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Publication date

2011

Document Version

Final published version

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Citation for published version (APA):

Vlahu, R. E. (2011). *Three essays on banking*. [Thesis, fully internal, Universiteit van Amsterdam]. Thela Thesis.

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tinbergen *institute**Three Essays on Banking*

Razvan Eduard Vlahu

This dissertation consists of three essays on banking and concentrates on two topics. The first two essays deal with strategic behavior of borrowers. The third essay explores the relation between bank capital and risk-taking. The first essay, "Collective Strategic Defaults: Bailouts and Repayment Incentives", studies a global game model of debtor runs on a bank and the role of a lender of last resort in mitigating strategic debtor behavior and bank moral hazard. The second essay, "Strategic Loan Defaults and Coordination: An Experimental Analysis" investigates the impact of uncertainty about bank and borrower fundamentals on loan repayment. These two sources of uncertainty are natural proxies for the regulatory rules for transparency and disclosure, and for the state of the economy. The third essay, "Capital Regulation and Tail Risks", analyses bank's risk-taking behavior in the presence of tail risk projects, and shows that it can take unintuitive non-linear forms, with incentives to take excessive risk increasing in capital.

Razvan Vlahu received his bachelor degrees in economics and in finance and banking from the Academy of Economic Studies (Bucharest, Romania). He obtained a master degree in financial economics at the Tinbergen Institute (Amsterdam). Thereafter he started his PhD in finance at the University of Amsterdam, Business School. He performed part of his research while attending the Toulouse University and IDEI as a visiting researcher. His work has been presented at several major conferences including the EFA and FIRS annual meetings. During the last two years he was lecturer for Corporate Finance and Investment and Portfolio Theory at the University of Amsterdam. As of November 2010, Razvan is employed as a research economist at De Nederlandsche Bank (Dutch Central Bank).

Three Essays on Banking

ISBN 978 90 3610 228 5

Cover design: Crasborn Graphic Designers bno, Valkenburg a.d. Geul

This book is no. 493 of the Tinbergen Institute Research Series, established through cooperation between Thela Thesis and the Tinbergen Institute.

A list of books which already appeared in the series can be found in the back.

Three Essays on Banking

ACADEMISCH PROEFSCHRIFT

ter verkrijging van de graad van doctor
aan de Universiteit van Amsterdam,
op gezag van de Rector Magnificus
prof. dr. D.C. van den Boom,
ten overstaan van een door het college voor promotie
ingestelde commissie,
in het openbaar te verdedigen in de Agnietenkapel
op vrijdag 25 maart 2011, te 12.00 uur

door

Razvan Eduard Vlahu

geboren te Braila, Roemenië

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Faculteit Economie en Bedrijfskunde

to my grandmother Eugenia

What a journey !

Someone said once that the risk of an adventure is more valuable than one hundred years of welfare and comfort. My Dutch adventure proves that he was right. It all started with a sack full of dreams and ended with certitudes and . . . other dreams. At the end of the road I would like to take the opportunity to thank people, old and new friends, for making the completion of this thesis possible and the years spent in Amsterdam a memorable period in my life.

I am particularly grateful to my advisor, Enrico Perotti. Enrico has encouraged me from the very beginning to develop my own research ideas and has given me the freedom to follow these ideas. His door was always open whenever I needed guidance and advice. His enthusiasm was truly contagious, and I often found myself refilled with energy and motivation after thoughtful discussions with him. Thank you Enrico for trusting my research capabilities, for contributing to my personal growth, for your tremendous patience, and for your unconditional support and understanding in some key moments of my personal life.

At various stages of my research I have benefited a lot from stimulating and insightful discussions with Bruno Biais, Martin Brown, Raj Iyer, Jean-Charles Rochet and Peter Spreij, who helped me sharpen my thoughts. I would also like to thank the members of the thesis committee, Arnoud Boot, Amil Dasgupta, Alexander Guembel and Joep Sonnemans who have offered important advice and constructive suggestions for my dissertation. Tinbergen Institute - where I have started my academic journey, the Finance Group at UvA and IDEI Toulouse - where I have spent my time during

PhD years, have all provided the perfect research environment and gave me excellent opportunities to meet well known academics. I am very grateful to the European Network for the Advancement of Behavioral Economics (ENABLE), to Amsterdam Center for Research in International Finance (CIFRA), to the C. Willems Foundation, and to the Gieskes-Strijbis Foundation for supporting my research and enabling visits to University Pompeu Fabra and University of Toulouse.

Not necessarily related to this dissertation, but nevertheless important to the path I have followed, have been those few people who taught me about the significance of perseverance, and who sowed in me the desire to know more and the passion for mathematics. I would not have been able to start writing this thesis without the contribution, at different stages of my life, of Marieta Nada, Enuta Lozneau, Gabriel Daniilescu, Petru Cosnita, Dan Savoiu and Marin Andreica.

Special thanks go to Lev and Stefan, who, apart from being fantastic co-authors, are great friends. With Lev I have shared the office; we went together to conferences, and we made tons of bad jokes virtually about everything. He taught me about French cognac (although he is Russian), and I taught him about Romanian tuica. With Stefan I have shared most of the happenings of the last few years and practically an identical life track. We both came to Amsterdam eager to learn new things after working outside academia. We became close friends during our master's studies. Our friendship tightened afterwards when we slowly changed our status from 'man in a stable relationship' to 'married with a child'. However, Stefan is a little bit ahead now, having the status 'married with children'. His wife Clara, an endless source of calm and patience, has always made my family visits to both Amsterdam Noord and Tilburg unforgettable.

My MPhil years at Tinbergen Institute marked my first experience of living abroad. I would like to thank Jaap Abbring and Maarten Lindeboom for giving me the opportunity to follow here the graduate program. Many thanks to Arriane, Marian and Nora for helping me to survive the bureaucratic chaos of the first years.

I was lucky enough to have beside me in these years, two good Romanian friends, who, by an inexplicable coincidence, came to the Netherlands at the same time I did. One was Ionut, my old friend and roommate from university years. We started again from where we had stopped just two years before. He and Rouxana made me feel like home in a foreign country and they were nice enough complementing my *carbonara*, the only recipe I was able to cook. They were a constant presence throughout my journey. The other one was Vali, the mathematics-computer science guru, now turned into an exotic derivatives trader, with whom I have shared the experience of tough course workload and never-ending assignments, as well as the exploration of Amsterdam's night life and the discovery of uncharted pubs. During Tinbergen years I have shared BBQs, concerts, dancing-nights, dinners, movie-nights, parties or simply enjoyable talks over a beer or a glass of wine with my colleagues and friends: Flora, Huang Jian, JiaJia, Linda, Pan Lei, Stefan, Stefka, as well as with 'senior' cohorts which welcomed me in their group and made me feel comfortable in the new environment: Ana, Carla, Ernesto, Hugo, Jasper, Jose, Marcos, Maria, Martijn, Miguel, Neeltje, Robert, Sebi, Suncica, Viktoria, Vitaly, Wendy and Yin-Yen. Later, Jonneke, Marcel, Mario, Marius, Sumedha, Tibor, and Tse-Chun and more recently Amanda, Andrei, Bernd, Eva, Nick, Stephen, and Thomas have joined these social 'exhausting' activities. Thank you guys for providing me great memories!

I was not able to see by then that the triple tours and the vivid discussions on academic, business and political related issues, which I have shared with Jasper, Robert and Wendy were actually 'the beginning of a beautiful friendship'. Slowly our bacchius meetings turned into picnics and parties with our kids. Together with their partners Monda, Trudy and Rens, we began talking about the good and tough moments of our new lives, things we couldn't dream of just few years before.

The Finance Group at UvA proved to be an excellent and stimulating working environment, as well as a lively and friendly place. I would like to thank Alessandro, Daniela, Enrique, Erasmo, Florencio, Florian, Ines, Jens, Ludo, Raj, Stefan, Wadia

and Zach for allowing me to ‘steal’ from their knowledge about financial markets and for giving me useful tips about teaching. The ‘No Team for Old Men’ will remain one of my favorite teams, an example of endurance, talent, and teamwork. I am especially grateful to Jeroen and Joost who had confidence in my skills and gave me the opportunity to lecture and coordinate various finance courses at an early stage of my academic career. Life in the office was made even more enjoyable by the humor and the jokes of my PhD colleagues and friends, as well as by the numerous brainstorming sessions I had with them. I thank Betty, Christel, Dion, Lev, Marcel, Mario, Rocco, and T.C. for these moments. A special thank goes to Yolanda, Jan Willem and Jolinda, who were always there, providing cheerful help and taking good care of all of us.

Outside Tinbergen and Finance Group, I am grateful to many people who have generously offered me their friendship and support and who made my stay in Amsterdam unforgettable. Adina – with her artistic spirit and unrivalled cooking skills, and Marius – with his sharp remarks and good knowledge of Romanian folk music, deserve a special mention here. I spent joyful moments at their place, mixing heavy BBQs with fresh fruits from their garden till late in the night, while talking about art, music, and traveling. Florin and the Hogeweg crew (Andrei, Marcel, Vincent and Txo) are close friends with whom I found myself cruising Amsterdam’s canals or sailing in the IJmeer in the summer, skiing in the French Alps in the winter, while having drinks in eetcafes and long dinners, watching football games and laughing together all over the year.

My too short and too rare visits back to Romania have demonstrated what a true friendship is all about. I am very much indebted to my dear friends back home, who were always there, happy to meet me even on short notice, at extremely inappropriate times and in difficult to reach places, eager to talk over one (and often too many) beers and to make fun about practically everything. Thank you Adi, Biju, Cata, Chelu, Claudia, Dizzy, Dorin, Geo, Ionut, Laura, Mihai, Nija, Razvan, Romi,

Sterga, Tibi, Vio.

I am deeply grateful to my family, who has always played an important role in my life. I would like to thank my grandmother, Eugenia, who has been a continuous source of inspiration, my parents, Sorina and Ilie, my brother Bogdan and his wife Oana, for their unconditional confidence and support, and for the inexhaustible source of enthusiasm, joy, love and optimism. They have always surprised me with their straightforward questions and with their refreshing way of thinking about life.

My final thoughts go to my lovely wife Carmen and to my son Tudor. Carmen has been by my side from the very beginning of this journey, encouraging me to go forward, witnessing my frustrations, understanding my sometimes crazy working schedule, not complaining about lost week-ends, and listening when I was talking and talking. She was my source of strength, encouraging me with her warm smile and her sense of reality, offering always a different perspective about life. She and our son Tudor, with his genuine curiosity and endless energy, made this journey more enjoyable and kept me always looking on the bright side of life. Thank you so much!

Razvan,

Amsterdam, February 2011

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Chapter 1

Introduction and Summary

The 2007-2009 financial crisis has shown that financial distress in banking system is a common threat in both developed and emerging economies. Losses in US subprime credit market spilled over to other markets through various channels (e.g., assets fire sales, illiquidity or interbank linkages), leading to the failure of hundreds of lenders since the onset of the crisis. One important mechanism through which the mortgage crisis amplified into a severe financial crisis was runs on financial institutions. Lenders such as Fortis Bank, Northern Rock, or Washington Mutual have experienced bank runs which caused erosion of their capital. Excessive withdrawals were triggered by concerns about the lenders' well being. However, the panic run in the financial sector has corresponded only to some extent to the classical bank runs of 19th century in which retail depositors withdrew their money fearing that others would do the same and bank would become insolvent.

One lesson that stands out from the recent events is that short-term funding of highly leveraged financial institutions, coupled with the reliance on the originate-and-distribute business model, in which the originators of loans pool them and afterward sell them via securitization, instead of holding the loans on their balance sheets until they are repaid as in traditional banking model, has perverse consequences. On one hand, it led to a decline in lending standards. On the other hand, it left

financial intermediaries exposed to modern types of runs. One prominent example is the liquidity runs and the demand for additional collateral by wholesale lenders, which forced massive distressed liquidation not predicted by the standard risk models. Wholesale financiers have exacerbated liquidity problems during Bear Sterns and Northern Rock episodes, when short-term creditors terminated their contracts and denied lending. In addition to the drying up of liquidity in short-term capital markets, counterparties demanded for extra collateral, as it happened during AIG episode. Bank runs have also occurred when large uninsured depositors have depleted their accounts during Fortis and Washington Mutual debacles.

In addition to the coordination failure by retail depositors in the form of premature withdrawals and bank runs (and other modern types of runs of debt-holders), banks can also be vulnerable to coordination failure from the asset side of their balance sheet. If borrowers believe that their bank will become distressed because of defaults by others, they may delay or even default on their loans. Commonly held beliefs that other borrowers will default may therefore create an amplification mechanism of bank problems and lead to a situation where borrowers are unable to coordinate on repayment, and thus fail to ensure bank survival. The borrowers' coordination problem has received less attention yet. Anecdotal evidence from developing countries and transition economies suggests that in circumstances when financial environment is characterized by inadequate bankruptcy laws and inefficient judiciary system, where bankruptcy and restructuring frameworks are deficient and creditor rights are poorly defined or weakly enforced, borrowers have a strong incentive to default on their obligations. For developed economies, the harmful effects of strategic defaults have become clear during the recent period of distress - with mortgage market being an important sector where banks have become subject to runs by their borrowers. In contrast to depositors withdrawing their own money, coordination failure resulting from borrowers strategically delaying or defaulting on loan payments involves a breach of contract. It will therefore be confined to situations

of diffused financial distress, as in the recent crisis. Because of its relevance to the stability of the banking system and its potential to amplify downward trends, a more thorough understanding of borrowers' coordination failure is warranted. Identifying the factors that drive borrowers' strategic default is important for banking system stability and allows for improvements with respect to the choice and the timing of regulatory measures.

The recent global financial turmoil has also revealed the need to rethink fundamentally how financial system is regulated. The policy debate on financial reform has focused on raising capital ratios of financial intermediaries. The recently adopted Basel III rules double the minimal capital ratio and, beyond that, create incentives for banks to hold excess capital in the form of conservation and countercyclical buffers. However, one of the lessons from the recent crisis is that banks are exposed to tail risks which, when realized, may trigger losses in excess of almost any plausible value of initial capital. Such risks can result from the reliance on wholesale funding, the underwriting of AIG-type contingent liabilities likely to be called during market panic, exposures to highly-rated senior structured debt standing to lose value in periods of extreme economic stress, as well as undiversified leveraged exposures to inflated housing markets. Since tail risks can wipe out almost any initial capital, it is unclear whether traditional capital regulation is effective in addressing it. This highlights the importance of understanding how higher capital ratios would affect bank's investment incentives.

An important motivation for the analysis done in this thesis follows from the larger picture described above and consists of the following open questions about debtors' behavior in credit markets and optimal regulation of banks: (1) is strategic default of borrowers a relevant threat for banks' solvency in times of distress, (2) what is the role played by information regarding banks' solvency in creating financial fragility, (3) how does regulatory disclosure rules affect borrowers' repayment decisions, (4) and do these rules have a different impact in different stages of the

business cycle, (5) does the safety net of a lender of last resort contribute to financial fragility, (6) does solvency regulation (in form of capital requirements) remain an efficient regulatory instrument in the presence of innovative financial instruments which created significant tail risks in the recent years. This thesis is composed by three different essays in banking which address the above questions. The first two essays deal with strategic behavior of borrowers. The third essay explores the relation between bank capital and risk-taking.

Each essay is distinct from the methodological point of view. In the first essay (chapter 2 of the thesis) I develop a theory for the collective strategic defaults of borrowers. I form the model in the context of the global games methodology first introduced by Carlsson and van Damme (1993) and later refined by Morris and Shin (1998). Global games are games of incomplete information in which an agent's incentive to take a particular action increases as more and more agents take the same action (i.e., individual actions are strategic complements). This realistic approach does not depend on common knowledge and helps to resolve the issue of multiple equilibria. Common knowledge, introduced in theoretical models through perfect public information, can create self-fulfilling beliefs which might destabilize an economy. Sudden crises without any fundamental reason might arise in such unstable economy due to changes in beliefs of market participants. In global games approach, a small amount of noise can be stabilizing and can pin down a unique equilibrium with agents playing threshold strategies. Using an iterated deletion of strictly dominated strategies, the unique Nash equilibrium can be derived. In the second essay (chapter 3 of the thesis), experimental economics methods are used to investigate empirically two factors which might have a significant impact on debtors repayment incentives. Experiments are extensively used to test the validity of economic theories and to test new markets mechanism. Several experiments have been successfully conducted to examine the impact of information sharing and long-term banking relationships on borrower and lender behavior (Brown et al. 2004, Brown and Zehnder

2007, 2010, Fehr and Zehnder 2009). Similarly, to study the causes of depositors and currency runs, theoretical accounts have been tested in controlled laboratory settings with clear identification of causal effects (Garratt and Keiser 2009, Heine-
mann et al. 2004, Madies 2006, Schotter and Yorulmazer 2009). Finally, in the third essay (chapter 4 of the thesis) a theoretical model for bank investment decision is presented. The model is close in spirit to asset substitution literature. In a stylized representation of the actual banking system, the bank operates in a prudential framework based on a minimal capital ratio, and has access to tail risk projects.

In general, this thesis contributes to the understanding of debtors repayment incentives in the presence of uncertainty (or imperfect information) and derive policy implications about the lender of last resort and banking regulation (in particular, about capital requirements and disclosure rules). Next, I will give a short description for each of the three essays.

The first essay, “*Collective Strategic Defaults: Bailouts and Repayment Incentives*”, studies a model of borrowers strategic defaults, and discusses the role of a lender of last resort and the bank’s screening effort incentives.¹ The crucial ingredient of the model I introduce here is that borrowers hold common prior beliefs about the state of their bank fundamentals (i.e., non-performing loans) and they also receive noisy signals about these fundamentals. I argue that banks may be subject to risk of failure even when they have strong fundamentals due to a coordination problem among debtors. This happens in a framework in which on one hand, banks understand that their assets choice will affect central bank intervention policy, while on the other hand the central bank (acting as a lender of last resort) recognizes the opportunity cost of forgone intermediation if the bank is closed. Debtors decide not to repay their loans if the signals they receive about bank fundamentals are above some threshold level (i.e., bank fundamentals are bad). Observing a high signal

¹This essay was partially completed while I was visiting IDEI Toulouse, whose hospitality is greatly appreciated. I gratefully acknowledge financial support from ENABLE.

induces a borrower to believe that other borrowers have also received high signals. Hence, the borrower infers that is very likely that other borrowers will stop repaying. Subsequently, if enough borrowers refuse to pay back, their actions would trigger bank's failure.

Since the bank failure is socially costly (i.e., it destroys relationship value for borrowers who repay their loans), there is scope for regulatory intervention. The lender of last resort can bail out the bank by providing the necessary amount of liquidity which will preserve bank's enforcement ability. However, I argue that ex-post bailout takes place only if the proportion of non-performing loans and the cost of providing liquidity are not too high. I also show that the presence of the lender of last resort mitigates the strategic behavior of debtors and reduces the extent of bank failures. Interestingly, when the intervention cost of providing liquidity is low, two counterbalancing effects take place. First, lower intervention cost induces moral hazard, with banks screening less their potential borrowers. Second, it increases the threshold in fundamentals that triggers collective strategic default. Put differently, a lower cost of intervention makes banks to behave less prudent and also makes debtors to behave less aggressive (i.e., knowing that the intervention of the lender of last resort is more likely when the cost of providing liquidity is low, borrowers will refrain from defaulting).

The second essay, "*Strategic Loan Defaults and Coordination: An Experimental Analysis*", experimentally investigates the impact of uncertainty about bank and borrower fundamentals on loan repayment.² Defaults are observed in real life, but one can not observe whether the default is strategic or not, with strategic defaulters mimicking the behavior of genuine distressed borrowers. Therefore, it is difficult to study empirically strategic default because it is an event hard to identify and to quantify. To overcome identification problems in empirical data, we study a

²Joint work with Stefan Trautmann. I gratefully acknowledge financial support from the Gieskes-Strijbis Foundation and from CIFRA.

coordination game which involves two features which are specific to credit markets. First, borrowers have an imperfect signal about the fundamentals of their bank, (i.e., the number of defaults that would trigger its failure). Second, borrowers are imperfectly informed about the fundamentals of other borrowers, and thus how many of these may be forced to default on their loans. These two sources of uncertainty are natural proxies for the regulatory rules for transparency and disclosure, and for the state of the economy. The design allows us to study whether transparency rules and economic environment affect the incidence of strategic default, and how the two factors interact.

We find clear evidence for strategic default, with both types of uncertainty affecting its occurrence. Surprisingly, we show that more information about bank fundamentals is not always better. When full disclosure reveals bank weakness, it increases strategic non-repayment regardless of economic conditions. Similarly, borrowers default strategically more during downturns when fundamentals of other borrowers are more uncertain, regardless of disclosure rules. Borrowing from the behavioral literature on coordination games we identify concepts that explain the observed variation in repayment. Our results show that repayment decision is very sensitive to the risk dominance properties of the game structure. In particular, both disclosure and uncertain borrower fundamentals make the defaulting equilibrium relatively more risk dominant, leading to more bank failures.

Second, analyzing individual borrower characteristics we find that risk attitudes, in particular attitudes toward financial losses, have a strong and robust influence on repayment decisions. Loss averse borrowers place a higher value on the available cash they hold than on the higher but uncertain future monetary outcome which is conditional on bank survival. Hence, they have a strong preference towards non-repayment, which allows them to avoid the immediate financial loss triggered by potential bank failure.

We also show that negative past experiences strongly affect individual repayment

decisions. People who have experienced more defaults from other borrowers and the subsequent bank failures, are more likely to default strategically. Hence, our findings suggest that in credit markets, similarly to the depositors market, there is the risk of contagion.

The third essay, “*Capital Regulation and Tail Risks*”, revisits the relationship between bank capital and risk-taking.³ The traditional view is that higher capital reduces excess risk-taking driven by limited liability. There are two key arguments in favor of higher capital. First is the classic notion that capital is a buffer that reduces the risk of insolvency. It also helps to reduce some systemic risk factors, such as uncertainty over counterparty risk, which had a devastating propagation effect during the recent crisis. Second, there is a more sophisticated argument that capital is not just a buffer, but has incentive effects. Higher capital increases shareholders’ losses in bank failure, and hence reduces their incentives to take excessive risk. We show here that the relationship between bank capital and risk-taking may take unintuitive forms in the presence of tail risk projects, with bank risk-taking being non-linear and possibly increasing in capital. This result demonstrates that capital requirements alone may be insufficient to control banks’ preferences when tail risk projects are available to them.

The argument is that while higher capital reduces risk-taking incentives caused by limited liability, in banks this may be dominated by an important opposite effect. Higher capital increases the distance to the minimal capital ratio, allowing the bank to take more risk without the fear of breaching regulatory requirements in case of a mildly negative project realization. We argue that in the presence of tail risks, when high capital ratios by themselves cannot insure against all losses, a highly capitalized bank may start taking a socially excessive level of risk. While a poorly capitalized bank may act risk-averse to avoid breaching the minimal capital ratio (which would

³Joint work with Enrico Perotti and Lev Ratnovski. I gratefully acknowledge financial support from the Gieskes-Strijbis Foundation.

force a costly recapitalization), a bank with higher capital may take more risk as it has a lower probability of breaching the ratio. This result is consistent with the stylized fact that U.S. banks were well capitalized pre-crisis, yet they took significant bets on house prices and on mortgage derivatives. We also find that well-capitalized banks' incentives for taking tail risks are increased in the extremeness of that tail risk (i.e., the availability of projects with heavier left tails). Our results therefore demonstrate the limits of traditional capital regulation in mitigating banks' incentives to take tail risks and support the view that dealing with tail risks requires new regulatory tools (e.g., macro-prudential measures that address systemic risk and negative spirals).

Chapter 2

Collective Strategic Defaults: Bailouts and Repayment Incentives

2.1 Introduction

This paper looks at the possibility of collective strategic default, leading to bank collapse. There is much anecdotal evidence of coordinated non repayment in emerging markets, such as Eastern European countries during transition, and banking crises in Mexico and East Asia. In many cases penalties for delaying repayments were usually lower than the cost of borrowing. This occurred in particular when bailouts were funded by monetary creation, leading to a massive inflation and thus devaluation of loan repayments. Moreover, the delays in the legal procedure to recover the loans were huge. Very often the governments in these countries decided to clear debtor firms obligations in order to avoid tough and unpopular social measures as in Eastern Europe and Russia (1992). While analyzing the strategies and policies implemented by Mexico to resolve their 1994 banking crisis, De Luna-Martinez (2000) identifies the reluctance of borrowers to repay their loans as one of the causes that exacerbated

the crisis. A large part of borrowers faced not only the lack of capability, but also the lack of incentives to repay their loans. Referring to the credit crunch Mexico experienced in mid 1990s, Krueger and Tornell (1999) also find that the lack of transparent and effective bankruptcy procedures combined with the fact that the crisis increased the number of insolvent borrowers created the incentives for some debtors with the capacity to service their debts not to do so, since non payment would be hardly punished. Hence, as evidence suggests, in circumstances when financial environment is characterized by inadequate bankruptcy laws, inefficient judiciary system and poor disclosure and accounting rules, where bankruptcy and restructuring frameworks are deficient and creditor rights are poorly defined or weakly enforced, potentially solvent firms would have a strong incentive to mimic the behavior of a distressed firm. They understand that the lending bank will be able to fully pursue non paying solvent firms only if it survives. Therefore, solvent firms action may depend on their beliefs about other firms actions and not only on the information regarding how strong the bank fundamentals are. This behavior may be a different determinant for low level of credit and high interest rate differential between deposit and loan rates in emerging economies beside the known factors that are studied in banking literature such as poor quality of corporate sector, low competition in banking, poor law enforcement or political favors in lending.¹

Although the claim in strict form predicts that many severe banking crises episodes have been exacerbated by the strategic default of solvent firms, particularly in those emerging economies where poor supervision and regulation of banking system were in place, I would still expect that this non repayment tendency to be met in developed western economies too. In the Financial Times' article (May 2008) discussing the subprime meltdown, Martin Feldstein was suggesting that structured

¹Haber (2005) and Haber and Maurer (2006) show that in Mexico bankers face large difficulty in enforcing loan contracts and therefore tend not to make many loans. Related lending practices are described by La Porta, Lopez-de-Silanes and Zamarripa (2003), Laeven (2001) and Claessens, Feijn and Laeven (2006).

finance and securitization has created a coordination failure among borrowers which might cause the deepest and longest recession in the US in the last decades. Due to the fact that commercial banks, acting like lenders, have no recourse to the house's owner beyond the value of the house, and given that more and more people see the value of their mortgages exceeding the value of their homes, individuals with negative equity, most of them real estate speculators, have a strong incentive to default. This temptation to turn in the keys and walk away is aggravated by the difficulty in voluntary negotiations between creditors and borrowers, because most of these mortgages have been securitized and a renegotiation with the mortgage originator proves impossible. According to Hull (2008), the downward trend in house prices during the credit crisis of 2007 was reinforced by the action of many borrowers who exercised their "*implicit put options and walked away from their houses and their mortgage obligations*". Guiso et al. (2009) find that 26% of mortgage defaults in US are strategic. They use a survey to study American households likelihood to default when they have negative equity. They argue that even if those households can afford to pay their mortgages, they prefer not to do so if the equity shortfall is high enough. They also show that the most important factors affecting the incentive to default are moral and social considerations (i.e., social stigma).

Anecdotal evidence is also provided by the interbank payment system. Kahn and Roberds (1998) examine the effects of settlement rules on banks' tendencies to honor interbank commitments rather than default. They found that default probability and the costs associated with potential defaults is higher when net settlement system is in place, while gross settlement increases the costs associated with holding reserves. Banks with large net debt position relative to their capital find tempting to default or to delay the sending of payment messages to other banks, these decisions being exacerbated by the imperfect monitoring by the managers of the payment network or governmental regulators. The recent credit market events demonstrated that the failure of one bank to meet payment obligations can have a negative impact on the

ability of other banks to meet their own payment obligations, particularly when interbank exposures are very large. The collapse of Lehman Brothers and the legal claims pursued by its creditors against JPMorgan Chase support to some extent the Kahn and Roberds (1998) argument that a bank might face a liquidity crisis when one of its main counterparties in the interbank market delays the sending of the payment message. JPMorgan had more than \$17 billion of Lehman's cash and securities three days before the investment bank filed for bankruptcy on Sept. 15, 2008. Lehman's creditors accused JPMorgan Chase to create an immediate liquidity crisis that could have been avoided if Lehman's access to these assets wouldn't have been denied on Sept. 12, 2008. As we have also seen in March 2008, when the US Fed decided to bail out Bear Stearns, regulators have a crucial role in solving the conflict between the interests of an individual bank and the social interest of the payment network.

The main goal of this paper is to evaluate the effect of Central Bank intervention policy as a Lender of Last Resort under opportunistic behavior from borrowers. I study a model in which a monopolistic commercial bank receives funds from depositors and invests them in a continuum of identical risky loans granted to risk-neutral firms. The bank faces a liquidity shortage which is aggravated by the strategic default of some solvent firms. Within this framework, the Central Bank acts as the only regulator. The Central Bank intervention policy should, on one hand, to minimize the ex-ante moral hazard problem for all parties involved and, on the other hand, to minimize the cost of intervention when it acts as a Lender of Last Resort (or LOLR, as I will refer to it from here). The commercial bank understands that its current assets choice will affect the Central Bank intervention policy, while the Central Bank recognizes the opportunity cost of forgone intermediation if the commercial bank is closed. I examine the borrowers' and commercial bank's behavior under two scenarios. In the first one, the Central Bank is *inactive*. I consider a Central Bank as being inactive if its ex-ante stated decision of non intervention is consistent with its

ex-post adopted policy. Under this scenario, the closure of the illiquid bank is the only alternative. In the second scenario, the Central Bank is *active*. I consider a Central Bank as being active when it might step in once the commercial bank is in trouble and provide help under some specific market conditions. In both scenarios the paper requires that any closure threats by the Central Bank be credible. Behind the main findings there are three crucial ingredients. First, the bank fundamentals are not common knowledge. The borrowers hold common prior beliefs about the state of fundamentals and receive private signals about its realization. The bank's fundamentals are the measure of insolvent debtor firms. Second, the lending bank will be able to fully pursue non paying solvent firms only if it survives. Third, the commercial bank and the borrowers know ex-ante the Central Bank's cost of intervention (it is common knowledge for all the players), while the Central Bank decision to bail out or not is not known ex-ante.

This paper derives the probability of a run by bank borrowers, while depositors are passive players.² Since banking sector problems and particularly bank runs represent a threat in both emerging and developed economies, a voluminous literature is dedicated to this topic.³ Nevertheless, the existing literature is centered around two traditional approaches. In one approach, bank runs are based on panics (i.e., coordination problems among depositors). Bryant (1980), Diamond and Dybvig (1983), Goldstein and Pauzner (2005) and Rochet and Vives (2005) are models which share

²The conventional explanation for a bank run is given by analyzing the liabilities side of bank balance sheet. Standard bank deposit contracts allow depositors to withdraw a nominal amount on demand. When depositors observe large withdrawals from their bank, they fear bankruptcy and respond by withdrawing their own deposits. Bank's probability of failure will increase due to the negative externality induced by withdrawals in excess of the current expected demand for liquidity.

³Lindgren, Garcia and Saal (1996) identify 133 countries facing banking problems between 1980 and 1996. Gorton (1988) analyzes panics during US National Banking Era from 1865 to 1914. Honohan and Laeven (2005) document banking crises throughout the world since 1970. Caprio and Klingebiel (1996), Lindgren et. al.(1999), Hoggarth, Reis and Saporta (2001), Honohan and Klingebiel (2003), Ongena et al. (2003), Calomiris and Mason (2003), Dell'Ariccia et al. (2008) document the costs of these banking problems. Comprehensive surveys on banking crises are Bhattacharya and Thakor (1993), Freixas and Rochet (1997), Gorton and Winton (2003), and Allen and Gale (2007).

this approach. In the other approach, bank runs are based on poor fundamentals and a result of asymmetric information among depositors regarding these fundamentals. Chari and Jagannathan (1988), Jacklin and Bhattacharya (1988) and Calomiris and Kahn (1991) are models which share this second approach. In all these models, the focus is on the liabilities side of bank balance sheet.⁴ I complement this literature by showing that collective strategic default of borrowers induces financial fragility when the bank is weak and financial environment is characterized by a poor quality of corporate sector.

The problem I study calls for a specific form of global games. In standard global games the number of agents who might coordinate is independent of fundamentals. In my model, the realization of fundamentals translates directly in the number of active agents who can play effectively the game. The value of the bank's fundamentals depends on the measure of firms that are in genuine financial distress and can not repay their loans. Hence, the number of solvent firms able to coordinate their actions is also a random variable.

The main findings are the following. Firstly, I derive an ex-post optimal solution for Central Bank intervention as a LOLR which has an influence ex-ante on commercial bank and firms behavior. This intervention policy is not known ex-ante and depends on the coordination of solvent firms. Secondly, I show that an active Central Bank can mitigate the strategic behavior of debtor firms. It allows commercial banks to survive more often when they face opportunistic behavior from borrowers. Debtor firms will behave strategically only when bank fundamentals are very poor, because in that case Central Bank intervention is very costly and thus improbable while bankrupt banks do not pursue failed debtors. Thirdly, the cost of intervention faced by the Central Bank has a double-edge effect. On one hand

⁴Most of the models on bank runs are concerned with an equilibrium selection problem. The depositors play a static simultaneous game, in which a coordination failure denies the players to participate in a higher equilibrium payoff due to the fact that they decide to withdraw their money early.

it reduces the moral hazard problem at the commercial bank level. A higher cost of intervention incurred by an active Central Bank reduces the commercial bank's risk-taking incentives. This translates ex-ante into a higher screening effort and, as a result, a better assets quality. On the other hand it can precipitate bank failure by lowering the fundamentals threshold that triggers collective strategic default. Anticipating that the active Central Bank will be reluctant to intervene when the cost of intervention is high, the solvent borrowers behave aggressively. Nevertheless, the threshold in bank fundamentals which triggers collective strategic default for the case of an active Central Bank is always higher than the threshold characterizing the case of an inactive Central Bank. Finally, I provide a different interpretation for the high interest rate differential between deposit and loan rates in emerging economies. I show that high expected profitability reduces the likelihood of collective strategic defaults.

Related literature

The modelling approach in this paper is related to various strands of literature. One strand studies strategic default as an individual borrower strategy. Townsend (1979) and Gale and Hellwig (1985) show that firms behave strategically under asymmetric information on firm profits.⁵ The cash diversion problem may be severe when contracts are incomplete in the sense that cash flows are not verifiable (Hart and Moore 1988, 1994, and Bolton and Scharfstein, 1990).⁶ A documented path for cash diversion is the tunneling transfer which is described by Akerlof and Romer (1993) and by Johnson, La Porta, Lopez-de-Silanes and Shleifer (2000).

⁵They study a costly state verification model in which the lender cannot observe the cashflow obtained by the borrower, unless a costly audit is performed. They show that the efficient incentive compatible contracts ensuring the truthful reporting by borrowers are standard debt contracts.

⁶Bolton and Scharfstein (1990) show that when the returns of the borrower's investment are not verifiable by a third party (and thus are noncontractible) the threat of termination (not to lend in the future) provides the incentive to repay. They argue that borrowing from multiple lenders decreases the incentive to strategically default since the firm manager must coordinate a restructuring plan with multiple claimants.

The second strand studies different aspects of regulators' intervention policies during banking crises. There is a growing literature on the regulators' choices between rescuing and closing troubled banks. The classical argument by Bagehot (1873) regarding the idea of the Central Bank as a LOLR is that the Central Bank should lend at a penalty rate to illiquid but solvent banks, against good collateral. Goodfriend and King (1988) criticize this view by arguing that a solvent bank will be able to find liquidity in an efficient interbank and money market. By using a 'too big to fail' approach Freixas (1999) argues that the LOLR should bail out an insolvent bank, while solvent banks are assumed to be bailed out by the interbank market. Rochet and Vives (1994) support Bagehot's doctrine by showing that even sophisticated interbank markets will not provide liquidity due to a potential coordination failure between investors which might have different opinions about bank solvency. Goodhart and Huang (2003) show that the Central Bank should act as a LOLR to avoid contagion during a banking crisis. Acharya and Yorulmazer (2006) argue that when the number of bank failures is low, the optimal ex-post policy is not to intervene, but when this number is sufficiently large, the regulator should choose randomly which banks to assist. The rationale behind this intervention mechanism is that the regulator sets a liquidity target which limits banks' assets sales and prevents the decrease in assets prices which might induce more bank failures. In this paper we abstract from contagion issue and we focus on an intervention mechanism based on the reporting and disclosure of non-performing assets. Commercial banks have to inform the Central Bank about their non-performing loans, and, by using this information, the Central Bank decides if its role as LOLR is requested. A similar approach is used by Mitchell (2001). She finds that bank managers have incentives to underestimate the size of non-performing loans under a tough intervention policy and show that this leads to inefficient liquidation of bad loans. Aghion, Bolton and Fries (1999) analyze both tough and soft recapitalization policies, arguing that soft intervention mechanism induces bank managers to exaggerate the recapitalization

needs. They also suggest that bank's incentives to misreport can be mitigated by an efficient bailout scheme which is conditional on the liquidation of firms in default.

Third, this paper complements the theoretical literature on bank runs. The analysis differs from ex-ante literature by examining a potential coordination problem between borrowers, in particular examining the possibility of a bank failure as result of asymmetric information among borrowers regarding bank fundamentals. To the best of my knowledge there are few formal models that are trying to determine the probability of a bank failure due to strategic coordination of its borrowers. Bond and Rai (2008) investigate the effect of borrower run in microfinance, for an environment where the threat of credit denial is an important source of repayment incentives. Unlike my paper they study only the relation between lenders and borrowers and try to identify the best lending policies which allow lenders to survive borrower run. My purpose is to understand the role of the Central Bank as a LOLR under opportunistic behavior from borrowers. Both Rochet and Vives (2004) and Naqvi (2006) endogenize the asset side of the bank balance sheet. Rochet and Vives (2004) model coordination failure on the interbank market. They find that there is a critical value of banks' assets above solvency threshold such that, whenever the value of the banks' assets falls below this threshold, the banks will not have access to liquidity. In a bank run model Naqvi (2006) shows that the presence of a perfectly informed LOLR can avoid costly liquidations and thus it is Pareto improvement. However, these papers abstract from the moral hazard problem between the borrowers and the bank, an issue which I take explicitly into account. The main novelty in my paper relative to these papers is that it focuses on the borrowers collective strategic default, while depositors are passive players.

Finally, from the methodological point of view, this paper is related with global games literature. My work complements this literature by looking to a particular coordination game, used to explain collective strategic default on the asset side of a commercial bank balance sheet. I form the model in the context of the global games

methodology first introduced by Carlsson and van Damme (1993) and later refined by Morris and Shin (1998). This realistic approach does not depend on common knowledge and helps to resolve the issue of multiple equilibria. Common knowledge, introduced in theoretical models through a perfect public information, can create self-fulfilling beliefs equilibria which might destabilize an economy. Sudden crises without any fundamental reason can arise in such unstable economy due to changes in beliefs of market participants. The presence of multiple equilibria in many macroeconomic models makes any policy analysis very difficult because is problematic to attach probabilities to different outcomes.⁷ The central assumption of the global games methodology is that individual actions are strategic complements: an agent's incentive to take a particular action increases as more and more agents take the same action.⁸ In this approach, a small amount of noise in fundamentals can be stabilizing and can pin down a unique equilibrium with agents playing threshold strategies. By using an iterated deletion of strictly dominated strategies, the unique Nash equilibrium can be derived for games with incomplete information. The theory of global games has been useful in modeling various economic applications.⁹ Fukao (1994) and Morris and Shin (1998) use this approach in modeling speculative currency attacks in the presence of identical speculators.¹⁰ Morris and Shin (2004) examine pricing of debt. Corsetti et al.(2004) and Peydro-Alcalde (2005) show how the presence of a large player affects the coordination problem in forex market and in a creditor's decision to renew its credit, respectively. Shin (1996) studies asset trading. Postlewaite and Vives (1987), Goldstein (1999), Morris and Shin (2000), Rochet and

⁷Diamond and Dybvig (1983) model bank runs; Diamond (1982), Hart (1982), Bryant (1983) examine unemployment or underemployment; currency crises are analyzed by Obstfeld (1996) in a model of a balance-of-payments crisis.

⁸See Morris, Rob and Shin (1995) and Kaji and Morris (1997) for generalizations of the logic behind the result of Carlsson and van Damme (1993).

⁹Morris and Shin (2003b) is a comprehensive review of the literature on global games. See also Vives (2005) for a review of recent applications to finance, macroeconomics and industrial organization.

¹⁰See also Heinemann (2000) comment on Morris and Shin (1998).

Vives (2004), Dasgupta (2004), Iyer and Peydro-Alcalde (2004), and Goldstein and Pauzner (2005) applied the theory of global games to model bank runs and to investigate contagion in the interbank market. Morris and Shin (2003a) and Corsetti, Guimaraes and Roubini (2004) use global games to study the impact of an international LOLR on adjustment policies of borrower countries. Atkeson (2000) and Edmond (2004) employ this method for explaining riots and political change. More advanced models allow not only for noisy private signals about fundamentals, but also for public signals and discuss their impact on the unique equilibrium.¹¹ Recent studies find empirical evidence for the financial fragility generated by strategic complementarities. Chen et al. (2008) use data on mutual fund outflows and find that when complementarities are stronger (i.e., funds with illiquid assets), the response of investors are more sensitive to fundamentals than in funds with liquid assets. Heinemann et al. (2004) use experimental methods to show that the predictions of global games theory are accurate.

The remainder of the chapter is organized as follows. Section 2.2 describes the basic model, the agents and their payoffs. Section 2.3 discusses the equilibrium and the thresholds derivation under imperfect information. Section 2.4 shows the comparative statics and the predictions of the model. Finally, Section 2.5 concludes and provides some directions for further research. The Appendix contains the mathematical detailed solutions for the main results.

¹¹Morris and Shin (1999) and Hellwig (2001) show that uniqueness of equilibria is preserved only if the private information is precise enough when compared with public information. Angeletos and Werning (2004) endogenize public information by allowing individuals to observe financial prices or other noisy indicators of aggregate activity.

2.2 The Model

I consider a static economy over three periods: 0, 1, 2. The economy is populated by a single bank which has no capital of its own, a continuum of identical risk-neutral firms of measure one, uniformly distributed over $[0, 1]$ and indexed by i , and a Central Bank.

2.2.1 Agents

The bank

The bank accumulates at date 0 uninsured deposits for a total amount q , which mature at date 1. Focusing on uninsured deposits avoids the moral hazard problem from any deposit insurance scheme with respect to bank incentives.¹² The bank has no cash or other reserves.¹³ The nominal return on deposits at date 1 is $Q > q$. Bank sets Q before choosing the investment strategy. The choice of investment is unobservable to depositors. In this case, the depositors will require a nominal return that provides them with (at least) zero expected return. As I focus on the assets side of the bank's balance sheet, I model depositors as passive players without alternative investment opportunities besides costless storage. Since depositors are passive players we abstract from the monitoring role of depositors.

Let the riskless interest rate be 0. The bank invests at date 0 the total amount of its funds q in a continuum of identical risky loans of size 1 each, granted to risk-neutral firms. Each loan matures in the next period and the nominal returns on

¹²The banking literature suggests that when depositors are uninsured, a deterioration in the quality of a bank's asset portfolio may trigger a run (Diamond and Dybvig 1993, Demirguc-Kunt and Detragiache 1998, 2000). In our model, as all deposits mature next period there is no intermediate period when a run might occur. Besides its positive attribute (elimination of self-fulfilling panics), both an implicit and an explicit deposit insurance creates incentives for excessive risk-taking by banks. The distortions and bank failures are more likely in the presence of full insurance, because depositors have no incentive in this case to monitor their banks. A comprehensive survey on deposit insurance schemes is Bhattacharya, Boot and Thakor (1998).

¹³The qualitative nature of our results is unchanged if the bank has initial capital, and it holds a certain amount of cash.

these loans at date 1 is $D > 1$. If all loans are repaid, the bank is able to repay depositors:

$$Q < qD \tag{2.1}$$

The bank's balance sheet at date 0 is the following:

TABLE 1. BANKS'S BALANCE SHEET AT DATE 0.

No cash	No Equity
$\sum \text{Loans} = q$	$\sum \text{Deposits} = q$

Before granting risky loans at date 0 the bank has to set up its loan screening strategy. Specifically, the bank has to implement a costly effort e to assure repayment by its borrowers. The screening effort is costly because is difficult to identify good firms to lend to. The effort lies in the interval $[0, 1]$ and it is exercised through activities such as extensively screening loans applications, hiring better loan agents or writing better contracts that can be easily enforced in a court. I assume the cost function is quadratic in effort and proportional to the returns on the loans, $c(e) = \frac{e^2}{2}qD$. Put differently, the screening cost is increasing with volume of loans q , and also it increases in the loan rate D since more effort is required in identifying the appropriate rate for risky loans. Once e has been chosen, it is common knowledge among all agents.

I assume that upon insolvency, the bank can no longer enforce contracts. As a result, once bank assets are below liabilities, the enforcement technology is lost if liquidity support is not provided to bank. Empirical evidence that supports this assumption comes from Perotti (1998). He shows that during the transition period in Eastern European countries and in Russia in early '90s, the bank credit was made more scarce because the banks couldn't pursue non-paying firms, leading to an increase in trade credit. As the accumulation of trade arrears also increased, the defaulted firms benefited mostly due to higher expectations for a collective bailout.

He concludes that in a weak institutional context characterized by inadequate bankruptcy laws and unreliable enforcement of contractual obligations, firms' perverse incentives and collusive behavior are generated by the impossibility to discriminate across viable and distressed firms.

The value of the bank's fundamentals in this model depends on d , the measure of firms that are in genuine financial distress and can not repay their loans. This random variable is normally distributed with mean $(\mu - e)$ and variance $1/\alpha$ (precision α). Here μ stands for *unconditional bank fundamentals* and it is interpreted as a measure for the health of economic environment. A healthy economy, in which the prospects for corporate sector performance are high, it is characterized by a lower μ . In such an environment most of the debtor firms are expected to generate positive cash flows. I assume that $0 \leq \mu \leq 1$. The level of effort directly affects the quality of assets the bank holds. Thus higher the effort e exerted by the commercial bank, better are the lending policies and lower the probability of insolvency. The bank fundamentals d are not common knowledge among market participants. From these insolvent firms the bank can not extract any liquidation value, whatever its effort.

Debtor firms have no information about bank value. Alternatively, the bank may not be listed on a stock exchange.¹⁴ This is not a very restrictive assumption since financial environment of most emerging economies is characterized by poor capital markets and even in well developed economies small banks might not be listed. There is no other source of financing for the bank in the short run (i.e., the bank has no access to interbank loans). A motive could be that fear of contagion might lead to low level of liquidity in the interbank system (Dasgupta 2004, Iyer and Peydro-Alcalde 2004, Allen and Gale 2000, Calomiris and Mason 2003).¹⁵

¹⁴Atkenson (2000) questioned the decision of agents to take different actions on the basis of their private signals when a publicly observed asset price accurately reflect which outcome will occur. This issue was examined by Morris and Shin (1999), Hellwig (2001) and Angeletos and Werning (2004).

¹⁵As the subprime loans crisis of 2007 showed, liquidity will dry up if mutual confidence falls in the interbank market.

I assume that the bank is the most efficient agent at extracting cash from the debtor firms due to its collection skills (Diamond and Rajan 2000, 2001). Its loans are not tradeable and selling the entire loans portfolio to other financial agents is not optimal while the bank can not insure itself against the costs of forcing a defaulting firm to repay. As evidence suggests, securitization and complex tools such as CDO or CDS reduce the quality of credit originated. Allowing for these tools will make the main results of this paper stronger by creating incentives for excessive risk-taking by commercial bank. I also implicitly assume that equity can not be raised overnight if the bank faces liquidity shortage.

I abstract from issues of renegotiation and lending against a collateral. Including both aspects together in the model is simply redundant. Although the loan agreement may stipulate that the collateral can be seized should the borrower not repay, it is expected if borrowers goes insolvent, the loan to be renegotiate, as banks are typically less efficient managers. While important, explicitly allowing only for the existence of collateral would complicate the model without significantly changing the main conclusions. With respect to renegotiation, although it is common for commercial banks to renegotiate non-performing loans the reduction is not explicitly stated. The new agreement relaxes the payment process through reduction of interest rates and extension of payment periods and more important, takes time to be implemented. A bank facing liquidity shortage and deposits withdrawals has no time to renegotiate its non-performing loans. It needs funds to pay its depositors, and needs those funds quickly. On the other hand, this paper does not study the perverse incentives borrowers might have under the possibility of contracts renegotiation. Hence, there is no credible avenue for renegotiation within this paper framework.

Firms

There are two types of firms in this economy. On one hand, there are firms which expect a positive cash flow in period 1 (henceforth, *good firms*). For simplicity I

assume that the cash flow is equal to D , which is firm's obligation to the bank. A good firm may take one of two actions. It may decide *not to repay* its loan, thus mimicking the situation of a firm in real financial distress. Alternatively it may decide *to repay* it in full. The second type are distressed firms. I assume that an insolvent firm (henceforth, a firm in genuine financial distress, or a *bad firm*) has zero cash, thus it has no option but to default. The critical question is whether the potentially solvent firms will choose to repay. They understand that the lending bank will be able to fully pursue non paying solvent firms only if it survives, otherwise the recovery process takes time due to the fact that a regulator (the Central Bank in this model) will be in charge with this process. Hence, it is possible that borrowers are less willing to honour their obligations in due time. However, if the bank survives it can enforce all contracts it has with solvent borrowers, and also it will break off the relation with strategic defaulters. In this model, the act of payment represents a decision. Kahn and Roberds (2009) argue that the choice of whether, when and how to pay depends on a variety of characteristics of the agents involved in the trade and on the environment, such as differential information, legal structure enforcing the contracts, importance of reputation and ease of damaging it among many others. In this model, solvent firms decisions to repay or not may depend on their beliefs about other firms' actions and not only on the information regarding how strong the bank fundamentals are. I assume that a good firm which is indifferent between repaying and not will choose not to repay.

The Central Bank

The Central Bank decides on its intervention policy based on the total number of non-performing loans reported by the commercial bank. Henceforth I make the assumption that the commercial bank can not misreport the non-performing loans

volume (the Central Bank can verify at zero cost this reported number).¹⁶ Note that the real number of non paying firms include all distressed firms plus those good firms mimicking the behavior of a distressed one. Within this framework I examine two polar cases. In the first one I assume no Central Bank intervention. This case corresponds to an inactive Central Bank. The Central Bank declares ex-ante that it will not bail out commercial bank if it faces trouble and it is consistent ex-post with this decision. Then I consider the case of an active Central Bank. An active Central Bank might step in and provide additional funds if necessary, by lending at a zero interest rate, in order to avoid the bank default. If the bank is rescued, its enforcement technology remains intact and the bank can identify the strategic defaulters and extract payments from them. The Central Bank decides on the *optimal BailOut Amount (BOA)* by balancing the cost of a successful intervention against the social cost of doing nothing. This social cost is the opportunity cost of forgone intermediation if the commercial bank is closed, while the administrative costs of closure are ignored. The bailout amount is unknown ex-ante to firms and commercial banker and since the Central Bank itself can not differentiate between bad firms and good firms that are not repaying, it will choose between two possible actions: full bail out or no bail out. This uncertainty may induce the bank to take costly effort to reduce the incidence of strategic default by debtor firms. I assume that if the active Central Bank is indifferent between helping the decapitalized bank and not, it will choose to bail out the bank. In both scenarios any closure threats by the Central Bank are credible.

Next I describe the payoff functions for market participants and the structure of the game they play.

¹⁶Mitchell (1997) looks at a specific too-many-to fail problem and shows that, if distressed but solvent banks expect the regulator to apply a policy of closure and if the probability of detection of loan rollovers is high enough, then banks will reveal and deal with their bad loans. See also Rajan (1994) and Aghion, Bolton and Fries (1999).

2.2.2 Payoff Functions

Firms' payoffs

The payoff structure for a debtor firm is as follows. If a healthy financial firm doesn't repay its loan and the bank fails, then it saves the repayment, producing a positive payoff of D , minus an amount X representing the positive value that the Central Bank can extract ex-post from non repaying good firm. This difference $D - X$ is positive and indicates that the original lender is the most efficient at extracting any hidden cash from borrower firms. Alternatively, this positive value suggests that the commercial bank is a more efficient user of its assets than outsiders (James, 1991). Without loss of generality I assume for the remainder of the paper that X is zero (i.e., the Central Bank recovers nothing from strategic good firms). If a good firm does not repay and the bank survives, the bank can force at no cost repayment D and also can force a contractual fine $F > 0$. This contractual fine represents penalties for non repaying or delaying the repayment. If a good firm decides to repay its loan, it will get either 0 if the bank fails or $V > D$ otherwise, where V represents the present value of future long term relation with the bank.¹⁷ The banking literature argues that long term interactions between a bank and its borrowers lower the cost of asymmetric information for the lender and improve the credit terms for the debtors. The coordination failure among good firms might deny those firms to participate in the higher payoff V due to the fact that they decide to default on their loans and to keep the entire amount D . I also assume that the value of relation with the bank is not as low as to make debtor firms to prefer to default on their obligation regardless

¹⁷Diamond (1991) shows that firms that have been successful in the past are able to obtain better credit terms, since they are more likely to be successful in the future. Fama (1985) points out that the value of intermediation and the firm-bank relationship is central to what makes a bank 'special'. According to Mayer (1988) firms and financial intermediaries develop long-term relationships. Boot (2000) and Ongena and Smith (2000) provide detailed surveys of the relationship banking literature.

the level of bank fundamentals:

$$V > F + \frac{QD}{qD - Q} \quad (2.2)$$

The payoff structure for a good firm is illustrated in the next table.

TABLE 2. GOOD FIRM'S PAYOFF.

	Firm repays loan	Firm does not repay
Bank survives	V	-F
Bank defaults	0	D

I abstract from issues such as good firms coordinating and bailing out either the commercial bank or the bad firms, or Central Bank monitoring the debtor firms. These issues will give a different twist to this paper and will also challenge the role played by commercial banks as financial intermediaries and delegated monitors.

Default condition

For both financially distressed and healthy firms, a default is triggered by non repayment at date 1. I introduce here the following function of d , representing a measure of solvent firms which should strategically default on their loans such that the bank becomes insolvent:

$$z(d) = 1 - d - \frac{Q}{qD}. \quad (2.3)$$

This function is strictly decreasing in d . The bank becomes insolvent if the value of its liabilities Q is higher than the value of its assets:

$$[1 - d - \underbrace{(1 - d)n(d)}_{z(d)}] * qD < Q \quad (2.4)$$

At date 1 the bank's assets depends on the measure of firms in genuine financial distress, d , and also on the measure of strategic firms, $z(d)$. The function $z(d)$ can

be written as $(1 - d)n(d)$, where the function $n(d)$ indexes the fraction of good firms which chooses the action *not repay*. I denote by $z'_d(d)$ the first derivative of $z(d)$ with respect to bank fundamentals d . Thus $z'_d(d) < 0$, meaning that higher the number of firms in real financial distress, the lower is the threshold number of mimicking good firms which should not repay such that the bank fails. I denote by \bar{d} the point at which $z(d) = 0$ and by \underline{d} the point at which $z(d) = 1$. The intuition for the solution of the model *if we assume* common knowledge about bank fundamentals is as follows.

The state of bank fundamentals affects the degree of coordination among good firms and thus the payoff from successful collective default. If the bank fundamentals are strong, only a high degree of coordination can undermine the bank capacity to collect unpaid loans. Therefore all good firms will repay their loans on time. On the other hand, when bank fundamentals are very poor, few firms which do not repay their loans can trigger the bank failure. In this situation the dominant strategy for all firms will be non repaying because this strategy will generate a positive payoff. While in these two regions there is one pure Nash equilibrium, in the intermediate region the model has multiple equilibria under a common knowledge assumption. With self-fulfilling beliefs two pure strategy equilibria will coexist: a 'bad' equilibria in which all firms decide not to repay because each one believes in bank's failure, and the 'good' equilibria in which all firms decide to repay because each one believes in bank's strength.¹⁸ We assume that there exists a level of extremely good fundamentals $\underline{d} > 0$, such that good firms always repay when they know that bank fundamentals are such that $d \leq \underline{d}$, independently of what they think other good firms would do. The idea behind this assumption is similar to Goldstein and Pauzner (2004), namely that for extreme situations when fundamentals are very good, an external

¹⁸This classification of fundamentals under common knowledge assumption was emphasized by Morris and Shin (1998) in their paper about currency attacks, by Obstfeld (1996) in his paper about balance-of-payments crises, and Rochet and Vives (2004) in their work on the coordination failure on the interbank market.

large enough investor exists and she is willing to buy the bank given the high returns which she can be sure of making if bank's enforcement ability is preserved. This assumption generates a supersolvency or upper dominance region which is crucial for selecting a unique equilibrium. To summarize, under common knowledge the classification of fundamentals will be:

- for $d \leq \underline{d}$ we have $z(d) > z(\underline{d}) = 1$. In this case all good firms repay because the bank's enforcement ability is preserved even if all borrowers default. Thus a good firm would obtain a higher payoff repaying the loan than strategically defaulting.
- for $\bar{d} \leq d$ we have $z(d) < z(\bar{d}) = 0$. In this case all good firms not repay because the bank goes bankrupt even if no firm defaults. This range of fundamentals is called insolvency or lower dominance region.
- for $\underline{d} < d < \bar{d}$ we have multiple equilibria. The outcome depends on firms' expectations of what other firms will do, and not on the underlying bank's fundamentals.

The rest of the paper assumes no common knowledge about fundamentals. The debtor firms hold common prior beliefs about the state of fundamentals d and receive private signals about its realization $x_i = d + \epsilon_i$, where ϵ_i is normally distributed with mean 0 and variance $1/\beta$ (precision β). Moreover, ϵ_i is independent of d and identically and independently distributed across firms. A firm's signal can be thought of as its private opinion regarding the prospects of the corporate sector and the impact that these may have on bank's assets. Based on their private signals, borrowers can infer under these circumstances a conditional distribution for bank fundamentals.

Bank's payoff

The model assumes that upon insolvency, the bank can no longer enforce contracts and thus it can not extract the available cash from good firms, conditional on liquidity

not being provided by the Central Bank. This gives to the Central Bank the incentive to keep the commercial bank alive, since the bank failure is socially costly. Since the bank has no other sources for financing at date 1, only the Central Bank's intervention can allow it to preserve enforcement technology and to collect payments from strategic defaulters in order to its obligations. Insolvency condition is captured by (2.4).

The bank's expected payoff if it survives is given by:

$$qD * \underbrace{E_d[(1-d) * (1-n(d))]}_{\text{expected measure of repaying firms}} + q(F+D) * \underbrace{E_d[(1-d) * n(d)]}_{\text{expected measure of mimicking firms}} - Q - c(e), \quad (2.5)$$

while the expected payoff if the bank goes bankrupt is: $-c(e)$.

If the bank survives, it can differentiate ex-post bad firms from good firms, and thus can extract a repayment from good firms (from bad firms, as I assumed earlier, it can extract nothing). Ex-ante, the bank tries to infer the measure of good firms repaying, conditional on the prior distribution of d . The payoff depends on the expected measure of good firms repaying their loans and on the expected measure of good firms that will be fined, adjusted for the cost of effort and depositors claim. When the bank fails, the payoff is negative and equals the cost of incurred effort (if any).

Central Bank's payoff

The Central Bank values the long term relation between good firms and their bank. The Central Bank recognizes the opportunity cost of forgone intermediation if the commercial bank is closed as all good firms which repay their loans will lose a positive value V if the bank fails. The Central Bank tries to minimize the social cost induced by the failure of the bank, trading it off against the cost of full intervention. Let γ be the Central Bank's marginal cost of intervention. We can interpret this cost from two different perspectives. The most straightforward interpretation is to consider

the intervention cost as being the fiscal cost of providing funds to the falling bank. Using this approach, this cost can be linked either with the negative effects of tax increases required to fund the bailout, or with the similar effect of government deficits on other macro variables such as exchange rate. An alternative interpretation is to consider the intervention cost as a proxy for Central Bank's independence and its commitment to maintain price stability.

The concept of independence means that, once appointed, the central banker is able to set policy without interference or restriction of the political authorities (Rogoff, 1985). The central banks' credibility depends on being prepared to do two unpopular things: raising interest rates despite the economic pain, and letting financial institutions to fail. For industrialized economies it has been shown that different measures of Central Bank independence are negatively correlated with average inflation, suggesting that, highly independent central banks are presumed to place more weight on achieving low inflation.¹⁹ Unlike in industrial countries, where nowadays domestic central banks are considered to be more independent and where they can limit the degree of instability in the banking system through LOLR operations, in emerging markets the credibility of central banks as an inflation-fighter is still in doubt. Mishkin (2007) argues that central banks intervention as LOLR in these economies, in which debt contracts are typically short term and denominated in foreign currencies, more likely exacerbates financial crises by rising inflation fears and by causing currency depreciation. Following this approach and considering the intervention cost γ as a proxy for Central Bank's independence and its commitment to maintain price stability, we can assume that an independent Central Bank, which is committed to deal with inflationary pressures, will have a higher γ .

Moving one step further from the independence issue and allowing the focus to be only on central banks' commitment to maintain price stability, an interesting ques-

¹⁹Comprehensive surveys on Central Bank independence are Cukierman (1992) and Eijffinger and de Haan (1996).

tion might be explored, namely what is the impact of a central bank's main mandate on the preference it has toward bailing out falling commercial banks. As we know, central banks are of two types: those concerned with both inflation and economic growth, and those targeting only inflation rate. Two of the most important Central Banks in the world, the US Federal Reserve (FED) and the European Central Bank (ECB), belong to different types. While the ECB has a single mandate - maintaining price stability by controlling inflation - and is not concerned with maximizing economic growth, the FED has two mandates - to preserve the value of the US dollar and to maintain full employment - the two being incompatible. To exemplify the distinction between these two central banks we can look to their policies adopted during 2007/2008 credit crisis. On one hand, the ECB was reluctant to cut interest rates because inflation was consistently above its target. On the other hand, FED governors chose to try to boost up the economy and let the inflation surge by reducing interest rates and they also flooded the market with liquidity (e.g. bailing out Bear Stearns, a primary broker which was not under direct supervision of the FED, setting up Term Lending Facilities and lengthen their maturity profiles periodically). According to the previous example, the ECB, which places a higher weight on inflation objectives due to its mandate, has a higher cost of intervention γ than the FED, which was concerned more about economic contraction during the credit crisis.

Further, I assume common knowledge about γ . It is a positive constant and a higher γ means higher cost of intervention. If the Central Bank decides to intervene and to bail out the commercial bank, the cost of intervention is proportional with lender's liquidity needs:

$$-\gamma[Q - \underbrace{qD * (1 - d) * (1 - n(d))}_{\text{repaid loans}}], \quad (2.6)$$

while the social cost incurred if the Central Bank allows the bank to go bankrupt is proportional with the destroyed relational value for those firms who choose to

repay:

$$-qV * \underbrace{(1 - d) * (1 - n(d))}_{\text{measure of repaying firms}}. \quad (2.7)$$

Thus, the Central Bank's cost function is given by:

$$\min \{qV * (1 - d) * (1 - n(d)), \gamma[Q - qD * (1 - d)(1 - n(d))]\}$$

If the Central Bank decides to step in, it provides all the necessary funds to recapitalize the bank (i.e., an amount equal to $Q - qD(1 - d)(1 - n(d))$). Otherwise, it provides no money, allowing the bank to fail.

The set of available information the Central Bank has when it takes the intervention decision is different than the one possessed by the commercial bank when it sets its loan screening strategy. While the commercial bank has information only about the prior distribution of its fundamentals d , the Central Bank is informed about the measure of reported non-performing loans, $d + (1 - d) * n(d)$, as well.

The extensive form of the game. We can now summarize the sequence of events:

$t = 0$

- The bank collects uninsured deposits;
- The bank exerts the screening effort which becomes common knowledge, and invests.

$t = 1$

- Nature draws the bank fundamentals d according to the prior normal distribution; d is not common knowledge;
- Each debtor firm receives a private noisy signal x_i ;
- Based on their signals, the debtor firms update their beliefs about the bank fundamentals and simultaneously decide to repay their loans or not;

- The bank reports the volume of non-performing loans to the Central Bank.

$t = 2$

- Central Bank decides on the optimal bailout amount;
- The payoffs of the game are revealed and distributed.

2.3 Equilibrium and Thresholds Derivation

Next I derive the probability of a run by bank borrowers, measuring a collective strategic default. Since a firm's signal provides information not only about bank fundamentals, but also about other firms' signals, it allows debtor firms to infer the beliefs of the others. Thus, observing a high signal induces a debtor firm to believe that other firms also received a high signal. Hence it assigns a high probability to an attack on the bank, while a low signal suggests exactly the opposite.

We solve the model backwards. First, we derive the optimal Central Bank's intervention policy at date 2. Then, we analyze the behavior of debtor firms at date 1, and finally we derive the optimal bank's effort at date 0.

In solving the game and deriving the unique equilibrium, I use the global games methodology first introduced by Carlsson and van Damme (1993) and later refined by Morris and Shin (1998). Two scenarios are considered in turn. First scenario assumes that the Central Bank is inactive and never intervenes, while in the second one I explore the borrowers' and commercial bank's behavior when the Central Bank is active.

2.3.1 Inactive Central Bank Case

Firms repayment incentives

A good firm has a dominant strategy to not repay its loan, when the expected payoff of doing so, conditional on the available information, is higher than the expected

payoff of repaying the loan:

$$\begin{aligned}
 &P(\text{BankSurvives} \mid x_i) * (-F) + P(\text{BankFails} \mid x_i) * D > & (2.8) \\
 &P(\text{BankSurvives} \mid x_i) * V + P(\text{BankFails} \mid x_i) * 0
 \end{aligned}$$

On the left side in (2.8), the expected payoff for a firm deciding not to repay is described. The first term denotes the firm's return when the bank survives, times the probability that the bank does not go bankrupt, while the second term denotes the return in the case of bank collapse, times the probability of bankruptcy. On the right side, the expected payoff for a firm deciding to repay is computed. The first term denotes the firm's expected return when the bank survives, while the second term denotes the expected return in the case of bankruptcy.

For each realization of the private signal x_i , a good firm i should decide for a specific action (either repay, or not). This decision rule which connects signals with actions represents the strategy of each good firm. Beside his own decision rule, the outcome for each good firm depends on all the other good firms' strategies. An equilibrium is characterized by a set of strategies maximizing the expected payoff for each good firm, conditional on the available information, given that each good firm is adopting a strategy from this set.

I focus on threshold strategies in which each debtor firm decides not to repay if and only if its signal is above some threshold level. Nevertheless, by focusing our attention to this type of strategies is without loss of generality. Morris and Shin (2000, 2003b) show that, when there is a unique symmetric equilibrium in thresholds strategies, there can be no other equilibrium. This switching equilibrium is the only set of strategies that survives iterated elimination of strictly dominated strategies. Since my model satisfies the symmetry condition due to the fact that all debtor firms are identical and also there are strategic complementarities between firms' actions, I can employ global games methodology for deriving the unique equilibrium.

Let us suppose that there are two thresholds x^* and d^* , such that all the firms which see a signal $x > x^*$ will not repay their loans, while d^* represents the threshold in bank fundamentals at which the bank fails for values of $d > d^*$. I prove the existence and uniqueness of these two thresholds by using an algebraic solution similar with Morris and Shin (1998). The detailed mathematical derivations are in the Appendix.

The equilibrium thresholds x^* and d^* are:

$$x^* = \frac{\alpha + \beta}{\beta}d^* - \frac{\alpha}{\beta}(\mu - e) - \frac{\sqrt{\alpha + \beta}}{\beta}\Phi^{-1}\left(\frac{D}{V + F + D}\right), \quad (2.9)$$

where x^* is the threshold signal at which a good firm is indifferent between repaying the loan or not, and

$$d^* + \frac{Q}{qD} = \Phi\left(\frac{\alpha}{\sqrt{\beta}}\left(d^* - (\mu - e) - \frac{\sqrt{\alpha + \beta}}{\alpha}\Phi^{-1}\left(\frac{D}{V + F + D}\right)\right)\right), \quad (2.10)$$

where d^* is the threshold value for commercial bank fundamentals above which the bank fails when the Central Bank is not active (*see the Appendix for detailed derivations*). Φ represents the cumulative distribution function of the standard normal distribution. The solution to equation (2.10) should belong to the region of fundamentals which is characterized by multiple equilibria under common knowledge assumption. Thus, d^* should lie in $[\underline{d}, \bar{d})$.

The right side of equation (2.10) is a cumulative normal distribution

$$N\left((\mu - e) + \frac{\sqrt{\alpha + \beta}}{\alpha}\Phi^{-1}\left(\frac{D}{V + F + D}\right), \frac{1}{\alpha^2}\right).$$

Thus, we may conclude that d^* is the intersection point between the cumulative normal distribution just described and a straight line (with a slope of 1) and positive intercept $\frac{Q}{qD}$. This intersection point exists and it is unique if the slope of cumulative normal distribution is less than one everywhere. This slope equals

$$\frac{\alpha}{\sqrt{\beta}}\phi\left(\frac{\alpha}{\sqrt{\beta}}\left(d^* - (\mu - e) - \frac{\sqrt{\alpha + \beta}}{\alpha}\Phi^{-1}\left(\frac{D}{V + F + D}\right)\right)\right),$$

where ϕ is the density function of the standard normal distribution. From statistical properties of standard normal density function $\phi \leq \frac{1}{\sqrt{2\pi}}$, thus a sufficient condition for a unique solution for d^* , under assumption (2.1), is given by:

$$\frac{\alpha}{\sqrt{\beta}} \leq \sqrt{2\pi} \quad (2.11)$$

Proposition 1 *When the precision of the private signal of debtor firms (β) is large enough relative to prior precision (α) so as to satisfy (2.11), there is a unique d^* defined in (2.10) such that, in any equilibrium of the game with imperfect information, the bank fails if and only if $d > d^*$.*

Proof. *See the Appendix. The proof is along the lines of Morris and Shin (2000).*

■

This proposition implies that by relaxing the assumption of common knowledge, one can eliminate the multiple equilibria only if the precision of private signals is large relative to the precision of the prior (i.e., β large when compared to α). This condition is sufficient for uniqueness of equilibrium because only this equilibrium survives iterated deletion of strictly dominated strategies (see Morris and Shin 2000, 2003b). The intuition behind this result is as follows. In the highly stylized banking model described, there is a unique value for the bank fundamentals, denoted d^* , which generates a distribution of private signals in such a way that there is only one signal, denoted x^* , which makes a good firm receiving this signal indifferent between repaying the loan or not. If all good firms with signals higher than x^* decide not to repay their loans, then the threshold d^* generates a proportion of mimicking firms that is sufficient to make the commercial bank insolvent.

In order to keep the model tractable and to derive closed form solutions I analyze the equilibrium values under the assumption that the private signal's precision is very high ($\beta \rightarrow \infty$). This approach is standard in the literature of symmetric binary global games. Importantly, Morris and Shin (2003b) show that this limiting assump-

tion will not restore common knowledge. The intuition for this result is as follows. As information concerning fundamentals become more precise and the noise smaller, the actions in equilibrium resemble the behavior when the uncertainty regarding the actions of other agents become more diffuse. Hence, strategic uncertainty regarding the actions of other agents is higher for $\beta \rightarrow \infty$ and limiting behavior can be identified independently of the prior beliefs and the shape of noise. This result holds in the framework of this paper. Under very high precision of the private signals, the marginal solvent debtor firm believes that the measure of good debtor firms choosing the action not repay is a uniform distributed random variable over $[0, 1]$. Under this result equation (2.10) becomes $d^* + \frac{Q}{qD} = \Phi(-\Phi^{-1}(\frac{D}{V+F+D}))$, which implies that:

$$d^* + \frac{Q}{qD} = \frac{V + F}{V + F + D} \quad (2.12)$$

This result shows that the decision to default or not strategically depends on the bank's expected profitability ($\frac{Q}{qD}$), the benefits of the on-going relation with the bank (V), and the penalty for shirking (F). According to (2.12), expected profitability plays an important role in preventing a strategic behavior of debtor firms, even when the Central Bank is inactive. A lower deposit-to-assets ratio for the bank ($\frac{Q}{qD}$) implies a higher threshold above which the bank fails when facing collective strategic default. Nevertheless, this result holds always when the decrease in this ratio is due to a decrease in Q , the nominal value of deposits at date 1, or an increase in q , the volume of loans. The impact of D , the returns on loans at date 1, on equilibrium threshold is ambiguous. Differentiating (2.12) with respect to D yields the following result:

$$\frac{\partial d^*}{\partial D} = \frac{Q}{qD^2} - \frac{V+F}{(V+F+D)^2}$$

If the difference on the right side of the above equation is positive, then keeping all other factors constant an increase in returns on loans implies a stronger position for the commercial bank facing strategic behavior from debtor firms, which is charac-

terized by a higher value for the equilibrium threshold d^* above which the bank fails. Otherwise, if the difference is negative, the increase in nominal returns on loans has the opposite effect, weakening bank position in front of a strategic attack of debtor firms.

The effects of changes in the contractual fine (F) that can be enforced by the surviving commercial bank, or in the present value of future long term relation between a good firm and the bank (V), are straightforward and intuitive. An increase in these parameters has a positive impact on the equilibrium threshold d^* , reducing the likelihood of successful strategic default. I interpret higher values of F as better loan contracts written by the bank, while higher values for V might be interpreted as an increased importance of the banking sector in the overall economy. Following to an increase in any of these two parameters the good firms will behave less aggressively when deciding to repay their loans or not because any potential gain driven by non repayment is reduced.

Bank optimal effort

Taking as given the optimal strategy for debtor firms, the bank chooses its optimal effort by maximizing its expected payoff, conditional on the available information. First, I present the expected payoff of the bank in the general case and then I derive the closed form solution for bank optimal effort in the limiting case. An increase in exerted effort e implies a lower value for average weakness of bank fundamentals ($\mu - e$). Thus, by reducing its portfolio's risk through costly activities (e.g. extensively screening loans applications, hiring better loan agents, or writing better contracts that can be easily enforced in a court), the bank might make a strategic attack from debtor firms less likely. This happens because by lowering the average weakness of its fundamentals the bank actually increases the probability of lower signals received by debtor firms while decreasing the measure of genuine non-performing loans. The expected payoff for the bank is given by:

$$\begin{aligned}
& P(\text{BankSurvives}) * qD * E_d[(1 - d) * (1 - n(d))] + \\
& + P(\text{BankSurvives}) * q(F + D) * E_d[(1 - d) * n(d)] + \quad (2.13) \\
& + P(\text{BankSurvives}) * (-Q - c(e)) + \\
& + P(\text{BankFails}) * (-c(e))
\end{aligned}$$

The first term represents the bank's return from the good firms which repay their loans, times the probability that the bank does not go bankrupt, times the expected number of repaying good firms; the second term denotes the bank's return from the good firms which do not repay their loans, times the probability that bank survives, times the expected number of non repaying good firms; the third term represents bank's outflow to depositors and for funding the exerted effort, times the probability that the bank does not go bankrupt; finally, the last term denotes the return in the case of bankruptcy, times the probability of bankruptcy.

If bank survives it will be able to collect D and also to fine with F all those good firms which choose not to repay their loans because its enforcement technology is preserved. This amount adds to all the repaid loans by the good firms which decided not to attack the bank. Out of this cash available at date 1 the commercial bank has to repay its depositors with notional amount Q and it also has to fund its cost of effort $c(e)$. If bank fails, the loss is given by the cost of incurred effort (if any). Ex-ante, the bank will try to infer the measure of good firms which will be repaying, conditional on the prior distribution of d .

The commercial bank has information only about the prior distribution of fundamentals. Thus, the probability of bank survival is given by:

$$P(\text{BankSurvives}) = P(d \leq d^*) = \Phi(\sqrt{\alpha}(d^* - (\mu - e))).$$

The bank anticipates the behavior of debtor firms and thus expects a measure of non repaying good firms equal to:

$$E_d[(1 - d) * n(d)] = E_d[P(x > x^*)] = 1 - H(x^*),$$

where $H(x^*)$ is the cumulative normal distribution function for signal x . Now we can determine the expected measure of repaying firms as:

$$E_d[(1 - d) * (1 - n(d))] = H(x^*) - (\mu - e).$$

See the Appendix for detailed derivations.

Finally, the expected payoff for commercial bank is given by:

$$\begin{aligned} & \Phi(\sqrt{\alpha}(d^* - (\mu - e))) * qD * [H(x^*) - (\mu - e)] + \\ & + \Phi(\sqrt{\alpha}(d^* - (\mu - e))) * q(F + D) * [1 - H(x^*)] \\ & + \Phi(\sqrt{\alpha}(d^* - (\mu - e))) * (-Q - c(e)) + \\ & + (1 - \Phi(\sqrt{\alpha}(d^* - (\mu - e)))) * (-c(e)) \end{aligned} \quad (2.14)$$

In order to have an explicit solution I take first limit with respect to β , and afterwards with respect to α . When $\alpha \rightarrow \infty$, the information about prior distribution of fundamentals is very precise. A very precise prior translates in less noise regarding the bank's fundamentals. The solution for optimal choice of effort in the limiting case is:

$$e^* = \begin{cases} 1, & \frac{V+F}{V+F+D} - \frac{Q}{qD} \leq \mu \leq 1 + \frac{V+F}{V+F+D} - \frac{Q}{qD} \\ 0, & \text{otherwise} \end{cases} \quad (2.15)$$

See the Appendix for detailed derivations.

According to (2.15), the commercial bank exerts *no effort* when its unconditional fundamentals (μ) are below $\frac{V+F}{V+F+D} - \frac{Q}{qD}$, in which case a strategic attack from debtor firms is not likely, or when the unconditional fundamentals are very high (above $1 + \frac{V+F}{V+F+D} - \frac{Q}{qD}$). Both thresholds are positive given (2.2). A poor quality of loans portfolio characterized by a high average weakness of bank fundamentals $\mu - e$ increases the probability for a successful strategic attack from debtor firms. I analyze this in depth in Section 2.4.

The choice of effort is unobservable to depositors. As a result, depositors require at date 0 a nominal return Q that provides them with (at least) zero expected

return in the worst case (i.e., bank chooses a risky portfolio and $e = 0$). Therefore, depositors participate only if

$$Q * P(\text{BankSurvives} \mid d, e = 0) \geq q, \quad (2.16)$$

where $P(\text{BankSurvives} \mid d, e = 0) = \Phi(\sqrt{\alpha}(d^* - \mu))$, and d^* is given by (2.10).

2.3.2 Active Central Bank Case

Central Bank intervention decision

I consider now the case when the Central Bank is active. The Central Bank intervention policy in the case of an illiquid bank should be designed to meet two challenges. First, it has to minimize the ex-ante moral hazard problem for all parties involved. This translates in a reduction of borrowers' incentive to default strategically and in higher incentives for banks to mitigate strategic behavior of debtor firms by exerting costly effort. Second, it has to minimize the cost of intervention.

The Central Bank compares the cost implied by a full intervention described in (2.6) with the social cost expected if the bank goes bankrupt, which is captured by (2.7)

Goodhart and Schoenmaker (2009) find that the recapitalization of a failing bank is efficient if the social benefits exceed the cost of recapitalization. Following a similar approach, the Central Bank in this model is more likely to intervene under high opportunity cost of forgone intermediation caused by the bank closure, and is more likely to allow bank failure in the case of high intervention costs. I denote the measure of non-performing loans by $NPL(d) = d + (1 - d)n(d)$. Following from the bank's insolvency condition (2.4) the Central Bank's cost function is given by:

$$C(NPL(d)) = \min \{qV * (1 - d) * (1 - n(d)), \gamma[Q - qD * (1 - d)(1 - n(d))]\} \quad (2.17)$$

The firms and the commercial bank know ex-ante the Central Bank's preference (i.e., γ is common knowledge) between helping the bank and letting it go. Although the cost of intervention γ is common knowledge for all the participants, ex-post intervention policy is affected by the degree of coordination between debtor firms. A high degree of coordination increases the cost of intervention while decreasing the social cost caused by the bank closure. Hence, the Central Bank decision to bail out or not is not known ex-ante. By implementing such a bailout policy which is focused on the above objective function, Central Bank introduces a lot of ambiguity regarding the bailout amount. Hence, its final decision induces the commercial bank to exert maximum of effort ex-ante even when fundamentals are strong and also helps to mitigate the strategic behavior of debtor firms. With respect to its cost function, the Central Bank decides for a full bailout when the social cost is higher than intervention cost. Alternatively, it chooses no intervention:

$$BOA \in \{0, Q - qD * [1 - NPL(d)]\} \quad (2.18)$$

Thus, given the above cost function, the Central Bank intervenes and saves the bank if $C(NPL(d)) = \gamma \{Q - qD * (1 - d)(1 - n(d))\}$. This translates in the following necessary condition for a full bailout:

$$NPL^* \leq \frac{qV + \gamma qD - \gamma Q}{qV + \gamma qD} \quad (2.19)$$

This expression is decreasing in γ . A higher cost of intervention implies a lower probability for a full bailout. The Central Bank steps in and provides the necessary amount only for a reduced measure of non-performing loans reported, given the higher cost of intervention γ . According to this inverse relation between the cost of intervention and the probability for a Central Bank bailout, we can argue that in countries where the central bankers are able to set policy without interference or restriction of the political authorities (i.e., independent central bankers) and

where their commitment to deal with inflationary pressures is credible (e.g. the main mandate is to maintain price stability by controlling inflation), the Central Bank's incentive to close the illiquid banks are higher. This result shed some light on the distinction between FED and ECB and between their expected policies towards banks closure. There are voices who claim that due to the fact that the Federal Reserve Act is easier to be changed than the Maastricht Treaty, the FED's independence is tenuous than the ECB's, particularly because in US political pressure is easy to exert. On the other hand, the FED has to preserve both full employment and price stability, whereas stable prices are the ECB's sole mandate. The policies adopted by these two central banks during 2007/2008 credit crisis support both the previous claims and the insights provided by this model with respect to the cost of intervention incurred by a regulator. While the ECB was reluctant to cut interest rates for a long period after the crisis' onset, the FED lowered the interest rate aggressively and lengthen the term on direct loans to banks from the FED's discount window and, when banks were slow to respond, the FED introduced its term auction facilities to make loans at the discount window cheaper.

Next I consider the impact that deposit-to-assets ratio has on the Central Bank's intervention policy. A high expected profitability increases the threshold NPL^* below which the Central Bank intervention allow commercial bank to avoid failure. This result holds for both a decrease in the nominal value of deposits at date 1, Q , or an increase in the volume of loans, q , and for an increase in the returns on loans at date 1, D . The positive relation between the expected profitability of the commercial bank and the threshold NPL^* suggests that, in the case of an active Central Bank, deposit-to-assets ratio plays an important role in preventing a strategic behavior of debtor firms because a lower ratio makes the bailout decision of Central Bank more likely. A similar result is generated by an increase in V , interpreted as the present value of future long term relation between a good firm and the bank. An increase in the opportunity cost of forgone intermediation if the commercial bank is closed

implies a higher probability for a bailout, thus a more relaxed policy towards closure.

Taking as given this optimal strategy for the Central Bank we can now explain the equilibrium strategies for both the debtor firms and the commercial bank.

Firms repayment incentives

When deciding its action, each good firm should try to infer when the Central Bank decides to step in and bail out the bank. Thus, the probability of bank survival in this case is given by:

$$P(NPL(d) \leq NPL^* | x)$$

If the measure of non-performing loans is below the threshold accepted by the Central Bank, then the commercial bank will be bailed out (if necessary) and a strategic attack from debtor firms will be contained. I start by deriving the equilibrium in threshold strategies. Let suppose as before that there is a threshold x^{**} such that all the firms which see a signal $x > x^{**}$ will not repay their loans to bank. Given NPL^* derived in (2.19) and following the same reasoning as when the Central Bank was inactive, we may derive the new thresholds x^{**} , the threshold signal at which a good firm is indifferent between repaying his loan or not, and d^{**} , the threshold value for commercial bank fundamentals above which the bank fails when Central Bank is active. Note however that the default condition in the presence of an active Central Bank is different than (2.4). Insolvency triggers are those values of fundamentals satisfying (2.4), but due to potential intervention of the Central Bank the bank might survive for some values of d satisfying the insolvency condition. Nevertheless, for values of d satisfying

$$d + (1 - d)n(d) \geq NPL^* \tag{2.20}$$

the bank is insolvent (since NPL^* derived in (2.19) satisfies insolvency condition (2.4)) and is not subject of liquidity injection. Hence, under default condition (2.20),

our thresholds are as follows:

$$x^{**} = NPL^* \frac{\alpha + C}{C} - \frac{\alpha(1 - d^{**} + \mu - e)}{C} - \sqrt{\frac{\alpha + C}{C\beta}} \Phi^{-1}\left(\frac{D}{V + F + D}\right), \quad (2.21)$$

$$d^{**+1-NPL^*} = \Phi\left(\sqrt{\beta} \frac{\alpha - C}{C} \left(d^{**} + NPL^* \frac{\alpha + C}{\alpha - C} - \frac{\alpha(1 + \mu - e)}{\alpha - C} - \frac{C}{\alpha - C} \sqrt{\frac{\alpha + C}{C\beta}} \Phi^{-1}\left(\frac{D}{V + F + D}\right)\right)\right), \quad (2.22)$$

where $C = \alpha + \beta + 2\rho\sqrt{\alpha\beta}$. ρ is the correlation coefficient between random variables d and $(1 - d)n(d)$. The detailed mathematical derivations are in the Appendix.

The right side of equation (2.22) is a cumulative normal distribution:

$$N\left(-NPL^* \frac{\alpha + C}{\alpha - C} + \frac{\alpha(1 + \mu - e)}{\alpha - C} + \frac{C}{\alpha - C} \sqrt{\frac{\alpha + C}{C\beta}} \Phi^{-1}\left(\frac{D}{V + F + D}\right), \frac{C^2}{\beta(\alpha - C)^2}\right).$$

Thus, we may conclude that d^{**} is the intersection point between the cumulative normal distribution just described and a straight line (with a slope of 1) and positive intercept $1 - NPL^*$. This intersection point exists and it is unique if the slope of cumulative normal distribution is less than one everywhere. The sufficient conditions for a unique solution for d^{**} are given by:

$$\begin{aligned} \frac{\sqrt{\beta}}{\alpha + \beta + 2\rho\sqrt{\alpha\beta}}(-\beta - 2\rho\sqrt{\alpha\beta}) &\leq \sqrt{2\pi} \\ \rho &< 0 \\ 0 &< \beta \leq -2\rho\sqrt{\alpha\beta} \\ \alpha &> -\beta - 2\rho\sqrt{\alpha\beta} \end{aligned} \quad (2.23)$$

Proposition 2 *When the precision of the private signal of debtor firms (β) and the prior precision (α) satisfy the conditions described by (2.23), there is a unique d^{**} defined in (2.22) such that, in any equilibrium of the game with imperfect information, the bank fails if and only if $d > d^{**}$.*

Proof. See the Appendix. ■

Put differently, Proposition 2 says that when the Central Bank is active, we can still have an unique equilibrium which survives iterated deletion of strictly dominated strategies. Nevertheless, from the individual borrower point of view, the inference regarding the probability of bank failure is much more complex compared with the case of an inactive Central Bank. A debtor firm cares not only about the true realization of fundamentals d , but she also cares about the measure of good firms deciding not to repay, $(1 - d)n(d)$. Hence, not only the precision of private signals relative to the precision of the prior (β relative to α) plays a determinant role in eliminating multiple equilibria, but also the negative correlation between random variables d and $(1 - d)n(d)$.

The solution in the limiting case when private signal's precision is very high ($\beta \rightarrow \infty$) is :

$$d^{**} = NPL^*. \tag{2.24}$$

Proposition 3 *The threshold d^{**} above which the bank fails even if the Central Bank is active is always larger than d^* , the threshold above which the bank fails if Central Bank is inactive.*

Proof. See the Appendix. ■

The intuition is straightforward. An active Central Bank can mitigate strategic default behavior of debtor firms, as it allows commercial banks to survive more often, preserving its loan enforcement capacity so that firms choose to repay more often. Actually it can provide an extra liquidity buffer under the condition that providing this is not too costly. Debtor firms will behave strategically only when commercial bank fundamentals are very poor, in which case they assign a low probability for an intervention by the Central Bank as it would be very expensive.

Deposit-to-assets ratio plays an important role in preventing a strategic behavior of debtor firms in this case too. A lower deposit-to-assets ratio for the bank ($\frac{Q}{qD}$) implies a higher threshold above which the bank fails when facing collective strategic

default. This result holds always both for a decrease in Q , the nominal value of deposits at date 1, and for an increase in D , returns on loans at date 1. This result is intuitive. By increasing expected profitability the commercial bank improves the threshold of non-performing loans (NPL^*) below which the Central Bank might intervene, hence making the bailout decision of Central Bank more likely. Anticipating this, good firms will behave less aggressively when deciding to repay their loans or not.

Bank optimal effort

Taking as given the optimal strategies for the Central Bank and for debtor firms, the bank chooses its optimal effort by maximizing its expected payoff, conditional on the available information. The equilibrium decision in this case can be derived using the same methodology as in the previous case. The bank knows that by exerting effort ex-ante it may reduce the probability for a strategic behavior on the debtor firms side, and also might reduce the measure of non-performing loans, making in this way the Central Bank intervention more likely (if it is necessary). The expected payoff for bank is given by:

$$\begin{aligned}
& P(\text{BankSurvives}) * qD * E_d[(1 - d) * (1 - n(d))] + \\
& + P(\text{BankSurvives}) * q(F + D) * E_d[(1 - d) * n(d)] + \\
& + P(\text{BankSurvives}) * (-Q - c(e)) + \\
& + P(\text{BankFails}) * (-c(e))
\end{aligned}$$

Next I study how an active Central Bank influences the behavior of commercial bank.

The only difference from the situation when Central Bank is inactive, comes from the building mechanism of probability of bank survival. Namely, when deciding its action, the bank should try to infer when the Central Bank decides to step in. Thus,

the probability of bank survival in this case is given by:

$$P(\text{BankSurvives}) = P(NPL \leq NPL^*) = \Phi\left(\sqrt{\frac{\alpha\beta}{\alpha+\beta+2\rho\sqrt{\alpha\beta}}}(NPL^* - (\mu - e + 1 - d))\right).$$

The choice of effort is unobservable to depositors. Therefore, depositors participate only if the nominal return Q provides them with (at least) zero expected return in the worst case (i.e., bank chooses a risky portfolio and $e = 0$). The participation constraint for depositors is as follows

$$Q * P(\text{BankSurvives} \mid d, e = 0) \geq q,$$

where $P(\text{BankSurvives} \mid d, e = 0) = \Phi\left(\sqrt{\frac{\alpha\beta}{\alpha+\beta+2\rho\sqrt{\alpha\beta}}}(NPL^* - (\mu + 1 - d))\right)$, and NPL^* is given by (2.19).

The optimal choice of effort for the limiting case (i.e., $\beta \rightarrow \infty$, and $\alpha \rightarrow \infty$) is:

$$e^{**} = \begin{cases} 1, & 1 - \frac{2\gamma Q}{qV + \gamma qD} \leq \mu \leq 2 - \frac{2\gamma Q}{qV + \gamma qD} \\ 0, & \text{otherwise} \end{cases} \quad (2.25)$$

See the Appendix for detailed derivations.

The optimal results for bank's effort suggest that bank's behavior is influenced in this case by its unconditional fundamentals (μ) and by the Central Bank cost of intervention (γ). From (2.25), the commercial bank exerts *no effort* when its unconditional fundamentals (μ) are below $1 - \frac{2\gamma Q}{qV + \gamma qD}$, in which case a strategic attack from debtor firm is less likely, or when the unconditional fundamentals are very high (above $2 - \frac{2\gamma Q}{qV + \gamma qD}$), which makes any effort useless in avoiding closure. Both thresholds should be positive in order to have economic significance due to the fact that fundamentals are defined in this model as a positive measure. It is straightforward to see that the lower threshold $(1 - \frac{2\gamma Q}{qV + \gamma qD})$ is positive only for values of γ below the threshold

$$\gamma_M = \frac{qV}{2Q - qD}. \quad (2.26)$$

Since the cost of intervention is always positive, I restrict the analysis according to the following condition:

$$Q > \frac{qD}{2} \quad (2.27)$$

This restriction allow us to have a positive and economically significant cost γ_M .

Proposition 4 *The optimal effort e^{**} has the same binary values as in the case with an inactive Central Bank, namely is either 1 or 0.*

Proof. *Following from (2.15) and (2.25), this is a direct result of my limiting assumptions, driven by the functional form of the screening cost, $c(e)$. ■*

Next I investigate how the Central Bank intervention mechanism influences the commercial bank behavior with respect to its fundamentals. As we will see, from the point of view of moral hazard induced at the commercial bank level, for some values of γ the presence of an active Central Bank is beneficial, while for others it is not.

In order to identify those γ values for which the presence of an active Central Bank mitigates the moral hazard not only for borrowers, but also for the commercial bank, I compare the two polar cases studied so far (active Central Bank and inactive Central Bank) focusing the attention on the impact that marginal cost of intervention has on the behavior of commercial bank.

I denote the thresholds in unconditional fundamentals identified in (2.15) and (2.25) such that $\mu_1 = \frac{V+F}{V+F+D} - \frac{Q}{qD}$, $\mu_2 = 1 - \frac{2\gamma Q}{qV+\gamma qD}$, $\mu_3 = 1 + \frac{V+F}{V+F+D} - \frac{Q}{qD}$ and $\mu_4 = 2 - \frac{2\gamma Q}{qV+\gamma qD}$. It is straightforward to prove that higher γ has a negative impact for μ_2 and μ_4 . When marginal cost of intervention γ is strictly lower than a certain threshold γ^* , with

$$\gamma^* = \frac{qVD^2 + VQ(V + F + D)}{D[Q(V + F + D) - qD^2]}, \quad (2.28)$$

the following classification for the unconditional bank fundamentals is met:

$$\mu_1 < \mu_2 < \mu_3 < \mu_4$$

The threshold γ^* is positive and $\gamma^* < \gamma_M$ from (2.2) and (2.27). Following this classification, the optimal effort exerted by the commercial bank is:

$$e = \begin{cases} 0, & \mu < \mu_1, & \text{with or without an active CB} \\ 1 & \mu_1 \leq \mu < \mu_2, & \text{with an inactive CB} \\ 1 & \mu_2 \leq \mu \leq \mu_3, & \text{with or without an active CB} \\ 1 & \mu_3 < \mu \leq \mu_4, & \text{with an active CB} \\ 0 & \mu > \mu_4, & \text{with or without an active CB} \end{cases}$$

When the Central Bank is inactive, the possibility of a collective strategic default induces the commercial bank to exert maximum optimal effort $e = 1$ even when the economic environment is healthy and the corporate sector prospects for good performance are high (i.e., unconditional fundamentals μ are low, $\mu_1 \leq \mu < \mu_2$). This happens for values of μ lower than μ_2 , the level which triggers a change in the behavior of commercial bank when Central Bank is active.

Figure 1 shows the level of effort exerted by the commercial bank for different values of its unconditional fundamentals when the cost of intervention is low ($\gamma < \gamma^*$). In this case, an inactive Central Bank induces commercial bank to exert maximum of effort sooner (with respect to the values of unconditional fundamentals) than when it is active.

<< FIGURE 1 HERE >>

On the other hand, a higher cost of intervention ($\gamma > \gamma^*$) justifies an active Central Bank presence and mitigates the moral hazard problem. When the cost of intervention is high enough, the following classification for the unconditional bank fundamentals will be met:

$$\mu_2 < \mu_1 < \mu_4 < \mu_3$$

Following this classification, the optimal effort exerted by the commercial bank is:

$$e = \begin{cases} 0, & \mu < \mu_2, & \text{with or without an active CB} \\ 1 & \mu_2 \leq \mu < \mu_1, & \text{with an active CB} \\ 1 & \mu_1 \leq \mu \leq \mu_4, & \text{with or without an active CB} \\ 1 & \mu_4 < \mu \leq \mu_3, & \text{with an inactive CB} \\ 0 & \mu > \mu_3, & \text{with or without an active CB} \end{cases}$$

Figure 2a shows the level of effort exerted by commercial bank for different values of its unconditional fundamentals when cost of intervention is high ($\gamma > \gamma^*$), but not extremely high ($\gamma < \gamma_M$). In this case, an active Central Bank induces commercial bank to exert maximum of effort sooner (with respect to the values of unconditional fundamentals) than when it is inactive. An extreme case for this scenario is depicted in Figure 2b which shows the level of effort exerted by commercial bank for very high cost of intervention ($\gamma > \gamma_M > \gamma^*$). In this particular case, an active Central Bank induces commercial bank to exert maximum of effort even when μ goes to zero.

<< FIGURE 2a HERE >>

<< FIGURE 2b HERE >>

I summarize these findings in the following three propositions.

Proposition 5 *For low cost of intervention ($\gamma < \gamma^*$), an active Central Bank induces moral hazard in commercial bank behavior. When Central Bank is inactive, the commercial bank finds optimal to exert maximum of effort ($e = 1$) when its unconditional fundamentals are stronger ($\mu_1 \leq \mu \leq \mu_2$) than when Central Bank is active. When the Central Bank is active the commercial bank exerts maximum of effort only when the unconditional bank fundamentals are above μ_2 . This result holds given that the exogenous parameters satisfy (2.2) and (2.27).*

Proof. *See the Appendix.* ■

The intuition behind this result is as follows. When the Central Bank is active in the economy and the cost of intervention is very low, either because the lack

of credibility in Central Bank's commitment to maintain price stability, or due the political inference in setting the intervention policy, the commercial bank's expectation for a bailout is very high. Under these circumstances it prefers to exert no effort and to bet on the preference that the Central Bank might have in avoiding tough and unpopular social measures such as closing the bank and denying access to credit to good firms which have been repaying their loans. Nevertheless, as bank unconditional fundamentals characterizing the health of economic environment worsen ($\mu \geq \mu_2$), the commercial bank starts to exert higher costly effort in screening loan applications, in order to improve the quality of its assets, knowing that, even for a very low cost of intervention, the Central Bank will not always decide for a bailout. A different behavior the commercial bank has when the Central Bank is inactive. In this situation, because the Central Bank never intervenes, the commercial bank has only one weapon against the possible collective strategic behavior of its borrowers, namely better screening. Hence, it prefers to exert costly effort even when its unconditional fundamentals are very strong ($\mu_1 \leq \mu \leq \mu_2$) in order to make the coordination between firms more difficult.

Proposition 6 *A high enough cost of intervention ($\gamma > \gamma^*$) mitigates the moral hazard generated by an active Central Bank when commercial bank unconditional fundamentals are strong enough ($\mu_2 \leq \mu \leq \mu_1$). This result holds given that the exogenous parameters satisfy (2.2) and (2.27).*

Proposition 7 *When cost of intervention is very high ($\gamma > \gamma_M > \gamma^*$), the presence of an active Central Bank has a double-edge effect. On one hand determines the commercial bank to exert maximum of effort for very strong unconditional fundamentals ($0 \leq \mu \leq \mu_1$), while on the other hand it induces commercial bank to exert no effort for poor unconditional fundamentals ($\mu > \mu_4$). This result holds given that the exogenous parameters satisfy (2.2) and (2.27).*

Proof. See the Appendix. ■

The first proposition asserts that a higher cost of intervention supports the presence of an active Central Bank as long as moral hazard mitigation is its main concern. The higher cost of intervention implies that strategic debtor firms behave more aggressively. They assign a lower probability for a bailout under this condition. The commercial bank understands this and decides to exert maximum of effort even under strong unconditional fundamentals. This chain effect translates in our model in the negative impact of intervention cost γ on the value of unconditional fundamentals which characterize the change in behavior for commercial bank (μ_2 and μ_4). To conclude, a higher cost of intervention, together with the ambiguity introduced by the Central Bank intervention mechanism allow commercial bank to survive more often when it faces opportunistic behavior from borrowers and in the same time induce the commercial bank to improve loans quality by exerting costly effort in good states of the economy.

The key implication of the second proposition is that under a very high cost of intervention, the ambiguity of Central Bank's intervention decision has a very strong positive impact on commercial bank incentives under strong ($0 \leq \mu \leq \mu_1$) unconditional fundamentals, while having a negative impact for very poor ($\mu > \mu_4$) unconditional fundamentals. The first part of this result implies that, under the prospect of collective strategic default, and knowing that Central Bank has a strong preference not to provide liquidity, commercial bank finds optimal to reduce its risk taking (e.g. by exerting maximum of effort) even when genuine distress is absent (μ is close to 0). The second part suggests that commercial bank assigns a low probability of intervention under poor unconditional fundamentals, because in these circumstances the intervention is very expensive for the Central Bank. Since it expects a high non repayment, it finds optimal to exert no effort.

2.4 Comparative Statics

2.4.1 Changes in Unconditional Bank Fundamentals

The effort exerted by the bank in period 0 has a direct impact on the loan quality. An increase in effort e implies a lower value for average weakness of bank fundamentals $(\mu - e)$. A higher average weakness of bank fundamentals caused either by a lower effort e exerted by the bank, or by a higher unconditional bank fundamentals μ , has a double impact: it lowers the thresholds which trigger strategic default, and it increases the probability of bank failure. I start by examining the changes in the exogenous variable μ , when effort e is given. I continue by investigating the changes in variable μ , when effort e is the optimal effort.

Firstly, when effort e is given, an increase in unconditional fundamentals μ lowers the equilibrium threshold in bank fundamentals (d^* or d^{**}) below which the bank survives when facing a strategic attack of debtor firms. This result comes from differentiating (2.10) and (2.22), respectively. Hence, $\frac{\partial d^*}{\partial \mu} < 0$ and $\frac{\partial d^{**}}{\partial \mu} < 0$. These results suggest that when the unconditional fundamentals become worse, commercial banks may be subject to risk of failure more often due to a coordination problem among debtors.

On the other hand, an increase in the unconditional bank fundamentals increases the probability of a bank failure. For the case when Central Bank is inactive, given the prior distribution of d , the probability of bank failure for a given value d^* is:

$$P(\text{BankFails}) = P(d > d^*) = 1 - \Phi(\sqrt{\alpha}(d^* - (\mu - e))).$$

Differentiating the above probability with respect to μ yields

$$\frac{\partial P(d > d^*)}{\partial \mu} = -\phi(\sqrt{\alpha}(d^* - (\mu - e))) * \sqrt{\alpha} * \left(\frac{\partial d^*}{\partial \mu} - 1\right),$$

which is positive given the negative impact of unconditional bank fundamentals on the equilibrium threshold d^* .

The result holds for the alternative case when Central Bank is active in the economy. In this case the probability of bank failure for a given value d^{**} is:

$$\begin{aligned} P(\text{BankFails}) &= P(NPL > NPL^*) = \\ &= 1 - \Phi\left(\sqrt{\frac{\alpha\beta}{\alpha+\beta+2\rho\sqrt{\alpha\beta}}}(NPL^* - (\mu - e + 1 - d))\right). \end{aligned}$$

Differentiating the above probability with respect to μ yields

$$\frac{\partial P(NPL > NPL^*)}{\partial \mu} = -\phi\left(\sqrt{\frac{\alpha\beta}{\alpha+\beta+2\rho\sqrt{\alpha\beta}}}(NPL^* - (\mu - e + 1 - d))\right) * \sqrt{\frac{\alpha\beta}{\alpha+\beta+2\rho\sqrt{\alpha\beta}}} * \left(-1 + \frac{\partial d^{**}}{\partial \mu}\right),$$

which is positive given the negative impact of unconditional bank fundamentals on the equilibrium threshold d^{**} .

To sum up these findings I can argue that the thresholds for successful collective strategic default and the probability of bank failure are directly related. The lower the threshold below which an attack is contained, the higher the prior probability of a bank collapse.

Secondly I examine the changes in the exogenous variable μ , when effort e is the optimal effort. The effects described above hold when all agents play their optimal strategies. Nevertheless, as the next three figures illustrate, due to the fact that the optimal effort e is not a continuous variable, we meet jumps for both the probability of bank failure and equilibrium thresholds in bank fundamentals. These jumps are generated by a change in strategy followed by the commercial bank.

Figures 3 to 5 illustrates what happens for a specific set of parameters by plotting the equilibrium thresholds in bank fundamentals and the probability of default as a function of unconditional fundamentals. The case of an inactive Central Bank is captured in Figure 3 for $\frac{Q}{qD} = 0.5$, $\Phi^{-1}\left(\frac{D}{V+F+D}\right) = 1.293$, $\alpha = 9$, and $\beta = 160$, while for the case of an active Central Bank parameters are $\frac{Q}{qD} = 0.5$, $\Phi^{-1}\left(\frac{D}{V+F+D}\right) = 1.293$, $\alpha = 10$, $\beta = 0.3$ and $\rho = -0.1$. Figure 4 illustrates a scenario with a low cost of intervention γ which translates in a higher threshold in non-performing loans below which the Central Bank intervenes ($NPL^* = 0.8$). Figure 5 illustrates a scenario with

a high cost of intervention γ which translates in a lower threshold in non-performing loans below which the Central Bank intervenes ($NPL^* = 0.2$).

<< FIGURE 3 HERE >>

<< FIGURE 4 HERE >>

<< FIGURE 5 HERE >>

The above results suggest that the economic environment has a very serious impact on the ability that commercial banks have to survive when facing strategic default. I interpret the unconditional bank fundamentals μ as a measure for development of corporate sector or health of economic environment. A high μ can be interpreted as weak corporate sector with poor performance (poor asset quality). A healthy economy, in which the prospects for corporate sector performance are high, it is characterized by a lower μ . The commercial banks can not influence directly this macro variable. Nevertheless, the level of effort chosen when screening loan applications affects the quality of assets the bank ends up holding. Thus, in countries where financial environment is characterized by poor quality of corporate sector, commercial banks are very exposed to the risk of collective strategic default.

Next I examine the impact that an increase in unconditional fundamentals μ has on the incidence of collective strategic default, measured here by the variable $(1 - d)n(d)$. Firstly I examine the changes in the exogenous variable μ , when effort e is given and afterwards I examine the case when effort e is the optimal effort. When the unconditional bank fundamentals increase, keeping the effort exerted by the commercial bank constant, the probability that good firms receive a higher signal increases. This implies that more solvent firms choose the action not repay. As we have seen previously, the unconditional bank fundamentals have a negative impact on the equilibrium thresholds. Intuition suggests that, due to the fact that bank fails for lower levels of fundamentals, the necessary number of good firms which should choose the action non repay such that the bank fails should increase. The result

holds true in both cases we have analyzed. The derivative $\frac{\partial(1-d)n(d)}{\partial\mu}$ is positive for the case of an inactive/active Central Bank. Complete derivations can be found in the Appendix.

When effort e is the optimal effort, and thus a change in unconditional bank fundamentals triggers a change of strategy from commercial bank, the effects described above hold when all agents play their optimal strategies. As we have seen before, due to the fact that the optimal effort e is not a continuous variable, we meet jumps in the incidence of collective strategic default. For the case of an inactive Central Bank I illustrate this in figure 6 via simulation by setting $\frac{Q}{qD} = 0.5$, $\Phi^{-1}(\frac{D}{V+F+D}) = 1.293$, $\alpha = 9$, and $\beta = 160$, and varying μ from 0 to 1. The case of an active Central Bank is captured in figure 7 for $\frac{Q}{qD} = 0.5$, $\Phi^{-1}(\frac{D}{V+F+D}) = 1.293$, $\alpha = 10$, $\beta = 0.3$, $\rho = -0.1$ and $NPL^* = 0.8$.

<< FIGURE 6 HERE >>

<< FIGURE 7 HERE >>

The simulation suggests that in both cases, when we compute the necessary measure of good firms which should behave strategically in order to trigger bank's default with respect to total number of debtor firms and also with respect to total numbers of good firms, these ratios are increasing with respect to bank unconditional fundamentals. I conclude that higher values for unconditional bank fundamentals increase the measure of good firms behaving strategically in equilibrium due to the negative impact on equilibrium thresholds d^* and d^{**} . Put differently, a higher μ implies an increase in the required degree of coordination among these good firms that can lead to bank failure.

2.4.2 Effect Changes in the Intervention Cost

Three directions are considered in turn: impact that changes in intervention cost have on commercial bank behavior; on the behavior of good debtor firms; and on the degree

of coordination between borrowers which triggers bank's failure. When the cost of intervention γ increases, the threshold values for unconditional bank fundamentals μ at which the commercial bank chooses to exert maximum of effort are reduced. This result comes directly from Proposition 6 which captures the switch between thresholds μ_1 and μ_2 . Higher cost of intervention has a negative impact for the value of μ_2 . This result suggests that moral hazard introduced by the Central Bank as a LOLR is mitigated by a higher cost of intervention. When the Central Bank is active in the economy and the cost of intervention is high, either because of the credible Central Bank's commitment to maintain price stability, or due the lack of political inference in setting the intervention policy, the commercial bank's expectation for a bailout is low. Under these circumstances it prefers to exert costly effort even when its unconditional fundamentals are very strong ($\mu \leq \mu_1$) in order to make the coordination between firms more difficult. Thus countries in which monetary authorities are concerned with the high inflationary costs induced by printing money, or countries in which central bankers are independent, create good incentives for banks to be pro-active and to reduce the risk of their portfolios by exerting maximum of effort in order to avoid collective strategic default of borrowers.

Another effect of intervention cost is on the thresholds in fundamentals above which the bank fails. By differentiating (2.22), we obtain a negative value for $\frac{\partial d^{**}}{\partial \gamma}$. This implies a lower threshold below which the bank survives when Central Bank is active. Thus, an increase in marginal cost of intervention translates into a lower equilibrium value for commercial bank fundamentals above which the bank fails. Good debtor firms behave more aggressive when the cost of intervention is high, in which case they assign a low probability for an intervention by the Central Bank as it would be very expensive. Hence, the commercial bank might fail even for strong fundamentals. Nevertheless, as Proposition 3 shows, the threshold in bank fundamentals which triggers collective strategic default for the case of an active Central Bank is always higher than the threshold characterizing the case of an inactive Central Bank.

The third effect of intervention cost I examine is on the degree of coordination between borrowers required to make a collective strategic default successful. By differentiating the necessary measure of firms which should decide not to repay in order to trigger the bank's default, we find a positive value for $\frac{\partial(1-d)n(d)}{\partial\gamma}$. Hence, the impact is identical with the effect that an increase in unconditional bank fundamentals has on the incidence of a strategic attack. A higher cost of intervention implies a higher degree of coordination between borrowers.

Figure 8 illustrates what happens for a specific set of parameters by plotting the equilibrium thresholds in bank fundamentals and the probability of default as a function of unconditional fundamentals for different values in cost of intervention. The cost of intervention γ and the measure of non-performing loans NPL^* changes from 0.1 to 0.2 and from 0.4 to 0.2, respectively, while other parameters are kept constant: $\frac{Q}{qD} = 0.05$, $\Phi^{-1}(\frac{D}{V+F+D}) = 1.67$, $\alpha = 10$, $\beta = 0.3$, and $\rho = -0.1$.

<< FIGURE 8 HERE >>

Thus, we may conclude that higher cost of intervention (γ) has a double-edge effect: on one hand it helps in reducing bank's moral hazard due to the fact that commercial bank has strong incentive to exert maximum of effort when its unconditional fundamentals are strong (μ is low); on the other hand it lowers the threshold in fundamentals that triggers collective strategic default (d^{**}) and increases the degree of coordination between good firms, thus precipitating bank failure.

2.5 Concluding Remarks and Further Research

In this paper I examine the impact of Central Bank intervention policy as a LOLR on borrowers' and commercial bank's incentives and I derive the probability of a run by bank borrowers. I study a model in which a monopolistic commercial bank faces a liquidity shortage which is aggravated by the strategic default of solvent firms. The main assumption behind the model is that the bank fundamentals are not common knowledge. The borrowers hold common prior beliefs about the state of fundamentals and receive private signals about its realization. Within this framework, the Central Bank acts as the only regulator. The commercial bank understands that its current asset choice will affect the Central Bank intervention policy, while the Central Bank recognizes the opportunity cost of forgone intermediation if the commercial bank is closed. The Central Bank tries to minimize the social cost induced by the failure of the bank, trading it off against the cost of full intervention. The paper's main findings are the following.

First, I show that banks may be subject to risk of failure even when fundamentals are strong due to a coordination problem among debtors. As a result of collective strategic default a financially sound firm may claim inability to repay if it expects a sufficient number of other firms to do so as well, thus reducing bank's enforcement ability. This occurs in particular when financial environment is characterized by poor quality of corporate sector.

Second, I find that an active Central Bank can mitigate the strategic behavior of debtor firms. I distinguished between two types of intervention policies: a tough policy, when the Central Bank is inactive, and a semi-tough policy, when the Central Bank is active. I show that an active Central Bank allows commercial banks to survive more often when they face opportunistic behavior from borrowers. Debtor

firms behave strategically only when bank fundamentals are very poor, because in that case Central Bank intervention is very costly and thus improbable.

Third, I find that under specific market conditions an active Central Bank induces commercial banks to affect loan quality ex-ante, which indirectly reduces debtors' incentives for strategic default. This result contradicts the idea that an ex-post bail-out policy often reduces bank incentives to exert effort and to improve the quality of its assets portfolio. The market conditions I refer to are represented by the marginal cost of intervention. I interpret this intervention cost as a proxy for Central Bank's independence and its commitment to maintain price stability. I argue that the cost of intervention faced by the Central Bank has a double-edge effect. On one hand a higher cost of intervention reduces the moral hazard problem at the commercial bank level. On the other hand, it can precipitate bank failure by lowering the threshold in fundamentals that triggers collective strategic default and by increasing the degree of coordination between good firms. Put differently, a higher cost of intervention makes the debtors to behave more aggressively and also it makes the commercial bank to behave more prudently. Nevertheless, the threshold in bank fundamentals which triggers collective strategic default for the case of an active Central Bank is always higher than the threshold characterizing the case of an inactive Central Bank.

Fourth, I show that high bank expected profitability reduces the likelihood of collective strategic default. As a measure of expected profitability I use the deposit-to-asset ratio. I show that this ratio plays an important role in preventing a strategic behavior of debtor firms, even if the Central Bank never intervenes to bail out a defaulting bank. A lower deposit-to-assets ratio implies a higher threshold above which the bank fails when facing collective strategic default. This result supports the existing empirical research which has shown that in developing economies high interest rate differential between deposit and loan rates is the main result of a poor development of corporate sector and lack of competition in banking industry. This paper adds a new interpretation, namely that in developing economies high interest

rate differential between deposit and loan rates can be seen as a risk management mechanism which helps commercial banks to protect themselves against a collective strategic default.

The model provides some testable implications. Three areas are considered in turn: related lending, portfolio diversification and business cycle. The backbone of related lending literature is that a large proportion of bank lending is granted to related parties. Under this condition, if borrowers are minority shareholders of bank, they may have an incentive to default as loan default hurts them as shareholders less than the gain from not repaying loans. One implication of this paper is that banks are fragile because related parties default strategically precisely when outside borrowers are in financial distress. Second, if one believes in the predictions of this analysis, particularly in the result that bank failure might be induced by strategic coordination of borrowers, the immediate implication is that in order to increase financial stability, regulators should force banks to make small loans in order to make the coordination between debtors more difficult. Thus, loan portfolio diversification is good because reduces the chances for a successful collective attack against the bank. Finally, a natural interpretation of the result that the higher measure of genuinely distressed firms implies a higher possibility for successful strategic defaults, is in terms of business cycle. In recessions one would expect more strategic defaults, particularly due to the poor quality of economic environment.

The model in this paper is highly stylized. Behind the main findings there are three crucial ingredients. First, the bank fundamentals are not common knowledge. Second, the lending bank will be able to fully pursue non paying solvent firms only if it survives. Third, the commercial bank and the borrowers know ex-ante the Central Bank's cost of intervention, while the Central Bank decision to bail out or not is not known ex-ante. Hence, I have studied the role of the Central Bank as LOLR under opportunistic behavior from borrowers in a highly simplified way in order to highlight the main points. The model is open to several interesting extensions. The

natural directions for future research are the following. First, the assumption of common knowledge about Central Bank's cost of intervention can be relaxed. The intuition suggests that in this case, the coordination between debtor firms will be much more difficult to attain. Second, the assumption that the Central Bank is the only regulator might be relaxed. It would be interesting to examine how a policy maker will allocate the LOLR responsibilities to that regulator (e.g. either a Central Bank, or a deposit insurer, or any other financial authority) whose lending decision minimizes the intervention cost.

This model ignores many complexities of real world banking system that affect both borrower and lender, such as the existence of the interbank market, or the presence of complex balance sheets, or the renegotiation between lender and borrowers issue. Relaxing the assumption of a monopolistic bank would allow us to study the impact of strategic default on systemic banking crises. It is possible to extract more policy implications if we allow for a complex balance sheet. The existing banking literature argues that liquidity requirements reduce the impact of strategic uncertainty on the bank conditions since they allow the bank to withstand larger runs from depositors. The same logic applies here: more liquidity (i.e., cash reserves) or more capital increase the threshold at which collective strategic default happens, thus reducing the probability of bank failure. Some particular forms of renegotiation are interesting to be explored too. A first form of renegotiation assumes that the Central Bank bails out some bad borrowers, leaving the commercial bank with a healthy balance sheet. This should be stabilizing because it reduces the measure of firms in genuine distress and increases the threshold at which collective strategic default happens. The critical question here will be to compare the costs of bailing out banks with the costs of identifying and bailing out firms in genuine financial distress. A second form of renegotiation assumes that the good firms which choose to repay will decide also to bail out their bank if necessary. The immediate result of such an action is that bank's enforcement ability is preserved. Both forms of renegotiation

might be preferable to closing the bank.

Further research should also focus on empirical tests of the implications of this analysis. To implement the tests, however, more detailed data are required than are available from sources such as anecdotal evidence.

2.A Derivations and Proofs

Signal and fundamentals thresholds derivation. The case of inactive Central Bank.

Let us suppose that there are two thresholds x^* and d^* , such that all the firms which see a signal $x > x^*$ will not repay their loans, while d^* represents the threshold in bank fundamentals at which the bank will fail for values of $d > d^*$.

The distribution of signals x_i across firms conditional on the realization of fundamentals d is given by cumulative distribution function (cdf) $P(x \leq x^* | d)$. This cumulative normal distribution function is decreasing in d , positive and continuous for any value of x^* . The higher d , the lower the probability that signal x lies below any threshold x^* . Given the normality assumption, we may derive this cdf:

$$P(x \leq x^* | d) = \Phi(\sqrt{\beta}(x^* - d)), \quad (2.29)$$

where Φ is the cumulative distribution function of the standard normal distribution.

This is a straightforward result of the following variable transformation:

$$P(x \leq x^* | d) = P(d + \epsilon \leq x^* | d) = P(\epsilon \leq x^* - d) = P\left(\frac{\epsilon - 0}{\sqrt{1/\beta}} \leq \frac{x^* - d}{\sqrt{1/\beta}}\right) = \Phi(\sqrt{\beta}(x^* - d)).$$

This means that a critical number of good firms should attack the bank in order to cause the bank's failure. This value is given by the cumulative mass of good firms who have seen a signal above the threshold signal x^* . Since we have assumed that a good firm which is indifferent between attacking and not will choose not to attack,

$$P(x > x^* | d) = z(d) = (1 - d)n(d) \quad (2.30)$$

By plugging the distribution of signals x_i across firms conditional on the realization of fundamentals d^* and the measure of good firms which choose not to repay

(in 2.29 and 2.4, respectively), one obtains the main equilibrium condition:

$$\Phi(\sqrt{\beta}(x^* - d^*)) = \frac{Q}{qD} + d^* \quad (2.31)$$

Following from (2.4), the bank insolvency (and subsequent default) is triggered by

$$[1 - d^* - (1 - d^*)n(d^*)] * qD = Q,$$

where d^* represents the threshold in bank fundamentals at which the bank fails for values of $d > d^*$.

Applying Bayesian inference under a normal distribution conditional on another normal distribution, we may derive the posterior distribution over bank's fundamentals d for a firm who has seen a signal x , as the following cdf: $P(d \leq d^* | x)$.²⁰ This function is decreasing in x , positive and continuous for any values of d^* . The higher x , the lower the probability that fundamentals d lies below any threshold d^* :

$$P(d \leq d^* | x) = \Phi\left(\sqrt{\alpha + \beta}\left(d^* - \frac{\alpha(\mu - e) + \beta x}{\alpha + \beta}\right)\right) \quad (2.32)$$

This result is derived using the same method of variable transformation. As a result of Bayesian inference, each borrower firm who sees signal x has a posterior distribution over d that is normal with mean $\frac{\alpha(\mu - e) + \beta x}{\alpha + \beta}$ and variance $\frac{1}{\alpha + \beta}$.

By replacing in (2.8) the probability of bank survival with the value we have found in (2.32), we may built the second main equilibrium condition:

$$d^* - \frac{\alpha(\mu - e) + \beta x^*}{\alpha + \beta} = \frac{1}{\sqrt{\alpha + \beta}} \Phi^{-1}\left(\frac{D}{V + F + D}\right) \quad (2.33)$$

²⁰To keep model tractable we start only with this level of inference. Borrower firms can calculate under these circumstances a conditional distribution based on their private signals only. We would obtain similar results for this model if we examined a more complicated structure for this game. In such a structure the first inference made by a good firm will be to update its beliefs about true value of fundamentals given the fact that it knows it belongs to the group of good firms (firms with cash that can repay their loans). The first Bayesian inference would be then $P(d | \text{Cash} > 0)$. The fact that firm has cash can be interpreted as a private signal.

By solving the system of equations formed by (2.31) and (2.33), equilibrium thresholds d^* and x^* can be found. Solving (2.33) for x^* , we obtain the threshold signal at which a good firm is indifferent between repaying the loan or not:

$$x^* = \frac{\alpha + \beta}{\beta} d^* - \frac{\alpha}{\beta} (\mu - e) - \frac{\sqrt{\alpha + \beta}}{\beta} \Phi^{-1}\left(\frac{D}{V + F + D}\right)$$

Solving now (2.31) for d^* and using the value we have just derived above for equilibrium signal x^* , gives the threshold value for bank's fundamentals above which the bank fails:

$$d^* + \frac{Q}{qD} = \Phi\left(\frac{\alpha}{\sqrt{\beta}}\left(d^* - (\mu - e) - \frac{\sqrt{\alpha + \beta}}{\alpha} \Phi^{-1}\left(\frac{D}{V + F + D}\right)\right)\right)$$

The right side of above equation is a cumulative normal distribution

$$N\left((\mu - e) + \frac{\sqrt{\alpha + \beta}}{\alpha} \Phi^{-1}\left(\frac{D}{V + F + D}\right), \frac{1}{\alpha^2}\right).$$

Thus, we may conclude that d^* is the intersection point between the cumulative normal distribution just described and a straight line (with a slope of 1) and positive intercept $\frac{Q}{qD}$. This intersection point exists and it is unique if the slope of cumulative normal distribution is less than one everywhere. This slope equals $\frac{\alpha}{\sqrt{\beta}} \phi\left(\frac{\alpha}{\sqrt{\beta}}\left(d^* - (\mu - e) - \frac{\sqrt{\alpha + \beta}}{\alpha} \Phi^{-1}\left(\frac{D}{V + F + D}\right)\right)\right)$, where ϕ is the density function of the standard normal distribution. From statistical properties of standard normal density function $\phi \leq \frac{1}{\sqrt{2\pi}}$, thus a sufficient condition for a unique solution for d^* is given by:

$$\frac{\alpha}{\sqrt{\beta}} \leq \sqrt{2\pi}$$

Proof of Proposition 1

In order to prove this proposition I use iterated deletion of dominated strategies. Let's denote by \underline{x}_1 the signal for which a good firm is confident in her posterior beliefs that $d \leq \underline{d}$ and find it a dominant strategy to repay regardless of what other

good firms do, and denote by \bar{x}_1 the signal for which a good firm is confident in her posterior beliefs that $d > \bar{d}$ and find it a dominant strategy to default regardless of what other firms do. The signal \underline{x}_1 is the highest value of x such that

$$P(d \leq \underline{d} | x) * (-F) + P(d > \underline{d} | x) * D \leq P(d \leq \underline{d} | x) * V.$$

On the left side the expected payoff when not repaying is described, and on the right side the expected payoff for repaying is depicted. The interpretation is as follows. Even if one good firm believes that all other good firms will stop repaying, and thus any individual firm which repays would get a payoff 0 if $d > \underline{d}$, the posterior probability that $d \leq \underline{d}$, for the firm who saw $x \leq \underline{x}_1$, makes repaying a dominant action. Analogously, the signal \bar{x}_1 is the smallest value of x such that

$$P(d \leq \bar{d} | x) * (-F) + P(d > \bar{d} | x) * D \geq P(d \leq \bar{d} | x) * V.$$

For a firm who saw $x > \bar{x}_1$, the posterior probability that $d \leq \bar{d}$ makes not repaying a dominant action even though one good firm believes that all other good firms will repay, and thus that they would get a high payoff V if $d \leq \bar{d}$. Hence, the first round of deletion of dominated strategies implies the following: all good firms receiving signals $x \leq \underline{x}_1$ will repay their loans, while good firms receiving signals $x > \bar{x}_1$ will choose to default.

Taken as given this restriction on dominated strategies, next step is to determine the thresholds in fundamentals above (below) which the bank fails (survives). The measure of good firms which choose to default when fundamentals are d , is given by the cumulative mass of good firms who have seen a signal above \bar{x}_1 . Given the assumption on signal's normal distribution, this fraction $P(x > \bar{x}_1 | d)$ equals $1 - \Phi(\sqrt{\beta}(\bar{x}_1 - d))$, and is always positive, continuous and increasing in d . Since $\Phi(\sqrt{\beta}(\bar{x}_1 - d))$ is decreasing in d , there is a maximum value $\bar{d}_1 < \bar{d}$ such that the bank fails when good firms receiving signals $x > \bar{x}_1$ default ($\Phi(\sqrt{\beta}(\bar{x}_1 - \bar{d}_1)) < \frac{Q}{qD} + \bar{d}_1$).

Similarly, the measure of good firms which choose to repay when fundamentals are d is given by the cumulative mass of good firms who have seen a signal below

\underline{x}_1 . Hence, at least a fraction $P(x \leq \underline{x}_1 \mid d)$ will repay, and the bank will fail when fundamentals are higher than a threshold $\underline{d}_1 > \underline{d}$, where \underline{d}_1 is the maximum value of d such that $\Phi(\sqrt{\beta}(\underline{x}_1 - \underline{d}_1)) < \frac{Q}{qD} + \underline{d}_1$.

The equilibrium strategy described so far can be summarized as follows: rational good firms receiving signals $x \leq \underline{x}_1$ will repay their loans, while good firms receiving signals $x > \underline{x}_1$ will default, and as a result the bank will fail when fundamentals $d > \underline{d}_1$, and it will survive for fundamentals $d < \underline{d}_1$.

This gives us the second round of deletion of dominated strategies. Good firms understand that for large value of fundamentals ($d > \bar{d}_1$) enough firms will behave strategically and as a result the bank enforcement ability will be lost. Hence, any good firm which receives a signal $x > \bar{x}_2$ finds as dominant strategy not to repay its loan. The signal \bar{x}_2 is the smallest value of x such that

$$P(d \leq \bar{d}_1 \mid x) * (-F) + P(d > \bar{d}_1 \mid x) * D \geq P(d \leq \bar{d}_1 \mid x) * V.$$

Analogously, repay is a dominant strategy for a good firm when her signal x is lower than \underline{x}_2 , where the signal \underline{x}_2 is the highest value of x such that

$$P(d \leq \underline{d}_1 \mid x) * (-F) + P(d > \underline{d}_1 \mid x) * D \leq P(d \leq \underline{d}_1 \mid x) * V.$$

By doing the same calculations as for the first round of deletion of dominated strategies, we can generate two sequences of restrictions on the equilibrium strategies. The "smallest" equilibrium strategy is defined by an increasing sequence $\underline{x}_1, \underline{d}_1 \leq \underline{x}_2, \underline{d}_2 \leq \dots \leq \underline{x}_n, \underline{d}_n \leq \dots \leq \underline{x}_\infty, \underline{d}_\infty$. The "largest" equilibrium strategy is defined by a decreasing sequence $\bar{x}_1, \bar{d}_1 > \bar{x}_2, \bar{d}_2 > \dots \bar{x}_\infty, \bar{d}_\infty$.

Any equilibrium strategy must be a solution to a couple of equations (2.31, and 2.33) in two unknowns (a signal threshold x^* and a failure threshold d^*). Since any limit points of the two sequences must be also a solution to these equations, if we show that these equations have a unique solution then we can conclude that there is a unique Bayesian equilibrium. For complete set of derivations please refer to

the **Signal and fundamentals thresholds derivation. The case of inactive Central Bank** section from Appendix. There is only one strategy remaining after eliminating all iteratively dominated strategies. In equilibrium, good firms use a threshold strategy: good firms with signals $x \leq x^*$ repay, while good firms with signals $x > x^*$ default, and the bank fails for fundamentals $d > d^*$, and survives otherwise.

Expected measure of non repaying good firms. Commercial bank inference. The case of inactive Central Bank

Taking as given the optimal strategy for debtor firms and knowing the prior distribution of d , the bank will infer $E_d[(1 - d) * n(d)]$ as

$$\begin{aligned} E_d[P(x > x^*)] &= E_d[1 - \Phi(\sqrt{\beta}(x^* - d))] = \\ &= 1 - E_d[\Phi(\sqrt{\beta}(x^* - d))] \end{aligned}$$

Recall that d is normally distributed and that Φ is the cumulative density function of the standard normal distribution. I denote by h the normal density function and by H the cumulative normal function for signal x , with mean $\mu - e$ and variance $\frac{1}{\alpha} + \frac{1}{\beta}$. Hence:

$$\begin{aligned} E_d[\Phi(\sqrt{\beta}(x^* - d))] &= \int H(x^* | d) * h(d) dd = \\ &= \int \left(\int_{-\infty}^{x^*} h(y | d) dy \right) * h(d) dd = \int \int_{-\infty}^{x^*} \underbrace{h(y | d) * h(d)}_{h(y,d)} dy dd = \\ &\stackrel{\text{by changing limits}}{=} \int_{-\infty}^{x^*} \int h(y, d) dd dy = \int_{-\infty}^{x^*} h(y) dy = H(x^*), \end{aligned}$$

Thus, we can conclude that: $E_d[(1 - d) * n(d)] = 1 - H(x^*)$.

Expected measure of good firms repaying. Commercial bank inference. The case of inactive Central Bank

Further to our intermediate result when we derived the expected measure of non repaying good firms under commercial bank inference we can write the expected

measure of repaying good firms as being

$$\begin{aligned}
E_d[(1-d) * (1-n(d))] &= E_d[1-d - (1-d)n(d)] = \\
&= 1 - E_d[d] - E_d[(1-d)n(d)] = \\
&= 1 - (\mu - e) - (1 - H(x^*)) = H(x^*) - (\mu - e).
\end{aligned}$$

Bank optimal effort derivation. The case of inactive Central Bank

Taking as given the optimal strategy for debtor firms, the bank will choose its optimal effort by maximizing its expected payoff, conditional on the available information.

The maximization problem with respect to e is:

$$\begin{aligned}
&\Phi(\sqrt{\alpha}(d^* - (\mu - e))) * qD * [H(x^*) - (\mu - e)] + \\
&+ \Phi(\sqrt{\alpha}(d^* - (\mu - e))) * q(F + D) * [1 - H(x^*)] \\
&+ \Phi(\sqrt{\alpha}(d^* - (\mu - e))) * (-Q - c(e)) + \\
&+ (1 - \Phi(\sqrt{\alpha}(d^* - (\mu - e)))) * (-c(e))
\end{aligned}$$

The explicit result is derived by assuming that both prior and private signal are very precise. This limiting assumption translates in allowing $\beta \rightarrow \infty$ and then $\alpha \rightarrow \infty$. When solving the maximization problem we have to take into account the relation between the equilibrium threshold d^* and the average weakness of bank fundamentals $(\mu - e)$. We have to distinguish between two cases:

1. $d^* > \mu - e$, which implies that $\Phi(\sqrt{\alpha}(d^* - (\mu - e))) \xrightarrow{\alpha, \beta \rightarrow \infty} 1$. The simplified maximization problem is:

$$\max_e \{-qD * (\mu - e) + qD * H(x^*) + q(F + D) - q(F + D) * H(x^*) - Q - c(e)\}$$

with solution $e = 1$. Recall that $c(e) = \frac{e^2}{2}qD$. Also in the limiting case when the precision of private signals is high the signal threshold is very precise and it does not depend on e . In this case $x^* = d^* = \frac{V+F}{V+F+D} - \frac{Q}{qD}$.

2. $d^* < \mu - e$, which implies that $\Phi(\sqrt{\alpha}(d^* - (\mu - e))) \xrightarrow{\alpha, \beta \rightarrow \infty} 0$. The simplified maximization problem is:

$$\max_e \{-c(e)\}$$

with solution $e = 0$.

Combining the last two results,

$$\begin{aligned} e^* &= \begin{cases} 1, & \mu - e < d^* \\ 0, & \text{otherwise} \end{cases} \Leftrightarrow e^* = \begin{cases} 1, & -1 \leq d^* - \mu \leq 0 \\ 0, & \text{otherwise} \end{cases} \Leftrightarrow \\ &\Leftrightarrow e^* = \begin{cases} 1, & -1 \leq \frac{V+F}{V+F+D} - \frac{Q}{qD} - \mu \leq 0 \\ 0, & \text{otherwise} \end{cases} \end{aligned}$$

Optimal strategy for an active Central Bank

The Central Bank is more likely to intervene under high social cost caused by the bank closure, and is more likely to allow bank failure in the case of high inflationary costs. Recall that the measure of non-performing loans was denoted by $NPL(d) = d + (1-d)n(d)$. Following from bank's default condition (equation (2.4)) the Central Bank's expected cost function is given by:

$$C(NPL(d)) = \min \{qV * (1-d) * (1-n(d)), \gamma[Q - qD * (1-d)(1-n(d))]\}$$

An active Central Bank indifferent between helping the decapitalized bank and not, is assumed to prefer bailing out the bank. Given the above cost function, the Central Bank will intervene and save the bank if $C(NPL(d)) = \gamma[Q - qD * (1-d)(1-n(d))]$. This implies following necessary condition for a full bailout:

$$\begin{aligned} qV * (1-d) * (1-n(d)) &\geq \gamma[Q - qD * (1-d)(1-n(d))] \Leftrightarrow \\ &\Leftrightarrow qV * (1 - NPL(d)) \geq \gamma[Q - qD * (1 - NPL(d))] \Leftrightarrow \\ &\Leftrightarrow qV + \gamma qD - \gamma Q \geq qV * NPL(d) + \gamma qD * NPL(d) \Leftrightarrow \\ &\Leftrightarrow NPL(d) \leq \frac{qV + \gamma qD - \gamma Q}{qV + \gamma qD} \end{aligned}$$

Signal and fundamentals thresholds derivation. The case of active Central Bank

When deciding its action, each good firm should try to infer when the Central Bank decides to step in and bail out the bank. Thus, the probability of bank survival in this case will be given by:

$$P(NPL(d) \leq NPL^* | x)$$

Let suppose as before that there is a threshold x^{**} such that all the firms which see a signal $x > x^{**}$ will not repay their loans to bank . The distributions of signals x_i across firms conditional on the realization of non-performing loans $NPL(d)$ is given by cumulative distribution function (cdf) $P(x \leq x^{**} | NPL(d))$. Since this function depends on d , and from the distribution of d we can easily infer the distribution of $(1 - d)n(d)$ and hence the distribution of $NPL(d)$, we may conclude that:

$$P(x \leq x^{**} | NPL(d)) = P(x \leq x^{**} | d)$$

This cumulative normal distribution function is decreasing in d , positive and continuous for any value of x^{**} . The higher d , the lower the probability that signal x lies below any threshold x^{**} . Given the normality assumption, we may derive this cdf:

$$P(x \leq x^{**} | d) = \Phi(\sqrt{\beta}(x^{**} - d)), \quad (2.34)$$

where Φ is the cumulative distribution function of the standard normal distribution.

We can derive now the cumulative mass of good firms who have seen a signal above the threshold signal x^{**} . Since we have assumed that a good firm which is indifferent between attacking and not will choose not to attack,

$$P(x > x^{**} | d) = z(d) = (1 - d)n(d) \quad (2.35)$$

Following from (2.20), the bank default will be triggered for

$$d^{**} + (1 - d^{**})n(d^{**}) = NPL^*,$$

By plugging the distribution of signals x_i across firms conditional on the realization of fundamentals d^{**} and the measure of good firms which choose not to repay (in (2.34) and (2.20), respectively), one obtains the main equilibrium condition:

$$d^{**} + 1 - NPL^* = \Phi(\sqrt{\beta}(x^{**} - d^{**})) \quad (2.36)$$

where d^{**} represents the threshold in bank fundamentals at which the bank will fail for values of $d > d^{**}$.

Given the fundamentals d 's distribution is $N(\mu - e, \frac{1}{\alpha})$ and the distribution for the measure of good firms who have seen a signal higher than x^{**} (from (2.34) we can infer that $(1 - d)n(d)$ is $N(1 - d, \frac{1}{\beta})$), the distribution of $NPL(d)$ can be computed as a normal one with mean $(\mu - e + 1 - d)$ and variance $(\frac{1}{\alpha} + \frac{1}{\beta} + \frac{2\rho}{\alpha\beta})$, where ρ is the correlation coefficient between random variables d and $(1 - d)n(d)$.

Applying again Bayesian inference under a normal distribution conditional on another normal distribution, we derive the posterior distribution over the measure of non-performing loans $NPL(d)$ for a firm who has seen a signal x , as the following cdf:

$$P(NPL(d) \leq NPL^* | x)$$

If for the case of an inactive Central Bank we have used as random variables $x | d$ (which was $N(d, \frac{1}{\beta})$) and d (which was $N(\mu - e, \frac{1}{\alpha})$), for the case of an active Central Bank we have to use as random variables $x | NPL$ (which is $N(d, \frac{1}{\beta})$) and NPL (which is $N(\mu - e + 1 - d, \frac{1}{\alpha} + \frac{1}{\beta} + \frac{2\rho}{\alpha\beta})$).

The probability of bank survival in this case will be given by:

$$P(NPL(d) \leq NPL^* | x) = \Phi\left(\sqrt{\frac{\beta(\alpha + C)}{C}}\left(NPL^* - \frac{\alpha(1 - d + \mu - e) + xC}{\alpha + C}\right)\right), \quad (2.37)$$

where $C = \alpha + \beta + 2\rho\sqrt{\alpha\beta}$. This function is decreasing in x , positive and continuous for any values of NPL^* . The higher x , the lower the probability that the measure of non-performing loans NPL lies below any threshold NPL^* . As a result of Bayesian inference, each borrower firm who sees signal x has a posterior distribution over NPL that is normal with mean $\frac{\alpha(1-d+\mu-e)+xC}{\alpha+C}$ and variance $\frac{C}{\beta(\alpha+C)}$.

Given NPL^* derived in (2.19) and following the same rationament we have used in the previous case when we have studied an economy in which Central Bank was inactive, we may derive the new thresholds x^{**} and d^{**} following the next steps:

By replacing in (2.8) the probability of bank survival with the value we have found in (2.37), we may built the second main equilibrium condition:

$$\frac{C}{C+\alpha}x = NPL^* - \frac{\alpha(\mu - e + 1 - d)}{C + \alpha} - \sqrt{\frac{C}{\beta(C + \alpha)}}\Phi^{-1}\left(\frac{D}{V + F + D}\right) \quad (2.38)$$

By solving the system of equations formed by (2.36) and (2.38), equilibrium thresholds d^{**} and x^{**} can be found. Solving (2.38) for x^{**} , we obtain the threshold signal at which a good firm is indifferent between repaying his loan or not:

$$x^{**} = NPL^* \frac{\alpha+C}{C} - \frac{\alpha(1-d^{**}+\mu-e)}{C} - \sqrt{\frac{\alpha+C}{C\beta}}\Phi^{-1}\left(\frac{D}{V+F+D}\right),$$

Solving now (2.36) for d^{**} and using the value we have just derived above for equilibrium signal x^{**} , gives the threshold value for bank's fundamentals above which the bank fails:

$$d^{**} + 1 - NPL^* = \Phi\left(\sqrt{\beta}\frac{\alpha - C}{C}(d^{**} + NPL^* \frac{\alpha + C}{\alpha - C} - \frac{\alpha(1 + \mu - e)}{\alpha - C} - \frac{C}{\alpha - C} \sqrt{\frac{\alpha + C}{C\beta}}\Phi^{-1}\left(\frac{D}{V + F + D}\right))\right).$$

The right side of threshold equation is a cumulative normal distribution:

$$N\left(-NPL^* \frac{\alpha+C}{\alpha-C} + \frac{\alpha(1+\mu-e)}{\alpha-C} + \frac{C}{\alpha-C} \sqrt{\frac{\alpha+C}{C\beta}}\Phi^{-1}\left(\frac{D}{V+F+D}\right), \frac{C^2}{\beta(\alpha-C)^2}\right).$$

Thus, we may conclude that d^{**} is the intersection point between the cumulative normal distribution just described and a straight line (with a slope of 1) and positive

intercept $1 - NPL^*$. This intersection point exists and it is unique if the slope of cumulative normal distribution is less than one everywhere. This slope equals

$$\sqrt{\beta}^{\frac{\alpha-C}{C}} \phi\left(\sqrt{\beta}^{\frac{\alpha-C}{C}} \left(d^{**} + NPL^* \frac{\alpha+C}{\alpha-C} - \frac{\alpha(1+\mu-e)}{\alpha-C} - \frac{C}{\alpha-C} \sqrt{\frac{\alpha+C}{C\beta}} \Phi^{-1}\left(\frac{D}{V+F+D}\right)\right)\right),$$

where ϕ is the density function of the standard normal distribution. Recall that from statistical properties of standard normal density function $\phi \leq \frac{1}{\sqrt{2\pi}}$. Thus, a sufficient condition for a unique solution is :

$$\sqrt{\beta}^{\frac{\alpha-C}{C}} \leq \sqrt{2\pi} \Leftrightarrow \sqrt{\beta}^{\frac{-\beta-2\rho\sqrt{\alpha\beta}}{\alpha+\beta+2\rho\sqrt{\alpha\beta}}} \leq \sqrt{2\pi}$$

Also $\sqrt{\beta}^{\frac{-\beta-2\rho\sqrt{\alpha\beta}}{\alpha+\beta+2\rho\sqrt{\alpha\beta}}}$ should be positive. We have to distinguish between two cases:

1. $-\beta - 2\rho\sqrt{\alpha\beta} \geq 0$ AND $\alpha + \beta + 2\rho\sqrt{\alpha\beta} > 0$, which implies $\rho < 0$ and $0 < \beta \leq -2\rho\sqrt{\alpha\beta}$ and $\alpha > -\beta - 2\rho\sqrt{\alpha\beta} > 0$.

2. $-\beta - 2\rho\sqrt{\alpha\beta} \leq 0$ AND $\alpha + \beta + 2\rho\sqrt{\alpha\beta} < 0$, which implies EITHER $\rho > 0$ and $\beta \geq -2\rho\sqrt{\alpha\beta}$ and $\alpha + \beta < -2\rho\sqrt{\alpha\beta} < 0$ (*FALSE*), OR $\rho < 0$ and $\beta \geq -2\rho\sqrt{\alpha\beta}$ and $\alpha + \beta + 2\rho\sqrt{\alpha\beta} < 0$ (*FALSE*).

Thus the sufficient conditions for a unique solution for d^{**} is given by:

$$\begin{aligned} & \frac{\sqrt{\beta}}{\alpha + \beta + 2\rho\sqrt{\alpha\beta}} (-\beta - 2\rho\sqrt{\alpha\beta}) \leq \sqrt{2\pi} \\ & \rho < 0 \\ & 0 < \beta \leq -2\rho\sqrt{\alpha\beta} \\ & \alpha > -\beta - 2\rho\sqrt{\alpha\beta} \geq 0 \end{aligned}$$

Proof of Proposition 2

In order to not overload the paper, I do not provide this proof. It follows the lines of Proof for Proposition 1.

Proof of Proposition 3

This proposition states that the threshold d^{**} above which the bank fails even if the Central Bank is active is always larger than d^* , the threshold above which the bank

fails if Central Bank is inactive. Recall that when $\beta \rightarrow \infty$, $d^* = \frac{V+F}{V+F+D} - \frac{Q}{qD}$ and $d^{**} = NPL^*$, with both d^* and d^{**} in $[0, 1]$. We have to show that $d^* < d^{**}$, which is $\frac{V+F}{V+F+D} - \frac{Q}{qD} < \frac{qV+\gamma qD-\gamma Q}{qV+\gamma qD}$. We can rewrite it as $\frac{\gamma Q}{qV+\gamma qD} - \frac{Q}{qD} < 1 - \frac{V+F}{V+F+D} \Leftrightarrow \frac{-qVQ}{(qV+\gamma qD)qD} < \frac{D}{V+F+D}(TRUE)$.

Bank optimal effort derivation. The case of active Central Bank

Expected measure of non repaying good firms and expected measure of good firms repaying were derived using the same inference mechanism as in the case of an inactive Central Bank. These measures are $1 - H(x^{**})$ and $H(x^{**}) - (\mu - e)$, respectively.

Taking as given the optimal strategy for Central Bank and debtor firms, the bank will choose its optimal effort by maximizing its expected payoff, conditional on the available information. The maximization problem with respect to e is:

$$\begin{aligned} & \Phi\left(\sqrt{\frac{\alpha\beta}{\alpha + \beta + 2\rho\sqrt{\alpha\beta}}}(NPL^* - (\mu - e + 1 - d^{**}))\right) * qD * [H(x^{**}) - (\mu - e)] + \\ & + \Phi\left(\sqrt{\frac{\alpha\beta}{\alpha + \beta + 2\rho\sqrt{\alpha\beta}}}(NPL^* - (\mu - e + 1 - d^{**}))\right) * q(F + D) * [1 - H(x^{**})] \\ & + \Phi\left(\sqrt{\frac{\alpha\beta}{\alpha + \beta + 2\rho\sqrt{\alpha\beta}}}(NPL^* - (\mu - e + 1 - d^{**}))\right) * (-Q - c(e)) + \\ & + (1 - \Phi\left(\sqrt{\frac{\alpha\beta}{\alpha + \beta + 2\rho\sqrt{\alpha\beta}}}(NPL^* - (\mu - e + 1 - d^{**}))\right)) * (-c(e)) \end{aligned}$$

The explicit result is derived by assuming that both prior and private signal are very precise. This limiting assumption translates in allowing $\beta \rightarrow \infty$ and then $\alpha \rightarrow \infty$. When solving the maximization problem we have to take into account the relation between the equilibrium threshold d^{**} , the non-performing loans threshold NPL^* and the average weakness of bank fundamentals $(\mu - e)$. We have to distinguish again between two cases:

1. $NPL^* > \mu - e + 1 - d^{**}$, which implies that $\Phi\left(\sqrt{\frac{\alpha\beta}{\alpha + \beta + 2\rho\sqrt{\alpha\beta}}}(NPL^* - (\mu - e + 1 - d^{**}))\right) = 1$

$e + 1 - d^{**})) \xrightarrow{\alpha, \beta \rightarrow \infty} 1$. The simplified maximization problem is:

$$\max_e \{-qD * (\mu - e) + qD * H(x^{**}) + q(F + D) - q(F + D) * H(x^{**}) - Q - c(e)\}$$

with solution $e = 1$. Recall that $c(e) = \frac{e^2}{2}qD$.

2. $NPL^* < \mu - e + 1 - d^{**}$, which implies that $\Phi(\sqrt{\frac{\alpha\beta}{\alpha+\beta+2\rho\sqrt{\alpha\beta}}}(NPL^* - (\mu - e + 1 - d^{**}))) \xrightarrow{\alpha, \beta \rightarrow \infty} 0$. The simplified maximization problem is:

$$\max_e \{-c(e)\}$$

with solution $e = 0$.

Combining the last two results,

$$\begin{aligned} e^{**} &= \begin{cases} 1, & \mu - e + 1 - d^{**} < NPL^* \\ 0, & \text{otherwise} \end{cases} \Leftrightarrow \\ \Leftrightarrow e^{**} &= \begin{cases} 1, & -1 \leq NPL^* + d^{**} - \mu - 1 \leq 0 \\ 0, & \text{otherwise} \end{cases} \Leftrightarrow \\ \Leftrightarrow e^{**} &= \begin{cases} 1, & -1 \leq \frac{2(qV + \gamma qD - \gamma Q)}{qV + \gamma qD} - \mu \leq 0 \\ 0, & \text{otherwise} \end{cases} \Leftrightarrow \\ \Leftrightarrow e^{**} &= \begin{cases} 1, & -1 \leq 1 - \mu - \frac{2\gamma Q}{qV + \gamma qD} \leq 0 \\ 0, & \text{otherwise} \end{cases} \end{aligned}$$

Proof of Proposition 5

This proposition states that when cost of intervention is low ($\gamma < \gamma^* = \frac{qVD^2 + VQ(V+F+D)}{D[Q(V+F+D) - qD^2]}$), an active Central Bank will induce moral hazard in commercial bank behavior. When Central Bank is not active, the commercial bank will decide to exert optimal effort $e = 1$ when its unconditional fundamentals are stronger ($\mu_1 \leq \mu \leq \mu_2$) than when Central Bank is active. When the Central Bank is active the commercial bank exerts effort only when the unconditional bank fundamentals are above μ_2 . The thresholds in unconditional bank fundamentals μ_1 and μ_2 are given by $\frac{V+F}{V+F+D} - \frac{Q}{qD}$ and $1 - \frac{2\gamma Q}{qV + \gamma qD}$, respectively. Given the fact that commercial bank will exert effort

when the Central Bank is inactive only for values of unconditional fundamentals higher than μ_1 , while it will exert effort when the Central Bank is active for values of unconditional fundamentals higher than μ_2 , the proof reduces to show that $\frac{V+F}{V+F+D} - \frac{Q}{qD} < 1 - \frac{2\gamma Q}{qV+\gamma qD}$ holds true for $\gamma < \gamma^*$.

$$\begin{aligned} \frac{V+F}{V+F+D} - \frac{Q}{qD} < 1 - \frac{2\gamma Q}{qV+\gamma qD} &\Leftrightarrow \frac{2\gamma Q}{qV+\gamma qD} - \frac{Q}{qD} < 1 - \frac{V+F}{V+F+D} \Leftrightarrow \\ &\Leftrightarrow \gamma < \frac{qVD^2+VQ(V+F+D)}{D[Q(V+F+D)-qD^2]}. \end{aligned}$$

Assumptions the restrictions (2.2) and (2.27) imply that the denominator $D[Q(V+F+D) - qD^2]$ is positive.

Proof of Proposition 6

This proposition states that a high enough cost of intervention ($\gamma > \gamma^*$) mitigates the moral hazard problem introduced by an active Central Bank when commercial bank unconditional fundamentals are strong enough ($\mu_2 \leq \mu \leq \mu_1$). The proof follows the lines of the proof given for Proposition 5. The only difference consists in the fact that we have to show that $\frac{V+F}{V+F+D} - \frac{Q}{qD} > 1 - \frac{2\gamma Q}{qV+\gamma qD}$ holds true for $\gamma > \gamma^*$.

Proof of Proposition 7

This proposition states that when cost of intervention is very high ($\gamma > \gamma_M > \gamma^*$), an active Central Bank will not convince the commercial bank to exert maximum of effort when its unconditional fundamentals are very poor ($\mu > \mu_4$). The thresholds in unconditional bank fundamentals μ_2 and μ_4 are given by $1 - \frac{2\gamma Q}{qV+\gamma qD}$ and $2 - \frac{2\gamma Q}{qV+\gamma qD}$, respectively. These values are decreasing in γ . For $\gamma > \gamma_M$ it is straightforward to prove that μ_2 is negative and μ_4 is less than 1. Since our attention is focused only on unconditional fundamentals μ in the range $[0, 1]$, and due to the fact that μ_1 and μ_3 are not influenced by the value of γ , where μ_1 is less than 1 and μ_3 is higher than 1 always, we have to analyze the commercial bank choice of effort when the following classification for fundamentals is met: $0 < \mu_1 < \mu_4 < 1$. The proof reduces to show that $2 - \frac{2\gamma Q}{qV+\gamma qD} < 1$ holds true for $\gamma > \gamma_M$.

$$2 - \frac{2\gamma Q}{qV + \gamma qD} < 1 \Leftrightarrow 1 - \frac{2\gamma Q}{qV + \gamma qD} < 0 \Leftrightarrow \\ \Leftrightarrow \gamma > \frac{qV}{2Q - qD} = \gamma_M.$$

Derivation for changes in unconditional bank fundamentals

Differentiating (2.10) and (2.22) with respect to μ , when effort e is given, yields:

$$\frac{\partial d^*}{\partial \mu} = \phi\left(\frac{\alpha}{\sqrt{\beta}}\left(d^* - (\mu - e) - \frac{\sqrt{\alpha+\beta}}{\alpha}\Phi^{-1}\left(\frac{D}{V+F+D}\right)\right)\right) * \frac{\alpha}{\sqrt{\beta}} * \left(\frac{\partial d^*}{\partial \mu} - 1\right) \Rightarrow \\ \frac{\partial d^*}{\partial \mu} = \frac{\frac{\alpha}{\sqrt{\beta}}\phi\left(\frac{\alpha}{\sqrt{\beta}}\left(d^* - (\mu - e) - \frac{\sqrt{\alpha+\beta}}{\alpha}\Phi^{-1}\left(\frac{D}{V+F+D}\right)\right)\right)}{\frac{\alpha}{\sqrt{\beta}}\phi\left(\frac{\alpha}{\sqrt{\beta}}\left(d^* - (\mu - e) - \frac{\sqrt{\alpha+\beta}}{\alpha}\Phi^{-1}\left(\frac{D}{V+F+D}\right)\right)\right) - 1},$$

which is less than 0 given (2.11), and

$$\frac{\partial d^{**}}{\partial \mu} = \phi\left(\sqrt{\beta}\frac{\alpha-C}{C}\left(d^{**} + NPL^*\frac{\alpha+C}{\alpha-C} - \frac{\alpha(1+\mu-e)}{\alpha-C} - \frac{C}{\alpha-C}\sqrt{\frac{\alpha+C}{C\beta}}\Phi^{-1}\left(\frac{D}{V+F+D}\right)\right)\right) * \\ \sqrt{\beta}\frac{\alpha-C}{C}\left(\frac{\partial d^{**}}{\partial \mu} - \frac{\alpha}{\alpha-C}\right) \Rightarrow \\ \frac{\partial d^{**}}{\partial \mu} = \frac{\sqrt{\beta}\frac{\alpha}{C}\phi\left(\sqrt{\beta}\frac{\alpha-C}{C}\left(d^{**} + NPL^*\frac{\alpha+C}{\alpha-C} - \frac{\alpha(1+\mu-e)}{\alpha-C} - \frac{C}{\alpha-C}\sqrt{\frac{\alpha+C}{C\beta}}\Phi^{-1}\left(\frac{D}{V+F+D}\right)\right)\right)}{\sqrt{\beta}\frac{\alpha-C}{C}\phi\left(\sqrt{\beta}\frac{\alpha-C}{C}\left(d^{**} + NPL^*\frac{\alpha+C}{\alpha-C} - \frac{\alpha(1+\mu-e)}{\alpha-C} - \frac{C}{\alpha-C}\sqrt{\frac{\alpha+C}{C\beta}}\Phi^{-1}\left(\frac{D}{V+F+D}\right)\right)\right) - 1},$$

which is less than 0 given (2.23).

When Central Bank is not active $(1 - d^*)n(d) = P(x > x^* | d^*) = 1 - \Phi(\sqrt{\beta}(x^* - d^*))$, where x^* and d^* are equilibrium values described in (2.9) and (2.10). Thus, we can imply that, when effort e is constant,

$$(1 - d^*)n(d) = 1 - \Phi\left(\sqrt{\beta}\left(\frac{\alpha}{\beta}d^* - \frac{\alpha}{\beta}(\mu - e) - \frac{\sqrt{\alpha+\beta}}{\beta}\Phi^{-1}\left(\frac{D}{V+F+D}\right)\right)\right) \xRightarrow{\text{by differentiating wrt to } \mu} \\ \frac{\partial(1-d^*)n(d)}{\partial \mu} = -\phi\left(\sqrt{\beta}\left(\frac{\alpha}{\beta}d^* - \frac{\alpha}{\beta}(\mu - e) - \frac{\sqrt{\alpha+\beta}}{\beta}\Phi^{-1}\left(\frac{D}{V+F+D}\right)\right)\right) * \frac{\alpha}{\sqrt{\beta}} * \left(\frac{\partial d^*}{\partial \mu} - 1\right)$$

which is positive for the case of an inactive Central Bank because $\frac{\partial d^*}{\partial \mu} - 1 < 0$.

The case when the Central Bank is active is analogous:

$$(1 - d^{**})n(d) = P(x > x^{**} | NPL^*) = P(x > x^{**} | d^{**}) = 1 - \Phi(\sqrt{\beta}(x^{**} - d^{**})),$$

where x^{**} and d^{**} are equilibrium values described in (2.21) and (2.22). Thus, we can imply that

$$\begin{aligned}
& (1 - d^{**})n(d) = \\
1 - \Phi\left(\sqrt{\beta}\left(NPL^* \frac{\alpha+C}{C} - \frac{\alpha(1-d^{**}+\mu-e)}{C} - \sqrt{\frac{\alpha+C}{C\beta}} \Phi^{-1}\left(\frac{D}{V+F+D}\right) - d^{**}\right)\right) & \xRightarrow{\text{by differentiating wrt to } \mu} \\
\frac{\partial(1-d^{**})n(d)}{\partial\mu} = -\phi\left(\sqrt{\beta}\left(NPL^* \frac{\alpha+C}{C} - \frac{\alpha(1-d^{**}+\mu-e)}{C} - \sqrt{\frac{\alpha+C}{C\beta}} \Phi^{-1}\left(\frac{D}{V+F+D}\right) - d^{**}\right)\right) * & \\
\left(-\frac{\alpha\sqrt{\beta}}{C} - \frac{\partial d^{**}}{\partial\mu} * \sqrt{\beta} * \frac{C-\alpha}{C}\right) = & \\
= \phi(\cdot) * \frac{\sqrt{\beta}}{C} * \left(\alpha + \frac{\partial d^{**}}{\partial\mu} * (\beta + 2\rho\sqrt{\alpha\beta})\right) &
\end{aligned}$$

which is positive for the case of an active Central Bank because $\frac{\partial d^{**}}{\partial\mu} - 1 < 0$ and $\alpha > -\beta - 2\rho\sqrt{\alpha\beta} \geq 0$.

Derivation for changes in intervention cost

Differentiating (2.22) with respect to γ , when effort e is given, yields:

$$\begin{aligned}
\frac{\partial d^{**}}{\partial\gamma} - \frac{\partial NPL^*}{\partial\gamma} &= \phi\left(\sqrt{\beta}\frac{\alpha-C}{C}(d^{**} + NPL^* \frac{\alpha+C}{\alpha-C} - \frac{\alpha(1+\mu-e)}{\alpha-C} - \frac{C}{\alpha-C}\sqrt{\frac{\alpha+C}{C\beta}}\Phi^{-1}\left(\frac{D}{V+F+D}\right))\right) * \\
& \sqrt{\beta}\frac{\alpha-C}{C}\left(\frac{\partial d^{**}}{\partial\gamma} + \frac{\alpha+C}{\alpha-C}\frac{\partial NPL^*}{\partial\gamma}\right) \Rightarrow \\
\frac{\partial d^{**}}{\partial\gamma} &= \phi(\cdot) * \sqrt{\beta}\frac{\alpha-C}{C}\left(\frac{\partial d^{**}}{\partial\gamma} - \frac{\alpha+C}{\alpha-C}\frac{qQV}{(qV+\gamma qD)^2}\right) + \frac{\partial NPL^*}{\partial\gamma} \Rightarrow \\
\frac{\partial d^{**}}{\partial\gamma} &= \frac{\sqrt{\beta}\frac{C-\alpha}{C}\phi(\cdot)\frac{\alpha+C}{\alpha-C}\frac{qQV}{(qV+\gamma qD)^2}}{1-\sqrt{\beta}\frac{\alpha-C}{C}\phi(\cdot)} - \frac{\frac{qQV}{(qV+\gamma qD)^2}}{1-\sqrt{\beta}\frac{\alpha-C}{C}\phi(\cdot)},
\end{aligned}$$

which is less than 0 given (2.23). Then, we can imply that:

$$\begin{aligned}
& (1 - d^{**})n(d) = \\
1 - \Phi\left(\sqrt{\beta}\left(NPL^* \frac{\alpha+C}{C} - \frac{\alpha(1-d^{**}+\mu-e)}{C} - \sqrt{\frac{\alpha+C}{C\beta}} \Phi^{-1}\left(\frac{D}{V+F+D}\right) - d^{**}\right)\right) & \xRightarrow{\text{by differentiating wrt to } \gamma} \\
\frac{\partial(1-d^{**})n(d)}{\partial\gamma} = -\phi(\cdot)\frac{\sqrt{\beta}}{C} * \underbrace{[(\alpha + C)\frac{-qQV}{(qV + \gamma qD)^2}]_{\text{negative}}}_{\text{negative}} + \underbrace{\frac{\partial d^{**}}{\partial\gamma}}_{\text{negative}} * \underbrace{(-\beta - 2\rho\sqrt{\alpha\beta})}_{\text{positive}} > 0 &
\end{aligned}$$

Derivation for changes in fundamentals

When Central Bank is not active $(1 - d)n(d) = P(x > x^* | d) = 1 - \Phi(\sqrt{\beta}(x^* - d))$, where x^* is equilibrium value described in (2.9). Thus, we can imply that

$$\begin{aligned}
(1 - d)n(d) &= 1 - \Phi\left(\sqrt{\beta}\left(\frac{\alpha}{\beta}d - \frac{\alpha}{\beta}(\mu - e) - \frac{\sqrt{\alpha+\beta}}{\beta}\Phi^{-1}\left(\frac{D}{V+F+D}\right)\right)\right) \xRightarrow{\text{by differentiating wrt to } d} \\
\frac{\partial(1-d)n(d)}{\partial d} &= -\phi\left(\sqrt{\beta}\left(\frac{\alpha}{\beta}d - \frac{\alpha}{\beta}(\mu - e) - \frac{\sqrt{\alpha+\beta}}{\beta}\Phi^{-1}\left(\frac{D}{V+F+D}\right)\right)\right) * \frac{\alpha}{\sqrt{\beta}}
\end{aligned}$$

which is negative.

The case when the Central Bank is active is analogous:

$$(1 - d)n(d) = P(x > x^{**} | NPL) = P(x > x^{**} | d) = 1 - \Phi(\sqrt{\beta}(x^{**} - d)),$$

where x^{**} is equilibrium value described in (2.21). Thus, we can imply that

$$\begin{aligned} (1 - d)n(d) &= \\ 1 - \Phi\left(\sqrt{\beta}\left(NPL^* \frac{\alpha+C}{C} - \frac{\alpha(1-d+\mu-\epsilon)}{C} - \sqrt{\frac{\alpha+C}{C\beta}} \Phi^{-1}\left(\frac{D}{V+F+D}\right) - d\right)\right) &\xRightarrow{\text{by differentiating wrt to } d} \\ \frac{\partial(1-d)n(d)}{\partial d} &= -\phi\left(\sqrt{\beta}\left(NPL^* \frac{\alpha+C}{C} - \frac{\alpha(1-d+\mu-\epsilon)}{C} - \sqrt{\frac{\alpha+C}{C\beta}} \Phi^{-1}\left(\frac{D}{V+F+D}\right) - d\right)\right) * \frac{-\beta-2\rho\sqrt{\alpha\beta}}{C} \end{aligned}$$

which is negative for the case of an active Central Bank because $-\beta-2\rho\sqrt{\alpha\beta} \geq 0$.

2.B Figures

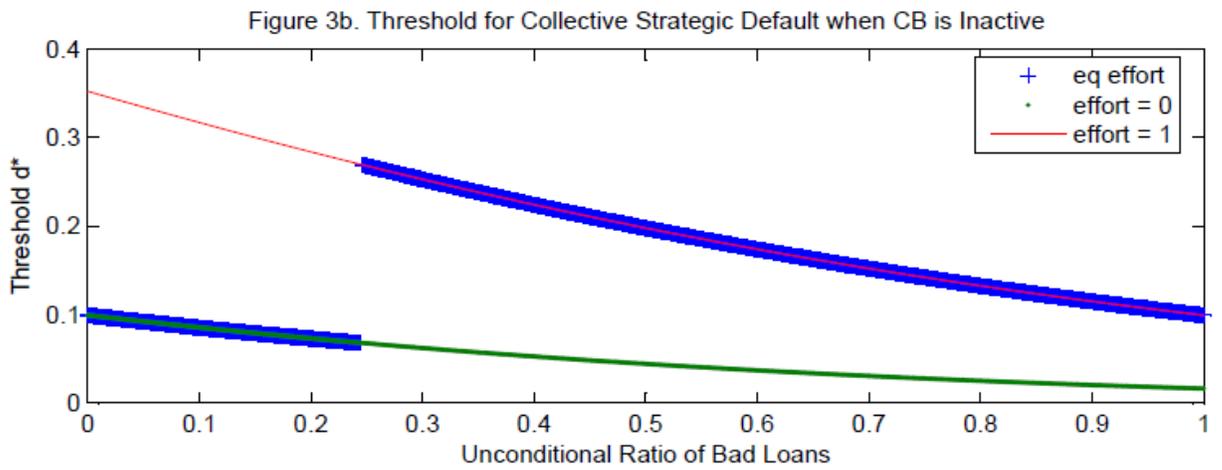
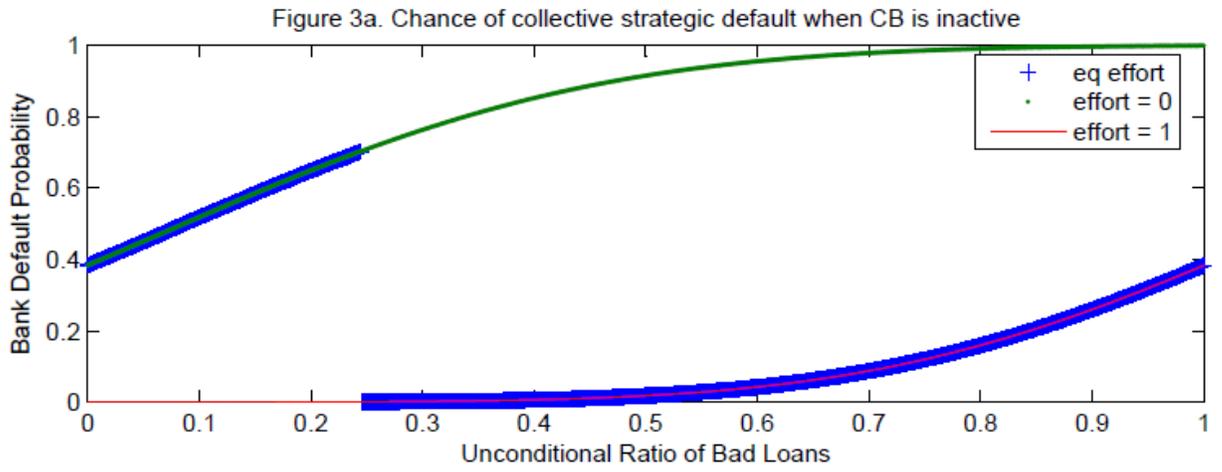


Figure 4a. Chance of collective strategic default when CB is Active.
 Cost of intervention is low. $NPL^* = 0.8$

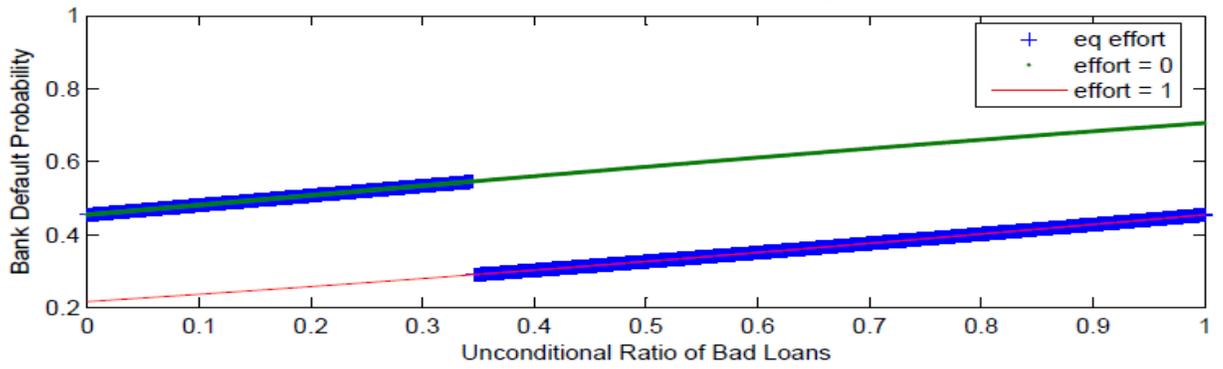


Figure 4b. Threshold for Collective Strategic Default when CB is Active.
 Cost of intervention is low. $NPL^* = 0.8$

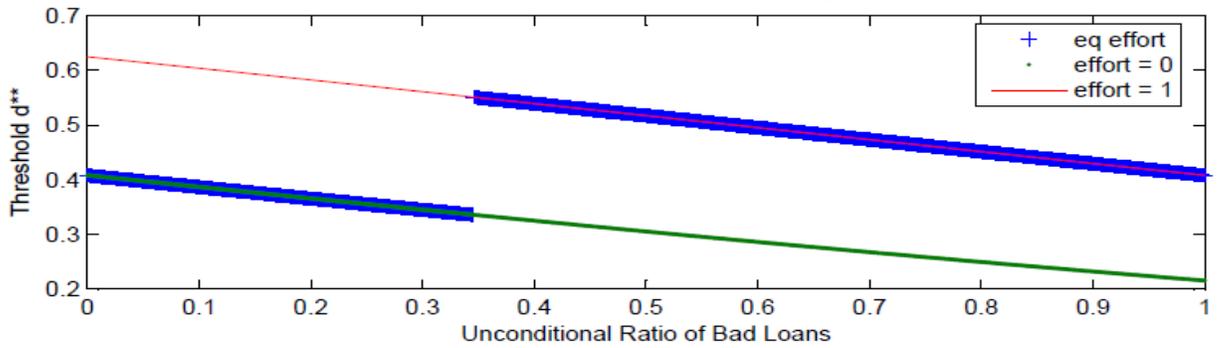


Figure 5a. Chance of collective strategic default when CB is Active.
 Cost of intervention is high. $NPL^* = 0.2$

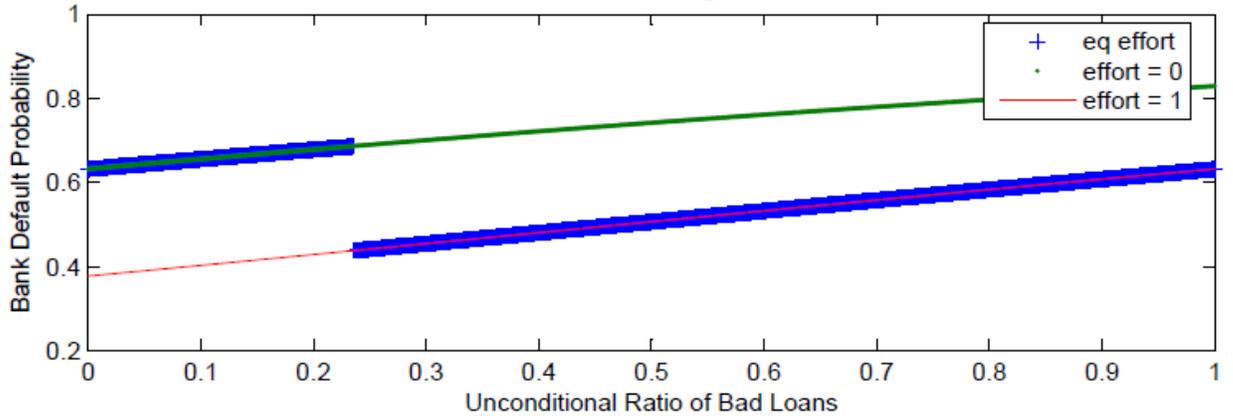


Figure 5b. Threshold for Collective Strategic Default when CB is Active.
 Cost of intervention is high. $NPL^* = 0.2$

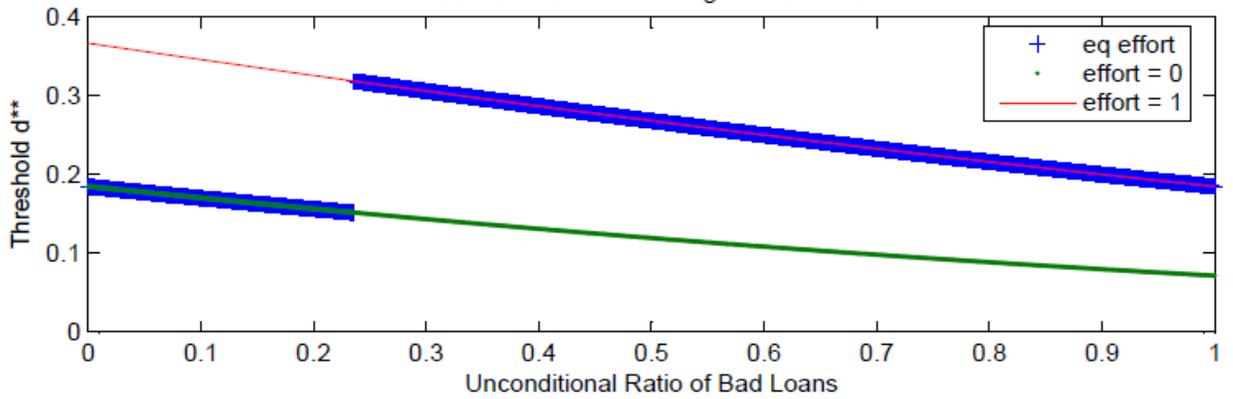


Figure 6a. Required Ratio for Successful Collective Strategic Default when CB is Inactive
The Ratio is out of Total No of Firms

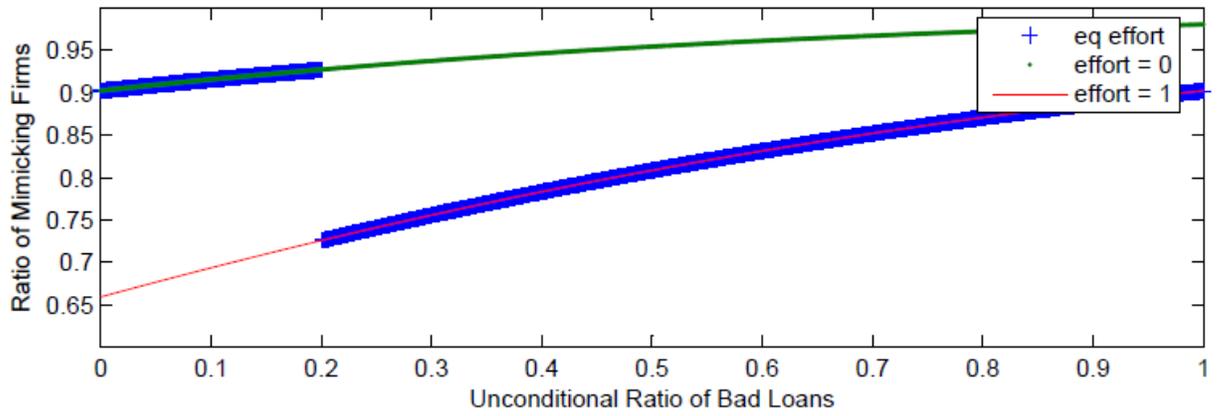


Figure 6b. Required Ratio for Successful Collective Strategic Default when CB is Inactive
The Ratio is out of Total No of Good Firms

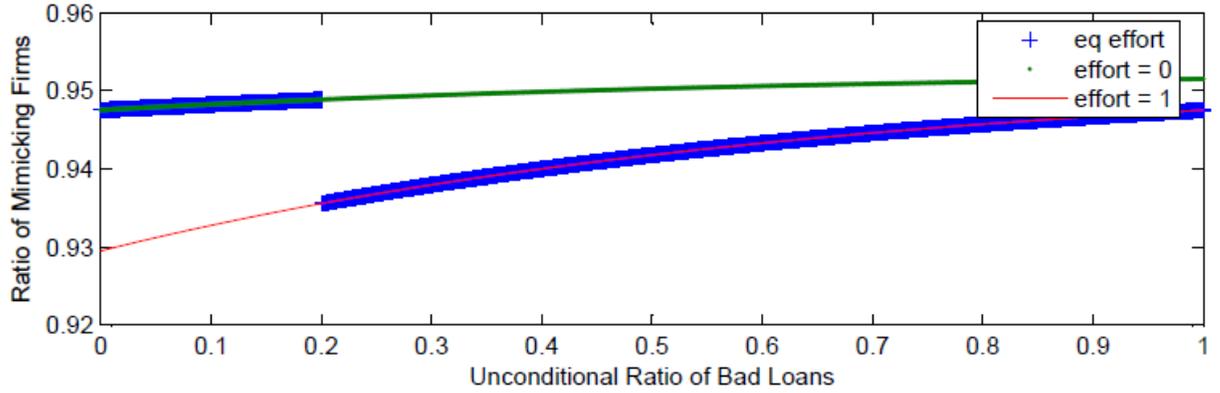


Figure 7a. Required Ratio for Successful Collective Strategic Default when CB is Active
 Cost of intervention is low. $NPL^* = 0.8$
 The Ratio is out of Total No of Firms

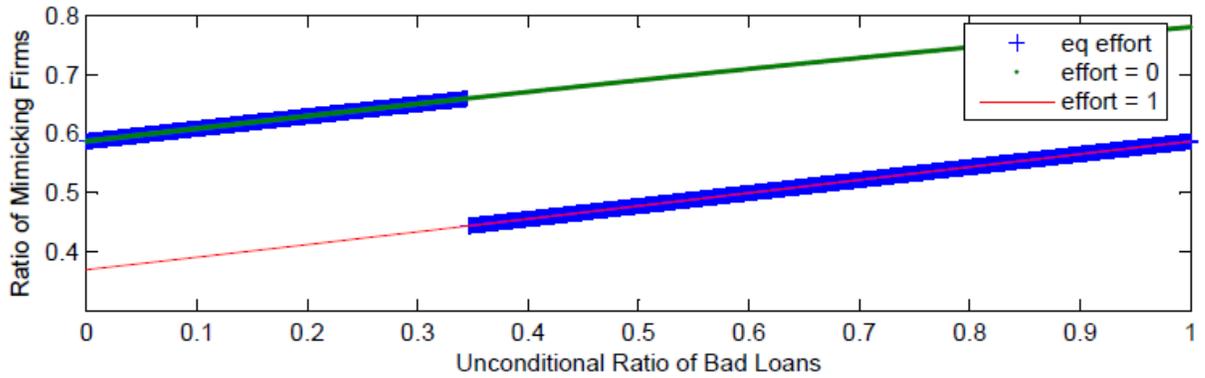


Figure 7b. Required Ratio for Successful Collective Strategic Default when CB is Active
 Cost of intervention is low. $NPL^* = 0.8$
 The Ratio is out of Total No of Good Firms

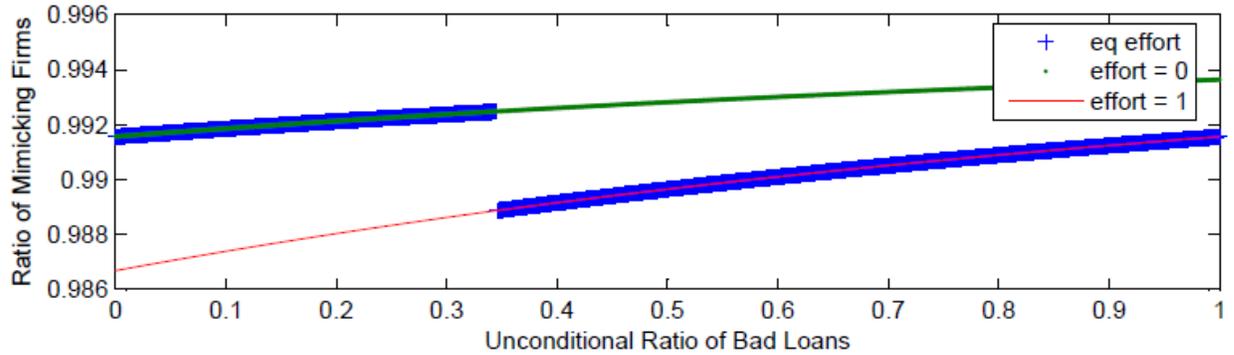


Figure 8a. Chance of collective strategic default when CB is Active.

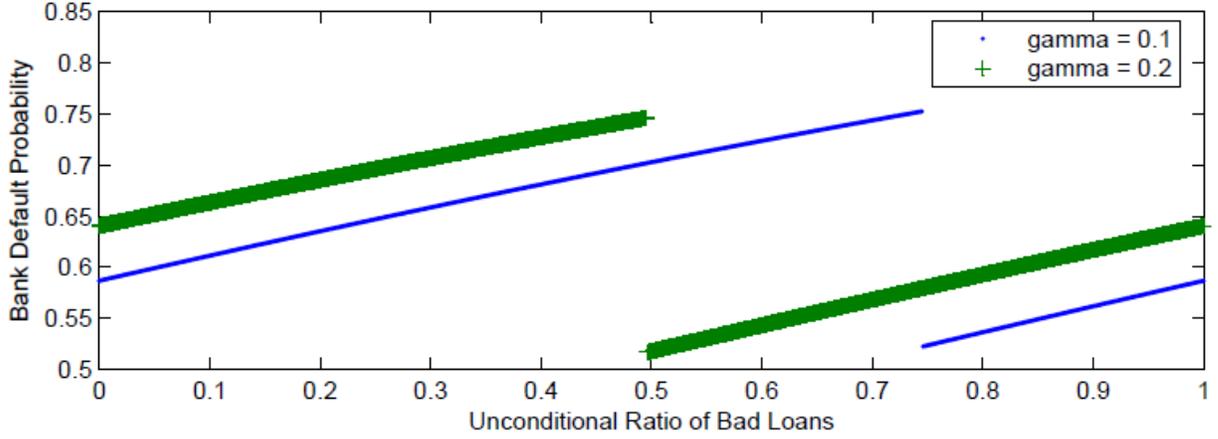
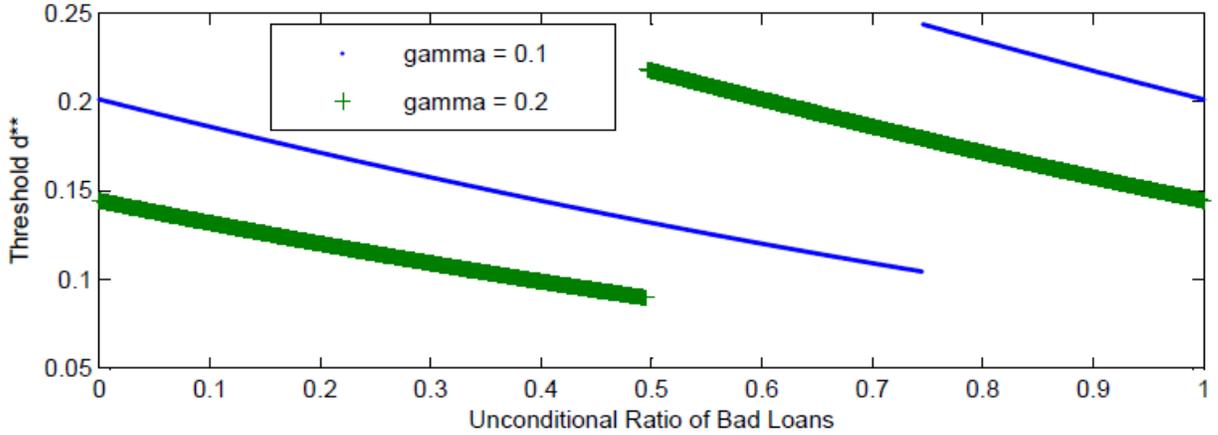


Figure 8b. Threshold for Collective Strategic Default when CB is Active



Chapter 3

Strategic Loan Defaults and Coordination: An Experimental Analysis

3.1 Introduction

A wide literature in finance shows how coordination failure by depositors in the form of premature withdrawals and bank runs may lead to the collapse of weak banks, and sometimes of healthy banks.¹ Had depositors successfully coordinated on keeping their funds in the bank, it could have survived, with mutual benefits for bank and depositors. Banks can also be vulnerable to coordination failure from the asset side of their balance sheet, however (Bond and Rai 2009, De Luna-Martinez 2000, Krueger and Tornell 1999, Vlahu 2009). If solvent borrowers believe that the bank will become distressed because of defaults by others, they may delay or even default on their loans. For a bank with good fundamentals, a borrower's default on

¹Bryant (1980), Calomiris and Kahn (1991), Chari and Jagannathan (1988), Diamond and Dybvig (1983), Goldstein and Pauzner (2005), Jacklin and Bhattacharya (1988), Rochet and Vives (2005) give theoretical models for bank runs. Kelly and O'Grada (2000), Iyer and Puri (2009), Saunders and Wilson (1996) provide empirical evidence.

a loan threatens her future relationship with the bank, providing strong incentives for timely and full repayment (Boot 2000, Brown and Zehnder 2007, Ongena and Smith 2000). Believing that the bank will become distressed, however, reduces the repayment incentive for solvent borrowers because of the expected loss of the benefits from the maintained relationship should the bank fail. Commonly held beliefs that other borrowers will default may therefore lead to a situation where solvent borrowers are unable to coordinate on repayment, and thus fail to ensure bank survival and future relational benefits. Borrowers' reluctance to repay their loans in a situation of expected distress has been identified by De Luna-Martinez (2000) and Krueger and Tornell (1999) as one of the main causes that exacerbated the 1994 Mexican banking crisis. More recently, a prominent example has been the delayed payments to Lehman by a number of other large banks (e.g., JP Morgan), in the wake of Lehman's demise on September 15, 2008. Lehman's creditors accused JP Morgan for having created a liquidity shortage on September 12, 2008, when denying access to \$8.6 billion in cash and other liquid securities.² Conversely, a large German borrower, KfW bank, was exposed to massive criticism because it made a €300M payment to Lehman on that day just before Lehman filed for bankruptcy (Kulich, 2008).

An important sector where banks may become subject to runs by their borrowers in times of distress is the mortgage market (Feldstein, 2008). US mortgage lenders in many states have no recourse to the borrower's wealth beyond the value of the house. Individuals with negative equity, many of them real estate speculators, therefore have a strong incentive to default. If many choose to do so, also borrowers with positive net value may decide to delay payments, anticipating a possible failure of their lender that would destroy their future relational value. This aggravates the lender's problems. In fact, hundreds of small lenders have failed during the 2007-2009 crisis (see, e.g. FDIC Bank Failures report 2010), and Guiso et al. (2009) provide evidence that

²Lehman Brothers Holdings Inc. et al., U.S. Bankruptcy Court, Southern District of New York, No. 08-13555.

approximately 1 in 4 defaults was driven by strategic behavior of solvent borrowers. Similarly, Hull (2008) claims that the downward trend in house prices during the credit crisis in 2007 was reinforced by the decision of many borrowers who exercised their "implicit put options and walked away from their houses and their mortgage obligations".

In contrast to depositors withdrawing their own money, coordination failure resulting from borrowers strategically delaying or defaulting on loan payments involves a breach of contract. It will therefore be confined to situations of diffused financial distress of either borrowers or banks or both, as in the recent crisis, and to situations characterized by slow and relatively costly law enforcement. By its mere nature, it is therefore difficult to study its causes empirically. Uncertainty regarding both bank fundamentals and borrower fundamentals may contribute to create coordination failure, but these effects are difficult to identify due to the lack of clear measurement and orthogonal variation. More generally, the causes of coordination failure in situations with multiple equilibria cannot easily be studied with real world financial data, and therefore little evidence is available yet.³ Evidence on borrowers' behavior is confined to cross-countries studies of credit registries' role in dissipating information, showing that repayment rates are higher where credit registries are more developed (Jappelli and Pagano, 2002).

To overcome identification problems in empirical data, in this paper we separate the effects of uncertainty about bank fundamentals and borrower fundamentals on borrowers' coordination failure in an experimental credit market. Experiments have successfully been used to examine the impact of information sharing and long-term banking relationships on borrower and lender behavior (Brown et al. 2004, Brown and Zehnder 2007, 2010, Fehr and Zehnder 2009). Similarly, to study the causes of depositor and currency runs, theoretical accounts have been tested in controlled laboratory settings with clear identification of causal effects (Garratt and

³Degryse et al. (2009) review the empirical literature on individual bank runs and systemic risk.

Keiser 2009, Heinemann et al. 2004, Madies 2006, Schotter and Yorulmazer 2009). The borrowers' coordination problem has received less empirical attention yet. The harmful effects of strategic defaults have not become clear until the recent period of distress, with previous episodes limited to developing countries (De Luna-Martinez 2000, Krueger and Tornell 1999), and transition economies (Perotti, 1998). Because of its relevance to the stability of the banking system and its potential to amplify downward trends, a more thorough understanding of borrowers' coordination failure is warranted. Identifying the factors that drive borrowers' strategic default is important for bank stability and allows for improvements with respect to the choice and the timing of regulatory measures.

The coordination game studied in the current paper involves two features which are specific to credit markets. First, borrowers have an imperfect signal about the fundamentals of their bank (i.e., the number of defaults that would trigger its failure). Second, borrowers are imperfectly informed about the fundamentals of other borrowers, and thus how many of these may be forced to default on their loans. These two sources of uncertainty are natural proxies for the regulatory rules for transparency and disclosure, and for the state of the economy. The design allows us to study whether transparency rules and economic environment affect the incidence of strategic default, and how the two factors interact. That is, we test whether public policy to improve disclosure has a different effect on repayment incentives in different stages of the business cycle, and vice versa, if the impact of changes in the economic environment depends on disclosure rules. Although the payoff structure studied here will be derived from a lending perspective, the potential interaction between uncertainties regarding the bank and the other borrowers is also relevant for depositors' coordination or currency runs. To our best knowledge, the interaction of these uncertainties has not yet been studied in either alternative setting, and our results therefore provide relevant insights beyond credit markets.

This paper complements the empirical literature on bank runs by departing from

the traditional view of runs and focusing on the assets side of the bank balance sheet. We compare four coordination games (with 2 borrowers) that have the same multiple Nash equilibria – default by both borrowers versus repayment by both borrowers – but differ in terms of the uncertainty about fundamentals. Because of the future benefits of the maintained banking relation, coordination on repayment is always efficient for solvent borrowers. We explore the behavior of these borrowers, and how their coordination failure due to strategic default reduces bank stability. Our main findings are as follows. First, we find that both types of uncertainty affect the incidence of strategic defaults, and that this effect can be explained by a change in the risk dominance characteristics of the coordination setting (Schmidt et al. 2003, Straub 1995).⁴ In particular, both disclosure and uncertain borrower fundamentals make the defaulting equilibrium relatively more risk dominant, leading to more coordination failures. Surprisingly, thus, more information about bank fundamentals is not always better. When full disclosure reveals bank weakness, it increases strategic non-repayment regardless of economic conditions. Similarly, solvent borrowers default strategically more during downturns when fundamentals of other borrowers are more uncertain, regardless of disclosure rules.

Second, analyzing individual borrower characteristics we find that risk attitudes, in particular attitudes toward financial losses, have a strong and robust influence on repayment decisions. Loss averse borrowers place a higher value on the available cash they hold than on the higher but uncertain future monetary outcome which is conditional on bank survival. Hence, they have a strong preference towards non-repayment, which allows them to avoid the immediate financial loss triggered by potential bank failure.

We also show that negative past experiences strongly affect individual repayment decisions. People who have experienced more defaults from other borrowers and

⁴Risk dominance measures in how far expected payoffs in one equilibrium are relatively less affected by uncertainty about the players' strategy choice than in the other equilibrium.

the subsequent bank failures, are more likely to default strategically. The role of negative experiences has been shown relevant in various financial decision settings (Malmendier and Nagel, 2010), and our results indicate that it will also affect behavior of borrowers who lost a banking relationship in times of crisis. While direct experiences of bank failures will mainly obtain in economies with weak institutions and repeated crises, the results also suggest a channel for contagious aggravation of beginning crises through observation or word-of-mouth (Guiso et al. 2009, Iyer and Puri 2009, Rincke and Traxler 2010).

Policy implications follow from our analysis. Clearly, the role of individual characteristics implies that credit markets in which participants do not self-select according to risk attitude, like the mortgage market, might be subject to more strategic default than those in which entrepreneurial types participate, like small business loans markets. Our results regarding experiences suggest some range for welfare improvements by not letting banks in distress fall in public. Hence, we provide a rationale for central banks' interventions as lender of last resort. Large scale intervention of financial authorities during the recent financial turmoil lead to immense liquidity support for banks and asset guarantees worth several trillions dollars. This support has helped most of the banks to avoid failure, and this, in the spirit of our paper, proved to have benefic impacts on the banking system. Keeping banks afloat, such interventions have buffered the impact of negative experiences and have mitigated the strategic default of borrowers. Further, disclosure may be harmful because it lays open the strategic uncertainty in the coordination problem. As we show in the experimental data, and as has also been observed in various cases during the current crisis, once the weakness of the bank is established, the coordination is too difficult a problem for market participants to solve. This will be particularly true in situations of a weak real economy and thus with a significant portion of borrowers potentially in genuine distress.

The chapter is laid out as follows. Section 3.2 introduces the model and Sec-

tion 3.3 formulates our hypotheses. In Section 3.4 we describe the experimental design. Results are presented in Section 3.5, and discussed in Section 3.6. Section 3.7 concludes.

3.2 The Model

We consider a risk-neutral economy with two dates: 0 and 1. The economy is populated by a single bank and two borrowers. There is no time discounting. We model depositors as passive players without alternative investment opportunities beside costless storage and lending to the bank.

3.2.1 Agents

The bank finances its investments through deposits Dep and equity E . We assume that deposits are fully insured at zero premium. The bank invests some of its funds in two identical risky loans of size L each. The difference C between the volume of liabilities (e.g., deposits Dep and equity E), and the volume of loans $2 * L$ represents cash reserves. We normalize L to 1, and all the other variables are normalized accordingly. Required nominal gross return per unit of loans is $R > 1$. Both deposits and loans are repaid at date 1. The balance sheet of the bank at date 0 is depicted in table 1.

TABLE 1. BANK'S BALANCE SHEET AT DATE 0.

Cash Reserves: C	Deposits: Dep
Loans: 2	Equity: E

In this model the bank is simulated. Since the focus of our analysis is on the borrowers' repayment behavior, we assume the bank's quality (i.e., capital to assets ratio adequacy, quality of loans as result of screening and monitoring efforts) to be exogenously given. The bank fundamentals might be either strong or weak. If the

fundamentals are *strong*, the bank survives if at most 1 loan is defaulted on. If the fundamentals are *weak*, the bank survives only if both loans are repaid. We denote by F the number of defaulted loans the bank can stand, conditional on its type. For a bank with strong fundamentals, F equals 1, while for a bank with weak fundamentals F equals 0. The economic intuition behind this classification is as follows. As the recent financial crisis has shown, the debt leverage was a major determinant of the property bubble and subsequent liquidity problems in the banking sector. Many large banks had 30 times leverage at the beginning of the crisis, which was well above the allowed 12 times leverage introduced by the international standard of 8 percent for bank's capital ratio. Thus, highly leveraged banks resemble weak banks, which are more likely to become illiquid when the volume of non-performing assets is low. On the other hand, strong banks are those with appropriate level of capital which might survive to a higher degree of deterioration of their assets.

We examine two scenarios for bank transparency. In the first one the bank's fundamentals are weak, and both borrowers know the type of their bank. Hence, there is common knowledge about bank's fundamentals. This case corresponds to a full transparency regime regarding the bank's weakness, where all agents understand that the bank will fail if only one loan is not repaid. All uncertainty is due to the strategic uncertainty in the coordination problem (Heinemann et al. 2009, Van Huyck et al. 1990). In the second scenario, the borrowers do not know the quality of their bank's fundamentals, due to partial disclosure. The type of bank is drawn randomly, and can be either strong (with probability p) or weak (with probability $1 - p$). The borrowers know the probability distribution, but they do not know the true type of their bank. That is, uncertainty about the bank's financial health is added to the strategic uncertainty. We call the scenario with full disclosure about weak bank fundamentals *Transparent Weakness* (TW), and the scenario with uncertainty about bank's weakness *Uncertain Weakness* (UW).

There are two types of borrowers in this economy: solvent borrowers with good fundamentals and financially distressed borrowers with bad fundamentals. When fundamentals are *good*, the borrower has a positive income and can repay her loan in full. When fundamentals are *bad*, the borrower is in genuine distress and she has no option but to default on her loan. We denote by K the borrower's available cash. For a borrower with good fundamentals, K equals R , while for a borrower with bad fundamentals K equals 0. Upon receiving information about the possible uncertain bank's fundamentals and other borrower's fundamentals, good borrowers may take either of two actions at date 1. They may decide to repay their loans in full, or to default. Both borrowers make their decisions simultaneously.

For borrowers we examine two cases. In the first case, the economic environment is characterized by robust growth, low unemployment, high prospects for corporate sector performance, rising assets prices including real estate, and stable personal income. Both borrowers have good fundamentals and they can repay their loans in full. In the second case, the economic environment is characterized by widespread weakness, contraction in business activity, rising unemployment, and falling assets prices including property prices. In such an environment many borrowers are faced with the lack of capability of repaying their debts. We model this uncertainty assuming that one of the borrowers' type is drawn randomly. We call her *Borrower B*. She can have either good fundamentals (with probability q) or bad fundamentals (with probability $1 - q$). When making the repayment decision, the other borrower (called *Borrower A*) has no information regarding Borrower B's true fundamentals, except for the probability distribution. On the other hand, there is common knowledge about Borrower A's good fundamentals.

This approach builds on the recent literature on the strategic defaults of borrowers. The papers most closely related to ours are by Guiso et al. (2009) and Cohen-Cole and Morse (2009), who study the behavior of mortgage borrowers in US during the subprime crisis of 2007. Cohen-Cole and Morse (2009) show that in situ-

ations of financial distress, consumers often prefer defaulting on mortgages rather than on credit card debt to secure liquidity. They also find that individual mortgage defaults increase the likelihood of other home owners defaulting on their mortgage; such an effect is not found for credit card debt. Similarly, Guiso et al. (2009) also report strategic defaults and social spillovers in mortgage delinquency. A theoretical analysis is Vlahu (2009), who shows that banks with sound fundamentals may collapse due to collective strategic loan defaults. Vlahu (2009) argues that if solvent borrowers have imprecise private signals about bank fundamentals, they may claim inability to repay if they expect a sufficient number of other borrowers to do so as well, thus reducing bank's enforcement ability.

In our model, the economic intuition behind the asymmetry in solvency and information (i.e., Borrower B knows with certainty that Borrower A is solvent while Borrower A has only an expectation about Borrower B's fundamentals) follows from typical patterns in economic crisis. For instance, during the recent financial crisis, some sectors in the economy (e.g., the financial, real estate, and car industry) were strongly hit in the beginning, while others (e.g., pharmaceuticals, transportation and utilities) were quite resilient at the onset of the crisis. Borrower A is employed in a strong sector of the economy. Everybody knows that her line of business is doing fine and believes that she is solvent and capable to repay her loan. Borrower B works in a sector which was severely affected by the crisis. There is a lot of uncertainty about her employment situation and a positive probability that she will experience financial distress. We call the economic environment with solvent borrowers *Good Economy* (GE), and the one with uncertainty about Borrower's B fundamentals *Bad Economy* (BE).

3.2.2 Payoff Functions

The borrowers' payoff structure is as follows. If a solvent borrower chooses to repay her loan she will get either 0 if the bank fails or $V > R$ otherwise, where V represents the present value of future long-term relation between the firm and the borrower. As Diamond (1991) argues, debtors that have been successful in repaying their loans in the past are able to obtain better credit terms since they are more likely to be successful in the future. We assume that the bank breaks off the relationship if a borrower defaults. If a solvent borrower chooses to default she keeps the contractually agreed repayment R . The intuition behind this is twofold. On one hand, the evidence suggests that due to its collection skills, the original lender is the most efficient in extracting any hidden cash from defaulting borrowers. Hence, if the bank fails, a new entity which takes over the bank's assets will recover less than R . Without loss of generality we set the recovery rate to zero. On the other hand, if the bank survives it might force the repayment R . Nevertheless, as evidence from recent credit crisis suggests, this might not happen. Guiso et al. (2009) analyze the behavior of mortgage borrowers and report two reasons for low recovery.

First, some states in US have mandatory non-recourse mortgages, and as a result the lenders can not pursue the house's owner beyond the value of the house. Second, the legal cost of enforcing the contract is usually high enough to make lenders unwilling to sue a defaulted borrower. The first reason is specific to mortgage loans. The second one has a broader interpretation. Lenders find it difficult to recover their loans in circumstances where the financial environment is characterized by inadequate bankruptcy laws and an inefficient judiciary system in which creditor rights are poorly defined or weakly enforced. The recovery rates are very low and the process is slow and bureaucratic as evidence from banking crises in Latin American countries in the mid 80's and transition economies in Eastern Europe in the early 90's show. According to the World Bank,⁵ the recovery rate in non-OECD countries averages

⁵World Bank's Statistics for Closing Business Indicators (2009); based on methodology discussed

$$\Pi_i(K_i, D_i, D_{-i}, F) = \begin{cases} K_i D_i + V(1 - D_i) & \text{if } F \geq D_i + D_{-i} \quad (\text{bank survives}) \\ K_i D_i & \text{if } F < D_i + D_{-i} \quad (\text{bank collapses}) \end{cases}$$

below 30%, while the recovering process may last between 3 and 4 years. The cost of proceedings is substantial, averaging 17% of the assets value. Even though for the OECD countries the statistics are not as dramatic (i.e., recovery rate 68%, average period 2 years and recovery costs 8.5% of assets), due to the collapse in asset prices following the turmoil of 2007-2010, and the subsequent erosion in value of collateral backing access to funds for many borrowers, there is an increased likelihood that these numbers will be worse. Thus, due to limited legal punishment, we can assume without loss of generality that a defaulting borrower ends up with a positive payoff R .

We denote by Π_i and by D_i the payoff and the action of borrower i , respectively, with $i \in \{A, B\}$. The available set of actions for borrower i at date 1 is to either repay the loan ($D_i = 0$), or to default ($D_i = 1$). The borrower's payoff depends not only on her fundamentals (K_i , with K_i either 0 or R) and her action (D_i), but also on the other borrower's action (D_{-i}) and bank's fundamentals (F , with F either 0 or 1). Further, if $K_i = 0$, $D_i = 1$ follows. The payoff function for borrower i is then given by:

Tables 2 and 3 provide the payoff matrices for the cases when the bank is strong and weak, respectively. If the bank has strong fundamentals ($F = 1$) it collapses only if both borrowers default. As a consequence, the borrowers' payoff matrix when both debtors are solvent (i.e., both borrower A and borrower B have good fundamentals) is given by:

in Djankov et al. (2008).

TABLE 2. THE BORROWERS' PAYOFF MATRIX FOR THE CASE OF A STRONG BANK AND SOLVENT BORROWERS

Borrower A \ Borrower B	Repay ($D_B = 0$)	Default ($D_B = 1$)
Repay ($D_A = 0$)	V, V	V, R
Default ($D_B = 1$)	R, V	R, R

If the Bank has weak fundamentals ($F = 0$) it collapses if either debtor defaults. If both borrowers are solvent we then have:

TABLE 3. THE BORROWERS' PAYOFF MATRIX FOR THE CASE OF A WEAK BANK AND SOLVENT BORROWERS

Borrower A \ Borrower B	Repay ($D_B = 0$)	Default ($D_B = 1$)
Repay ($D_A = 0$)	V, V	$0, R$
Default ($D_B = 1$)	$R, 0$	R, R

3.2.3 Scenarios of Interest and Extensive Form of the Game

The combination of full vs. partial disclosure and subsequent uncertainty regarding bank fundamentals, and a good vs. a bad economy implies four scenarios of interest. These scenarios are as follows: (1) *Good Economy – Transparent Weakness* (GE-TW), (2) *Good Economy – Uncertain Weakness* (GE-UW), (3) *Bad Economy – Transparent Weakness* (BE-TW), and (4) *Bad Economy – Uncertain Weakness* (BE-UW). Figure 1 gives the extensive form of the game for each scenario.

FIGURE 1: EXTENSIVE FORM OF THE GAME FOR DIFFERENT SCENARIOS

	t=0	t=1/2	t=1
GE-TW	F and K_i are exogenously given	F and K_i become common knowledge	Borrowers decide simultaneously to repay their loans or not
GE-UW	The nature draws F from $(p, 1-p)$, K_i are exogenously given	$(p, 1-p)$ and K_i become common knowledge	Borrowers decide simultaneously to repay their loans or not
BE-TW	F and K_A exogenously given, nature draws K_B from $(q, 1-q)$	F , K_A and $(q, 1-q)$ become common knowledge	Good borrowers decide to repay their loans or not; bad borrowers default
BE-UW	K_A exog. given, nature draws K_B from $(q, 1-q)$ and F from $(p, 1-p)$	K_A , $(p, 1-p)$ and $(q, 1-q)$ become common knowledge	Good borrowers decide to repay their loans or not; bad borrowers default

3.3 Theoretical and Behavioral Predictions

3.3.1 Theoretical Predictions

In this section we discuss the equilibria in different scenarios. Each scenario is defined by a combination of uncertainty about bank's fundamentals and about the second borrower's solvency. We begin by describing two additional benchmark scenarios involving unique equilibria, the first involving a credit market with a strong bank, and the second scenario involving a credit market with one good borrower and one bad borrower. Because of the unique equilibria we will not study these scenarios in the experiment. We next describe the theoretical predictions for the scenarios of interest defined in Section 3.2.3 that we examine empirically. Assuming risk neutrality, it will be shown that these four scenarios involve the same multiple pure Nash equilibria. Table 4 summarizes the pure Nash equilibria for all possible scenarios.

TABLE 4: THEORETICAL PREDICTIONS

Bank Fundamentals Borrower Fundamentals	Strong $F = 1$	Uncertain (UW) $Prob(F=1) = p$	Weak (TW) $F = 0$
Good (GE) $K_A=R$ $K_B=R$	[Repay, Repay]	[Repay, Repay] or [Default, Default] ^a	[Repay, Repay] or [Default, Default]
Uncertain (BE) $K_A=R$, $Prob(K_B=R) = q$	[Repay, Repay if $K_B=R$]	[Repay, Repay if $K_B=R$] ^c or [Default, Default] ^a	[Repay, Repay if $K_B=R$] ^b or [Default, Default]
Bad $K_A=R$, $K_B=0$	[Repay, Default]	[Repay, Default] ^d or [Default, Default] ^a	[Default, Default]

Notes: ^aEquilibrium depends on the condition $pV < R$; ^bEquilibrium depends on the condition $qV > R$;
^cEquilibrium depends on the condition $(q+p-pq)V > R$; ^dEquilibrium depends on the condition $pV > R$

All proofs are in the Appendix. We focus on pure strategy equilibria in this paper, thus mixed equilibria are given in the Appendix and are not discussed in detail. In the Appendix we also show that our data imply that participants did not play these mixed equilibria.

Benchmark scenarios

In the benchmark scenario with strong bank fundamentals both borrowers know that the bank collapses only if both default. If at least one borrower repays, the bank survives and can maintain the relation with her loyal customer. It is therefore the dominant strategy for Borrower A to always repay, and for Borrower B to repay if she is solvent. Intuitively, if repaying her loan keeps the bank afloat, the future value of the relation is always more valuable than the repayment. In the other benchmark scenario, Borrower B is in financial distress for sure, and will therefore not repay.

Borrower A will repay if the bank is strong and default if the bank is weak. With uncertainty about the bank fundamentals, defaulting is an equilibrium strategy for Borrower A if the expected value from repaying, pV , is smaller than the value of the loan, R . Intuitively, if the other borrower is in distress for sure, only a high probability p of the bank having strong fundamentals will induce the solvent borrower to repay. With low probability $p < R/V$ the expected value of the future relationship is too low compared to the immediate gain from defaulting strategically.

Scenarios of interest

We next describe the pure strategy equilibria for the four scenarios that we investigate experimentally. In Good Economy – Transparent Weakness both borrowers are solvent and everybody knows this, and the credit market is transparent, hence, both borrowers know that their bank is weak. Consequently, with one default enough to let the bank fail, borrowers' actions depend on their beliefs about the other borrower's action. This case is similar to the standard multiple equilibria bank runs model (Diamond and Dybvig, 1983). There are two pure Nash equilibria: one in which both borrowers choose to default on their loans and to keep the gross value of the repayment R , and one in which both borrowers repay and participate in the higher payoff V . The bank survives if the repayment equilibrium prevails, and fails otherwise.

In Good Economy – Uncertain Weakness the borrowers are not perfectly informed about the quality of their bank as a result of partial disclosure. With some probability p the bank has strong fundamentals and it might survive if only one loan is not repaid. On the other hand, with probability $1 - p$ the bank is weak and fails if at least one loan is not repaid. In this market, borrowers' actions depend on their beliefs about true bank fundamentals rather than only on the beliefs about the other borrower's action. For low enough probability $p < R/V$ of the bank having strong fundamentals, the multiple equilibria (repay, repay) and (default, default) obtain again.

In the Bad Economy – Transparent Weakness scenario, there is common knowledge about the bank weakness. As a result, market participants know that the bank fails if at least one loan is defaulted on. In this scenario bank failure can be caused by the financial distress of one of the borrowers, irrespective of repayment intentions. With probability $(1 - q)$ Borrower B is insolvent and forced to default, such that the bank fails. Therefore, borrowers’ actions depend not only on their beliefs about the other borrower’s action but also about their beliefs about the borrowers’ fundamentals. In particular, if the probability that the second borrower is solvent is not too low, $q > R/V$, the multiple equilibria (repay, repay) and (default, default) obtain. Note that repayment of Borrower B in the former equilibrium is conditional on her being solvent (i.e., $K_B = R$).

In the Bad Economy – Uncertain Weakness scenario both uncertainties prevail. Repayment by both borrowers, conditional on their solvency, is an equilibrium if Borrower B’s insolvency risk $(1 - q)$ is not too high or if bank fundamentals are likely to be good. Default by both borrowers is an equilibrium if, as above, the probability of strong bank fundamentals is not too high. Thus, under the joint condition $pV < R$ and $qV > R$, we obtain the multiple equilibria (repay, repay) and (default, default). We are now ready to state our main hypothesis.

HYPOTHESIS 1 (IDENTITY OF EQUILIBRIA): *For any configuration of parameters p , q , R and V satisfying simultaneously the restrictions $pV < R$ and $qV > R$, the four scenarios GE-UW, GE-TW, BE-UW, and BE-TW involve the same multiple equilibria. We therefore predict no differences in loan repayment across scenarios.*

3.3.2 Behavioral Alternative Hypotheses

Hypothesis 1 has been derived from risk neutral Nash equilibrium and provides the null hypothesis for our experimental investigation. In this section we state alternative behavioral hypotheses based on variation in payoff and risk dominance properties of the equilibria, individual risk attitudes, and negativity bias in the effect of exper-

iences.

HYPOTHESIS B1 (PAYOFF DOMINANCE): *Uncertainty affects the payoff dominance properties of the two multiple equilibria across treatments. We predict that stronger payoff dominance for the (repay, repay) equilibrium leads to more coordination on repayment.*

HYPOTHESIS B2 (RISK DOMINANCE): *Uncertainty affects the risk dominance properties of the equilibria across treatments. We predict that stronger risk dominance of the (default, default) equilibrium leads to less coordination on repayment.*

Hypothesis B1 and B2 derive from the literature on behavior in coordination games. Dominance criteria have been studied to predict actual play in situations where Nash equilibrium does not allow us to give a unique prediction (Schmidt et al. 2003, Straub 1995, van Huyck et al. 1990). Payoff dominance measures the degree that an equilibrium is more Pareto-efficient than the other equilibrium, while risk dominance measures in how far expected payoffs in an equilibrium are relatively less affected by uncertainty about the players' strategy choice than in the other equilibrium. Both risk dominance and payoff dominance are expected to increase the likelihood of an equilibrium to be selected, although the empirical evidence is stronger for risk dominance (Cabrales et al. 2000, Schmidt et al. 2003). In contrast to prior literature, in our setting the variation in payoff dominance and risk dominance emerges endogenously from differences in the uncertainty about fundamentals in the different scenarios. For our parameterization of the coordination problem, we derive rank orderings in terms of the payoff and risk dominance criteria for the strength of the repayment equilibrium, using the definitions in Schmidt et al. (2003, p.284). In Section 3.4.1 we show that the two criteria predict different orderings, allowing us to distinguish them empirically.

HYPOTHESIS B3 (LOSS AVERSION): *Individual aversion to losses influences equilibrium selection. In particular, because repayment involves the risk of losing*

all value after a default by the other borrower if the bank is weak, and defaulting guarantees the lower sure payoff, higher loss aversion is predicted to lead to a higher probability of default.

People's risk attitudes have been found to influence play in coordination games (Heinemann et al. 2009). In particular, Cachon and Camerer (1996) and Rydval and Ortmann (2005) provide evidence that aversion to downside risk and losses influences equilibrium selection in coordination games. In our setup, losses provide a relevant economic intuition for the borrowers' coordination problem also, as stated in hypothesis B3. Repayment involves the loss of the cash paid on top of the lost relational continuation value. While not normative, a potentially costly overweighting on losses in default decisions is empirically supported by recent evidence on irrational default decision in the mortgage market. Gerardi et al. (2010) found that lower numerical ability is correlated with a higher incidence of mortgage borrowers becoming delinquent. The above discussed Cohen-Cole and Morse (2009) result of liquidity preference at high economic cost can similarly be interpreted as an irrational focus on the downside.

HYPOTHESIS B4 (NEGATIVE EXPERIENCES): *Negative experiences increase the likelihood of coordination failure more strongly than positive experiences reduce this likelihood.*

The role of personal experiences in financial decisions has been shown for instance by Malmendier and Nagel (2010) for macroeconomic shocks and portfolio choices. In repeated coordination games, a convergence to the payoff dominated equilibrium, thus mutual default in our study, has often been observed (Schmidt et al. 2003, Van Huyck et al. 1990). In repeated play, participants will collect positive experiences in case of coordination success, and negative experiences in case of coordination failure and out of equilibrium play. The psychological literature suggests that the negative experiences will impact future play more strongly than positive experiences (Baumeister et al. 2001, Rozin and Royzman 2001), explaining the downward trend

in coordination observed before. We therefore hypothesize that for the borrowers' problem under uncertainty negative experience has the stronger impact.

3.4 Experimental Design and Procedures

3.4.1 The Experimental Credit Market

We study repayment decisions in the two player coordination games shown in tables 1 and 2 under the four scenarios of interest defined in Section 3.2.3. The parameterization of the games in terms of experimental units is such that $V = 55$ and $R = 40$ in all conditions. Further, under uncertainty the probabilities for strong bank and for good borrower fundamentals, respectively, are set to $p = 0.5$ and $q = 0.75$. Note that these numbers satisfy the conditions for multiplicity of equilibria shown in Table 4.

We have four treatments based on the four scenarios of interest defined by orthogonal variation in the uncertainty about borrower fundamentals, good economy (GE) vs. bad economy (BE), and about the bank fundamentals, uncertain weakness (UW) vs. transparent weakness (TW). In all treatments players made their decisions simultaneously and were informed about the implemented coordination decisions and the outcome after each round.

In GE treatments both borrowers are solvent. Their decisions will be implemented for sure. In BE treatments, one of the two borrowers, Borrower A, will be solvent for sure and the other borrower, called borrower B, will be solvent with probability 0.75. It is common knowledge among players who will be solvent for sure and who might be insolvent in a game. Both borrowers always make a repayment decision. For borrower B that decision may then not be implemented. In particular, after having made their repayment decision, borrower A's decision will always be implemented for sure while borrower B's decision will be implemented only if she is solvent. If B is insolvent, her decision will be forced to be default. From the information given

TABLE 5. PAYOFF AND RISK DOMINANCE EFFECTS OF UNCERTAIN FUNDAMENTALS

	Payoff dominance		Risk dominance	
	Level	Rank	Level	rank
GE-UW	0.27	1	1.2	1
GE-TW	0.27	1	-0.43	3
BE-UW	0.17	3	-0.19	2
BE-TW	0.03	4	-1.51	4

Note: Calculated according to Schmidt et al. (2003, p. 284)

about the decisions and the outcome it is not possible for borrower A to distinguish between strategic default by B, and a forced default because of genuine insolvency.

In TW treatments, the bank's weak status is common knowledge and the players therefore play the coordination game in Table 3 where one default is enough to let the bank fall. In UW treatments, the players know that they play either the game in Table 2 where the bank is strong or the game in Table 3 where the bank is weak. The probability of being in either game is 0.5, and this is common knowledge. After players have made their decisions, the relevant state of the world is revealed and the decisions are implemented for the selected game. Players learn the coordination decisions, the game, and the resulting outcome. Note that a repaying borrower may therefore observe a default by the other player that turned out to not affect his payoffs because the bank was strong.

As detailed in hypotheses B1 and B2, the variation in uncertainty affects the degree of risk and of payoff dominance for the repayment and the default equilibria. Table 5 shows the level of payoff dominance and the level of risk dominance of the repayment equilibrium given the experimental parameters, using the definitions in Schmidt et al. (2003). That is, both criteria measure how attractive the repayment equilibrium is relative to the defaulting equilibrium, across treatments. We always

interpret payoff and risk dominance from the viewpoint of repayment, thus larger numbers indicate a stronger criterion for the repayment equilibrium. Positive numbers indicate that the repayment equilibrium is dominant in the respective sense. For example, in treatment BE-UW, repayment is *payoff dominant*, but less so than in GE-TW ($0.27 > 0.17$). Similarly, in BE-UW repayment is risk-dominated (negative value), but less so than in GE-TW ($-0.19 > -0.43$). We say that by moving from GE-TW to BE-UW, repayment becomes more *risk dominant*. As can be seen from the table, the two criteria predict a different ordering in terms of favorability of repayment, allowing us to differentiate between hypotheses B1 and B2.

3.4.2 Elicitation of Loss Attitudes

To test hypothesis B3 we need to measure borrowers' attitudes toward losses. Various measures of risk attitude have been used in the experimental literature, but these measures usually cannot separate different factors like variance aversion or loss aversion. Recently, a choice list method has been proposed that has been interpreted in terms of loss aversion and has a high external validity, that is, successfully predicting behavior outside the experiment that involves potential losses (Fehr and Götte 2007, p. 316, Fehr et al. 2008, Gächter et al. 2007).

We elicit loss attitudes by offering subjects a series of risky lotteries that give an equal chance of either a gain or a loss in terms of experimental units. For each lottery, subjects could choose to play or not to play (see Table 6). Subjects were free to accept or reject any prospect, that is, we did not require single switching from acceptance to rejection as the loss increases along the list. They earned experimental units according to their decision in *all* six choices, depending on the outcome of the risky prospects.

For losses smaller than 45, rejecting to play the prospect implies a significant loss in expected value that may be explained more easily by a gain-loss framing and a kinked utility function of wealth changes, than by a concave utility of wealth. It

TABLE 6. CHOICE LIST MEASURE OF LOSS AVERSION

Lottery (50%–50%)	Accept to play?
Lose 5 units or win 45 units	Yes O No O
Lose 15 units or win 45 units	Yes O No O
Lose 25 units or win 45 units	Yes O No O
Lose 35 units or win 45 units	Yes O No O
Lose 45 units or win 45 units	Yes O No O
Lose 55 units or win 45 units	Yes O No O

has also been shown that the predictions of reference-dependent utility models hold mainly for people who reject many of the lotteries in this choice list (Fehr and Götte, 2007). We call subjects who reject more lotteries in this task *more loss averse*, in line with the alternative behavioral hypothesis we aim to test.⁶ Note that the payoffs in this task were similar in size to the payoffs of the coordination task.

3.4.3 Laboratory Protocol and Procedures

Computerized experiments were run with 180 undergraduate students at the University of Amsterdam, using *z-Tree* software (Fischbacher, 2007).⁷ A session consisted of two sets of five rounds of the borrowers' coordination game (part I and part II), followed by the loss aversion task. In each part, subjects were randomly matched in groups of 6 players and played five rounds of the two-person coordination game in a

⁶Keeping with the behavioral finance and games literature on which our alternative hypotheses are based, we interpret the results in terms of loss avoidance. Note, however, that an interpretation of the loss aversion results in terms of general risk aversion, and without reference to any specific psychological process, is obviously possible.

⁷Sample instructions and screenshots of the design are in the Appendix. We thank Center for Research in Experimental Economics and Political Decision-Making at University of Amsterdam (CREED) for allowing us to use their facilities.

strangers design, that is, meeting each other person exactly once. After part I was finished, subjects were reshuffled and matched in new groups of six. Within each part all subjects played the same treatment condition, and part I and II always involved different treatments as shown in Table 7. The treatment in part I of each session gives us observations that are unaffected by previous experiences (except obviously within-part experience). Part II gives us observations on behavior after a regime shift. In particular, in sessions 1 to 4 the shift was from transparent weakness to uncertain weakness of the bank, and vice versa. In sessions 5 and 6 the bank was always weak, and the shift regards the state of the economy.

Subjects received written instructions that were also read aloud to implement common knowledge. General instructions were distributed in the beginning, and for each part subjects received the specific instructions directly before the respective part (see the Appendix for details). Subjects therefore did not know about the details of the later tasks when making their decisions. Before each coordination game part, subjects received an example game situation on-screen and had to calculate the payoffs for both players to make sure that they understood the payoff structure and the effect of the uncertainties regarding bank and borrower fundamentals. Payoffs in these test questions were unrelated in size and structure to the game studied in the real task, but the game scenario was identical to the one studied in the respective part. Only after all subjects correctly calculated the payoffs did the program continue to the main task.

The experiment was framed in neutral terms. No reference to concepts like borrower or default was made to avoid any negative connotations with actions or social desirability effects that distort incentives. In each of the in total ten rounds of the experiment subjects chose between option A and option B, with A representing loan repayment and B representing default. Depending on the coordination outcome, subjects could earn between 0 and 55 experimental units in a round, and at the end of the experiment one round from each part was randomly selected for real payment

TABLE 7. SESSIONS AND TREATMENTS

Session	Treatment Part I	Treatment Part II	Number of participants (groups)
1	GE-TW	GE-UW	30 (5)
2	BE-TW	BE-UW	30 (5)
3	GE-UW	GE-TW	30 (5)
4	BE-UW	BE-TW	30 (5)
5	GE-TW	BE-TW	30 (5)
6	BE-TW	GE-TW	30 (5)

Note: All sessions were run in two groups of subjects with 12 and 18 people, respectively, due to lab size limitations.

to avoid wealth effects. In the loss aversion measurement task subjects could earn between -180 and $+270$, with extreme outcomes very unlikely. Each experimental unit translated into $\text{€}0.05$ at the end of the experiment for real payment, on top of a show up fee of $\text{€}7$. On average subjects earned $\text{€}13$ and the experiment lasted approximately one hour.

3.5 Results

We analyze the data at the group level and at the individual level. If not stated otherwise, group level analyses are based on part I choices only and all tests are two-sided.

3.5.1 Group Level Analysis

Table 8 shows coordination results at the group level. The pattern of equilibrium selection is similar if we analyze first round, last round or average repayment. GE-UW elicits higher rates of coordination than the other conditions, and BE-TW elicits

TABLE 8: FIRST ROUND, LAST ROUND, AND AVERAGE PERCENTAGE OF REPAYMENT

	First round			Last round			Average		
	UW	TW	Δ	UW	TW	Δ	UW	TW	Δ
GE	90	72	18	90	45	45*	91	60	31*
BE	80	48	32*	70	22	48**	75	32	43**
Δ	10	24*		20	23		16*	28**	

Note: *significant at 5 % level, ** significant at 1% level, Mann-Whitney U test.

the lowest rates of repayment, with the other two treatments in between. In the BE treatments these percentages do not include forced defaults by insolvent borrowers, only strategic defaults.⁸ The results show that transparency may be harmful in the current setting. Under purely strategic uncertainty, borrowers are not able to coordinate successfully on the efficient repayment Nash equilibrium. Similarly, economic uncertainty in the form of possible forced defaults by genuinely distressed borrowers increases the likelihood of coordination failure. From the game theoretic perspective, this pattern is consistent with the prediction of risk dominance, but not payoff dominance, because in BE-UW there is more repayment than in GE-TW. Clearly, hypothesis 1 of identical repayments rates is rejected by the data.

To test the overall pattern and the effect of dominance criteria and loss aversion as stated in hypotheses B1, B2 and B3, we run regression analyses on the group level using OLS on average repayment rates.⁹ Table 9 shows the results. Regression I confirms the pattern predicted by risk dominance. With GE-TW the excluded category, we find significantly more repayment in GE-UW and BE-UW and less in BE-TW, but GE-UW not significantly larger than BE-UW ($p=.177$). B1 is clearly rejected.

⁸In all analyses we only study the determinants of strategic defaults. Defaults caused by insolvent borrowers are included as experienced defaults of the other borrower, however. We do not distinguish between borrower type in the analysis, which changes between rounds. Restricting analyses to borrower A types only replicates the results.

⁹Controlling for censoring by using tobit models does not affect any results.

A loss aversion index per group was constructed by splitting the sample of elicited individual loss attitudes at the median number of loss averse choices and categorizing subjects into loss averse and not loss averse.¹⁰ We then counted the number of loss averse subjects in each group and included it as a covariate. Model I shows that each loss averse subject reduces the repayment percentage in the group by 7.4 points, supporting hypothesis B3.

Model III directly includes payoff and risk dominance given in Table 5 in the regression, confirming the observed pattern. Risk dominance and loss aversion significantly affect repayment, while payoff dominance has no influence. Models II and IV test for interactions of loss aversion with the treatment conditions and dominance criteria directly. The results show no significant treatment interactions, but risk dominance seems to be more effective for loss averse borrowers. The direct and interacted effects in model II are jointly significant for each treatment, and in model IV the direct and interacted effects of risk dominance and those of loss aversion are jointly significant, but not for payoff dominance.

Table 8 implies a deterioration of the repayment coordination in groups over time. Across all treatments repayment declines from 68% in the first to 49% in the last round ($p < 0.01$, Wilcoxon signed rank test). A fixed effects panel regression with round as the only explanatory variable shows a significant decline of 7.2 and 6.3 percentage points repayment in treatments GE-TW and BE-TW ($p < 0.01$), respectively. In the UW treatments there was no significant decline over time (0 and 4 percentage points, not significant).

Further, using the group level data from both part I and part II we can test for dynamic effects on the group level, due to regime shifts as shown in Table 7. We run a regression on repayment rates for the TW treatments including a dummy indicating whether the treatment followed after an UW treatment, controlling for

¹⁰We call a subject loss averse if she rejects more than 3 prospects. A discussion of the loss aversion results is in the Appendix. There we also show that the loss aversion measure is exogenous in the sense that loss attitudes are not driven by previous experiences in the coordination games.

TABLE 9: COORDINATION BEHAVIOR: DETERMINANTS OF REPAYMENT
(GROUP LEVEL ANALYSIS)

	I	II	III	IV
GE-UW	.306** (.091)	.051 (.185)		
BE-TW	-.279** (.080)	-.497* (.182)		
BE-UW	.213* (.077)	.146 (.177)		
# loss averse subjects In group (lasg)	-.074* (.027)	-.139* (.057)	-.056* (.027)	.123 (.080)
GE-UW×lasg		-.127 (.067)		
BE-TW×lasg		.109 (.071)		
BE-UW×lasg		-.043 (.060)		
Risk dominance			.218** (.058)	.052 (.112)
Payoff dominance			.103 (.557)	1.788 (1.189)
Risk dominance×lasg				.082* (.038)
Payoff dominance×lasg				-.833 (.425)
Constant	.747** (.096)	.878** (.166)	.790** (.124)	.425 (.225)
# Obs	30	30	30	30
R ²	.72	.76	.65	.70

Note: Dependent variable: average repayment percentage in group; robust standard errors in parenthesis; in model I and II the excluded category is the GE-TW treatment with pure strategic uncertainty; *significant at 5 % level, ** significant at 1% level

the state of the economy and loss aversion. Similarly, we run a regression for the UW treatment including a dummy indicating whether the treatment followed after an TW treatment, including the state of the economy and loss aversion. The results show that repayment rates are 27 percentage points higher in TW conditions if they follow after a UW condition ($p < 0.01$). Repayment rates are 21 percentage points lower in UW if they follow after a TW condition ($p < 0.01$). In both regressions loss aversion leads to significant reduction in repayment rates of about 7 percentage points per loss averse subject. These results suggest that past experiences influence repayment behavior, leading to effects of previous regimes after a regime shift. It is not clear from these results, however, whether negative or positive experiences cause the effect. The individual level data analysis below suggest that negative experiences (observed defaults) have stronger effects. However, these effects may be mitigated by positive experiences of strong banks.

3.5.2 Individual Level Analysis

Individual level analysis allows us to study in more detail the effects of loss aversion and experiences. Splitting the sample at the median of loss aversion, we obtain a repayment rate of 58% for the high loss aversion group and 69% for low loss aversion group ($p < 0.05$, Mann-Whitney U test), corroborating the results from the group level analysis. To test for loss aversion and experience effects we run a set of regressions on individual choices, controlling for clustering of errors within groups. We include a dummy for high loss aversion showing group differences due to loss aversion. The results are similar if we use the absolute number of loss averse choices.

Regressions I and II replicate the results for groups at the individual level. Clearly, individual level loss aversion is affecting repayment decisions, with loss averse subjects repaying 12 percentage points less often. Treatment differences can be explained by the risk dominance properties, but not by the payoff dominance properties of the repayment equilibria. Regression III studies behavior in part II, controlling for ex-

TABLE 10: REPAYMENT BEHAVIOR (INDIVIDUAL LEVEL ANALYSIS)

	I	II	III	IV
	Random effects panel, part I and II		OLS, part II	Probit, part II
GE-UW	.219** (.062)			
BE-TW	-.298** (.063)			
BE-UW	.019 (.080)			
High loss aversion	-.122** (.041)	-.119** (.040)	-.145** (.044)	-.228** (.080)
Risk dominance		.142** (.040)	.111 (.064)	.139 (.227)
Payoff dominance		.601 (.415)	.913 (.587)	-.186 (.813)
Part I defaults experienced			-.078** (.020)	-.082** (.029)
Round 1-4 defaults experienced				-.197** (.043)
Part1	.063 (.041)	.063 (.041)		
Constant	.623** (.068)	.526** (.077)	.638** (.112)	
# Obs	360	360	180	180
R ²	.29	.29	.32	.32

Note: Dependent variable: in model I to III repayment percentage over five rounds and in model IV last round repayment decision; robust standard errors in parentheses, corrected for clustering on group level; marginal effects reported for probit regression; *significant at 5 % level, ** significant at 1% level

periences in part I. While loss aversion remains a strong predictor, risk dominance becomes marginally insignificant. Part I experienced defaults by coordination partners negatively affect repayment. Each default reduces the average repayment of the individual by about 8 percentage points. Finally, regression IV considers only the last round of part II, including as an additional covariate the number of defaults experienced in part II before the last round. As before, loss aversion and negative part I experiences reduce repayment. The more recent part II negative experiences also reduce repayment, and their effect is stronger than the effect of part I experience ($p < 0.05$). At this point risk dominance does not add significantly to explain repayment probability beyond its possible effects through experiences. Note that these results remain the same if we include subjects' own first round decision as a covariate in the probit regression (not shown in the table), although the own first round repayment is clearly predictive of last round repayment.

Table 10 suggests that the effect of loss aversion increases over time, as predicted by psychological research showing that negative experiences increase the impact of loss aversion (Baumeister et al. 2001, p.326). Including separate loss aversion effects for each part in regression II as covariates, we find indeed a larger effect of loss aversion in part II, but the difference is not statistically significant ($-.09$ vs. $-.14$ in part I and II, $p = 0.384$).

While the individual data analyses show clear effects of negative experiences, the effect may also in principle be due to more repayment driven by positive experiences. We take a closer look at negative versus positive experiences by studying behavioral changes after unexpected outcomes between the first and second rounds after out-of-equilibrium play. The first round is not affected by any experiences and the second round only by one single past experience, allowing us to separate the effects of negative from positive experience. We define a *negative surprise* as a situation where the subject repaid but the coordination partner defaulted. Similarly, a *positive surprise* occurs if the subject defaulted but observed the other player repaying. Equilibrium

TABLE 11: COORDINATION BEHAVIOR: THE ROLE OF NEGATIVE VERSUS POSITIVE EXPERIENCES

	I	II
	Probit, part I	Probit, part II
Neg. surprise round 1	-.570** (.102)	-.510** (.105)
Pos. surprise round 1	.132 (.084)	.183 (.127)
Neg. surprise \times bank survives	.252 (.106)	.347** (.060)
Pos. surprise \times bank survives	.247 (.114)	-.090 (.174)
Own repayment decision round 1	.709** (.076)	.764** (.076)
Part1 defaults experienced		-.060 (.031)
# Obs	180	180
R ²	.29	.36

Note: Dependent variable: round 2 repayment. Excluded category is neutral experience. robust standard errors in parentheses, corrected for clustering on group level; marginal effects reported; *significant at 5 % level, ** significant at 1% level

play we count as neutral experience. We also include a variable that measures if the bank survived in treatments UW after a borrowers' default because of strong fundamentals. That is, the negative surprise may be mitigated because the bank did survive although there was observable coordination failure. Table 11 shows probit regressions of round 2 repayment in part I and part II. While in part I the subjects are completely inexperienced, part II is affected by part I play, for which we control.

As shown in the table, negative surprises have a strongly negative effect on subsequent behavior, reducing the probability of repayment by more than 50 percentage points. Positive surprises have no influence, however. We also find that the effect of a negative surprise can be mitigated if the bank survives after a coordination

failure because of strong fundamental. This effect is significant only for the part II data. The total effect of a negative surprise with bank survival is still negative in both regressions, but this total effect is not significantly different from zero in either regression. This suggests that bank survival can effectively eliminate the negative effect of coordination failure on future repayment behavior. The lack of a positive surprise effect explains why in the treatments with high initial repayment coordination (that is, larger than 50%), behavior does not converge towards full repayment. The minority initial negative surprises have much stronger impact than the majority positive surprises, leading to an overall demise of repayment coordination.

3.6 Discussion

Bank runs are difficult to study empirically. For depositors, a few studies have identified runs from real world micro data (Kelly and O’Grada 2000, Iyer and Puri 2009 and Saunders and Wilson 1996). Observing runs from the asset side of the bank’s balance sheet is even more difficult because of the problem of distinguishing genuine insolvency from strategic default. We therefore studied an experimental credit market that allows us to observe strategic default, varying the degree of uncertainty regarding bank and borrower fundamentals. Multiple equilibria exist in our market which are not affected by the uncertainty, but uncertainty does affect the risk and payoff dominance of the repayment equilibrium. Consistent with previous literature on coordination, we find strong effects of risk dominance but no effects of payoff dominance. Our results extend the current literature by showing how uncertainty endogenously affects these dominance criteria and thereby the coordination outcomes. We also find that in situations of strategic uncertainty, individual loss attitudes and negative experiences become relevant in repayment decisions.

We find clear evidence for strategic default. The experiment shows that disclosure of weak banks can have harmful effects on repayment in both a strong economy and

in a weak economy with a significant portion of borrowers potentially insolvent. Similarly, a weak economy always increases the incidence of strategic default. In times of financial and real crises our results suggest that only strong legal institution may overcome coordination failure. The borrower behavior observed in the U.S. mortgage market during the current financial turmoil suggest that moral constraints on defaulting, which may not be as pronounced in the laboratory, will not be strong enough to prevent strategic default (The Economist 2010, p.5, Guiso et al. 2009).

The current study complements the recent experimental literature on depositor runs. Garratt and Keiser (2009) and Madies (2006) explore the occurrence of depositor runs, while Schotter and Yorulmazer (2009) study the dynamics and severity of such events. Garratt and Keiser (2009) argue that bank runs occur mainly when fundamental withdrawal demand is stochastic. Madies (2006) finds that in the presence of healthier banks, depositor runs are less frequent, while Schotter and Yorulmazer (2009) show that withdrawal incidence is lower when bank has strong fundamentals and depositors have multiple opportunities to withdraw. These papers also suggest that in the basic pure multiple equilibria model with strategic uncertainty bank runs may be rather rare. Our results show that successful coordination is very sensitive to the risk dominance properties of the game structure. Any perturbation that affects risk dominance, such as liquidity shocks for depositors, the strength of the bank, or in our case the borrower fundamentals, is therefore likely to affect the likelihood of bank failures.

Our findings on individual level loss attitudes and negative experience effects suggest that coordination failure may be most relevant in markets with small individual borrowers such as mortgage markets and retail loans. On the other hand, the events surrounding recent large scale bank failures show that repayment to a falling bank can also permanently destroy the reputation of an institution and its management. As such, incentive structures for management may induce loss aversion in the sense of an increased weight on the available cash than on the more distant and uncer-

tain outcomes if the relation with their bank is maintained. Negative experiences are important in financial decisions as shown by Malmendier and Nagel (2010). In their study, people who have experienced inflationary periods are less likely to hold assets sensitive to inflation such as bonds. Similarly, Guiso et al. (2009) find that people who know or hear about other people defaulting strategically are more likely to do so as well. They identify these social experiences as one of the main factors in predicting the incidence of strategic default. Interestingly, we find that bank survival can mitigate the effect of negative experiences. Model II in Table 11 suggests that borrowers are more likely to repay their loans after experiencing a defaulting borrower if the bank does not fall. In a larger context, government support may prevent bank collapse from materializing.

Runs on individual banks from either the borrower or depositors side are economically harmful, but of the real concern are systemic crises. Uncertainty about the nature of a run may lead to contagion of otherwise stable banks which may trigger a system-wide collapse or panic. If one bank goes bankrupt, borrowers and deposit holders may interpret this event as a signal for the existence of solvency problems in the entire financial sector and react by delaying the repayments of their loans or massive withdrawal of funds, respectively. Our findings suggest that in the credit market, similarly to the depositors market, there is the risk of contagion. Past experience is relevant in reality because it can be one of those factors driving the systemic risk. People who have experienced directly bank failures or who have learned about strategic default of others are more likely to stop repaying if they hear bad news about their bank. Kelly and O'Grada (2000) and Iyer and Puri (2009) documented the occurrence of pure-panic contagion for depositor market.

The recent financial crisis of 2007-2010 has shown the limits of market discipline, and consequently, there are many initiatives that promote more disclosure and transparency by banks. Proponents of such initiatives argue that more information about bank fundamentals enhances investors' assessment of bank activities and im-

proves market discipline (Baumann and Nier 2003, Bliss and Flannery 2000). On the other hand, the opposing view suggests that too much disclosure of information about bank's fundamentals may increase the probability of failure. Public confidence is crucial for the banking sector. Once the trust in the financial sector is lost banks can be subject to runs or panics which affect the entire banking sector. Our study helps to evaluate the effects of such regulatory policies on bank stability. The results support the latter view, by showing that borrowers may not be able to overcome coordination problems if banks are transparently weak. Moreover, if disclosure rules are strengthened during time of widespread banking weakness, more bad information may be revealed to market participants. Non-repayment rates will increase because borrowers have already accumulated negative experiences regarding bank failures, so they are more likely to default, exacerbating the problems in the banking system. Thus, we may argue that disclosure requirements should not become stricter during ongoing banking crises or immediately after. Similarly, experiences accumulated during a banking crisis may reduce any positive effect following the softening of disclosure rules, and such regulatory changes may therefore not lead to fast improvements in bank stability. These effects should be considered in the evaluation of the two opposing policies, particularly in time of distress. The current findings provide a rationale for central banks' interventions as lender of last resort. The large scale intervention of financial authorities during the recent financial turmoil led to immense liquidity support for banks and this support has helped most of them to avoid failure, and thus helped to regain the stability of the banking system. Beside other potential positive effects not discussed here, it has allowed banks to maintain the relation with their customers and to perform normal lending activities. Keeping banks afloat, such interventions have also mitigated the impact of negative experiences market participants had, reducing the problems of strategic delay or default of borrowers.

3.7 Concluding Remarks

We identify strategic defaults in credit markets experimentally and study the effect of uncertain bank and borrower fundamentals. Borrowing from the behavioral literature on coordination games we identify concepts that explain the observed variation in repayment. In our study the bank's fundamentals were defined exogenously to maximize control and obtain unambiguous effects on borrower behavior. Future research may take a closer look at the supply side of the market, studying how disclosure rules and business cycle affect banks' lending behavior.

The current results confirmed a role for contagion in coordination problems as suggested in real world data. For regulatory policy it is crucial to identify the conditions under which contagion occurs and how it can be avoided. Experimental control along the lines applied in the current paper may be used to implement various market conditions and lay bare its effects on behavioral contagion in credit or depositor markets.

3.A Derivation of Equilibria

3.A.1 Pure Strategy Equilibria

GE-TW (Repay, repay) and (default, default) are obvious equilibria. (Default, repay) and (repay, default) cannot form equilibria because the repaying borrower strictly prefers to deviate to default.

GE-UW (Repay, repay) is an obvious equilibrium. (Default, default) forms an equilibrium if and only if the probability of strong bank fundamentals is not too high. A borrower's expected payoff from deviating to repayment is pV , thus implying the condition $pV < R$. If $pV < R$, (default, repay) and (repay, default) cannot form equilibria because the repaying borrower strictly prefers to deviate to default.

BE-TW (Default, default) is an obvious equilibrium. (Repay, repay) forms an equilibrium if and only if the probability of a solvent borrower B is not too low. A borrower's expected payoff from repayment is qV , thus implying the condition $qV > R$. (Default, repay) and (repay, default) cannot form equilibria because the repaying borrower strictly prefers to deviate to default.

BE-UW (Repay, repay) forms an equilibrium if and only if the probability of a solvent borrower B is not too low or the probability of the bank being strong is high. A borrower's expected payoff from repayment is $(qp + q(1 - p) + (1 - q)p)V$, thus implying the condition $(q + p - pq)V > R$. In particular, if p is small $qV > R$ is sufficient, and if q is small, $pV > R$ is sufficient for repayment being an equilibrium. A necessary and sufficient condition for the (default, default) equilibrium is that $pV < R$. If these conditions hold, (default, repay) and (repay, default) cannot form equilibria because the repaying borrower strictly prefers to deviate to default.

3.A.2 Mixed Strategy Equilibria

We first derive the mixed equilibria and then show that it is unlikely that subjects in the experiment played these equilibria.

GE-TW A mixed strategy for borrower B is the probability distribution $(s, 1 - s)$, where s is the probability of playing repay, $1 - s$ is the probability of playing default, and $0 \leq s \leq 1$. Suppose that borrower A plays repay with probability t and default with probability $1 - t$, where $0 \leq t \leq 1$. Then borrower B's expected payoff from playing repay is tV and her expected payoff from playing default is R (the coordination game is depicted in Table 3). Expected payoffs are equal for $t = R/V$. By a similar argument, we find that borrower's B probability of playing repay must be $s = R/V$, such that borrower A is indifferent between repay and default. Each borrower repaying with probability R/V is a mixed Nash equilibrium. For our parametrization this implies a probability of repay of 0.73.

GE-UW The type of bank is drawn randomly in this treatment, and can be either strong (with probability p) or weak (with probability $1 - p$). The coordination games are depicted in Tables 2 and 3. A mixed strategy for borrower B is the probability distribution $(s, 1 - s)$, where s is the probability of repaying, $1 - s$ is the probability of defaulting, and $0 \leq s \leq 1$. Suppose that borrower A plays repay with probability t and default with probability $1 - t$, where $0 \leq t \leq 1$. Then borrower B's expected payoff from playing repay is $tV + (1 - t)pV$ and her expected payoff from playing default is R . Expected payoffs are equal for $t = \frac{R-p}{1-p}$. By symmetry, we find that borrower B's probability of playing repay must be $s = \frac{R-p}{1-p}$, such that A is indifferent. If the probability of strong bank fundamentals is too high (i.e., $p > R/V$), then $t = s = 1$ and (repay, repay) is the dominant strategy. Otherwise, each borrower repaying with probability $\frac{R-p}{1-p}$ is a mixed Nash equilibrium. For our parametrization this implies a probability of repay of 0.46.

BE-TW The type of borrower B is drawn randomly in this treatment. She can have either good fundamentals (with probability q), or bad fundamentals (with probability $1 - q$). The coordination game for the case of solvent borrower B is depicted in Table 3. If borrower B turns out to be insolvent, borrower A will get either 0 or R , depending if she repays or not. A mixed strategy for a solvent borrower B is the probability distribution $(s, 1 - s)$ as above. Borrower A repays with probability t and defaults with probability $1 - t$. Borrower B expected payoff from repaying is tV and her expected payoff from playing default is R . Expected payoffs are equal for $t = R/V$. By a similar argument, borrower A's expected payoff from playing repay is qsV and her expected payoff from playing default is R . Hence, the probability of repay must be $s = R/qV$, implying indifference between repay and default. If the probability of a solvent borrower B is too low (i.e., $q < R/V$), then $t = s = 0$ and (default, default) is the dominant strategy. Otherwise, borrower B repaying with probability R/qV and a solvent borrower A repaying with probability R/V is a mixed Nash equilibrium. For our parametrization this implies borrower B repaying with probability 0.97, and borrower A repaying with probability 0.73.

BE-UW For this treatment the type of bank is drawn randomly and can be either strong (with probability p) or weak (with probability $1 - p$), and also borrower B's type is drawn randomly such that she can have either good fundamentals (with probability q), or bad fundamentals (with probability $1 - q$). The coordination games for the case of solvent borrower B are depicted in Tables 2 and 3. If borrower B turns out to be insolvent, borrower A will get an expected payoff of either pV or R , depending on whether she repays or not. A mixed strategy for a solvent borrower B is the probability distribution $(s, 1 - s)$ as above. Borrower A repays with probability t and defaults with probability $1 - t$. Borrower B' expected payoff from repaying is $tV + (1 - t)pV$ and her expected payoff from playing default is R . Expected payoffs are equal for $t = \frac{R - pV}{1 - p}$. By a similar argument, borrower A's

TABLE A1: MIXED EQUILIBRIUM VERSUS OBSERVED PERCENTAGE OF REPAYMENT

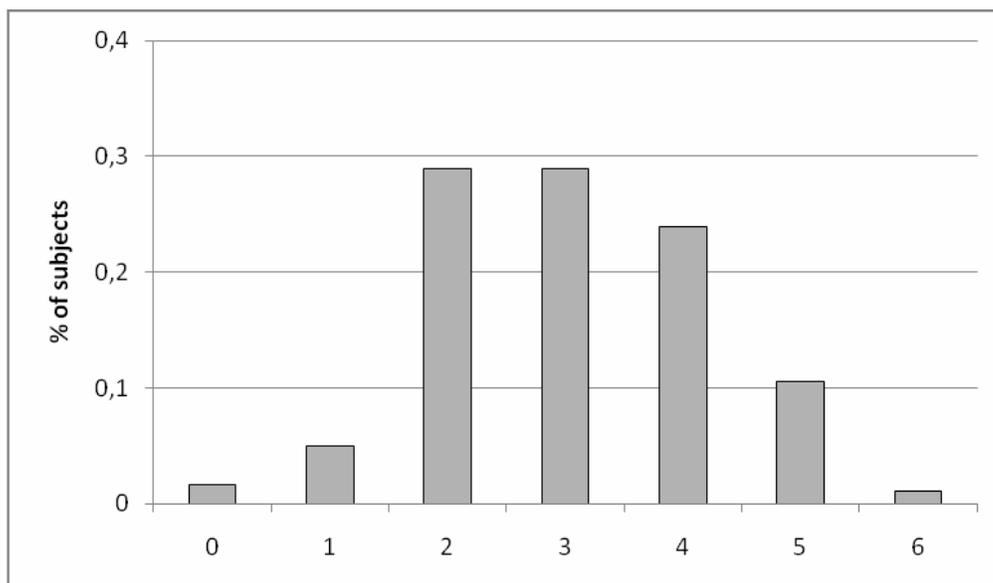
	Mixed equilibrium			Observed average		
	UW	TW	Δ	UW	TW	Δ
GE	46	73	-27	91	60	31*
BE	53.5	85	-31.5	75	32	43**
Δ	-7.5	-12		16*	28**	

Note: average of player A and B used in left panel; *significant at 5 % level, ** significant at 1% level, Mann-Whitney U test.

expected payoff from repaying is $qsV + q(1-s)pV + (1-q)pV$ and her expected payoff from defaulting is R . Hence, the probability of B repaying must be $s = \frac{\frac{R}{V}-p}{q-pq}$ such that A is indifferent. If the probability of strong bank fundamentals is too high (i.e., $p > R/V$), then $t = s = 1$ and (repay, repay) is always the dominant strategy if B is solvent. If the probability of a solvent borrower B is too low (i.e., $q < R/V$), then $t = s = 0$ and (default, default) is the dominant strategy if $p < R/V$. Otherwise, when conditions $p < R/V$ and $q > R/V$ are jointly satisfied, borrower A repaying with probability $\frac{\frac{R}{V}-p}{1-p}$ and a solvent borrower B repaying with probability $\frac{\frac{R}{V}-p}{q-pq}$ is a mixed Nash equilibrium. For our parametrization this implies borrower A repaying with 0.46 probability, and borrower B playing repay with 0.61 probability.

Mixed equilibrium versus observed behavior Table A1 summarizes the mixed equilibrium predictions for repayment across treatments and also replicates the observed average percentages of repayment. Observed repayment percentages are not well described by the predicted mixing. Our statistical tests (see Section 3.5) between treatments clearly reject mixed equilibrium, with all differences pointing in the wrong direction. This result is consistent with findings in Heinemann et al. (2009) on the poor predictive power of mixed equilibrium in coordination games.

FIGURE B1: DISTRIBUTION OF LOSS AVERSE CHOICES



Note: six choices made by subjects between safe option and risky option involving gains and losses.

3.B Loss Aversion Results

The loss aversion task resulted in an index of loss averse (safe) choices between 0 and 6. The median loss aversion was 3 and the mean was 3.04. The distribution is shown in Table B1.

In the regression analysis of repayment behavior we include loss aversion as an explanatory variable. To test if loss aversion is not affected by previous game play, we use the exogenous variation in treatment to test for the endogeneity of loss attitude. In particular, treatments with bad economy involve more defaults beyond the influence of the subjects. Comparing loss attitude of subjects participating in BE only with those participating in GE only, we find no differences (mean 3 vs. mean 3.18, $p = .389$, Mann-Whitney-U test). Similarly, comparison between the BE-TW condition with least coordination and the GE-UW treatment with most repayment yields no significant differences (mean 3 vs. mean 3.22, $p = .479$, Mann-Whitney-U

test). These findings support the assumption that our loss aversion task measures an individual preference parameter that is not affected by the preceding coordination game.

3.C Sample Instructions

General Instructions

This is an experiment about decision-making. If you follow these instructions carefully and make good decisions you can earn a considerable amount of money, which will be paid to you at the end of this experiment in cash. The duration of the experiment will be maximum 80 minutes. During the entire experiment, communication of any kind is strictly prohibited. Communication with other participants will lead to your exclusion from the experiment and the forfeit of all your monetary earnings. Please put your mobile phone away.

All your decisions and answers to questions remain anonymous. At the end of the experiment we will pay you in private.

The experiment consists of **three parts**. Each part will consist of several choices between two or more options. Detailed instructions for Part I follow. After Part I has been completed you will receive instructions for the second part. After Part II is completed you will receive instructions for the third part.

You will first make all choices in all three parts. The first two parts consist of 5 rounds each, while the third part consists of only one round. There are 11 rounds in total. During the first two parts, your choices and the choices of other participants will determine how much your earnings are for each round. For the third part of the experiment, your earnings are based on your own choices only.

After you made all choices in all rounds, your payoff for the experiment is computed as follows:

One round from Part I and one round from Part II will be selected ran-

domly with equal probability out of the five rounds in each part to be payoff relevant. Your earnings from these part completely depend on the results of these selected rounds therefore.

Note: each **of your choices can be the one that is determining the total payoff for each part**: you should therefore make sure that in each choice during the experiment you make a decision that is in your best interest. For every participant the payoff relevant rounds are determined randomly by the computer independently of the other participants.

In Part III, **all the choices** you make are payoff relevant.

Your payoff for the entire experiment will be equal to the sum of show-up fee, your earnings in the randomly chosen rounds from Part I and Part II, and your earnings from Part III.

In each round, your earnings will be denoted in experimental units. At the end of the experiment, all experimental units that you have gained will be transferred into Euro. The exchange rate will be:

$$1 \text{ Experimental unit} = 0.05 \text{ Euro}$$

For each choice you have a certain amount of time only. Make sure you always choose one of the available Options before time runs out.

After each decision that you make in the experiment you will receive information about the result, and you may take notes of the results during the experiment.

If you have any questions during the experiment or any difficulties in understanding these instructions, please raise your hand and wait for an experimenter to come to your cubicle and answer your question privately.

After reading the instructions for Part I we will start with 2 unpaid warm up rounds that test your understanding of the decision situation. Similarly, before Part II we will have two unpaid warm up and test rounds. *No experimental units can be earned during these rounds.*

Instructions Part I

In this part of the experiment you are randomly assigned to a group of 6 people who will be in your group for the entire 5 rounds of this part. In each of the 5 rounds participants in a group are matched in pairs of 2. Hence there are 3 pairs in each group, for each round. Each pair will play a game which is described below. New pairs of 2 players are formed every round from the 6 people forming a group. You are matched with a **different person** from your group in each round, and you will meet each other member of your group **only exactly once**. You will not learn with whom you are matched.

You will make 1 decision in each of the 5 rounds. You have to choose between two options A and B which pay some amount of experimental units depending on your own choice and the choice of the other player you were matched with. Each round is independent of the other rounds, and the choice you make in a particular round has no influence on other rounds.

At the beginning of each round, a screen similar to the one depicted below will appear.

<screenshot shown here>

On the screen there will be two **payoff matrices**:

The **left matrix shows your payoffs**, and the **right matrix shows the other persons' payoff**.

As you see in the screen shot, your choice between A and B influences the potential payoffs that you and the other person can obtain. The payoffs do also depend on the choice of the other person. Both of you choose **simultaneously** between the two options A and B, that is, none of the players in a matched pair knows the choice of the other player before he makes his own choice. The combination of your choices determines your payoffs as shown in the matrices.

In the example provided, if you choose A and the other player chooses B, you

will earn 80 experimental units and the other player will earn 90 units. The other outcomes are determined accordingly.

To make a choice between option A and B you have to click the option you want to choose in the lower middle of the screen and then click the SUBMIT button to confirm. Only after the “Submit” button is clicked your choice is registered by the computer!

The screen also shows the round number and the time left for the decision.

After all players have made a decision the payoffs are calculated according to the choices made and the results are shown on the screen. In particular, you will be informed about the other player’s decision and your payoff from this round.

Remember that only one round from each part is paid for real. That is, **the payoff from any round may be the one that completely determines your total profit from this part, whether high or low, conditional on this round being selected for real pay later on.** That also means that you do not accumulate earnings: having made some profit in one round does not mean you necessarily can take this profit home. Another round may be selected for pay.

After you have read the results, please click the READY button to continue to the next round. Only after the “Ready” button is clicked the next round will start!

All the participants in this experiment will see the same screens and share the same information.

You will be informed when this part of the experiment ends but you will not be informed about how many experimental units you have earned in this part. The earnings will be determined after all three parts have been played.

Please remember that any communication between participants is strictly prohibited during the experiment.

Instructions Part II [distributed after part I was finished]

In this part you are randomly assigned to a **new** group of 6 people as described in Part I. You will play again 5 rounds, each round with a different person from your group, and meet each person only exactly once. The people in your group will be different from the people in Part I.

The game you play in each of these rounds is similar to the one in Part I: your decision and the decision of the other player between two options A and B jointly determine the outcomes for both of you. Again, you have to make your decisions simultaneously. Your payoffs will be shown in matrices on the left side of the screen, and the other player's payoff will be shown in the matrix on the right side of the screen.

In this part, however, you **will not know for sure the game you will play**. In particular, you will be presented with **two games, each of which has a 50% chance to be the one you actually play**. Only after both players made their choice will you learn which game was the one that was played.

The following screen shot shows a typical decision situation:

<screenshot shown here>

The basic structure is identical to that in Part I. Now, however, you see one game, Game 1, in the **upper part** of the screen, and the other game, Game 2, in the **lower part** of the screen.

Each of these two games has an equal chance to be the payoff relevant game, **but only after your decision** between options A and B **will you learn which game was played**.

Note that in each of the 5 rounds the payoff relevant game is randomly determined anew.

Note that while the upper game matrices show game 1 and the lower matrices show game 2, left matrices always represent your earnings, and right matrices rep-

resent the other player's earnings, as in Part I.

In the example provided, imagine you choose A and the other player chooses B.

If Game 1 is randomly selected to be played, then you win 110 and the other player wins 80.

If Game 2 is randomly selected to be played, then you win 80 and the other player wins 90.

For other combinations of choices the payoffs are determined accordingly.

Note again: you make your decision simultaneously with the other person, and before learning which game will actually be played.

After all players made their decisions, you will learn the results of the round. In particular, you receive information about the other player's choice, the game that was relevant, and your earnings (conditional on this round being selected for real pay later on).

Again, only one round will be selected to completely determine your payoff for this part.

Instructions Part III. Risky Decisions

In this part of the experiment we offer you to participate in any number out of six risky lotteries. Each lottery gives a 50-50 chance to either **win** a certain amount of experimental units or **lose** a certain amount of experiment units.

For each lottery you must decide **if you want to play it or not**.

- For each lottery that you decide to play, your current level will be increased or decreased according to the random outcome of the lottery.

- If you do not play in any lottery, your current level of experimental units earned in the first two parts of the experiment, will not be affected.

The random outcomes of all six lotteries are drawn by the computer, for each lottery an independent draw is made.

Note that **all** lotteries that you decide to play will be payoff relevant: for each lottery your gain or loss will be determined, and the total sum of these outcomes will be subtracted or added to your experimental units.

Note also that if you choose to play very risky lotteries **you may lose all of your experimental units and even your show-up fee (partially or totally)**. You do not have to play any lotteries if you do not want to.

3.D Screenshots

Screenshot for the GE-TW treatment.

Remaining time (sec): 81

Period 1

Your earnings are given by:

	Other picks A	Other picks B
You pick A	55	0
You pick B	40	40

The other player's earnings are given by:

	Other picks A	Other picks B
You pick A	55	40
You pick B	0	40

Which option do you choose: A B

Submit

Screenshot for the BE-UW treatment (Borrower B).

Remaining time (sec): 07

Period 1

Your choice will be implemented with 75% probability,
 - with 25% probability alternative B will be implemented whatever you choose,
 The other player's choice will be implemented for sure BUT he knows about your situation and the above probabilities.

With 50% probability you are in Game 1

Your earnings are given by:

	Other picks A	Other picks B
You pick A	55	55
You pick B	40	40

The other player's earnings are given by:

	Other picks A	Other picks B
You pick A	55	40
You pick B	55	40

With 50% probability you are in Game 2

Your earnings are given by:

	Other picks A	Other picks B
You pick A	55	0
You pick B	40	40

The other player's earnings are given by:

	Other picks A	Other picks B
You pick A	55	40
You pick B	0	40

Which option do you choose: A B

Submit

Chapter 4

Capital Regulation and Tail Risks

4.1 Introduction

The policy debate on financial reform in the wake of the 2007-2008 crisis has focused on raising capital ratios of financial intermediaries. The recently adopted Basel III rules double the minimal capital ratio and, beyond that, create incentives for banks to hold excess capital in the form of conservation and countercyclical buffers (BIS, 2010). This complements moral suasion and individual targets, traditionally used by regulators to assure that banks have capital cushions above the regulatory minimum.

There are two key arguments in favor of higher capital. First is the classic notion that capital is a buffer that reduces the risk of insolvency. It also helps to reduce some systemic risk factors, such as uncertainty over counterparty risk, which had a devastating propagation effect during the recent crisis. Second is a more sophisticated argument that capital is not just a buffer, but has incentive effects. Higher capital increases shareholders' losses in bank failure, and hence reduces their incentives to take excessive risk (Jensen and Meckling, 1976, Holmstrom and Tirole, 1997).

Yet one of the lessons from the crisis is that banks are exposed to tail risks which, when realized, may trigger losses in excess of almost any plausible value of initial capital. Such risks can result from the reliance on wholesale funding (the

freeze of which forced massive distress liquidation, Gorton, 2010), the underwriting of AIG-type contingent liabilities likely to be called during market panic, exposures to highly-rated senior structured debt standing to lose value in periods of extreme economic stress (Acharya and Richardson, 2009), as well as undiversified leveraged exposures to inflated housing markets (Shin, 2009).

Since tail risks can wipe out almost any initial capital, it is unclear whether traditional capital regulation is effective in addressing it. The aim of this paper is to shed light on the subject. Specifically, we focus on the relationship between bank capital and risk-taking, in the presence of tail risk projects. We show that this relationship may take unintuitive forms, with bank risk-taking being non-linear and possibly increasing in capital.

The argument is that while higher capital reduces risk-taking incentives caused by limited liability, in banks this may be dominated by an important opposite effect. Higher capital increases the distance to the minimal capital ratio, allowing the bank to take more risk without the fear of breaching regulatory requirements in case of a mildly negative project realization. If the second, excess capital-driven effect is stronger than the limited liability effect, the bank will respond to higher capital by taking more risk.

Of course, when all negative project realizations are contained by the bank's capital buffer, any additional risk-taking is fully internalized by the bank, and therefore happens only when economically efficient. However in the presence of tail risks, when high capital ratios by themselves cannot insure against all losses, a highly capitalized bank may start taking a socially excessive level of risk. Recall, excessive risk-taking will not be present in banks with lower capital. Thus, under tail risks, inefficient risk-taking may increase in bank capital. This result is consistent with the stylized fact that U.S. banks were well capitalized pre-crisis (Berger et al., 2008), yet they took significant bets on house prices and on mortgage derivatives. We show that well-capitalized banks' incentives for taking tail risks are increased in the extremeness of

that tail risk – the availability of projects with heavier left tails.

The results have a number of implications for the optimal design of capital regulation. First, they caution on limits to the effectiveness of capital buffers in dealing with bank risk, particularly when capital comes in unencumbered (excess; free to put to risk) form. Second, the results suggest that the penalties for breaching conservation and countercyclical buffers of Basel III should be significant enough to avoid the highlighted ‘excess capital’ effects. Finally, the results shed light on the link between financial innovation and regulation. With the advent of structured debt and debt derivatives, and with the development of the wholesale business model, banks gained easier-than-before access to tail risk projects. This broke the established relationship between capital and risk-taking, and compromised the effectiveness of traditional capital regulation. The results therefore support the view that dealing with tail risks requires new regulatory tools (e.g., macro-prudential measures that address systemic risk and negative spirals, see Acharya et al., 2010, Acharya and Yorulmazer, 2007, Brunnermeier and Pedersen, 2008, and Perotti and Suarez, 2010).

The paper has two key contributions to the banking literature. First, we formalize a novel channel of bank risk-taking, based on incentives to put to risk excess capital. Second, we show that bank risk-taking may be increasing in bank capital, specifically when the bank has access to tail risk projects.

Our analysis is related to several strands of the literature on capital regulation. Earlier studies of unintended effects of bank capital regulation (Kahane 1977, Kim and Santomero 1988, Koehn and Santomero 1980) were motivated by the idea of banks as risk-averse portfolio managers, who act as price takers when choosing the composition of their assets (and liabilities) portfolio. By taking this portfolio optimization approach, these studies show how capital requirements can lead to an increase in risk of the risky part of the bank’s portfolio, and hence an overall higher bank’s default probability (even if the relative size of the risky part with respect to the overall portfolio decreases). The main critique of the mean-variance model em-

ployed by these earlier studies is the absence of limited liability in bank's objective function. Once this limited liability is taken into account, capital regulation in form of minimum capital requirements is shown to have a beneficial effect in preventing bank's risk-taking incentives (Keeley and Furlong, 1990, Rochet 1992).

Later studies examine incentive effects. Boot and Greenbaum (1993) show that capital requirements can negatively affect assets quality due to a reduction in monitoring incentives. Flannery (1989) argues that capital adequacy requirements lead banks to prefer risky portfolio returns, with only insured banks having a rational preference for safe individual loans. Blum (1999), Caminal and Matutes (2002) and Hellman et al. (2000) suggest that higher capital can lead banks to take more risk as they attempt to compensate for its cost. The empirical evidence on whether capital requirements are efficient tools for limiting bank risk-taking is ambiguous. Basel Committee on Banking Supervision (1999) survey finds the evidence on the effects of capital requirements as being inconclusive. On the other hand, Bichsel and Blum (2004) and Angora, Distinguin and Rugemintwari (2009) provide empirical support by finding a positive correlation between levels of capital and bank risk-taking. Our paper follows this literature, with a distinct and contemporary focus on tail risks¹ and the dangers of non-binding capital.

Finally, Repullo and Suarez (2009), Peura and Keppo (2006) and Zhu (2008) explore the economic role of capital over the business cycle, highlighting that banks build up excess capital in booms and rapidly lose it in busts, possibly as a result of significant risk-taking. Ayuso, Perez and Saurina (2004) provide empirical evidence using a sample of Spanish banks on the negative correlation between business cycle and capital buffers.

The rest of the chapter is structured as follows. Section 4.2 outlines the theoretical

¹Recent studies develop different measures for banks' tail risks. Acharya and Richardson (2009), Adrian and Brunnermeier (2009), and De Jonghe (2009) compute realized tail risks exposure over a certain period by using historical evidence of tail risks events, while Knaup and Wagner (2010) propose a forward-looking measure for bank tail risks.

model. Sections 4.3 and 4.4 solve it and offer the key result that bank risk-taking may be increasing in capital when bank has access to tail risk projects. Section 4.5 discusses the comparative statics, policy implications and alternative model's specifications. Section 4.6 concludes. The proofs are in the Appendix.

4.2 The Model

The model has three main ingredients. First, the bank is run by an owner-manager (hereafter, the banker) with limited liability, who can opportunistically engage in asset substitution. Second, the bank operates in a prudential framework based on a minimal capital ratio, where a capital adjustment cost is imposed upon the breach of the minimal ratio. Finally, the bank has access to tail risk projects. Such a setup is a stylized representation of the key relevant features of the actual banking system. There are three dates $(0, \frac{1}{2}, 1)$, no discounting, and everyone is risk-neutral.

The bank

At date 0, the bank is endowed with capital C and deposits D . For convenience, we normalize $C + D = 1$. Deposits are fully insured at no cost to the bank; they carry a 0 interest rate and need to be repaid at date 1.

The bank has access to two alternative investment projects. Both require an outlay of 1 at date 0 (all resources available to the bank), and produce return at date 1. The return of the *safe* project is certain: $R_S > 1$. The return of the *risky* project is probabilistic: high, $R_H > R_S$, with probability p ; low, $0 < R_L < 1$, with probability $1 - p - \mu$; or extremely low, $R_0 = 0$, with probability μ . We consider the risky project with three outcomes in order to capture both the second (variance) and the third (skewness, or "left tail", driven by the R_0 realization) moments of the project's payoff.

In the spirit of asset substitution literature, we assume that the net present value

(NPV) of the safe project is higher than that of the risky project:

$$R_S > pR_H + (1 - p - \mu)R_L, \quad (4.1)$$

and yet the return on the safe asset, R_S , is not as high as to make the banker always prefer the safe project regardless the level of initial capital:

$$R_S < pR_H + (1 - p). \quad (4.2)$$

Inequality (4.2) is equivalent to $R_S - 1 < p(R_H - 1)$, where the left-hand side is the banker's expected payoff from investing in the safe project, and the right-hand side is the expected payoff from shifting to the risky project, conditional on bank having no capital (i.e., $C = 0$). The economic intuition is as follows. When the return on the safe project is too high, bank risk-taking incentives are mitigated at any level of initial capital, since the bank is better off selecting the safe project even when it is financed only with deposits (i.e., $D = 1$). In the Appendix we show that when assumption (4.2) is relaxed, the bank selects the safe project for any level of initial capital.

We consequently study conditions under which the bank's leverage creates incentives for it to opportunistically choose the suboptimal, risky project.

The bank's project choice is unobservable and unverifiable. However, the return of the project chosen by the bank becomes observable and verifiable before final returns realize, at date $\frac{1}{2}$.² This enables the regulator to undertake corrective action if the bank is undercapitalized.

²The fact that project choice is unobservable while project returns are, is a standard approach to modelling (Hellman et al., 2000, Rochet, 2004).

Capital Regulation

Capital regulation is based on the minimal capital (leverage) ratio, a key feature of Basel regulation. We take the presence of a minimal ratio as exogenous.

At each point in time, the bank's capital ratio is defined as $(A - D)/A$, where A is the value of bank assets, D is the face value of debt, and $A - D$ is economic capital. At date 0, before the investment is undertaken, the bank's capital ratio is therefore $c = C/(C + D) = C$. At dates $\frac{1}{2}$ and 1 the bank's capital ratio is $c_i = (R_i - D)/R_i$, where $i \in \{S, H, L, 0\}$. The fact that the date $\frac{1}{2}$ capital position is defined in a forward-looking way is consistent with the practice of banks recognizing known future gains or losses.

The bank is subject to a minimal capital ratio: at any point in time, the ratio must exceed c_{\min} . We assume that the minimal ratio is satisfied at date 0: $c > c_{\min}$. Note that, consequently, the minimal ratio is also satisfied for realizations R_S (when the bank chooses the safe project) and R_H (when the bank chooses the risky project and is successful): $c_H > c_S > c > c_{\min}$, since $R_H > R_S > 1$. The minimal capital ratio is never satisfied for R_0 (in the extreme low outcome of the risky project), since the bank's capital is negative, $c_0 = -\infty < 0 < c$. The banks' capital sufficiency under a low realization of the risky project R_L is ambiguous. As we will observe below, depending on the bank's initial capital, it can be either positive and sufficient, $c_L > c_{\min}$, or positive but insufficient, $0 < c_L < c_{\min}$, or negative, $c_L < 0$.

The bank's capital ratio becomes known at date $\frac{1}{2}$, as it is derived from information on future returns that becomes available at that time. If the bank capital does not satisfy the minimal capital ratio — under R_0 and possibly R_L realizations of the risky project — the regulator imposes a corrective action on the bank. Specifically, the banker is given two options. One is to surrender the bank to the regulator. Then, banker's stake (equity value) is wiped out and the banker receives a zero payoff. Alternatively, the bank may attract additional capital to bring its capital ratio to the regulatory minimum, c_{\min} . Attracting additional capital is costly. In the main setup,

we use a fixed cost of recapitalization, denoted T . In Section 4.5 we discuss a more general specification of such cost, and find that it does not affect qualitatively the results. The capital adjustment cost imposed on a bank in breach of the minimal capital ratio is the key ingredient of the model. This cost is effectively a penalty on risk-taking (as opposed to the risk-taking subsidy offered by limited liability), binding for marginally capitalized banks.

In the main setup we also abstract from the continuation value of the bank's activity (i.e., charter value) and consider that the bank is closed at date 1. As a result, the rational banker is concerned only about her short term profits since she is the only claimant of any excess returns generated by the investment projects. We address the impact of charter value on bank risk-taking in Section 4.5.

Timeline

The model outcomes and the sequence of events are depicted in Figure 1.

4.3 Bank Payoffs and Recapitalization Decision

We consider in this section the bank's payoffs, depending on its project choice, on initial capital ratio c , and, if appropriate, on recapitalization decision at date $\frac{1}{2}$. Since we are primarily interested in the positive analysis of banking regulation, we take c_{\min} as exogenous, with $c_{\min} > 0$.

With the safe project, the bank always has sufficient capital: since $R_S > 1$, $c_S > c > c_{\min}$. The banker's payoff after repaying depositors is $\Pi_S = R_S - D = R_S - (1 - c)$.

The banker's payoff to the risky project is more complex. We start with two simpler outcomes. With probability p , the risky project returns a high payoff, R_H . The bank has sufficient capital: since $R_H > 1$, $c_H > c > c_{\min}$. The banker repays depositors and obtains $\Pi_H = R_H - D = R_H - (1 - c)$. With probability μ , the risky project returns $R_0 = 0$. The bank is worthless, and the banker gets a 0 payoff.

With probability $1 - p - \mu$ the bank obtains a low return, R_L . This case requires a more detailed analysis, because depending on the relative values of c and R_L , the bank may have three capital positions: positive and sufficient, positive but insufficient, or negative. If the bank's capital falls below the minimal value, the banker will have to either attract additional capital at a cost, or surrender the bank to the regulator. The capital falls below the regulatory minimum, $c_L < c_{\min}$, whenever project returns R_L fall below a threshold R_{\min} , where

$$R_{\min} = \frac{1 - c}{1 - c_{\min}}. \quad (4.3)$$

The above threshold is derived from the condition of a minimal capital ratio of c_{\min} (i.e., $c_{\min} = (R_{\min} - D)/R_{\min}$), by solving for the value of bank's assets (i.e., R_{\min}), subject to balance sheet identity (i.e., $D = 1 - c$).

Therefore, the bank has positive and sufficient capital $c_L > c_{\min}$ when $R_L > R_{\min}$. In particular this happens when initial capital c is larger than a threshold $c^{Sufficient}$, where we denote

$$c^{Sufficient} = 1 - (1 - c_{\min})R_L. \quad (4.4)$$

Then, the bank continues to date 1, repays depositors, and obtains $R_L - (1 - c)$.

Below the threshold $c^{Sufficient}$, the bank can be either abandoned or recapitalized. The bank is abandoned when it has negative capital: $c_L < 0$. This happens for $R_L < D$. In this case, the bank is worthless and the banker gets a 0 payoff.

The most interesting case is the one where the bank has positive but insufficient capital, $0 < c_L < c_{\min}$. This is the case for returns R_L below the critical threshold R_{\min} , but above the total volume of deposits, D :

$$D < R_L < R_{\min}. \quad (4.5)$$

Since the bank is in breach of the minimal capital ratio, the banker has to either

abandon the bank and get 0 payoff, or to recapitalize the bank at cost T . The banker chooses to recapitalize when her expected payoff of doing so is positive:

$$R_L - (1 - c) - T > 0. \quad (4.6)$$

Solving for the level of initial capital c satisfying both (4.5) and (4.6) we find that the banker decides to raise additional capital only when initial capital c is higher than a certain threshold we denote by $c^{\text{Recapitalize}}$, where

$$c^{\text{Recapitalize}} = 1 + T - R_L. \quad (4.7)$$

For values of initial equity below $c^{\text{Recapitalize}}$, the banker chooses the abandonment of bank. The banker's payoff is therefore $\max\{R_L - (1 - c) - T; 0\}$. Note that both thresholds $c^{\text{Recapitalize}}$ and $c^{\text{Sufficient}} \in (0, 1)$.

We focus our principal analysis on the most rich case where $c^{\text{Sufficient}} > c^{\text{Recapitalize}}$, corresponding to values of T that are not too high:

$$T < c_{\min} R_L. \quad (4.8)$$

The case of T higher is discussed in the Appendix.

Overall, the banker's payoffs and recapitalization choices in the low realization of the risky project are characterized by the following two lemmas:

Lemma 8 *If initial capital c is above threshold $c^{\text{Sufficient}}$, the bank has sufficient capital when R_L is realized. Below this threshold, the banker decides between costly recapitalization and abandonment of the bank. The banker raises additional capital at cost T for $c \in (c^{\text{Recapitalize}}, c^{\text{Sufficient}})$ and abandons the bank for $c < c^{\text{Recapitalize}}$.*

Lemma 9 *When R_L is realized, the banker's payoff is Π_L , where*

$$\Pi_L = \begin{cases} R_L - (1 - c), & \text{if } c \geq c^{Sufficient} \\ R_L - (1 - c) - T, & \text{if } c^{Re\ capitalize} \leq c < c^{Sufficient} \\ 0, & \text{if } c < c^{Re\ capitalize} \end{cases} .$$

Overall, the banker's payoff to choosing the risky project is

$$\Pi_R = p[R_H - (1 - c)] + (1 - p - \mu) * \Pi_L. \quad (4.9)$$

The first term on the right-hand side captures the banker's expected payoff when the risky project is successful. The second term captures the banker's expected payoff when the low outcome R_L is realized, depending on bank's initial capital c , on low project realization R_L , as well as on the cost of recapitalization T .

Figure 2 illustrates our findings on the bank's recapitalization decision.

4.4 Bank Risk-Taking

In this section we solve the model and examine the relationship between bank capital and risk-taking. We first consider a setting without tail risks and show that risk-taking falls in bank capital. This classic result is the foundation of traditional bank capital regulation. We then examine bank's behavior in the presence of tail risks and show that banks with higher capital may demonstrate excess risk-taking incentives.

4.4.1 Bank Risk-Taking Without Tail Risks

We start with an illustrative benchmark of the bank's project choice without tail risks (i.e., $\mu = 0$). We consider in this section a simplified version of the risky project described above. The return on the risky project is either high, $R_H > R_S$, with probability q , or low, $0 < R_L < 1$, with probability $1 - q$. The return on the safe project is certain and identical with the one described in the previous sections, $R_S > 1$. Likewise, we make the similar two assumptions:

(1) The net present value (NPV) of the safe project is higher than that of the risky project

$$R_S > qR_H + (1 - q)R_L, \quad (4.10)$$

(2) The return on the safe asset, R_S , is not as high as to make the banker always prefer the safe project regardless the level of initial capital:

$$R_S < qR_H + (1 - q). \quad (4.11)$$

We validate the traditional intuition that the bank's incentives to opportunistically choose the risky project monotonically decrease in its initial capital. The reason, a standard one, is that the bank with low capital does not internalize the losses in the downside R_L realization of the risky project (its limited liability is binding). In contrast, a bank with a high capital has more "skin in the game" and would therefore internalize more of the downside.

The banker's payoffs and recapitalization decision in the low realization of the risky project are characterized by Lemmas 8 and 9 from the previous section. Accordingly, the banker's payoff to choosing the risky project is

$$\Pi_R^{NTR} = q[R_H - (1 - c)] + (1 - q) * \Pi_L, \quad (4.12)$$

(with NTR for no tail risks).

The first term on the right-hand side captures the banker's expected payoff when the risky project is successful. The second term captures the banker's expected payoff when the low outcome R_L is realized, depending on bank's initial capital c , on low project realization R_L , as well as on the cost of recapitalization T .

Bank project choice

We now consider bank project choice at date 0, depending on its initial capital ratio, c . The bank chooses the safe project over the risky project for:

$$R_S - (1 - c) \geq q[R_H - (1 - c)] + (1 - q) * \Pi_L. \quad (4.13)$$

The following proposition describes the bank investment decision.

Proposition 10 *The bank's project choice can be characterized by one threshold as follows: there exist $c_{Benchmark}^*$, with $0 < c_{Benchmark}^* < c^{Recapitalization}$, and*

$$c_{Benchmark}^* = 1 - \frac{R_S - qR_H}{1 - q},$$

such that the bank chooses the risky project for $0 < c < c_{Benchmark}^$, and the safe project for $c_{Benchmark}^* < c < 1$, where R_S and R_H are the returns on the safe and on the risky project (conditional on being successful), respectively, and q is the success probability of the risky project.*

Proof. *Following from Lemma 8 there are three important levels of initial capital: low (i.e., $c < c^{Recapitalize}$), intermediate (i.e., $c^{Recapitalize} \leq c < c^{Sufficient}$) and high (i.e., $c \geq c^{Sufficient}$). Consider first the case when $c \in (0, c^{Recapitalize})$. The banker never finds optimal to recapitalize for low realization of the risky project. The relevant incentive compatibility condition derived from (4.13) is $R_S - (1 - c) \geq q[R_H - (1 - c)]$, where the left-hand side is the return on investing in the safe project and the right-hand side is the expected return on selecting the risky project. The condition can be rewritten as $c \geq 1 - \frac{R_S - qR_H}{1 - q}$. We denote $c_{Benchmark}^* = 1 - \frac{R_S - qR_H}{1 - q}$. The threshold $c_{Benchmark}^*$ exists if and only if the next two constraints are jointly satisfied:*

$$R_S < 1 - q + qR_H, \quad (4.14)$$

$$R_S > qR_H + (1 - q)(R_L - T). \quad (4.15)$$

The former condition guarantees a positive $c_{\text{Benchmark}}^*$, while the latter forces the threshold to be lower than $c^{\text{Recapitalize}}$, the upper limit for the interval we analyze. Assumption (4.11) implies that (4.14) is always fulfilled, hence $c_{\text{Benchmark}}^* > 0$. Likewise, assumption (4.10) implies that (4.15) is always fulfilled, hence $c_{\text{Benchmark}}^* < c^{\text{Recapitalize}}$. Since both constraints are simultaneously satisfied, $\exists c_{\text{Benchmark}}^* \in (0, c^{\text{Recapitalize}})$ such that $\forall c \in (0, c_{\text{Benchmark}}^*)$ the risky project is selected and $\forall c \in (c_{\text{Benchmark}}^*, c^{\text{Recapitalize}})$ the safe project is chosen.

Consider now the case when $c \in (c^{\text{Recapitalize}}, c^{\text{Sufficient}})$. The banker finds optimal to recapitalize for low realization R_L . The relevant incentive compatibility condition is $R_S - (1 - c) \geq q[R_H - (1 - c)] + (1 - q)[R_L - (1 - c) - T]$, with the certain return on choosing the safe project depicted on the left-hand side, and expected return on investing in the risky project depicted on the right-hand side. Rearranging terms the condition can be rewritten as

$$R_S > qR_H + (1 - q)(R_L - T). \quad (4.16)$$

The above condition is always satisfied following from assumption (4.10). This implies that $\forall c \in (c^{\text{Recapitalize}}, c^{\text{Sufficient}})$, the bank prefers the safe project.

Consider now the final interval, when $c \in (c^{\text{Sufficient}}, 1)$. For low realization R_L the bank always complies with the regulatory requirements. No additional capital is needed. The relevant incentive compatibility condition is $R_S - (1 - c) \geq q[R_H - (1 - c)] + (1 - q)[R_L - (1 - c)]$. Rearranging terms the condition becomes

$$R_S > qR_H + (1 - q)R_L. \quad (4.17)$$

Assumption (4.10) implies that the above condition is always fulfilled, thus $\forall c \in (c_{\text{Sufficient}}, 1)$ the safe project is selected. ■

The intuition is that the banker's downside is limited to the bank's initial capital, due to limited liability. A bank with smaller initial capital internalizes less of the

downside of the risky project (while enjoying the full upside), and hence has incentives to take on more risk. Bank risk-taking is monotonically decreasing in initial capital.

This benchmark result validates the basic rationale for traditional capital regulation: higher capital increases banker's "skin-in-the-game" and reduces incentives for excess risk-taking. In particular, a bank with initial capital $c \geq c_{Benchmark}^*$ has no incentives to undertake the risky project. We take this intuition further in the next section, and consider the consequences of introducing tail risk projects in the traditional framework.

4.4.2 Bank Risk-Taking With Tail Risks

Consider now a bank operating under a minimal capital ratio, in an environment where tail risk projects are available for investment (i.e., $\mu > 0$). We show that, due to the existence of tail risk projects, the relationship between bank capital and risk-taking becomes more complex than under a simple limited liability-based story without tail risk projects.

Indeed, recall that under limited liability, a banker did not internalize the downside of low realizations, and that drove excess risk-taking. Higher capital made limited liability less binding, reducing bank risk-taking incentives. The minimal capital requirement has an *opposite* effect. Banks with a positive but *insufficient* capital are punished through the corrective action mechanism, because they have to either raise extra capital (at a cost) or give up the bank. Therefore, a banker may experience losses that exceed the downside of the bank's asset value. Put differently, while limited liability effectively *subsidizes* risk, the minimal capital requirement and corrective action have the capacity to *penalize* risk. Capital further above minimal capital ratio makes the corrective action less binding, potentially allowing banks to increase risk. Once the two effects of limited liability and minimal capital ratio are taken into account, the relationship between bank capital and risk-taking may

become non-linear in the presence of tail risk projects.

We again solve the model backwards. We start from the banker's payoffs conditional on project realization and recapitalization decision at date $\frac{1}{2}$, which were derived in Section 4.3. We now consider bank project choice at date 0, depending on its initial capital ratio, c .

Bank project choice

The bank chooses the safe project over the risky project for:

$$R_S - (1 - c) \geq p[R_H - (1 - c)] + (1 - p - \mu) * \Pi_L. \quad (4.18)$$

Before describing the results we introduce the following two thresholds. We denote

$$W = pR_H + (1 - p)R_L - \mu c_{\min} R_L, \quad (4.19)$$

and

$$Z = pR_H + (1 - p)(R_L - T) + \mu(T - c_{\min} R_L), \quad (4.20)$$

A full description of the derivation of these two thresholds is given in the Appendix. The intuition is as follows. First, consider the point W . If the bank selects the risky project then, upon R_L being realized the bank has positive and sufficient capital at any levels of initial capital such that $c > c^{Sufficient}$. Conditional on bank holding this level of capital, the banker is better off selecting the safe project (i.e., condition (4.18) is fulfilled) only when the return on the safe project is high enough: $R_S \geq W$. Second, consider the point Z . Upon the realization of R_L following from an investment in the risky project, the bank ends up with positive but insufficient capital when initial capital $c \in (c^{Recapitalize}, c^{Sufficient})$. However, for this level of initial capital the banker decides for recapitalization when subject to regulator's corrective action. The banker is better off selecting the risky project (i.e., condition (4.18) is

not fulfilled) only when the return on the safe project is low enough: $R_S < Z$.

Lemma 11 *Consider W and Z .*

1. $Z < W$;

2. *Point W is a threshold for asset substitution, conditional on bank having a high level of initial capital (i.e., $c \geq c^{\text{Sufficient}}$), that is for $R_S < W$, the banker chooses the risky project over the safe project in the absence of corrective action;*

3. *Point Z is a threshold for the binding impact of the corrective action, conditional on bank having an intermediate level of capital (i.e., $c^{\text{Recapitalize}} \leq c < c^{\text{Sufficient}}$), that is for $R_S > Z$, the bank chooses the safe project over the risky project in the presence of corrective action.*

Lemma 11 describes the main two key effects of the paper. These effects offset each other and the following proposition describes when one effect dominates the other.

Proposition 12 *The bank's project choice can be characterized by two possible thresholds as follows:*

(a) *for $Z < R_S < W$, exists c^* , $0 < c^* < c^{\text{Sufficient}}$, and c^{**} , $c^{\text{Sufficient}} < c^{**} < 1$, such that the bank's risk preference is non-monotonic in initial capital. The bank chooses the risky project for $0 < c < c^*$, the safe project for $c^* < c < c^{\text{Sufficient}}$, again the risky project for $c^{\text{Sufficient}} < c < c^{**}$, and the safe project for $c > c^{**}$;*

(b) *for $R_S < Z$, exists c^{**} , $c^{\text{Sufficient}} < c^{**} < 1$, such that for any levels of initial capital $0 < c < c^{**}$, the bank selects the risky project, while for $c^{**} < c < 1$ the safe project is preferred;*

(c) *for $R_S > W$, exists c^* , $0 < c^* < c^{\text{Sufficient}}$, such that for any levels of initial capital $0 < c < c^*$, the bank selects the risky project, while for $c^* < c < 1$, the safe project is preferred,*

where R_S is the return on the safe project, and W and Z are defined in (4.19) and (4.20), respectively.

Proof. *The proof is in the Appendix.* ■

Case (a) of Proposition 12 contains the key novel result of our paper. The two effects identified in Lemma 11 interact as follows. When the bank has low capital (i.e., $0 < c < c^*$), it does not internalize the downside of low realizations (i.e., R_0 and R_L). Hence, limited liability subsidizes risk-taking in the presence of negative capital. As a result, the limited liability effect dominates the effect of corrective action and drives excess risk-taking. For higher levels of initial capital (i.e., $c^* < c < c^{Sufficient}$), the bank might be subject to regulator's corrective action when it has positive but insufficient capital (i.e., for realization R_L). Hence, corrective action penalizes the risk-taking and this effect dominates the limited liability effect. The banker would prefer the safe project. However, when the bank has enough initial capital such that upon realization of R_L the capital is sufficient to satisfy the minimal requirements (i.e., $c^{Sufficient} < c < c^{**}$), the bank is subject to regulator's corrective action only for extremely low realization R_0 . However, in such extreme event the bank does not internalize much of the losses. Hence, limited liability effect dominates the corrective action effect, which is less binding in this case. Finally, for very high levels of capital (i.e., $c > c^{**}$), the bank absorbs more of the extremely low downside realization R_0 . Hence the banker has lower incentives to take excess risk and selects the safe project.

Our findings suggest that for a certain large range of model's parameters, highly capitalized banks find optimal to take excessive risk in equilibrium. For the remainder of the paper we focus our discussion on Case (a) of Proposition 12. This case provides us with the most complex scenario which is relevant for the model's core results. A full description of thresholds c^* and c^{**} defined in Proposition 12 is given in the Appendix. For our case of interest, these thresholds are as follows:

$$c^* = 1 - \frac{R_S - pR_H - (1 - p - \mu)(R_L - T)}{\mu}, \quad (4.21)$$

and

$$c^{**} = 1 - \frac{R_S - pR_H - (1 - p - \mu)R_L}{\mu}, \quad (4.22)$$

with $c^* \in (c^{\text{Re capitalize}}, c^{\text{Sufficient}})$ and $c^{**} \in (c^{\text{Sufficient}}, 1)$, where $c^{\text{Re capitalize}}$ and $c^{\text{Sufficient}}$ are defined in (4.7) and (4.4), respectively.

Figure 3 depicts bank's project choice in this particular case.

4.5 Discussion

In this section we first offer comparative statics and study how a change in the probability distribution of the risky project affects the model outcomes. We show that highly capitalized banks have stronger incentives to invest in tail risk projects when that risk is more extreme. Second, we offer two extensions for our model and examine the implications of charter value and of different specification for recapitalization costs. We show that our results from previous section are robust to these generalizations.

4.5.1 The Role of Left Tails

The setup of the model allows us to investigate the role played by heavier left tail, or tail risk, in the investment selection process for leveraged intermediaries. A tail risk is caused by extremely low realizations of the risky project, R_0 , and is characterized by μ , its probability. Thus, higher μ reflects a heavier left tail. We investigate whether banks have greater incentives to increase the risk of their investments by shifting to the risky project when the risk profile of available investments exhibits heavy left tails. Surprisingly, we show that *better capitalized banks* are in particular the ones demonstrating risk-taking preferences when tail risk projects are available for investments.

To study this effect, we consider a change in probability distribution for the risky asset. We denote the expected value of the risky project by $E(Risky)$. We keep $E(Risky)$ constant by increasing both μ and p , other else being equal. In other words, following to an increase in μ by $\Delta\mu$, the value of p should increase by $\frac{R_L}{R_H - R_L} \Delta\mu$, in order to keep $E(Risky)$ constant. Therefore, a project displaying the same expected return as the initial risky project, but with more polarized returns (i.e., heavier left and right tails), is considered to be riskier.

This change in the return profile of the risky asset affects both thresholds c^* and c^{**} . To focus on bank's incentives to take the excessively risky strategy, we consider the area $(c^{Sufficient}, c^{**})$, corresponding to levels of initial bank capital for which the bank prefers the risky project. As $c^{Sufficient}$ is given by the exogenous regulation, the left boundary of the interval analyzed is not affected by the return profile of the risky project (see 4.4). Hence, the critical threshold for our discussion is c^{**} .

Consider the impact of the change in probability distribution of the risky project on c^{**} . Observe that the first derivative is positive:

$$\frac{\partial c^{**}}{\partial \mu} \Big|_{E(Risky)=constant} = \frac{R_S - E(Risky)}{\mu^2} > 0$$

This holds due to the fact that $R_S > E(Risky)$ by (4.1).

This means that when the left tail of the risky project becomes heavier following to an increase in μ , the interval $(c^{Sufficient}, c^{**})$ widens and the banks start choosing the risky project for a wider range of initial capital values. This result suggests that availability of investments with heavier left tails induces precisely banks with larger capital buffers to take excessive risk. Figure 4 depicts the impact of increased tail risk (i.e., heavier left tail) on bank's project choice.

The intuition is that when investment return becomes more polarized, it enables well-capitalized banks to earn higher profits in good time, while at the same time reducing the expected cost of recapitalization since the low return R_L (which triggers the recapitalization decision) is less frequent. In the extreme case when $\mu + p = 1$,

the risky project never returns R_L , so it either produces a high return R_H , or a large loss R_0 , when the bank is worthless and recapitalization is useless. A less capitalized bank will earn a return too infrequently in this case, and will avoid the risky project, unlike a bank with larger buffers.

4.5.2 Alternative Capital Regimes

In Section 4.2 we considered a simple fixed cost of recapitalization. We now show that results are robust to a more general specification of this cost function.

In this section we discuss a variation of the model in which the cost of recapitalization has a fixed component and a variable component as well. The variable component is proportional to the amount of new capital that the bank has to raise in order to comply with regulatory requirements. If the bank does not satisfy minimal capital ratio (under R_L realization of the risky project), the bank has to attract additional capital to bring its capital ratio to the regulatory minimum, c_{\min} . Specifically, the bank has to raise a capital level $R_{\min} - R_L$, where R_{\min} is given in (4.3).³ In this new setting, the recapitalization cost is concave in capital level, and has the following specification:

$$Cost(c, R_L) = T + \beta \left(\frac{1-c}{1-c_{\min}} - R_L \right). \quad (4.23)$$

We assume that the marginal cost of recapitalization (i.e., β) is not as low as to make the banker to abandon the bank regardless the level of initial capital:

$$T < R_L(1 + \beta) \quad (4.24)$$

The banker's payoff from the safe project, as well as the realizations of the risky project are the same as in the basic model. However, when the low realization R_L is

³Consider the following example. Assume that the bank has to raise δ units of capital to satisfy the regulatory minimum when R_L is realized. Hence, $c_{\min} = \frac{R_L - (1-c) + \delta}{R_L + \delta}$. This implies that $R_L + \delta = \frac{1-c}{1-c_{\min}}$, which equals R_{\min} according to (4.3). We can conclude that $\delta = R_{\min} - R_L$.

obtained, the bank is abandoned for higher levels of initial capital than in the basic model. The bank is closed when $c < c_{CC}^{\text{Re capitalize}}$, where

$$c_{CC}^{\text{Re capitalize}} = 1 + \frac{T - R_L(1 + \beta)}{1 + \frac{\beta}{1 - c_{\min}}}, \quad (4.25)$$

(with CC for concave cost).

Under assumption (4.8), $c_{CC}^{\text{Re capitalize}} > c^{\text{Re capitalize}}$. On the other hand, the level of capital which guarantees that the bank satisfies ex-post the regulatory minimal upon realization of R_L (i.e., $c^{\text{Sufficient}}$) remains unchanged. Hence, the interval $(c_{CC}^{\text{Re capitalize}}, c^{\text{Sufficient}})$ shrinks, suggesting that the bank is less likely to raise additional capital under corrective action of the regulator for a concave cost of recapitalization.

We denote

$$B_{CC} = pR_H + (1 - p) \frac{R_L(1 + \beta) - T}{1 + \frac{\beta}{1 - c_{\min}}}. \quad (4.26)$$

The next proposition characterizes the project's choice in the presence of concave recapitalization cost.

Proposition 13 *There exist two thresholds c_{CC}^* and c_{CC}^{**} for the level of initial bank capital such that under assumption (4.8) and for level of return on the safe project satisfying $Z < R_S < B_{CC}$, with Z and B_{CC} defined in (4.20) and (4.26), respectively, the bank's investment preference is as follows:*

(a) *the bank prefers the risky project for $0 < c < c_{CC}^*$, while for $c_{CC}^* < c < c^{\text{Sufficient}}$ the safe project is preferred, with $c_{CC}^* \in (c_{CC}^{\text{Re capitalize}}, c^{\text{Sufficient}})$, where $c_{CC}^{\text{Re capitalize}}$ and $c^{\text{Sufficient}}$ are defined in (4.25) and (4.4), respectively, and*

$$c_{CC}^* = 1 - \frac{R_S - pR_H - (1 - p - \mu)[R_L(1 + \beta) - T]}{\mu - \frac{\beta}{1 - c_{\min}}(1 - p - \mu)} \quad (4.27)$$

(b) *the bank prefers the risky project for $c^{\text{Sufficient}} < c < c_{CC}^{**}$, and the safe project for $c > c_{CC}^{**}$, where $c_{CC}^{**} \in (c^{\text{Sufficient}}, 1)$ and $c_{CC}^{**} = c^{**}$, with c^{**} defined in (4.22).*

Proof. The proof is similar with the proof for Proposition 12. ■

Observe that the introduction of a variable component for recapitalization cost leaves both boundaries of the interval $(c^{Sufficient}, c_{CC}^{**})$ unchanged. Thus, our model is robust and a concave cost of recapitalization does not affect the risk-taking preferences of well-capitalized banks, when they are allowed to invest in projects exhibiting heavier left tails.

4.5.3 Charter Value

In Section 4.2 we have assumed that there is no charter value for the continuation of bank's activity. In this section we introduce a positive charter value $V > 0$ and show that our results are robust to this extension. Our model suggests that low competition in banking, which provides a high charter value, leads to investment in the efficient safe project even by well-capitalized banks.

The role of banks' franchise values have been shown relevant in other studies. Hellmann et al. (2000) and Repullo (2004) argue that prudent behavior can be facilitated by increasing banks' charter value. They study the links between capital requirements, competition for deposits, charter value and risk-taking incentives, and point out that banks are more likely to gamble and to take more risk in a competitive banking system, since competition erodes profits and implicitly the franchise value. A similar idea is put forward by Matutes and Vives (2000). They argue that capital regulation should be complemented by deposit rate regulation and direct asset restrictions in order to efficiently keep risk-taking under control. Acharya (2002) explores how continuation value affects risk preferences in the context of optimal regulation, and demonstrates the disciplinating effect of charter value on bank risk-taking. Finally, Keeley (1990) and Furlong and Kwan (2005) explore empirically the relation between charter value and different measures of bank risk, and find strong evidence that bank charter value disciplined bank risk-taking.

In the new setting, the banker's payoff to the safe project after repaying depositors becomes $\Pi_S^V = R_S - (1 - c) + V$. The banker's payoff to the risky project is as follows: when R_H is realized, the banker gets $\Pi_H^V = R_H - (1 - c) + V$, while the payoff is 0 for extremely low realization R_0 . When the low return R_L is realized and capital is positive but insufficient ex-post, the banker prefers to recapitalize at a cost T for lower levels of initial capital c . The reason for this is that banker's expected payoff depicted in equation (4.6) increases by V if the bank is not closed by the regulator. Hence, the bank raises additional capital when initial capital c is higher than $c_V^{\text{Recapitalize}}$, where

$$c_V^{\text{Recapitalize}} = 1 + T - R_L - V, \quad (4.28)$$

and $c_V^{\text{Recapitalize}} < c^{\text{Recapitalize}}$. On the other hand, the threshold point $c^{\text{Sufficient}}$ does not change since it is given by the exogenous regulation.

We make the simplifying assumption that the charter value is not larger than a certain threshold:

$$V < 1 + T - R_L. \quad (4.29)$$

This makes threshold $c_V^{\text{Recapitalize}}$ positive and assures the existence for the area $(0, c_V^{\text{Recapitalize}})$ where the bank is abandoned for low realization of the risky asset. Consider the area $(c_V^{\text{Recapitalize}}, c^{\text{Sufficient}})$. When initial capital c is in this range, a bank which is subject to regulator's corrective action prefers to raise additional capital. Since $c_V^{\text{Recapitalize}} < c^{\text{Recapitalize}}$, while right boundary of the interval is left unchanged by any increase in V , we can argue that any reduction in banking competition, which increases bank charter value, makes the decision to raise fresh capital more likely.

We introduce the following two thresholds:

$$Z_V = pR_H + (1 - p)(R_L - T) + \mu(T - V - c_{\min}R_L), \quad (4.30)$$

as the new threshold for the binding impact of the prompt corrective action (with $Z_V < Z$), and

$$B = pR_H + (1 - p)(R_L - T). \quad (4.31)$$

The next proposition characterizes the project's choice in the presence of charter value.

Proposition 14 *There exist two thresholds c_V^* and c_V^{**} for the level of initial bank capital such that under assumption (4.8) and for levels of return on the safe project satisfying $Z_V < R_S < B$, with Z_v and B defined in (4.30) and (4.31), respectively, the bank's investment preference is as follows:*

(a) *the bank prefers the risky project for $0 < c < c_V^*$, while for $c_V^* < c < c^{Sufficient}$ the safe project is preferred, with $c_V^* \in (c_V^{Re\,capitalize}, c^{Sufficient})$, where $c_V^{Re\,capitalize}$ and $c^{Sufficient}$ are defined in (4.28) and (4.4), respectively, and*

$$c_V^* = 1 - V - \frac{R_S - pR_H - (1 - p - \mu)(R_L - T)}{\mu}, \quad (4.32)$$

(b) *the bank prefers the risky project for $c^{Sufficient} < c < c_V^{**}$, and the safe project for $c > c_V^{**}$, where $c_V^{**} \in (c^{Sufficient}, 1)$ and*

$$c_V^{**} = 1 - V - \frac{R_S - pR_H - (1 - p - \mu)R_L}{\mu}, \quad (4.33)$$

Proof. *The proof is similar with the proof for Proposition 12. ■*

Observe that a positive charter value has a negative impact on all relevant thresholds which drive bank's preferences (i.e., $c_V^{Re\,capitalize}$, c_V^* , and c_V^{**}), except for $c^{Sufficient}$. Hence, we can argue that higher charter value plays the role of a counterbalancing force to the risk-taking incentives generated by the presence of risky projects with heavy left tails. This means that when the continuation value of bank's activity is high enough, both intervals $(0, c_V^*)$ and $(c^{Sufficient}, c_V^{**})$ shrink. This suggests that low competition in the banking industry induces banks with larger capital

buffers to take less risk. Figure 5 illustrates the impact of charter value on bank's project choice.

In summary, the results of our basic model are therefore robust to the introduction of charter value, conditional on the fact that this value is not too large. For large values of franchise value V , there are no risk-taking problems in banks, regardless the level of initial capital.

4.6 Concluding Remarks

This paper examined the relationship between bank capital and risk-taking, in the presence of tail risk projects. We have identified a novel channel of bank risk-taking, based on incentives to put to risk excess capital. While a poorly capitalized bank may act risk-averse to avoid breaching the minimal capital ratio (which would force a costly recapitalization), a bank with higher capital may take more risk as it has a lower probability of breaching the ratio. Still, in the presence of tail risks, the highly capitalized banks do not internalize all the consequences of its risk-taking. The key result is that when banks have access to high tail risk projects, this can lead to excess risk-taking by highly capitalized banks in equilibrium. This demonstrates the limits of traditional capital regulation in mitigating banks' incentives to take tail risks. The capital requirements alone may be insufficient to control banks' preferences when tail risk projects are available to them. In fact, in the presence of both limited liability effect and corrective action effect (triggered by minimal capital requirement), the relationship between bank capital and risk-taking may become non-linear. We related our results with stylized facts about pre-crisis bank behavior, and discussed implications for capital regulation.

4.A Proofs

Proof of Proposition 12 under the assumption of low cost of recapitalization (i.e., $T < c_{\min}R_L$)

We consider two scenarios in turn. We start by analyzing a scenario in which the cost of recapitalization is such that $\frac{\mu}{1-p}c_{\min}R_L < T < c_{\min}R_L$. Subsequently we show that our results are similar for $T < \frac{\mu}{1-p}c_{\min}R_L$.

$$\frac{\mu}{1-p}c_{\min}R_L < T < c_{\min}R_L$$

We study bank's behavior for three levels of initial capital: low (i.e., $c < c^{\text{Recapitalize}}$), intermediate (i.e., $c^{\text{Recapitalize}} \leq c < c^{\text{Sufficient}}$) and high (i.e., $c \geq c^{\text{Sufficient}}$).

Consider first the case when $c \in (0, c^{\text{Recapitalize}})$. The banker never finds optimal to recapitalize for low realization of the risky project. The relevant incentive compatibility condition derived from (4.18) is $R_S - (1 - c) \geq p[R_H - (1 - c)]$, where the left-hand side is the return on investing in the safe project and the right-hand side is the expected return on selecting the risky project. The condition can be rewritten as $c \geq 1 - \frac{R_S - pR_H}{1-p}$. We denote $c_1^* = 1 - \frac{R_S - pR_H}{1-p}$. The threshold c_1^* exists if and only if the next two constraints are jointly satisfied:

$$R_S < 1 - p + pR_H, \tag{T1a'}$$

$$R_S > pR_H + (1 - p)(R_L - T). \tag{T1a}$$

The former condition guarantees a positive c_1^* , while the latter forces the threshold to be lower than $c^{\text{Recapitalize}}$, the upper limit for the interval we analyze. If (T1a') is not fulfilled, then $c_1^* < 0$ and $\forall c \in (0, c^{\text{Recapitalize}})$, the bank prefers the safe project. If (T1a) is not fulfilled, then $c_1^* > c^{\text{Recapitalize}}$ and $\forall c \in (0, c^{\text{Recapitalize}})$ the bank invests risky. When both constraints are simultaneously satisfied, $\exists c_1^* \in (0, c^{\text{Recapitalize}})$ such that $\forall c \in (0, c_1^*)$ the risky project is selected and $\forall c \in (c_1^*, c^{\text{Recapitalize}})$ the safe

project is chosen. Assumption (4.2) implies that (T1a') is always fulfilled.

Consider now the case when $c \in (c^{\text{Recapitalize}}, c^{\text{Sufficient}})$. The banker finds optimal to recapitalize for low realization R_L . The relevant incentive compatibility condition is $R_S - (1 - c) \geq p[R_H - (1 - c)] + (1 - p - \mu)[R_L - (1 - c) - T]$, with the certain return on choosing the safe project depicted on the left-hand side, and expected return on investing in the risky project depicted on the right-hand side. Rearranging terms the condition can be rewritten as $c \geq 1 - \frac{R_S - pR_H - (1 - p - \mu)(R_L - T)}{\mu}$. We denote $c_2^* = 1 - \frac{R_S - pR_H - (1 - p - \mu)(R_L - T)}{\mu}$. Similarly with the previous case, the threshold c_2^* exists if and only if it is simultaneously higher and lower than the lower and the higher boundary of the analyzed interval, respectively. The conditions are as follows:

$$R_S < pR_H + (1 - p)(R_L - T), \quad (\text{T2a})$$

$$R_S > pR_H + (1 - p)(R_L - T) + \mu(T - c_{\min}R_L). \quad (\text{T2b})$$

Condition (T2a) is the opposite of (T1a). Thus, a satisfied condition (T1a) implies that (T2a) is not fulfilled. Condition (T2a) not satisfied implies that $c_2^* < c^{\text{Recapitalize}}$ and $\forall c \in (c^{\text{Recapitalize}}, c^{\text{Sufficient}})$, the bank prefers the safe project. If the second condition is not fulfilled, then $c_2^* > c^{\text{Sufficient}}$ and $\forall c \in (c^{\text{Recapitalize}}, c^{\text{Sufficient}})$ the bank invests risky. When both constraints are simultaneously satisfied, $\exists c_2^* \in (c^{\text{Recapitalize}}, c^{\text{Sufficient}})$ such that $\forall c \in (c^{\text{Recapitalize}}, c_2^*)$ the risky project is selected. The safe project is preferred $\forall c \in (c_2^*, c^{\text{Sufficient}})$.

Consider now the final interval, when $c \in (c^{\text{Sufficient}}, 1)$. For low realization R_L the bank always complies with the regulatory requirements. No additional capital is needed. The relevant incentive compatibility condition is $R_S - (1 - c) \geq p[R_H - (1 - c)] + (1 - p - \mu)[R_L - (1 - c)]$. Rearranging terms the condition becomes $c \geq 1 - \frac{R_S - pR_H - (1 - p - \mu)R_L}{\mu}$. We denote $c^{**} = 1 - \frac{R_S - pR_H - (1 - p - \mu)R_L}{\mu}$. The threshold c^{**} exists if and only if $c^{**} > c^{\text{Sufficient}}$ and $c^{**} < 1$. The later is always fulfilled following from the assumption (4.1) of higher NPV for the safe project. The former

condition is depicted in (T3a) below. When (T3a) is not satisfied, the bank prefers the safe project for any level of initial capital larger than $c^{Sufficient}$. Otherwise, $\forall c \in (c^{Sufficient}, c^{**})$ the risky project is selected, while the safe project is preferred $\forall c \in (c^{**}, 1)$.

$$R_S < pR_H + (1 - p)R_L - \mu c_{\min} R_L. \quad (\text{T3a})$$

Next we discuss the process of project selection. Recall that $Z = pR_H + (1 - p)(R_L - T) + \mu(T - c_{\min}R_L)$ and $W = pR_H + (1 - p)R_L - \mu c_{\min}R_L$, from (4.20) and (4.19), respectively. We also denote $B = pR_H + (1 - p)(R_L - T)$. Under assumption (4.8), $Z < B < W$. We distinguish among four possible scenarios.

Scenario S1: $R_S < Z$. As a consequence, condition (T2b) is not satisfied and $\forall c \in (c^{Re\text{capitalize}}, c^{Sufficient})$ the bank selects the risky project. $R_S < Z$ also implies that $R_S < B$ and $R_S < W$. Condition (T1a) is not satisfied but (T3a) is. As a result, the bank invests risky $\forall c \in (0, c^{Re\text{capitalize}}) \cup (c^{Sufficient}, c^{**})$, and the bank invests safe $\forall c \in (c^{**}, 1)$.

Scenario S2: $Z \leq R_S \leq B$. The right-hand side implies that condition (T1a) is not satisfied. For initial capital c lower than $c^{Re\text{capitalize}}$ the bank prefers the risky project. The left hand side implies that condition (T2b) is fulfilled. Also condition (T2a) is satisfied being the opposite of (T1a). Hence, we can conclude that $\exists c^* \in (c^{Re\text{capitalize}}, c^{Sufficient})$ with $c^* = c_2^*$, such that $\forall c \in (c^{Re\text{capitalize}}, c^*)$ the risky project is selected, while the safe project is preferred $\forall c \in (c^*, c^{Sufficient})$. Condition (T3a) is also satisfied. Similarly with the previous scenario, the bank invests risky $\forall c \in (c^{Sufficient}, c^{**})$, and safe $\forall c \in (c^{**}, 1)$.

Scenario S3: $B < R_S < W$. The left hand-side implies that condition (T1a) is satisfied. We can argue that $\exists c^* \in (0, c^{Re\text{capitalize}})$ with $c^* = c_1^*$, such that $\forall c \in (0, c^*)$ the risky project is selected, while the safe project is preferred $\forall c \in (c^*, c^{Re\text{capitalize}})$. Condition (T1a) implies that (T2a) is not satisfied. Thus, $\forall c \in (c^{Re\text{capitalize}}, c^{Sufficient})$ the safe project will be selected. The bank investment decision is identical with the one from previous scenarios when the level of capital is

high enough (i.e., c larger than $c^{Sufficient}$).

Scenario S4: $R_S \geq W$. Neither condition (T3a) nor condition (T2a) are satisfied anymore. The bank selects the safe project $\forall c \in (c^{Re\text{capitalize}}, 1)$. However, condition (T1a) is fulfilled. Hence, $\exists c^* \in (0, c^{Re\text{capitalize}})$ with $c^* = c_1^*$, such that $\forall c \in (0, c^*)$ the risky project is selected, while the safe project is preferred $\forall c \in (c^*, c^{Re\text{capitalize}})$.

The values for thresholds c^* and c^{**} for Case (a) of Proposition 12, are derived under Scenario S2 above, for $Z \leq R_S \leq B$, with Z and B defined in (4.20) and (4.31), respectively.

$$T < \frac{\mu}{1-p} c_{\min} R_L$$

We consider now the scenario under which the cost of recapitalization is very low. Lowering T has no quantitative impact on $c^{Sufficient}$ and $c^{Re\text{capitalize}}$, the thresholds in initial capital which trigger bank's decision between raising additional capital or letting the regulator to overtake the bank. Their relative position is unchanged: $c^{Sufficient}$ is larger than $c^{Re\text{capitalize}}$ following from easily verifiable identity $\frac{\mu}{1-p} c_{\min} R_L < c_{\min} R_L$ combined with our restriction on T . However, the process of project selection under assumption (4.8) is marginally affected. In this scenario $Z < W < B$, as a consequence of lower T . As discussed before, we distinguish among four possible scenarios (S1') $R_S < Z$, (S2') $Z \leq R_S < W$, (S3') $W \leq R_S < B$ and (S4') $R_S > B$. Discussions for scenarios S1', S2' and S4' are identical with our previous discussion for scenarios S1, S2, and S4. We discuss scenario S3' next. $W \leq R_S$ implies that condition (T3a) is not satisfied. Hence, the bank prefers the safe project for any level of initial capital larger than $c^{Sufficient}$. $R_S < B$ implies that condition (T1a) is not satisfied. For initial capital c lower than $c^{Re\text{capitalize}}$ the bank prefers the risky project. However, condition (T2a) is satisfied being the opposite of (T1a), and also condition (T2b) is implied by the fact that $W > Z$. Hence, we can conclude that $\exists c^* \in (c^{Re\text{capitalize}}, c^{Sufficient})$ with $c^* = c_2^*$, such that $\forall c \in (c^{Re\text{capitalize}}, c^*)$ the risky project is selected, while the safe project is preferred $\forall c \in (c^*, c^{Sufficient})$.

Proof of Proposition 12 under the assumption of high cost of recapitalization (i.e., $T > c_{\min}R_L$)

We relax assumption (4.8) and explore the case of high cost of recapitalization: $T > c_{\min}R_L$. Although the main results are not qualitatively affected, the modified assumption has a quantitative impact on our results. Therefore, we start by deriving the new conditions which drive the results. As was previously explained, the bank is subject to corrective action and receives a request to raise additional capital after investing in the risky project whenever bank capital is below minimal ratio as a result of a low return R_L . The bank has incentives to attract new costly equity only if the payoff of doing so is positive. It is optimal for the bank to raise additional capital (if this was demanded by the regulator) when conditions (4.5) and (4.6) are simultaneously satisfied. The former condition implies that $c < 1 - R_L(1 - c_{\min})$, while from the latter $c > 1 + T - R_L$. Under our modified assumption of high cost of recapitalization T , these conditions can not be satisfied simultaneously. For any levels of initial capital c below $1 - R_L(1 - c_{\min})$, the bank receives a request for adding extra capital but she never finds optimal to do so because such an action will not generate positive payoffs. As a result, the bank is closed and the shareholder expropriated. Conversely, when the level of initial capital is above $1 - R_L(1 - c_{\min})$ the banking authority doesn't take any corrective action against the bank since returns R_L are above the critical level R_{\min} . We denote

$$c_{NEW}^{\text{Re capitalize}} = 1 - R_L(1 - c_{\min}), \quad (4.34)$$

where $c_{NEW}^{\text{Re capitalize}} \in (0, 1)$. Next, we explore the bank's project choice for levels of initial capital below and above this critical threshold.

Consider first the case when $c \in (0, c_{NEW}^{\text{Re capitalize}})$. The bank never recapitalizes for the low realization of the risky project. The bank would have incentive to select the safe project when $R_S - (1 - c) \geq p[R_H - (1 - c)]$, which implies that initial capital c

to be larger than $1 - \frac{R_S - pR_H}{1-p}$. We previously denoted $c_1^* = 1 - \frac{R_S - pR_H}{1-p}$. This threshold exists if and only if (T1a') and the following condition are jointly satisfied:

$$R_S > pR_H + (1-p)R_L(1 - c_{\min}). \quad (\text{T1a NEW})$$

The second condition guarantees that c_1^* is lower than $c_{NEW}^{\text{Re capitalize}}$, the upper boundary for the interval we analyze. For large returns on the safe project (i.e., condition (T1a') is not fulfilled), $\forall c \in (0, c_{NEW}^{\text{Re capitalize}})$, the bank prefers the safe project. If (T1a NEW) is not fulfilled, then $\forall c \in (0, c_{NEW}^{\text{Re capitalize}})$ the bank invests risky. Otherwise, when both constraints are simultaneously satisfied, $\forall c \in (0, c_1^*)$ the risky project is selected and $\forall c \in (c_1^*, c_{NEW}^{\text{Re capitalize}})$ the safe project is chosen. Our assumption (4.2) implies that (T1a') is always fulfilled.

Consider now the second case when $c \in (c_{NEW}^{\text{Re capitalize}}, 1)$. The bank always complies with the regulatory requirements when R_L is obtained due to high initial capital. No additional capital is needed. The bank would have incentive to select the safe project when $R_S - (1-c) \geq p[R_H - (1-c)] + (1-p-\mu)[R_L - (1-c)]$, which implies $c \geq 1 - \frac{R_S - pR_H - (1-p-\mu)R_L}{\mu}$. We previously denoted $c^{**} = 1 - \frac{R_S - pR_H - (1-p-\mu)R_L}{\mu}$. The threshold c^{**} exists if and only if condition (T3a) is satisfied. The safe project is preferred for any level of initial capital larger than $c_{NEW}^{\text{Re capitalize}}$ whenever (T3a) is not satisfied. Otherwise, $\forall c \in (c_{NEW}^{\text{Re capitalize}}, c^{**})$ the risky project is selected, while the safe project is preferred $\forall c \in (c^{**}, 1)$.

Recall that $W = pR_H + (1-p)R_L - \mu c_{\min}R_L$. We also denote $Q = pR_H + (1-p)R_L(1 - c_{\min})$. It is easy to show that $Q < W$ due to the identity $1 - p - \mu > 0$. We distinguish among only three possible scenarios.

Scenario S1'': $R_S \leq Q$. As a consequence, condition (T1a NEW) is not satisfied and $\forall c \in (0, c_{NEW}^{\text{Re capitalize}})$ the bank selects the risky project. $R_S < Q$ implies that $R_S < W$. Condition (T3a) is satisfied. As a result, the bank invests risky $\forall c \in (c_{NEW}^{\text{Re capitalize}}, c^{**})$, while she prefers the safe project $\forall c \in (c^{**}, 1)$.

Scenario S2'': $Q < R_S < W$. The left hand-side implies that condition (T1a

NEW) is satisfied. This implies that $\exists c^* \in (0, c_{NEW}^{Re\ capitalize})$ with $c^* = c_1^*$, such that $\forall c \in (0, c^*)$ the risky project is selected, while the safe project is preferred $\forall c \in (c^*, c_{NEW}^{Re\ capitalize})$. Similarly with the previous scenario, the bank invests risky $\forall c \in (c_{NEW}^{Re\ capitalize}, c^{**})$, and safe $\forall c \in (c^{**}, 1)$. This result is implied by R_S being lower than W .

Scenario S3'': $R_S \geq W$. Condition (T1a NEW) is satisfied while condition (T3a) is not. Hence, the bank selects the risky projects $\forall c \in (0, c^*)$, with $c^* = c_1^*$, and she selects the safe project $\forall c \in (c^*, 1)$.

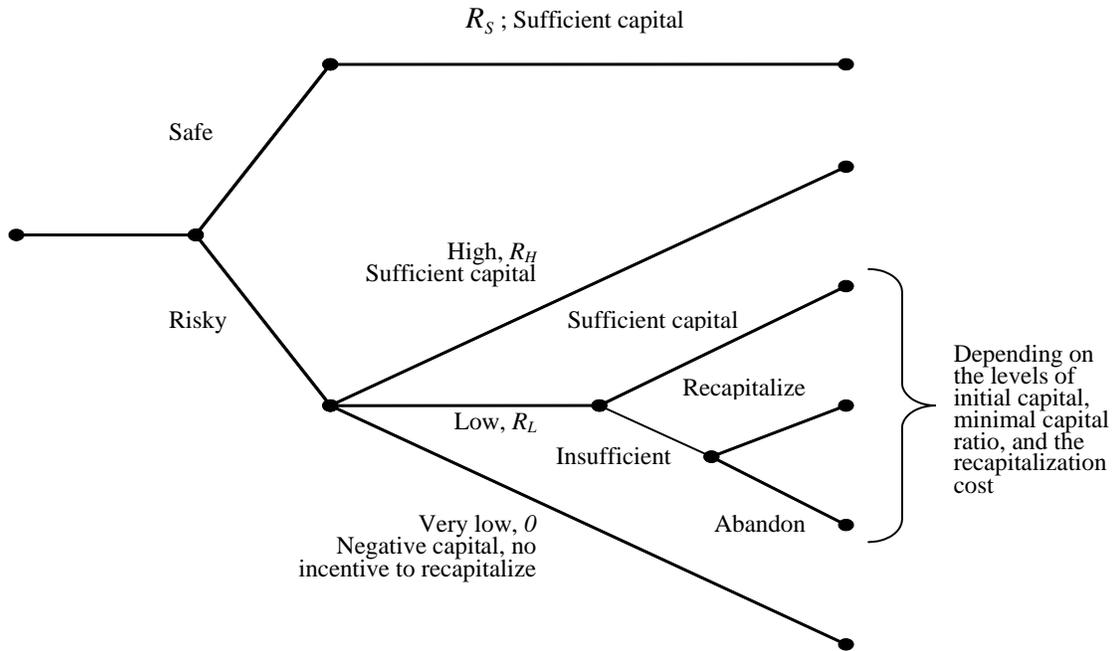
To conclude, we can argue that the qualitative results of Proposition 2 are valid under the relaxed assumption. Nevertheless, condition (T2b) has to be replaced by the relevant condition (T1a NEW).

Bank's choice when the return on safe project is large

Let us consider here that the return on the safe asset is large, that is $R_S > 1 - p + pR_H$. This drives the following results under assumption (4.8): (1) condition (T1a') is not satisfied, implying that $\forall c \in (0, c^{Re\ capitalize})$, the bank prefers the safe project; (2) condition (T1a) is satisfied, which implies that condition (T2a) is not and as a result $\forall c \in (c^{Re\ capitalize}, c^{Sufficient})$, the bank prefers the safe project; (3) condition (T3a) is not satisfied and as a consequence $\forall c \in (c^{Sufficient}, 1)$, the bank invests in the safe project. Summing up, for any levels of initial capital c , the bank prefers the safe project when the certain return R_S is high enough.

4.B Figures

Figure 1.
The timeline



Date 0

- Bank is endowed with capital C and deposits D
- Bank selects one project

Date 1/2

- Information about future returns becomes available
- Regulator takes corrective action (if necessary)
- Bank decides for recapitalization if subject to regulatory penalty

Date 1

- Returns are realized and distributed

Figure 3.

Bank's project choice

The figure depicts the bank's project choice depending on the level of initial capital, in Case (a) of Proposition 12. The relationship between bank capital and risk-taking is non-linear and is characterized by two thresholds as follows. When the level of capital is low ($c < c^*$), the bank prefers the risky asset, while for high level of capital ($c > c^{**}$) the safe asset is chosen. For intermediate level of capital ($c^* < c < c^{**}$), the bank prefers either the safe asset (for $c^* < c < c^{Sufficient}$) or the risky one (for $c^{Sufficient} < c < c^{**}$).

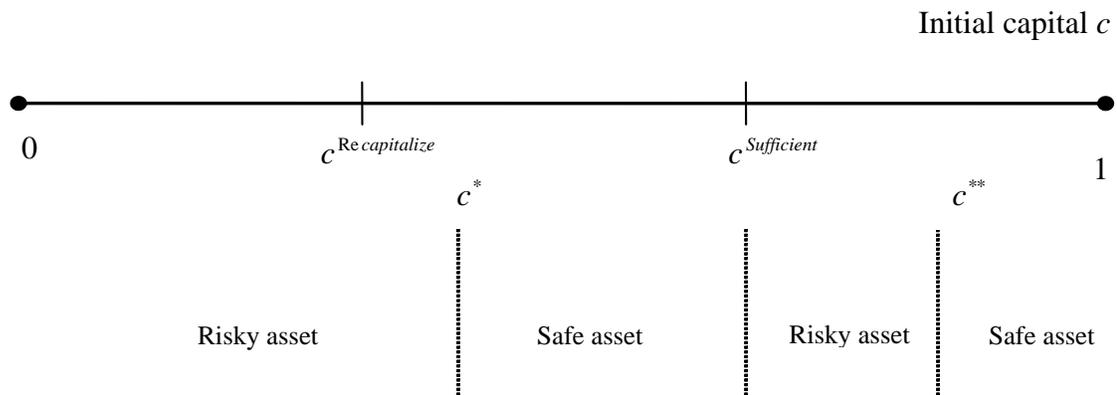


Figure 4.

Bank's project choice when the risky project has a heavier left tail

A heavier left tail is characterized by a higher probability for the extremely low outcome (i.e., a higher μ). A change in the return profile of the risky asset following a change in probability distribution (i.e., both p and μ are increased, other else equal, such that the expected value of the risky project remains the same), affects both thresholds c^* and c^{**} . The interval $(c^{Sufficient}, c^{**})$ widens, suggesting that well-capitalized banks which behave prudently in absence of tail risk projects, have a strong incentive to undertake more risk, if projects with heavier left tail are available in economy.

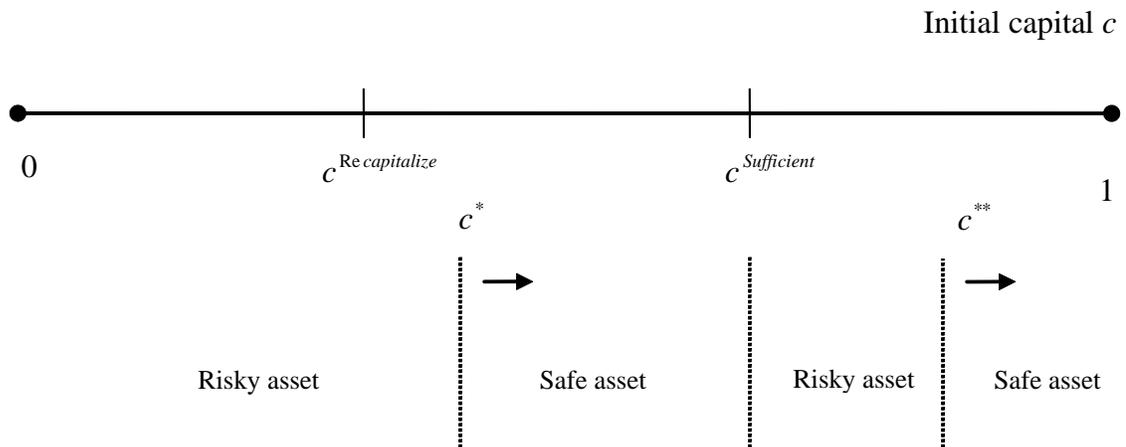
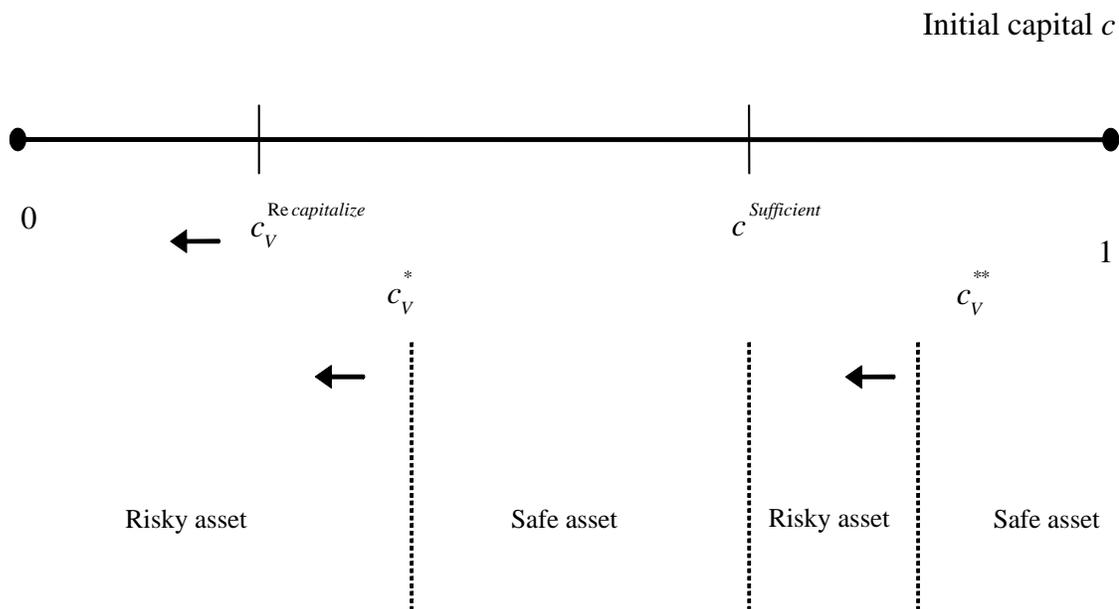


Figure 5.

Bank's project choice when the charter value is positive

The figure shows that charter value has a disciplining effect on bank risk-taking. It has a negative impact on the thresholds driving risk-shifting, and as a result, both intervals $(0, c_V^*)$ and $(c^{\text{Sufficient}}, c_V^{**})$ shrink.



Chapter 5

Conclusion

In this thesis, three essays are presented in each chapter. Chapter 2 studies a global game model of debtor runs on a bank and the role of a lender of last resort in mitigating strategic debtor behavior and bank moral hazard. I argue in this chapter that banks may be subject to risk of failure even when they have strong fundamentals due to a coordination problem among debtors. As a result of collective strategic default a solvent borrower may claim inability to repay if she expects a sufficient number of other borrowers do so as well, thus reducing bank's enforcement ability. I provide a model in which borrowers take simultaneous actions on the basis of imprecise private signals about bank's portfolio. The model has a unique equilibrium in which an attack against the bank occurs when bank's fundamentals are above some threshold level (i.e., bank fundamentals are bad). The model also helps us understand the role of the central bank as a lender of last resort under opportunistic behavior from borrowers. While an ex-post bailout policy is often believed to reduce bank incentives, in this case it mitigates moral hazard, with banks screening more their potential borrowers when the intervention cost of providing liquidity is high. I find that the presence of the lender of last resort reduces the extent of bank failures by lowering debtors' incentives for strategic default.

Chapter 3 experimentally studies the impact of uncertainty about bank and borrower fundamentals on loan repayment. These two sources of uncertainty are natural proxies for the regulatory rules for transparency and disclosure, and for the state of the economy. I show in this chapter that solvent borrowers are more likely to default strategically when stricter disclosure creates common knowledge about bank weakness. Borrowers are also less likely to repay during phases of higher uncertainty regarding other borrowers' financial health (i.e., during economic downturns), regardless of disclosure rules. Borrowing from the behavioral literature on coordination games I identify concepts that explain the observed variation in repayment. I show that uncertainty about fundamentals changes the risk dominance properties of the coordination problem, and that these changes subsequently explain borrower's default. For the individual borrower, loss aversion and negative past experiences reduce repayment, suggesting that bank failure can be contagious in times of distress.

Finally, chapter 4 revisits the relationship between bank capital and risk-taking. The traditional view is that higher capital reduces excess risk-taking driven by limited liability. I argue that this effect is diminished when banks can choose projects with high tail risk. Moreover there is an important opposing effect, associated with the costs of compliance with capital regulation. While a poorly capitalized bank may act risk-averse to avoid breaching the minimal capital ratio (which would force a costly recapitalization), a bank with higher capital may take more risk as it has a lower probability of breaching the ratio. Still, in the presence of tail risks, the highly capitalized banks do not internalize all the consequences of its risk-taking. The key result is that when banks have access to high tail risk projects, this can lead to excess risk-taking by highly capitalized banks in equilibrium. This demonstrates the limits of traditional capital regulation in mitigating banks' incentives to take tail risks. The results are consistent with stylized facts about pre-crisis bank behavior, and have implications for the optimal design of capital regulation.

Samenvatting (Summary in Dutch)

Dit proefschrift bevat drie essays. Hoofdstuk 2 presenteert een mondiaal speltheoretisch model over runs op banken en de rol van een “lender of last resort” (geldschieter in laatste instantie) bij het terugdringen van strategisch gedrag van debiteuren en moreel risico voor banken. Betoogd wordt dat zelfs banken met sterke fundamentele verhoudingen het risico lopen om te vallen als gevolg van coördinatieproblemen bij debiteuren. Bij collectieve wanbetaling op strategische gronden kunnen solvabele kredietnemers betalingsonmacht claimen als zij verwachten dat een voldoende aantal andere kredietnemers hetzelfde zal doen. Dit vermindert het handhavingspotentieel van banken. Een model wordt gepresenteerd waarbij kredietnemers gelijktijdig handelen op basis van onnauwkeurige private signalen over de portefeuille van een bank. Het model kent een uniek evenwicht waarbij een aanval op een bank plaatsvindt als de fundamentele verhoudingen van een bank zich boven een bepaald niveau bevinden (dat wil zeggen dat deze slecht zijn). Het model helpt ons ook de rol van de centrale bank als “lender of last resort” te begrijpen bij opportunistisch gedrag van kredietnemers. Hoewel vaak wordt gedacht dat een reddingsoperatie achteraf de prikkels voor banken doet afnemen, wordt in dit geval ook het moreel risico verminderd omdat banken potentiële kredietnemers strenger screenen als de kosten van interventie hoog zijn. De aanwezigheid van een “lender of last resort” reduceert het aantal bankfaillissementen door de prikkels voor strategische wanbetaling bij debiteuren te verlagen.

Hoofdstuk 3 beschrijft een experimentele studie naar het effect van onzekerheid over de fundamentele verhoudingen bij banken en debiteuren op het aflossen van leningen. Deze twee bronnen van onzekerheid vormen een natuurlijk substituuut voor de regelgeving met betrekking tot transparantie en openbaarheid en voor de staat van de economie. Solvabele debiteuren neigen vaker naar strategische wanbetaling wanneer strikte regelgeving leidt tot meer openbaarheid over de zwakheden van banken. Debiteuren zullen hun schuld ook minder snel aflossen in tijden van grotere onzekerheid over de financiële soliditeit van andere kredietnemers (dat wil zeggen tijdens een economische neergang), ongeacht de regelgeving. Op basis van de gedragsliteratuur met betrekking tot coördinatiemodellen worden variabelen in kaart gebracht die het waargenomen verschil in aflosgedrag verklaren. Aangetoond wordt dat onzekerheid over fundamentele verhoudingen leidt tot veranderingen in risicodominantie van het coördinatieprobleem, welke veranderingen vervolgens een verklaring vormen voor wanbetaling door debiteuren. Voor de individuele kredietnemer kunnen aversie tegen verlies en slechte ervaringen uit het verleden de kans op wanbetaling vergroten, hetgeen wijst op het gevaar van besmetting als een bank tijdens een crisis failliet gaat.

Hoofdstuk 4 bekijkt nog eens de relatie tussen bankkapitaal en risicovol gedrag. De traditionele zienswijze is dat buitensporig risicovol gedrag door beperkte aansprakelijkheid afneemt bij een groter kapitaal. Betoogd wordt dat dit effect geringer wordt als banken kunnen kiezen voor projecten met een hoog staartrisico. Bovendien is er een belangrijk tegengesteld effect dat voortvloeit uit de kosten van naleving van de solvabiliteitsregels. Hoewel een slecht gekapitaliseerde bank risicomijdend optreedt om niet onder de minimum kapitaalratio uit te komen (hetgeen tot een kostbare herkapitalisatie kan leiden), zal een bank met een groter kapitaal meer risico willen nemen omdat het minder moeite zal hebben om de kapitaalratio boven het vereiste minimum te houden. In het geval van staartrisico's zullen goed gekapitaliseerde banken echter niet alle consequenties van hun risicovol gedrag overzien. Het

voornaamste resultaat is dat wanneer deze banken toegang hebben tot projecten met een hoog staartrisico, dit in een evenwichtssituatie kan leiden tot buitensporig risicovol gedrag. Deze bevindingen leggen de grenzen bloot van de traditionele solvabiliteitsregels bij het beperken van de prikkels voor banken om een hoog staartrisico aan te gaan. De resultaten zijn consistent met de gestileerde feiten over het pre-crisis gedrag van banken. Dit brengt implicaties met zich mee voor de optimale structurering van de solvabiliteitsregels.

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