, there is more gain for the regulator to disclose information promoting bail-ins in this ring network structure.

It would be interesting to extend the results of this chapter to more general networks. It will be also challenging to study the question of the optimal disclosure rule in networks by taking into account for endogenous fire sales spillovers, in addition to accounting for counterparty risk.

In this dissertation, research on systemic risk has therefore focused on three main aspects. The results have interesting policy implications. Nevertheless, most of the recommendations that can be made come from a theoretical study. Hence, there remains a promising avenue of research using real data to simulate these theoretical models and check the consistency of these results with the reality of what is happening.

The lesson from previous crises is that every crisis is different. The new regulatory framework has benefited from the additional knowledge derived from the 2007 crisis. However, the next crisis may be significantly different, so the new regulation should not only be designed to deal with a similar crisis to the previous one, but should also incorporate the challenges of our time. For instance, climate change is one of the most serious challenges facing our economy nowadays. Benmir, Jaccard, and Vermandel (2020) show that climate risk can affect financial markets by reducing the natural rate of interest. Hence, the ecological transition will be achieved partly through monetary policy. They also suggest to implement a carbon tax to "cool down" the economy during booms and stimulate it in recessions. This underlines the fact that we are embarking on a new paradigm, involving radical changes like ten years ago, in which new procyclical regulatory tools are needed.

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RÉSUMÉ

Le secteur financier est en constante évolution et maintenir ce système financier stable est devenu un défi pour tous les régulateurs. Ainsi les récentes crises financières et le ralentissement subséquent de l'activité économique ont suscité une intervention sans précédent de la part des principales banques centrales et des régulateurs à travers le monde. Ces derniers ont vu leur rôle se développer. Désormais, la banque centrale européenne (BCE) suit les évolutions des secteurs bancaires de la zone euro afin d'identifier leurs vulnérabilités et de vérifier la capacité de résistance du système financier global. Un mécanisme de résolution unique (MRU) a également été mis en place au niveau de l'Union Européenne. Ces nouvelles démarches visent à renforcer au mieux la stabilité financière, évitant ainsi l'apparition de nouvelles crises et à limiter l'impact de l'actuelle. L'objectif général cette thèse est (i) de vérifier si des politiques inspirées des politiques non conventionnelles de la banque centrale peuvent répondre à des objectifs macroprudentiels, notamment à des objectifs de stabilité financière ; (ii) d'étudier l'information optimale que doit divulguer le régulateur sur la santé des banques pour limiter le coût de son intervention lors d'opérations de résolution bancaire en proposant des renflouements internes (*bail-ins*) et externes (*bailouts*); et (iii) d'examiner l'impact de la structure du réseau financier sur les décisions des banques appelées à participer aux opérations de renflouements internes ainsi que sur les décisions du régulateur en matière de divulgation d'informations lorsqu'il intervient dans les plans de résolution.

MOTS CLÉS

Risque systémique, Politiques monétaire non conventionnelles, Politique de résolution bancaires, Réseaux financiers, Contagion financière, Jeux de persuasion

ABSTRACT

The financial sector is constantly evolving, and maintaining a stable financial system has become a challenge for regulators. Therefore, the recent financial crises and the subsequent downturn in economic activity have elicited an unprecedented response from major central banks and regulators around the world. The latter have seen their role developed. The European Central Bank (ECB) now monitors evolutions in the banking sectors to identify any vulnerabilities and check the resilience of the financial system. A single resolution mechanism (SRM) has also been set up at the European Union level. These new approaches aim to strengthen financial stability, thus avoiding the emergence of new crises and limiting the impact of the current one. The general objective of this thesis is (i) to verify whether policies inspired by the unconventional policies of the central bank can address macroprudential objectives; (ii) to examine the optimal information to be disclosed by the regulator on banks health in order to limit the cost of its intervention during banks resolution operations by proposing bail-ins and bailouts; and (iii) to study the impact of the financial network structure on the decisions of banks involved in bail-ins as well as on the decision of the regulator regarding information disclosure when it intervenes in resolution mechanisms.

KEYWORDS

Systemic risk, Unconventional monetary policies, Bank resolution policies, Financial networks, Financial contagion, Persuasion games