Three Essays in Banking

Theory and Empirics

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Alla mia famiglia e al Circolo

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> Se vi siete accorti che esiste una condizione umana che si possa vivere con un inquieto realismo, e che a volte prescinda dalla vostra volontà ma non per questo vi rassegnate, se non pretendete di essere soddisfatti quando non lo siete, ma anche se non avete mai pensato niente di tutto ciò perché la vostra intelligenza non arriva a 70, fatevi coraggio, il mondo è vostro, la situazione è eccellente!

Fabrizio Spargoli, May 2013

Abstract

This thesis revolves around financial instability and banking regulation. The first chapter examines whether the disclosure of information about banks maximizes welfare in times of crisis. Contrary to conventional wisdom, we demonstrate that transparency is optimal only if banks' distress can be efficiently resolved. The second chapter provides an explanation for the observed inability of market participants to assess banks' solvency in times of crisis. We demonstrate that banks' incentives to understate losses lead to an equilibrium where no information is available in the market in times of crisis, and this makes banks take excessive risk ex-ante. The third chapter, coauthored with Philipp Ager, provides an empirical analysis of the effects of liberalization on bank competition and bank failures. Using the relaxation of bank entry barriers in the 19th century US as a case study, we find that liberalization increases bank entry by 11% and bank failures by 2.6%.

Resum

Aquesta tesi tracta sobre la inestabilitat financera i la regulació bancària. El primer capítol examina si la divulgació d'informació sobre els bancs maximitza el benestar en temps de crisi. Contràriament a la saviesa convencional, es demostra que la transparència és òptima només si els problemes dels bancs es poden resoldre de manera eficient. El segon capítol ofereix una explicació de la incapacitat observada dels participants del mercat per avaluar la solvència dels bancs en temps de crisi. Es demostra que els incentius dels bancs a subestimar les pèrdues porten a un equilibri en el qual no hi ha informació disponible al mercat en temps de crisi, i on els bancs prenen riscos excessius ex-ante. El tercer capítol, en coautoria amb Philipp Ager, proporciona una anàlisi empírica dels efectes de la liberalització sobre la competència bancària i fallides bancàries. Utilitzant la relaxació de les barreres a l'entrada dels bancs als EUA al segle XIX com a cas d'estudi, ens trobem que la liberalització augmenta l'entrada de bancs en un 11% i la fallida de bancs en un 2,6%.

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Foreword

This thesis is composed of three self-contained chapters that revolve around financial stability and bank regulation.
The first chapter examines the trade-off faced by a welfare-maximizing regulator who can choose whether to disclose banks' capital shortfall in crisis times. This study is motivated by the fact that, during the recent financial crisis, uncertainties about banks' solvency paralyzed financial markets and persuaded regulators to reveal an unprecedented amount of information about banks. While conventional wisdom suggests that stress test results should be disclosed to enable the market to sort out the good from the bad banks, we demonstrate that full information disclosure might not be optimal in times of crisis. Disclosure forces banks to reduce their risk of default, but leads them to downsize unless the regulator is able to recapitalize the banks that do not replenish their shortfall. We show that a regulator who cannot recapitalize banks will prefer less information to be disclosed if the costs of downsizing are greater than expected default costs. In the opposite case, or in case the regulator is able to recapitalize banks, we demonstrate that banks' capital shortfall will be fully revealed. Our model explains why the market's reaction to stress tests was favorable in the U.S. and negligible in Europe. Our results also have implications for bank regulation. Among them, we highlight that recapitalizing banks through the European Stability Mechanism would make bank stress tests more effective in Europe.
The second chapter demonstrates that the observed inability of the market to judge banks' solvency in times of crisis arises from a signaling externality that ailing banks exert on other banks. The intuition is that banks might want to hide their bad loans in order to raise debt at a lower cost. In times of crisis, sounder banks cannot bear the cost of disclosing fewer losses and signal their better financial condition. Hence we show that all banks reveal the same information in equilibrium. Our results have implications for bank regulation. First, banks' capital matters not only as a cushion to absorb losses, but also for the incentives to disclose information in crisis times. Second, consistent with empirical evidence, market discipline per se is not effective in crisis times. Regulators should accompany market discipline with higher capital requirements, or conduct stress tests and efficiently resolve banks' distress.
The third chapter, coauthored with Philipp Ager, examines the impact of removing bar-

riers to bank entry on bank failures exploiting the introduction of free banking laws in US states during the 1837-1863 period. Focusing on this historical event allows us to: (1) rule out the confounding effects of state implicit guarantees; (2) identify the causal relation using contiguous counties on the border of states with different regulation. Our main finding is that counties in free banking states experienced significantly more bank failures. We also provide evidence that the individual probability of failure of both incumbent and entering banks was significantly higher in free banking states. We argue that the destabilizing effect of free banking is consistent with the view that bank competition leads to more risk taking. Our results suggest that the introduction of free banking led to more bank entry and caused a significant drop in the market share of incumbent banks.

Chapter 1

BANK RECAPITALIZATION AND THE INFORMATION VALUE OF A STRESS TEST IN A CRISIS

1.1 Introduction

Regulators responded to the recent financial crisis with extraordinary measures, including bank stress tests. Stress tests are simultaneous and forward-looking bank examinations that aim to assess the value of banks' capital in a hypothetical adverse scenario. Unlike ordinary bank examinations, the results of bank stress tests in the U.S. and Europe were publicly disclosed. The rationale behind this unprecedented information disclosure rests on the view that banks' opacity contributed to the recent financial crisis[1]. According to this view, banks' opacity impaired the ability of investors to assess banks' solvency after the subprime crisis exploded in August 2007. Investors became reluctant to lend fearing information asymmetries. This caused the worsening of banks' funding conditions over the course of the recent financial crisis.

The conventional wisdom is that regulators should disclose stress test results because this would enhance the transparency of banks, as stress tests provide more thorough information than available to the market. Transparency would revive financial markets enabling market participants to sort out the good from the bad banks. While restoring trade in financial markets is surely a benefit of information disclosure, the nature of the information revealed by stress tests, that is banks' capital shortfall, implies that the conventional wisdom might not always be true. The reason is that banks' undercapitalization entails social costs per se, especially in times of crisis. First, the lower

[1]Heider et al. (2009) describe the functioning of interbank markets during the recent financial crisis, and provide a theoretical explanation based on adverse selection. Gorton (2008), Dudley (2009), and Lewis (2008) argue that banks' opacity contributed to the 2007-2009 financial crisis.

bank's capital, the more likely bank default. A bank default generates social costs, as the turmoil that followed Lehman Brothers' bankruptcy has demonstrated. Second, governments often inject taxpayers' money into banks in times of crisis. The costs of rescuing banks became evident during the recent crisis, with southern European countries and Ireland caught in a bank-sovereign downward spiral. Third, the lack of capital impairs the ability of banks to supply credit. The reduction in the credit supply is one of the channels through which a shock to banks turned into a severe economic crisis. All in all, other frictions besides information asymmetries exist in times of crisis. Hence it is unclear from a theoretical point of view whether information disclosure is optimal in times of crisis.

This paper examines whether the disclosure of information about banks maximizes welfare in times of crisis. We are interested in the interaction among the disclosure of banks' capital shortfall, regulator's ability to recapitalize banks, and the choice of banks to replenish their capital. The disclosure of banks' capital shortfall leads banks to replenish their capital and hence to reduce their probability of default. However, replenishing capital in times of crisis requires either state recapitalization or a reduction in banks' size. This leads to the following trade-off: Information disclosure leads to a reduction in banks' risk of default, but costs either taxpayers' money or a lower supply of credit.

We provide a positive analysis of bank stress tests, and abstract from socially optimal regulatory policies. We take as our starting point that regulators adopted bank stress tests as a response to the recent financial crisis, and examine the effectiveness of bank stress tests in times of crisis. Our crisis environment includes some key features of financial crises: Asymmetric information about banks' capital shortfall, banks' reluctance to raise capital in the market[2], costs of recapitalization, default[3], and downsizing. We consider a regulator who discloses information about banks' capital shortfall and can recapitalize banks. The regulator can manage information disclosure choosing the accuracy of the stress test. We interpret accuracy as the amount of information the stress test is based on, and the effort in extracting this information from banks. The higher accuracy, the greater the probability that a stress test identifies a bank with a capital shortfall out of the pool of banks. We prefer this interpretation to one where regulators lie about banks because regulators usually disclose data about banks' risk exposure and the stress testing methodology[4]. This enables the market to verify the results of stress tests.

We show that a welfare-maximizing regulator fully reveals banks' capital shortfall if it

[2]Banks' reluctance to raise capital in the market is consistent with the empirical evidence in Adrian and Shin (2011), who show that adjustments in banks' leverage occur through changes in banks' asset size

[3]Banks' default destroys the value of bank-borrower relationships (see Slovin et al. (1999)), and generates contagion (see Allen and Gale (2000b), Freixas et al. (2000)).

[4]This was the case for the U.S. SCAP program and the 2011 EU-wide stress test. The 2010 EU-wide stress test did not require the disclosure of risk exposures, but most of banks voluntarily disclosed them. The 2009 EU-wide stress test did not require the disclosure of any information.

can recapitalize banks. In case it cannot, we demonstrate that partial disclosure might be optimal. The logic of our argument is that market discipline forces banks to replenish their capital. Banks will raise capital in the market only if the regulator has easy access to funds and hence can credibly threaten recapitalization. In this case, the regulator will fully reveal banks' capital shortfall because banks fill their capital shortfall and invest. If the regulator cannot recapitalize banks, banks will downsize and a trade-off will arise. Downsizing reduces the probability of default, but at the cost of foregoing valuable investment opportunities. Optimal information disclosure will depend on the relative magnitude of these two costs. In case the foregone returns are greater than expected default costs, the regulator will prefer less information to be disclosed. However, the regulator will have incentives to reveal at least part of banks' capital shortfall to prevent the remaining banks from downsizing. In spite of not being able to recapitalize banks, the regulator will fully reveal banks' capital shortfall if expected default costs are greater than the foregone returns on assets.

Our results explain some empirical and anecdotal evidence about stress tests in the US and Europe. First, our model links the favorable market's response to the U.S. stress test (see Greenlaw et al. (2012), Peristiani et al. (2010), Hirtle et al. (2009), and Schuermann (2012)) to the implementation of the Capital Assistance Plan (CAP). As the U.S. could raise funds at relatively low costs, the CAP was a credible backstop mechanism[5]. Indeed, U.S. banks filled the $ 75 bn capital shortfall raising capital in the market. Second, our model relates the skeptical market's reaction to the European stress tests (Greenlaw et al. (2012), Hirtle et al. (2009), and Schuermann (2012)) to the lack of a credible EU-wide backstop mechanism and to the different incentives of EU's members. Countries in EU's periphery were reluctant to borrow from the European Financial Stability Facility (EFSF) fearing that this would precipitate a bank-sovereign downward spiral. Using taxpayers' money to save banks would have been politically costly for core EU countries. Regulators had little powers to prevent European banks failing the stress test from downsizing. Downsizing was presumably more costly in Germany, where the economy was performing well, than in Spain, which was in the midst of a crisis originated by the burst of a property bubble. According to our model, and consistent with anecdotal evidence, the German regulator should have preferred less information to be disclosed than the Spanish. As the different incentives of EU's members had presumably to be considered, European stress tests ended up being not as effective as in the U.S. Few banks failed the European stress tests, and all of them were either restructured or acquired by other banks.

Our model implies that the recapitalization of banks is crucial for the effectiveness of bank stress tests in times of crisis. The reason is that only second best equilibria arise

[5]The CAP program would provide mandatory convertible shares (MCP) in case banks failing the stress test were unable to raise capital privately. MCP shares would convert to common equity if the condition of banks did not improve within a defined time period.

if banks failing the stress test do not raise capital in the market. In equilibrium, either some banks default and/or downsize. We highlight two policy implications following from this result. First, directly injecting capital into struggling banks through the European Stability Mechanism (ESM) would make stress tests more effective in Europe. The costs of recapitalization would fall on the ESM and not on the countries. Second, banks should be required to maintain a certain absolute level of capital rather than a capital to assets ratio, as argued by the supporters of the macroprudential approach to banking regulation (see Greenlaw et al. (2012) for example). Banks would downsize independently of regulator's funding costs if capital requirements are expressed in ratio terms.

A broader implication of our model is that the efficient resolution of banks' distress matters for the effectiveness of bank stress tests in times of crisis. In a more general model than ours, bank distress could be resolved not only by injecting capital, but also by restructuring banks. Restructuring consists in renegotiating banks' liabilities, as in debt-for-equity swaps, or both banks' assets and liabilities, as in "good-bank/bad-bank" solutions. If restructuring gives banks enough capital to sustain the lending activity, and does not cost taxpayers' money, there would be no social costs associated to the disclosure of banks' capital shortfall. This would make bank stress tests effective policy instruments in times of crisis. In our model there is a gain from recapitalizing banks failing the stress test, as the net present value of their assets in place is positive. Recapitalization would not be worth in case financial distress is more severe, and banks cannot continue as going concerns. In this case, efficient bankruptcy procedures would lower the costs of disclosing banks' capital shortfall and make bank stress tests effective policies instruments.

The resolution of banks' distress and the disclosure of bank supervisory information have been considered in isolation by most of the existing literature. A strand of literature has examined the reasons why regulators might have incentives to forbear rather than resolve a weak bank[6]. In our model, the regulator faces a similar choice having to decide whether to reveal the capital shortfall of a bank. Another strand of literature has addressed the question whether regulators should disclose the results of ordinary bank examinations, which are usually kept confidential. Jordan et al. (1999) argued in favor, showing that announcing formal enforcement actions enhanced market discipline during the U.S. "Savings and Loan" crisis. Berger et al. (2000), Berger and Davies (1998), and Flannery and Houston (1999) find evidence that bank examinations have an information value. However, Prescott (2008) provides a theoretical argument against disclosure pointing out that disclosure might reduce the incentives of regulators to collect information from banks. Goldstein and Sapra (2012) provide a survey of second best theoretical environments where information disclosure might not be socially opti-

[6]See for example Mailath and Mester (1994), Morrison and White (2011), Boot and Thakor (1993), Repullo (2000), and Kahn and Santos (2005).

mal. They argue that disclosing aggregate stress test results could minimize the social costs of disclosure. Our main contribution is to bridge these two strands of literature and point out that the resolution of banks' distress is crucial for regulators' incentives to disclose information.

The closest paper to ours is Shapiro and Skeie (2012). The authors also relate the disclosure of stress test results to regulator's ability to recapitalize banks. They demonstrate that a high funding cost regulator prefers transparency in times of crisis, that is when priors about the banking system are negative. In their model the regulator reveals bank's type because asymmetric information leads investors to run good banks if priors are unfavorable. Bank's type might be revealed by a stress test or might be signaled by an equity injection. A regulator will prefer to run a stress test rather than inject equity if its funding costs are high and priors are unfavorable. Our contribution is to model banks' reaction to information disclosure, which Shapiro and Skeie (2012) do not consider. Modeling banks' reaction allows us to consider the trade-offs between costs of recapitalization and costs of reducing the credit supply, and costs of reducing the credit supply and default costs. These trade-offs are crucial in the macroprudential approach to banking regulation.

Other theoretical papers about bank stress tests examine whether disclosure is optimal, but do not relate disclosure to bank resolution policies. Bouvard et al. (2012) demonstrate that transparency is optimal in times of crisis but not in normal times. The reason is that disclosing stress test results prevents a bank run on the whole banking system in bad times (when priors are unfavorable). In good times opacity is optimal because it prevents bank runs on weak banks. Gick and Pausch (2012) demonstrate that disclosing stress test results together with the stress test methodology is optimal in a context where regulators can affect investors' beliefs about the banking system.

This paper is structured as follows. Section 2 outlines the model setup. Sections 3 and 4 describe the equilibrium of the game between investors, banks, and the regulator. Section 5 highlights the empirical predictions, while Section 6 outlines the policy implications. Section 7 concludes the paper.

1.2 The Model Setup

We consider a game with a regulator, a continuum of risk neutral and competitive investors, and a measure 1 of banks.

1.2.1 The Payoff of Banks

Banks start out with a predetermined stock of debt D, a measure 1 of assets, and an amount of cash c. Cash can be exogenous profits realized at the beginning of the period, or the liquidity previously stored by banks. The value of assets at time 1 differs across banks and is not known to investors. A measure $1 - \beta$ of banks, which we define bad (B) banks, has a capital shortfall $D - A_B^A$ in the adverse state of the world (A). In the favorable state of the world, bad banks have positive equity as their assets are worth $A_B^F + b$, and $A_B^F > D$. We assume that b is not verifiable and cannot be pledged to investors[7]. The complementary fraction β of banks, which we define good (G) banks, has positive equity in both states of the world. For simplicity, we assume that their assets are worth A_G $(> D)$ independently of the state of the world. The state of the world realizes at time 1 and can be adverse or favorable with probability α and $1 - \alpha$. At time 0, banks need to rollover debt and refinance a fraction ρ of assets. We assume $\rho = c$ for simplicity, so that banks can potentially use their cash to refinance the assets in place. Table 1.1 summarizes banks' payoffs. If the bank downsizes, it foregoes the return at time 1 but keeps the cash. As in Holmstrom and Tirole (1998), refinancing might capture additional cash needs or operational expenditures of firms borrowing from the bank. If firms do not meet this cash needs, their investment will not succeed and the bank will not be repaid. As in the baseline version of Holmstrom and Tirole (1998), the bank can only choose whether to refinance assets or not. Partial refinancing is not allowed.

Table 1.1: Payoff structure

	Good Banks	**Bad Banks**	
	A & F State	*A State*	*F State*
Refinance (R)	A_G	A_B^A	$A_B^F + b$
Downsize (DS)	$c + (1-c)A_G$	$c + (1-c)A_B^A$	$c + (1-c)(A_B^F + b)$

1.2.2 Banks' Reaction to Disclosure

We consider an environment where banks' capital shortfalls, together with the non verifiability of the return b, generate funding problems for bad banks and give them incentives to increase their capital. The following assumptions describe this environment.

[7]The return b might represent the return from opaque activities which is difficult to assess by outside investors. It can also be interpreted as the compensation that makes the bank manager willing to implement the efficient investment project (see, for example, Hart and Moore (1994) and Holmstrom and Tirole (1998)).

Assumption 1.

$$\alpha A_B^A + (1-\alpha)(A_B^F + b) > 1 > D.$$

Assumption 2.

$$\alpha A_B^A + (1-\alpha)A_B^F < D.$$

Assumption 3.

$$c + (1-c)A_B^A > D.$$

Assumptions 1, 2, and 3 represent an environment where downsizing allows bad banks to regain access to market funding, but at the costs of giving up assets with a positive net present value. Investors rollover bank's debt if the return from lending to the bank equals the return from keeping D and investing it at the risk free rate, which we assume to be zero. Assumptions 1 and 2 imply that there is a wedge between the return on banks' assets and the return that can be pledged to investors. By Assumption 2, this wedge is such that investors would run bad banks if they do not increase their capital. For simplicity, I assume that investors recover $\alpha A_B^A + (1-\alpha)A_B^F$ in case they run bad banks[8]. By Assumption 3, downsizing allows banks to restore solvency.
Bad banks might avoid downsizing by raising equity in the market. In order to raise E, bad banks must promise investors a return on equity such that

$$s_B(E)V_B(E) = (1+\eta)E.$$

Bad banks must promise investors a return on equity at least as large as the outside option. We assume that η is greater than zero, meaning that investors require a higher compensation for investing in equity rather than debt[9]. The return on equity is a fraction $s_B(E)$ of bank's value after the equity injection E. This value, which we denote $V_B(E)$, is given by

$$\begin{aligned} V_B(E) &= (1-\alpha)(A_B^F + b + E - DR) + \alpha \max\{A_B^A + E - DR,\ 0\} \\ &= \mathbb{E}[A_B] + (1-\alpha)b - D + E. \end{aligned}$$

Bank's value after the equity injection E is the sum of the new equity E and the value of the old shares. The value of the old shares equals the profit from refinancing the assets in place.

[8] Assuming the inefficient liquidation of banks' assets is not necessary to have socially costly bank runs. In fact, bank runs cost the loss of the return b on all the assets in place, and the default cost C.

[9] The higher compensation for investing in equity rather than debt depends on various reasons. For example, η might represent a shortcut for the premium required by risk adverse investors in order to invest in equity rather than debt. It might also be interpreted as the compensation for the higher level of expertise and sophistication required by an investment in equity.

Bad banks choose how much equity to raise given investors' optimal strategy. The optimal choice solves the following problem:

$$\max_{E} \; (1 - s_{B}(E))\, V_{B}(E)$$
$$\text{subject to } E \geq D - \mathbb{E}[A_{B}].$$

The amount of equity that must be raised is at least such that the value of debt equals the value of assets that can be pledged to investors. As the new equity is invested in cash and has a marginal cost of η, the optimal choice is $E^{*} = D - \mathbb{E}[A_{B}]$.

1.2.3 The Crisis Environment

We take as given two facts that characterize crisis times: Banks' reluctance to raise capital and asymmetric information.

Banks' Reluctance to Raise Capital

Examining the balance sheet of financial intermediaries, Adrian and Shin (2011) find that equity is constant over time, and deleveraging occurs mainly through adjustments in the size of assets. Their finding holds both in normal and crisis times. The fact that banks are reluctant to raise equity emerges also from anecdotal evidence. The following statement, by a bank board member from the eurozone's periphery, is enlightening: "*What you want to do in the current environment is shrink and lend less, not issue capital at a discount to lend more"*[10]. The environment he was referring to was characterized by bank stocks trading at a price equal to 50-60% the book value of equity. Raising capital would have implied high dilution costs for existing shareholders.
Consistent with this evidence, we make the following assumptions.

Assumption 4.
$$\eta(D - E[A_{B}]) > c(\mathbb{E}[A_{B}] - 1)$$

Assumption 5. We rule out "*money burning*" signals.

Assumption 4 states that the costs of raising bad banks' optimal amount of equity is greater than the net present value of bad banks' assets. Bad banks prefer to downsize rather than raise equity in the market. Assumption 5 means that banks can only raise the amount equity required by the investment opportunity[11]. In our model, Assumption 5 implies that bad banks can raise equity but good banks cannot. Bad banks have to raise equity in order to refinance assets and rollover their debt. By contrast, good banks do not need additional funds because they are solvent even if they reinvest cash. Good

[10] From "Banking: That shrinking feeling", FT May 3, 2012.
[11] See Myers and Majluf (1984) and Noe (1988) for theoretical models making this assumption.

banks would be "burning money" by raising equity, as they would make a loss η on each unit of capital they raise. As the empirical and anecdotal evidence shows that banks are reluctant to raise capital in the market, and in our model good banks make losses by raising equity, Assumption 5 seems to be plausible in a crisis situation.

Asymmetric Information

In line with the view linking the recent financial crisis to banks' opacity, we consider a setup where investors cannot distinguish bank's type. Investors know only the prior distribution of banks, and the actions of banks do not reveal their type. The model setup rules out all the possible separating equilibria. First, there exists no separating equilibrium where the bad bank refinances assets without raising capital. Investors would not rollover debt and the bank would make zero profits. Mimicking the good bank would always be more profitable for the bad bank. Second, there exists no separating equilibrium where the bad bank downsizes and the good bank refinances assets. The bad bank could refinance its assets in place pretending to be good as investors would rollover the debt D.

1.2.4 Bank Recapitalization and Information Disclosure

The objective of the regulator is to maximize aggregate welfare. Aggregate welfare is the sum of banks' and investors' payoffs net of the cost C in case a bank defaults and λE in case the regulator injects E in banks. Default costs capture the inefficiencies from disorderly bank liquidation, like fire sales or contagion, the direct costs of bank liquidation, and the loss of bank-borrower relationships. The parameter λ represents a shortcut for regulator's access to funds. For example, a country experiencing a sovereign crisis will have a higher λ than a country with sound public finances.

The regulator chooses the accuracy of the stress test and discloses the results at time 0. Stress tests allow the regulator to ameliorate adverse selection. We model the stress test as a signaling technology detecting good banks with no error and bad banks only with probability a. The probability a represents the accuracy of the stress test. We interpret accuracy as the choice of the quality and quantity of information to acquire and disclose. For example, a stress test might examine the banking book besides the trading book, dig into banks' funding conditions, and exclude hybrids and sovereign support measures from the core tier 1 capital[12]. Banks usually submit stress test disclosures to the regulator, which checks their consistency with the guidelines and with the results of other banks. If the regulator checks banks' disclosures with more diligence, it will

[12]These are among the proposals that some commentators have made to improve the disappointing 2010 EU-wide stress test exercise. See 'Building a better European stress test', FT Alphaville December 07, 2010; 'Doubts return on stress tests credibility', FT 23 November, 2010.

be able to detect banks' misreports and improve the quality of disclosures[13]. Accuracy determines the size and the quality of the pool of banks passing the stress test. This pool is composed of all good banks (β) and the fraction $(1-\beta)(1-a)$ of bad banks that are not detected. In line with our interpretation of the stress test accuracy, assuming one-sided errors captures the fact that bad banks might be more opaque or more likely to use accounting tricks. As a result, bad banks are more difficult to detect.
The regulator chooses whether to inject equity in banks failing the stress test at time t_1. We make the following assumption.

Assumption 6.

$$\min\{\lambda E_H,\, \lambda E_L + \alpha C\} < (1-\alpha)b + C$$

where $E_H = D - A_B^A$ and $E_L = D - \mathbb{E}[A_B]$.

Assumption 6 states that the costs of injecting the amount of capital that prevents a run on bad banks is smaller than the social costs of a bank run. Therefore the regulator prefers the recapitalization of banks failing the stress test to a bank run. This assumption reduces the number of cases to consider, and allows us to focus on the trade-off between bank recapitalization and downsizing.

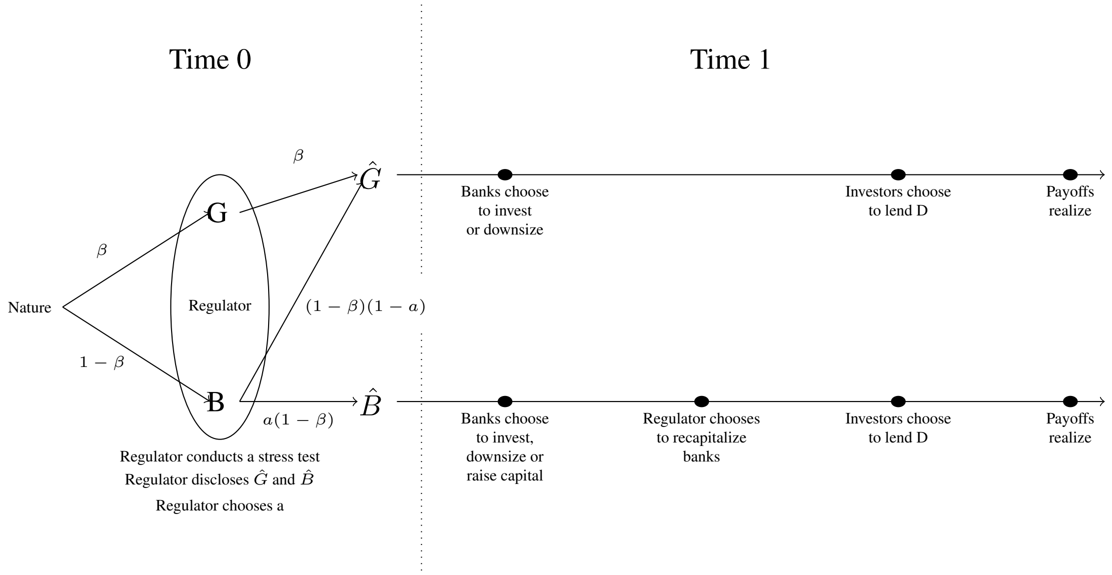
1.2.5 Timing

Figure 1.1 illustrates the timeline of the game. At time 0, the regulator conducts a stress test, chooses its accuracy, and discloses the results. By our assumption on the stress testing technology, $a(1-\beta)$ bad banks fail the stress test and $1-a(1-\beta)$ pass it. The pool of banks passing the stress test includes $(1-a)(1-\beta)$ bad banks. Banks play at time 1 conditional on the results of the stress test. They choose whether to refinance assets and raise capital at the beginning of time 1. Conditional on this choice, the regulator decides whether to inject equity in bad banks unable to replenish their capital[14]. Investors decide whether to rollover D conditional on banks' and regulator's choices. Finally, payoffs realize at the end of time 1.

[13]Commentators have found out a number of misreports by banks. For example, '*UniCredit did not disclose market-by-market data relating to its operations in eastern European countries within the EU, appearing instead to lump it into its Austrian numbers*'. Lloyds Banking Group suffered large losses from its Irish business and '*revealed its European credit exposures only in the UK in this years tests, saying exposures in other countries fell below the EBAs threshold for disclosure, at 5 per cent of total exposures*'. See 'Quality of stress test disclosures a mixed bag', FT 17 July, 2011.

[14]We assume that the bank can refinance assets until t_1. If assets could be refinanced only at time 0, the regulator will never find it optimal to inject equity as the investment opportunity would be lost.

Figure 1.1: The Timing of the Game



1.3 The Equilibrium in Period 1

At time 0 there are $a(1-\beta)$ banks that have failed and $\beta + (1-\beta)(1-a)$ banks that have passed the stress test. These banks play simultaneously, but there is no interaction among them. We can split the analysis and consider two subgames. The first is between banks that have failed the stress test, the regulator and investors. The second game is between banks that have passed the stress test and investors. The regulator does not participate to this subgame. Policies in favor of banks deemed under capitalized usually accompany stress tests. Banks passing the stress test are not required to raise capital. We take this fact as given and abstract from the reasons why this happens and whether this is the optimal choice. This modeling choice allows us to focus on the issue of our interest.

Before proceeding with the analysis, it is useful to introduce the following definition.

Definition 1. Social value of banks.

$$W_G^{DS} = (1-c)A_G + c$$
$$W_B^{DS} = (1-c)\left[\mathbb{E}[A_B] + (1-\alpha)b\right] + c$$
$$W_G^{R} = A_G$$
$$W_B^{R} = \mathbb{E}[A_B] + (1-\alpha)b$$

Definition 2 defines the social value of good and bad banks in case they refinance assets (R) or downsize (DS). The social value of bank is the sum of the payoffs of new shareholders, old shareholders, and investors.

1.3.1 The Equilibrium Conditional on Failing the Stress Test

This game is between banks that have failed the stress test, the regulator, and investors. There is no asymmetric information among agents because the stress test perfectly identifies bad banks. Bad banks play anticipating the optimal choices by investors and the regulator. Investors force bad banks to increase their capital by threatening not to rollover the debt. By Assumption 4, bad banks prefer to downsize rather than raise capital in the market. The regulator might force banks to raise capital by threatening equity injections. While investors' threat is always credible, regulator's threat might not be. We will proceed by analyzing regulator's optimal behavior, and then showing the equilibrium of the subgame.

Regulator's Behavior

The regulator can choose whether to inject an amount of capital E_{Reg} in the banks that have failed the stress test. It requires a share s_{Reg} of their value in exchange of the equity injection. The regulator decides at time t_1 conditional on the choice of banks whether to downsize or raise capital in the market.
In case bad banks downsize, the optimal equity injection E_{Reg} solves the following problem:

$$\max_E W(E) = \begin{cases} a(1-\beta)(W_B^R - \lambda E) & \text{if } E \geq D - A_B^A \equiv E_H \\ a(1-\beta)(W_B^R - \alpha C - \lambda E) & \text{if } E \in \left[D - \mathbb{E}[A_B],\ D - A_B^A\right) \\ a(1-\beta)(W_B^{NR} - \lambda E) & \text{if } E < D - \mathbb{E}[A_B] \equiv E_L \end{cases}$$

At this stage, regulator's choice does not affect the banks that have passed the stress test. The welfare function only includes the value of banks that have failed the stress test. There are two discontinuities in the choice of equity. The bad bank refinances assets if $E \geq E_L$. It becomes solvent in both states of the world if $E \geq E_H$, whereas it defaults in the adverse state if $E \in [E_L,\ E_H)$. The regulator bears the default cost C if this state realizes. The bad bank downsizes if $E < E_L$ because investors would not rollover debt otherwise.
Assumption 6 states that the regulator prefers recapitalization to a bank run. Therefore the regulator injects either E_L or E_H in the banks failing the stress test that do not raise capital in the market and refinance assets.
In case banks failing the stress test raise E_L in the market, the regulator solves the following problem:

$$\max_E W(E) = \begin{cases} a(1-\beta)(W_B^R - \lambda E) & \text{if } E \geq E_H - E_L \\ a(1-\beta)(W_B^R - \alpha C - \lambda E) & \text{if } E < E_H - E_L \end{cases}$$

The regulator can prevent banks' default by injecting at least $E_H - E_L$ and filling banks' capital shortfall. If the regulator injects a lower amount of equity, banks failing the stress test will invest but default with probability α.
The following Lemma illustrates regulator's optimal behavior.

Lemma 1. *If banks failing the stress test do not raise capital and refinance assets, the optimal equity injection is:*

$$E^*_{Reg} = \begin{cases} E_H & \text{if } \lambda E_H \leq \lambda E_L + \alpha C \\ E_L & \text{if } \lambda E_H > \lambda E_L + \alpha C, \end{cases}$$

where $E_H \equiv D - A^A_B$, *and* $E_L \equiv D - \mathbb{E}[A_B]$.
If banks failing the stress test downsize, the optimal equity injection is:

$$E^*_{Reg} = \begin{cases} E_H & \text{if } \lambda E_H \leq \min\{cNPV_B,\ \lambda E_L + \alpha C\} \\ E_L & \text{if } \lambda E_L + \alpha C \leq \min\{cNPV_B,\ \lambda E_H\} \\ 0 & \text{if } cNPV_B < \min\{\lambda E_H,\ \lambda E_L + \alpha C\}, \end{cases}$$

where $NPV_B \equiv \mathbb{E}[A_B] + (1-\alpha)b - 1$.
If banks failing the stress test raise E_L *in the market, the optimal equity injection is:*

$$E^*_{Reg} = \begin{cases} E_H - E_L & \text{if } \lambda E_H \leq \lambda E_L + \alpha C \\ 0 & \text{if } \lambda E_H > \lambda E_L + \alpha C. \end{cases}$$

If banks failing the stress test raise E_H *in the market, the optimal equity injection is 0.*

Proof. The optimal solution to regulator's problem is either E_H, E_L or 0 because welfare is strictly decreasing in E.
Investors would run banks failing the stress test if they do not raise capital and refinance assets. By Assumption 6, the regulator prefers bank recapitalization to a bank run. The optimal equity injection is either E_H or E_L. The regulator injects the amount of capital that minimizes social costs.
In case banks failing the stress test downsize, it holds that:

- E_H is optimal if

$$W^R_B - \lambda E_H \geq \max\{W^R_B - \lambda E_L - \alpha C,\ W^{NR}_B\}.$$

  This inequality holds if

$$\lambda E_H \leq \min\{cNPV_B,\ \lambda E_L + \alpha C\}.$$

- E_L is optimal if

$$W_B^R - \lambda E_L - \alpha C \geq \max\{W_B^R - \lambda E_H,\ W_B^{NR}\}.$$

  This inequality holds if

$$\lambda E_L + \alpha C \leq \min\{cNPV_B,\ \lambda E_H\}.$$

- 0 is optimal if

$$W_B^{NR} \geq \max\{W_B^R - \lambda E_H,\ W_B^R - \lambda E_L - \alpha C\}.$$

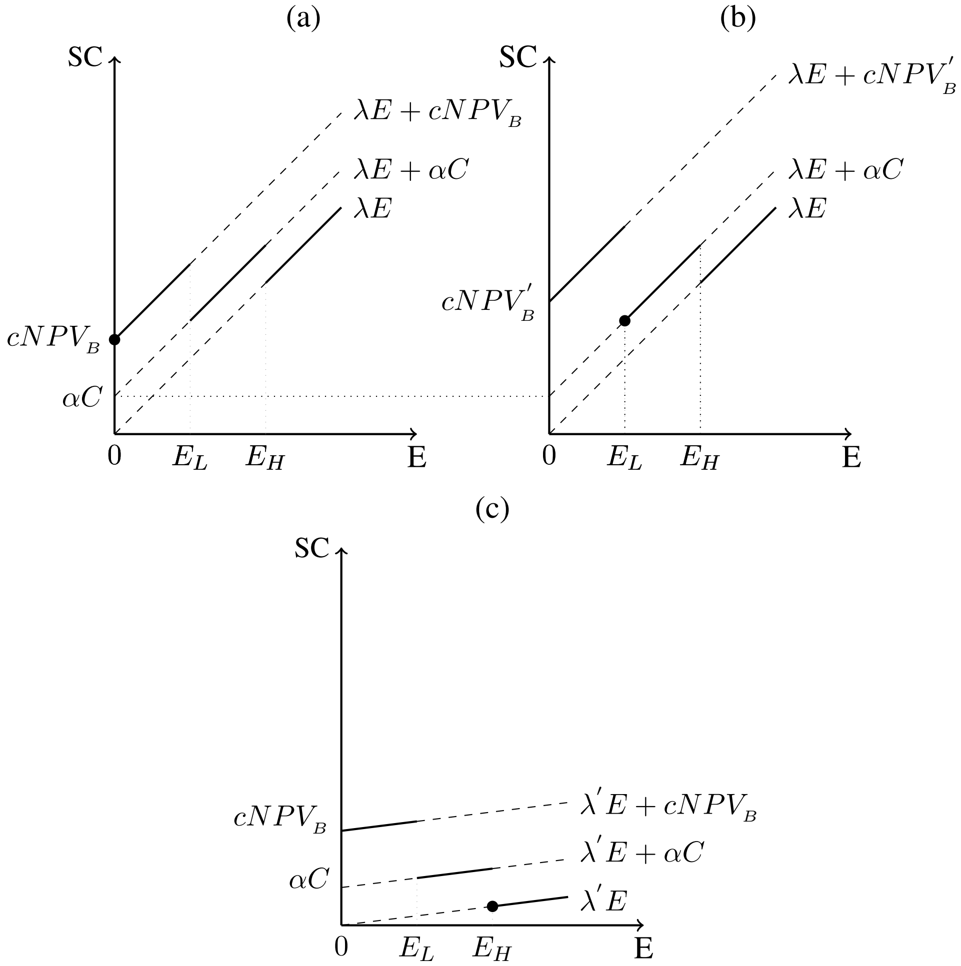
  This inequality holds if

$$cNPV_B \leq \min\{\lambda E_L + \alpha C,\ \lambda E_H\}.$$

The result in the Lemma follows from rearranging these conditions.
Banks failing the stress test refinance assets and default with probability α if they raise E_L in the market. By injecting $E_H - E_L$, the regulator prevents banks' default. This is optimal if $\lambda(E_H - E_L) < \alpha C$. □

By Assumption 6, the regulator prefers bank recapitalization to a bank run. Therefore the regulator injects equity in banks failing the stress test that do not raise capital and refinance assets. The optimal equity injection is the one minimizing social costs. In case banks downsize, the regulator faces a trade off between the cost of equity injections and the costs of downsizing. Figure 1.2 shows the social costs of injecting equity (solid line) as a function of the equity injection. Notice that the optimal solution is the minimum value of either interval $E \in [0,\ E_L)$, $E \in [E_L,\ E_H)$, or $E \geq E_H$. Any greater amount of capital injected in banks has a marginal cost λ, but yields no marginal gain. Subfigure (a) illustrates the case where not injecting capital is optimal. The net present value of the assets to refinance is lower than the social cost of injecting either E_H or E_L. In subfigure (b), the net present value of assets is greater than in subfigure (a). It is optimal to inject E_L because it costs less than downsizing. In subfigure (c), regulator's cost of funds is lower than in subfigures (a) and (b). Injecting E_H is optimal because foregoing the return on assets, and letting bad banks default, would be more costly.
In case banks failing the stress test raise E_L in the market, the regulator can prevent default by filling banks' capital shortfall. This is optimal if the costs of injecting the additional equity $E_H - E_L$ are lower than expected default costs. The regulator injects no equity if banks failing the stress test raise E_H in the market, as these banks refinance assets and do not default.

Figure 1.2: Optimal Equity Injection



The Response of Banks That Have Failed the Stress Test

Banks that have failed the stress test anticipate regulator's strategy. The following Lemma illustrates their optimal choice.

Lemma 2. *Banks that have failed the stress test raise E^*_{Reg} if the regulator can credibly threaten to inject E^*_{Reg} and requires a share of bank's value $s_{Reg} \geq s_B$.*

Regulator's strategy affects the outside option of banks that have failed the stress test. If banks failing the stress test do not raise capital in the market and refinance assets, regulator's threat is credible by Assumption 6. Recapitalizion at a cost higher than the market is enough to give these banks incentives to raise capital in the market.

In case banks failing the stress test downsize or raise E_L in the market, the threat of recapitalization is not always credible. If $E^*_{Reg} = 0$, banks that fail the stress test choose not to raise equity in the market because this is optimal by Assumption 4. Revealing bad banks is socially costly because they downsize. If the regulator finds it optimal to inject $E^*_{Reg} > 0$, banks that have failed the stress test face a credible threat. Raising equity in the market becomes optimal because the regulator would inject equity at a higher cost otherwise. If $E^* = E_L$, revealing bad banks is socially costly because they might default. There are no costs associated to information disclosure if $E^* = E_H$, as bad banks refinance assets and are solvent in both states of the world.

1.3.2 The Equilibrium Conditional on Passing the Stress Test

Among the banks that have passed the stress test, β are good and $(1-\beta)(1-a)$ are bad. Investors and banks passing the stress test play a signaling game because investors choose conditionally on observable actions. As described in Section 1.2.3, there exists no equilibrium where actions reveal bank's type. The only possible equilibria are those where banks pool on the same actions. Two pooling equilibria may exist: One where banks refinance assets (R), and another where they downsize (DS).
The pooling equilibrium where banks raise capital and refinance assets is ruled out by Assumption 5. Assumption 5 simplifies the analysis because it avoids multiple equilibria. As the pooling where banks refinance assets, the pooling where banks raise capital requires a low adverse selection premium in order for the incentive constraint of good banks to be satisfied. Ruling out multiple equilibria simplifies the analysis and allows us to get sharper insights on regulators' incentives to disclose information. The non existence of a pooling where banks passing the stress test raise capital is consistent with banks' reluctance to raise capital.

Banks that Pass the Stress Test Refinance Assets

Investors face default risk if the bad banks that have passed the stress test refinance assets and do not raise capital. They choose to rollover the debt of banks that have passed the stress test if

$$p_B\left[(1-\alpha)\min\{A^F_B,\ DR\} + \alpha\min\{A^A_B,\ DR\}\right] + (1-p_B)\min\{A_G,\ DR\} = D. \quad (1.1)$$

Equation (1.1) states that investors must be indifferent between lending and investing in the outside option. Lenders' outside option yields a zero net return. The return from lending equals the expected repayment from banks and depends on the fraction of bad banks passing the stress test (p_B). Investors rollover debt at the interest rates

$$R = \begin{cases} \frac{D-\alpha p_B A_B^A}{(1-\alpha p_B)D} & \text{if } p_B \leq \frac{A_G - D}{\alpha(A_G - A_B^A)} \equiv \overline{p}_1 \\ \frac{D-\alpha p_B A_B^A - (1-p_B)A_G}{(1-\alpha)p_B D} & \text{if } p_B \leq \frac{A_G - D}{A_G - E[A_B]} \equiv \overline{p}_2. \end{cases}$$

Investors do not rollover debt if $p > \overline{p}_2$.

A pooling equilibrium where banks passing the stress test refinance assets exists if no bank has incentives to deviate. The incentive to deviate depends on the specification of out of equilibrium beliefs. We assume that investors attribute the choice not to refinance assets to type B and G with probability p_B and $1-p_B$. The incentive constraints of good and bad banks are the following:

$$A_G - \frac{D - \alpha p_B A_B^A}{1 - \alpha p_B} \geq (1-c)A_G + c - D \tag{1.2}$$

$$(1-\alpha)(A_B^F + b - DR) \geq (1-c)\left(\mathbb{E}[A_B] + (1-\alpha)b\right) + c - D. \tag{1.3}$$

Inequalities (1.2) and (1.3) state that the equilibrium payoff must be greater than the payoff from not refinancing assets for good and bad banks. The equilibrium payoff of the bad bank is positive if $p_B \leq \overline{p}_2$, whereas that of the good bank is positive only if $p_B \leq \overline{p}_1 (< \overline{p}_2)$. Adverse selection makes the interest rate so high that the good bank defaults if $p_B > \overline{p}_1$. Downsizing is the best deviation for bad banks by Assumption 4, and is the only possible deviation for good banks by Assumption 5.

The existence of a pooling equilibrium might depend exclusively on the specification of out of equilibrium beliefs. The Cho-Kreps intuitive criterion is typically used to impose additional structure on out of equilibrium beliefs. The intuitive criterion suggests that investors should believe $\mu(B|\,DS) = 0$ if the deviation DS is equilibrium dominated for the bad bank. The out of equilibrium beliefs $\mu(G|\,DS) = 1 - p_B$ and $\mu(B|\,DS) = p_B$ would be unreasonable in this case. The deviation DS is equilibrium dominated if

$$(1-\alpha)\left(A_B^F + b - \frac{D - \alpha p_B A_B^A}{(1-\alpha p_B)}\right) > (1-c)\left(E[A_B] + (1-\alpha)b\right) + c - D. \tag{1.4}$$

Inequality (1.4) states that the equilibrium payoff is greater than the payoff from deviating to DS given investors attribute the deviation to good banks. Note that investors' beliefs do not affect the payoff from deviating as investors rollover the debt of both banks at the risk free rate in case they downsize. In case inequality (1.4) holds, and the deviation DS is not equilibrium dominated for good banks, the pooling equilibrium where banks that pass the stress test refinance assets does not exist. The deviation DS is not equilibrium dominated if

$$A_G - \frac{D - \alpha p_B A_B^A}{1 - \alpha p_B} < (1-c)A_G + c - D. \tag{1.5}$$

Inequality (1.5) states that the equilibrium payoff is lower than the payoff from deviating to DS for the good bank. The good bank has incentives to deviate from the equilibrium strategy if inequality (1.5) holds.
The following Lemma states the conditions under which a pooling equilibrium where banks refinance assets exists.

Lemma 3. *There exists a pooling equilibrium where banks refinance assets if* $p_B \leq \overline{p}^F$.

Proof. The incentive constraint of the good bank is satisfied if

$$p_B \leq \frac{c(A_G - 1)}{\alpha(c(A_G - 1) + D - A_B^A)} \equiv \overline{p}^F.$$

The incentive constraint of the bad bank is always satisfied because

$$D - \alpha A_B^A - (1-\alpha)\frac{D - \alpha p_B A_B^A}{(1-\alpha p_B)} \geq -c(E[A_B] + (1-\alpha)b - 1),$$

which is always true since the left hand side is positive and the right hand side is negative. Note that it is sufficient to check the incentive constraint with the interest rate $\frac{D-\alpha p_B A_B^A}{(1-\alpha p_B)D}$ because the good bank would make zero profits and have no incentives to pool.
Both incentive constraints are satisfied if $p_B \leq \overline{p}^F$. Note that the good bank can separate by deviating to (DS), but finds it worth if $p_B > \overline{p}^F$. There is no pooling equilibrium for this range of p_B. Therefore the pooling equilibrium exists if $p_B \leq \overline{p}^F$. □

A pooling equilibrium where banks refinance assets exists when the fraction of bad banks that pass the stress test is lower than the threshold $\overline{p}^F$. Intuitively, good banks can borrow at a low adverse selection premium if p_B is small. Deviating to downsizing is not attractive for the good bank because the equilibrium profit is high enough if $p_B \leq \overline{p}^F$. Bad banks have no incentives to deviate because borrowing and refinancing assets represent a subsidy for them. There exist a range of p_B for which deviating to downsizing is equilibrium dominated for the bad bank. The good bank would have incentives to deviate from the equilibrium strategy if $p_B > \overline{p}^F$, but the incentive constraint is not satisfied for this values of p_B. The pooling equilibrium where banks refinance assets survives the Cho-Kreps intuitive criterion.

Banks that Pass the Stress Test Downsize

All banks that have passed the stress test will be solvent in both states of the world if they downsize. Investors rollover the debt at the risk free rate because they face no default risk. A pooling equilibrium where banks that have passed the stress test downsize exists if no bank has incentives to deviate. Assuming the same out of equilibrium beliefs as in the previous section, the incentive constraints of bad and good banks are:

$$\begin{aligned}&(1-c)\left(\mathbb{E}[A_B]+(1-\alpha)b\right)+c-D\geq\\&\max\{(1-\alpha)(A_B^F+b-DR),\ \mathbb{E}[A_B]+(1-\alpha)b-D-\eta E^*\}\end{aligned} \tag{1.6}$$

$$(1-c)A_G+c-D\geq A_G-DR. \tag{1.7}$$

Inequalities (1.6) and (1.7) state that the equilibrium payoff must be greater than the payoff from the most profitable deviation. The equilibrium payoffs do not depend on adverse selection as investors rollover debt at the risk free rate. Bad banks can make two possible deviations, that is refinancing assets with (C,R) and without (R) raising capital. Good banks can deviate to R. The payoff from deviating to (R) equals the equilibrium payoff in equations (1.2) and (1.3). The amount of capital bad banks would deviate to is $E^* = \arg\max_E(1-s_B(E))V_G(E)$.
The out of equilibrium belief $\mu(B|\ R) = p_B$ is reasonable as

$$(1-c)(\mathbb{E}[A_B]+(1-\alpha)b)+c-D<(1-\alpha)(A_B^F+b-D).$$

The equilibrium payoff of the bad bank is lower than the payoff from deviating to R given investors attribute the deviation to the good bank. The pooling equilibrium where banks do not refinance assets exists as long as the incentive constraints of good and bad banks hold. The following Lemma illustrates the conditions under which this is the case.

Lemma 4. *There exists a pooling equilibrium where banks downsize if* $p_B \geq \overline{p}_2$.

Proof. The optimal amount of capital a bad bank would raise is $E = D - E[A_B]$. Assumptions 4 implies that the payoff from not refinancing assets is greater than raising $E = D - E[A_B]$ for the bad bank, so that the incentive constraint always holds. When the most profitable deviation is (R), i.e. when $p_B < \overline{p}_2$, the incentive constraint is not satisfied because

$$(1-c)(E[A_B]+(1-\alpha)b)+c-D\geq(1-\alpha)(A_B^F+b-\frac{D-\alpha p_B A_B^A-(1-p_B)A_G}{(1-\alpha)p_B})$$

$$\rightarrow -c(E[A_B]+(1-\alpha)b-1)\geq(1-\alpha)(1-p_B)(A_G-D)$$

never holds.
The good bank has incentives not to deviate to (R) if $p_B > \overline{p}^F$. Both incentive constraints are satisfied if $p_B \geq \overline{p}_2$ because $\overline{p}^F < \overline{p}_2$. □

The pooling where banks downsize is the most inefficient and least profitable for banks. It exists because the fraction of bad banks that pass the stress test is so large ($p_B \geq \overline{p}_2$) that investors do not rollover the debt of banks passing the stress test. Raising capital and refinancing assets is not an attractive deviation for bad banks because investors require too high a compensation for capital. Good banks cannot separate by refinancing assets because the bad bank would always mimic this deviation.

Graphical Illustration

Before proceeding with the illustration, it is useful to introduce the following definition.

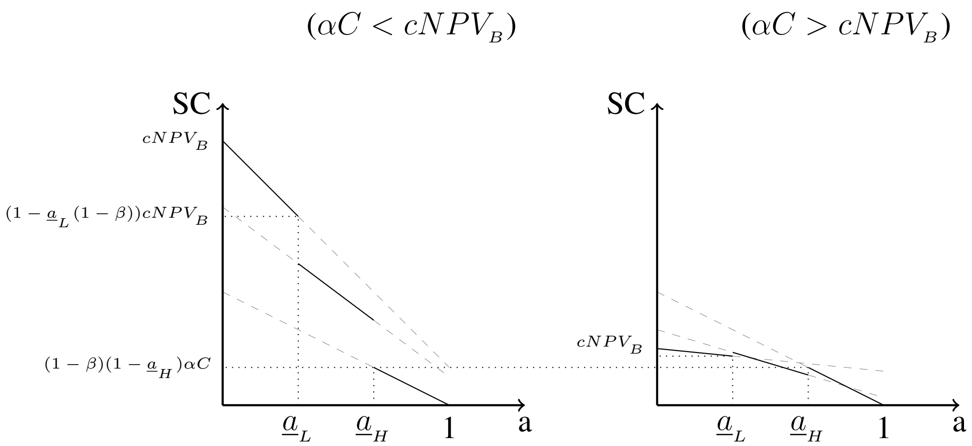
Definition 2. Thresholds in terms of accuracy

$$p_B \leq \overline{p}^F \iff a \geq \frac{\alpha(D - A_B^A)(1-\beta) - (1-(1-\beta)\alpha)c(A_G - 1)}{(1-\beta)(\alpha(D - A_B^A) - (1-\alpha)c(A_G - 1))} \equiv \underline{a}_H$$

$$p_B \geq \overline{p}_2 \iff a \leq \frac{D - \beta A_H - (1-\beta)E[A_G]}{(1-\beta)(D - E[A_G])} \equiv \underline{a}_L$$

Recall that p_B is the probability of a bank being of bad type given it has passed the stress test. As $p_B = \frac{(1-\beta)(1-a)}{\beta+(1-\beta)(1-a)}$, it is possible to rewrite the thresholds defining the pooling equilibria in terms of accuracy. Note that $\underline{a}_H > \underline{a}_L$ because $\overline{p}_2 > \overline{p}^F$ and accuracy is inversely related to p_B. It holds that $\underline{a}_H > \underline{a}_L$.
Figure 1.3 illustrates the social costs due to banks that have passed the stress test as a function of accuracy.

Figure 1.3: Social Cost Due to Banks Passing the Stress Test as a Function of Accuracy



The slope of the function (solid line) is negative, because the greater accuracy, the fewer the banks that pass the stress test. Only good banks pass the stress test if accuracy takes the maximum value. The function is piecewise linear. If accuracy is greater than $\underline{a}_H$, banks that have passed the stress test refinance assets. The social costs are due to the fact that the bad banks default with probability α. As good banks are solvent in both states of the world, social costs are nil if $a = 1$. If accuracy is smaller than $\underline{a}_L$, banks that have passed the stress test downsize because investors require too high an adverse selection premium. There is an equilibrium in mixed strategies for intermediate levels

of accuracy. Social costs are an average of those in the other accuracy intervals. The function is discontinuous because banks' behavior, and the ensuing social costs, vary over the three regimes.
The convexity of the function depends on how default costs compare to downsizing costs. Since banks downsize when accuracy is too low, the marginal cost of decreasing accuracy is greater when downsizing is less efficient than default. This implies that the function is convex. By contrast, the function is concave if default is less efficient than downsizing.

1.4 The Equilibrium in the First Stage

The regulator plays in the first stage of the game taking into account the optimal equity injection choice and the optimal strategies of banks that pass and fail the stress test. The regulator chooses the accuracy of the stress test with the objective to maximize aggregate welfare. Aggregate welfare is piecewise linear in accuracy and depends on the amount of capital the regulator can inject. Conditional on $E^*_{Reg} \in \{0,\ E_L,\ E_H\}$, the welfare function is

$$W(0) = \begin{cases} \beta W_G^{DS} + (1-\beta)W_B^{DS} & \text{if } a \leq \underline{a}_L \\ a(1-\beta)W_B^{DS} + \beta W_G^R + (1-\beta)(1-a)(W_B^R - \alpha C) & \text{if } a \geq \underline{a}_H \end{cases}$$

$$W(E_L) = \begin{cases} a(1-\beta)(W_B^R - \alpha C) + \beta W_G^{DS} + (1-\beta)(1-a)W_B^{DS} & \text{if } a \leq \underline{a}_L \\ a(1-\beta)(W_B^R - \alpha C) + \beta W_G^R + (1-\beta)(1-a)(W_B^R - \alpha C) & \text{if } a \geq \underline{a}_H \end{cases}$$

$$W(E_H) = \begin{cases} a(1-\beta)W_B^R + \beta W_G^{DS} + (1-\beta)(1-a)W_B^{DS} & \text{if } a \leq \underline{a}_L \\ a(1-\beta)W_B^R + \beta W_G^R + (1-\beta)(1-a)(W_B^R - \alpha C) & \text{if } a \geq \underline{a}_H. \end{cases}$$

Banks that pass the stress test play a mixed strategy in case $a \in (\underline{a}_L,\ \underline{a}_H)$. Aggregate welfare is an average of the welfare from the strategies in the support of the mixed strategy. Independently of the optimal equity injection in banks that fail the stress test, banks that pass the stress test refinance assets if $a \geq \underline{a}_H$ but do not if $a \leq \underline{a}_L$. The optimal choice of banks that fail the stress test depends on the optimal equity injection. If the regulator can credibly threaten to inject equity $E^*_{Reg} > 0$, banks that fail the stress test raise E^*_{Reg}. These banks default only if $E^*_{Reg} = E_L$. Banks that fail the stress test downsize if the regulator cannot credibly threaten an equity injection.
The trade off arising from this setup is that a higher effort allows banks that pass the stress test to refinance assets, but implies failing more bad banks. Failing bad banks is socially costly in terms of equity injections or foregone investment opportunities. The following Proposition illustrates the optimal choice by the regulator.

Proposition 1. *The optimal accuracy choice is*

$$a^* = \begin{cases} 1 & \text{if } E^*_{Reg} = E_H \\ 1 & \text{if } E^*_{Reg} = 0 \text{ and } \alpha C > cNPV_B \\ \underline{a}_H & \text{if } E^*_{Reg} = 0 \text{ and } \alpha C < cNPV_B, \end{cases}$$

whereas $a^* \in [\underline{a}_H,\ 1]$ *if* $E^*_{Reg} = E_L$.

Proof. If $E^*_{Reg} = E_H$, maximization of $W_{ST}(E_H)$ with respect to a yields the following first order condition:

$$(1-\beta)\alpha C - \delta_1 + \delta_2 = 0 \text{ if } a \geq \underline{a}_H$$
$$(1-\beta)cNPV_B - \delta_3 + \delta_4 = 0 \text{ if } a \leq \underline{a}_L,$$

where δ_1, δ_2, δ_3, and δ_4 are the multipliers of the constraints $a \leq 1$, $a \geq \underline{a}_H$, $a \leq \underline{a}_L$ and $a \geq 0$. The first order condition if $a \in (\underline{a}_L,\ \underline{a}_H)$ is the average of the previous two because banks that pass the stress test play a mixed strategy. The solution of the two first order conditions implies that accuracy is the maximum in each interval. The optimal choice is $a^* = 1$ because

$$-\beta c(A_G - 1) - (1-\beta)(1-\underline{a}_L)cNPV_u < 0.$$

If $E^*_{Reg} = E_H$, maximization of $W_{ST}(E_L)$ with respect to a yields the following first order condition:

$$-\theta_1 + \theta_2 = 0 \text{ if } a \geq \underline{a}_H$$
$$(1-\beta)(cNPV_B - \alpha C) - \theta_3 + \theta_4 = 0 \text{ if } a \leq \underline{a}_L,$$

where θ_1, θ_2, θ_3, and θ_4 are the multipliers of the constraints $a \leq 1$, $a \geq \underline{a}_H$, $a \leq \underline{a}_L$ and $a \geq 0$. The first order condition if $a \in (\underline{a}_L,\ \underline{a}_H)$ is the average of the previous two because banks that pass the stress test play a mixed strategy. The first condition implies that any accuracy choice $a \in [\underline{a}_H,\ 1]$ is optimal. The second condition implies that $a^* = \underline{a}_L$ because it is optimal to inject E_L when $cNPV_B > \alpha C + \lambda E_L > \alpha C$. The optimal choice is any accuracy $a \in [\underline{a}_H,\ 1]$ because

$$-\beta c(A_G - 1) - (1-\beta)(1-\underline{a}_L)(cNPV_B - \alpha C) < 0.$$

If $E^*_{Reg} = 0$, maximization of $W_{ST}(0)$ with respect to a yields the following first order condition:

$$(1-\beta)(\alpha C - cNPV_B) - \gamma_1 + \gamma_2 = 0 \text{ if } a \geq \underline{a}_H$$
$$-\gamma_3 + \gamma_4 = 0 \text{ if } a \leq \underline{a}_L,$$

where γ_1, γ_2, γ_3, and γ_4 are the multipliers of the constraints $a \leq 1$, $a \geq \underline{a}_H$, $a \leq \underline{a}_L$ and $a \geq 0$. The first order condition if $a \in (\underline{a}_L,\ \underline{a}_H)$ is the average of the previous two because banks that pass the stress test play a mixed strategy. The first condition implies that $a^* = 1$ if $\alpha C > cNPV_B$ and $a^* = \underline{a}_H$ otherwise. The second condition implies that any accuracy $a \in [0,\ \underline{a}_L]$ is optimal. If $\alpha C > cNPV_B$, the optimal choice is $a^* = 1$ because

$$-\beta c(A_G - 1) < 0.$$

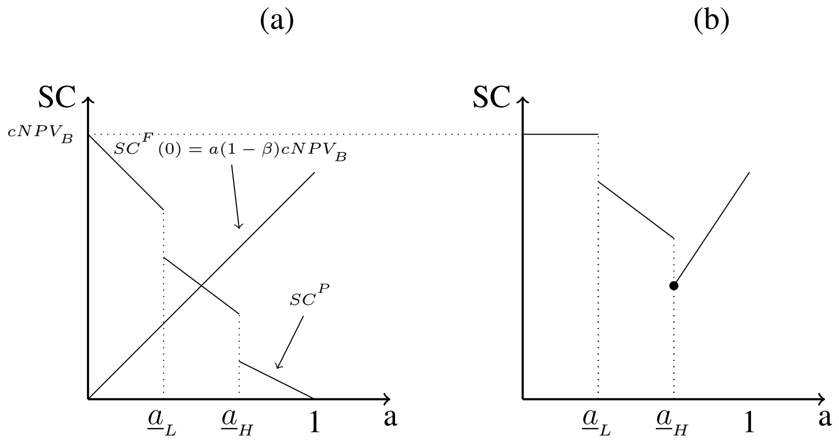
If $\alpha C < cNPV_B$, the optimal choice is $a^* = \underline{a}_H$ because

$$-\beta c(A_G - 1) + (1 - \beta)(1 - \underline{a}_H)(\alpha C - cNPV_B) < 0.$$

□

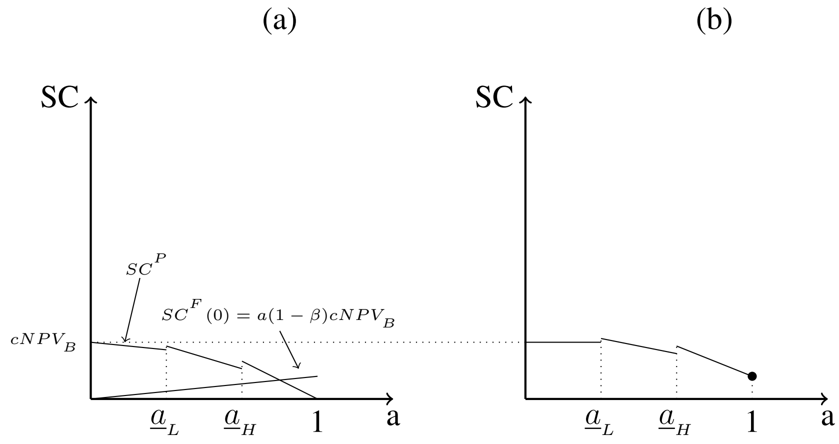
The choice of accuracy depends on the amount of equity the regulator finds it optimal to inject. If the regulator can credibly threaten to inject E_H, it will choose the maximum accuracy. The reason is that banks failing the stress test will raise E_H and become solvent in both states of the world. The regulator can implement the first best allocation choosing the maximum accuracy.
In case injecting no equity is optimal, the regulator will choose $a^* = 1$ or $a^* = \underline{a}_H$ depending on whether αC is greater or smaller than $cNPV_B$. Banks that fail the stress test downsize, whereas bad banks that pass the stress test refinance assets and default with probability α. Figures 1.4 illustrates the case where $cNPV_B > \alpha C$. The higher ac-

Figure 1.4: Social Costs Due to Banks Passing and Failing the Stress Test (a) and Total Social Costs (b) *(Case $E^* = 0$ and $cNPV_B > \alpha C$)*



curacy, the greater the social costs from downsizing ($SC^F(0)$ function in subfigure (a)), but the lower the social costs due to banks passing the stress test ($SC^P(0)$ function). The level of accuracy minimizing total social costs (subfigure (b)) is $\underline{a}_H$. For lower accuracy levels, even the good banks would downsize, at least with some probability. For greater accuracy levels, banks that have passed the stress test refinance assets, whereas those that have failed the stress test downsize and become solvent. Since default costs are lower than downsizing costs, it is optimal to choose $\underline{a}_H$, as this level of accuracy minimizes the social costs from downsizing. Figures 1.5 illustrates the opposite case where $cNPV_B < \alpha C$. Since default is less efficient than downsizing, downsizing is

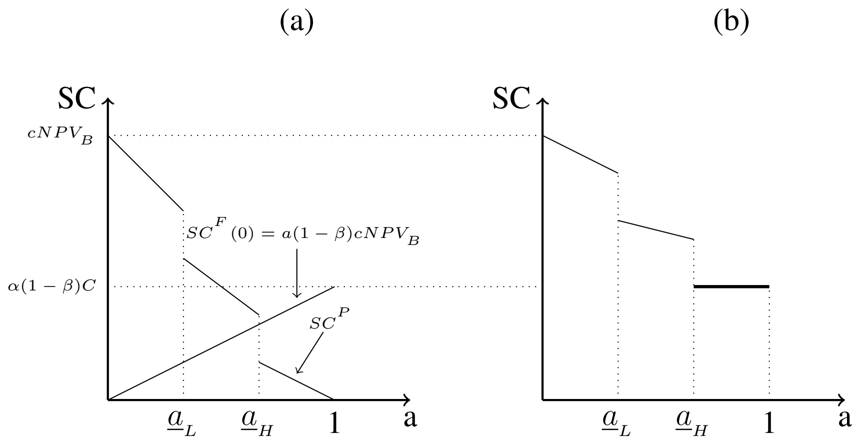
Figure 1.5: Social Costs Due to Banks Passing and Failing the Stress test (a) and Total Social Costs (b) *(Case* $E^* = 0$ *and* $cNPV_B < \alpha C$*)*



optimal because banks become solvent. The optimal choice is $a = 1$, as this level of accuracy minimizes default costs.

In case the optimal equity injection is E_L, the regulator finds any accuracy $a^* \in [\underline{a}_H, 1]$ optimal. Figure 1.6 illustrates this case. Banks that fail the stress test raise E_L and refinance assets in equilibrium. Investors rollover debt but require a risk premium because banks will default with probability α. The marginal cost of accuracy equals the expected default cost of bad banks. The marginal gain equals the reduction in the social costs due to banks passing the stress test. These social costs are a convex function of accuracy (Figure 1.3.b) because, by Lemma 1, the net present value of assets is greater than the expected bankruptcy costs in case injecting E_L is optimal. The regulator will choose at least $a = \underline{a}_H$ in order to make sure that the good banks passing the stress test choose to refinance assets. Any effort $a \in [\underline{a}_H, 1]$ will be optimal because bad banks refinance assets and default independently of whether they pass or fail the stress test.

Figure 1.6: Social Costs Due to Banks Passing and Failing the Stress Test (a) and Total Social Costs (b) *(Case* $E^* = E_L$*)*



1.5 Implications and Anecdotal Evidence

We highlight four main implications of our model:

1. banks failing the stress test raise capital in the market only if the regulator can credibly threaten recapitalization;

2. a stress test will be fully informative if the regulator can credibly threaten to fill the equity gap of bad banks;

3. a stress test will be partially informative if the regulator cannot inject equity in banks that fail the stress test and expected default costs are smaller than the net present value of assets;

4. a stress test will be fully informative if the regulator cannot inject equity in banks that fail the stress test and expected default costs are greater than the net present value of assets.

No clear prediction can be made in case the regulator finds it optimal to inject E_L as $a^* \in [\underline{a}_H, 1]$. However, under the reasonable assumptions that effort is costly in terms of time and resources, the prediction would be that the stress test will be partially informative.

The empirical and anecdotal evidence on banks failing the stress tests in the U.S. and Europe is consistent with these predictions. The U.S. could raise funds at a relatively low cost and implemented the CAP program. The CAP program, which accompanied the stress test in the U.S., would provide equity to the banks unable to replenish their capital privately. The U.S. stress test identified an aggregate capital shortfall of \$ 75 bn among 10 of the 19 participating banks. Consistent with prediction 1), the 10 banks deemed under capitalized raised \$ 77 bn of equity in the 6 months following the stress test. None of them needed to draw on CAP funds. Prediction 2) suggests that the U.S. should have implemented a fully informative stress test. In line with this prediction, Peristiani et al. (2010) find that markets used the information from U.S. stress tests to revalue banks. Greenlaw et al. (2012) point out that U.S. banks have seen a remarkable decline in CDS prices and a consistent surge in equity prices in the three months following the stress test.

The costs of state recapitalization were much higher in Europe. Sovereign debt problems limited the firepower of peripheral EU countries. Core EU countries would have presumably faced political costs from using taxpayers' money to save banks. For example, Germany wound the national bail out fund down in December 2010, and since then state help was no longer available for German banks. State recapitalization was an idle threat in Europe. Consistent with prediction 1), none of the few banks that failed the EU-wide stress test exercises raised capital in the market. Among these banks, the Spanish ones either merged with or were acquired by other banks, whereas the Greek ones, the German Hypo Real Estate, and the Austrian OeVAG underwent a restructuring process.

The 2011 EU-wide stress test also revealed 16 banks with a core tier 1 capital slightly above the 5% passing threshold. The EBA conducted the *EBA capital exercise* with the aim to encourage these banks to raise capital. The EBA identified an aggregate capital shortfall of Euro 115 bn and required banks to fill the gap by June 2012. In October 2012, the EBA reviewed the fulfillment of the recapitalizon plans of 27 banks, which had a total capital shortfall of Euro 76 bn. These banks have raised Euro 115.7 bn. From the results that EBA published, it emerges that only Euro 46 bn consist of core tier 1 capital. The rest includes ongoing backstops and mainly measures affecting risk weighted assets. The Euro 46 bn include the issuance of new ordinary shares, the scheduled conversion of hybrid bonds, but also measures, like retained earnings, that some commentators believe not to be fully credible[15]. Commentators' concerns are justified also by the fact that "*People familiar with its thinking insist that even if the EBA executive believes some banks capital plans to be aggressive and unachievable, it will seek to resolve the issues quietly, behind the scenes, and may ultimately have to back down in some cases if national regulators are determined that their banks are healthy. Even if the EBA is sceptical of an individual banks plan, it does not have direct authority to order a change*".

The concerns about banks' recapitalization plans are consistent with a more nuanced

[15]Some commentators showed concern for the too optimistic earning expectations. See "EBA set to opt for pragmatism over publicity", FT February 6, 2012.

prediction than ours: The regulator will accept not fully credible recapitalization plans if it cannot provide any credible guarantee of bank recapitalization. The intuition behind this alternative prediction is the same as ours. It does not arise from our model because we only let banks choose whether to raise capital or not.

According to predictions 2) and 3), the information value of the European stress tests should depend on the relative size of the default and downsizing costs. EU members differed in this respect. Peripheral EU countries were in the midst of an economic and sovereign crisis, whereas core EU countries showed a better economic performance. Expected default costs were presumably greater than the costs of foregoing investment opportunities in peripheral EU countries. Core EU countries were likely to be in the opposite situation. Consistent with prediction 4), Spain applied an extra level of stress to its banks and encouraged the disclosure of sovereign risk exposure by banks[16]. The fraction of Spanish banks subject to stress test was the largest in Europe, and most of the banks that failed the stress tests were from Spain. In line with prediction 3), "*some bankers, analysts and officials are pointing the finger at German regulators and lenders, claiming they have led efforts to push for weaker testing standards and less transparency in the results.*"[17].

As the European supervisory authority had presumably to take into account the heterogeneity among EU countries, European stress tests were less informative than in the U.S. The reaction of EU banks' CDS and stock prices was weak after the stress tests (Greenlaw et al. (2012)). Skepticism around European stress tests was widespread among commentators and practitioners (Hirtle et al. (2009), Schuermann (2012)). The capital shortfall of European banks amounted to Euro 3.5 bn in 2010 and Euro 2.5 in 2011, way below market expectations[18]. Only 8 banks in 2011, and 7 banks in 2010, failed the EU-wide stress tests. Allied Irish Banks did not need any additional capital according to the 2010 EU-wide stress test, but received a Euro 3 bn bailout after a few months. Three months after passing the 2011 EU-wide stress test, Dexia underwent a restructuring process involving state guarantees and the creation of a "bad bank".

1.6 Discussion and Policy Implications

We have deliberately used a simple model to sharpen the analysis of regulator's incentives to disclose information in a crisis. We have taken as a starting point an environment similar to the recent financial crisis. Investors face uncertainty about banks' risk exposures and the market for funds gets tighter. Banks are reluctant to raise capital in the market because its cost is too high. Regulators react by disclosing stress test results. Since we focus on a crisis situation, we have taken capital shortfalls as given and not

[16]See "Stress test results 'underwhelming'", FT July 26, 2010.

[17]From "EU Defends Stress Tests as Standards Draw Doubts", WSJ March 10, 2011.

[18]See "Banks: Again under strain", FT July 7, 2011.

modeled bank's risk taking behavior. We have considered a setup where the bad banks have a capital shortfall, but can continue operating without renegotiating pre-existing contracts. The capital shortfall is such that bad banks cannot borrow against all their assets in place, but become solvent by downsizing. Downsizing is an inefficient way to increase equity because there is a wedge between bank's value and the value that can be pledged to investors. We do not endogenize this wedge, which we interpret as the returns on opaque assets or as the compensation for managers not to shirk. Assuming a run by investors and the inefficient liquidation of bank's assets would deliver similar results. However, banks would not be able to raise capital if the value of assets is lower than the value of debt. Our modeling choice gives banks the possibility to replenish the capital shortfall either through raising capital in the market or downsizing.

Our model relates the effectiveness of bank stress tests in times of crisis to the costs of default, recapitalization and downsizing. If the regulator has easy access to funds and hence can recapitalize banks, the disclosure of stress test results will lead to the first best allocation. The reason is that banks fill their capital shortfall by raising capital in the market and invest. By contrast, only second best equilibria arise if the regulator cannot recapitalize banks. There are inefficiencies either in terms of downsizing or default. These results imply a link between bank stress tests and a number of well-debated issues in banking regulation.

First, directly recapitalizing weak banks through the European Stability Mechanism would make stress tests more informative in Europe. The costs of recapitalization would be borne by the ESM and not added to countries' sovereign debt. Countries, especially in the EU's periphery, would face lower funding costs. In the context of our model, recapitalization through the ESM would imply a reduction in λ. The reduction in λ could shift the optimal equity injection from zero to E_H, as in Figures (1.2.a) and (1.2.c), and give the regulator incentives to resolve information asymmetries.

Second, improving bankruptcy procedures, for example by requiring banks to write their "living wills"[19], would have a twofold effect. On the one hand, it would make regulators more reluctant to reveal capital shortfalls in countries like the EU's periphery, where raising money to recapitalize banks is costly. On the other hand, it would reduce the social costs of injecting E_L in banks. The first effect can be illustrated by Figures 1.4 and 1.5. In Figure 1.5 the regulator chooses the maximum accuracy because injecting equity in banks is not optimal and expected default costs are greater than downsizing costs. A reduction in default costs could shift the optimal accuracy choice to $\underline{a}_H$, as in Figure 1.4. The intuition is that the regulator will minimize downsizing if expected default costs are lower than downsizing costs. The second effect can be illustrated as a downward shift of the $\lambda E + \alpha C$ schedule in Figure 1.2. A consistent reduction in

[19]"Living wills" are guidelines for unwinding banks in case of default. The 2010 Dodd Frank Act required more than 100 large financial firms to submit "living wills" to the Federal Reserve and the Federal Deposit Insurance Corporation. In November 2011, the leaders of the G-20 nations agreed to require the 29 largest banks worldwide to submit "living wills".

default costs might make injecting E_L the optimal choice for the regulator. This would increase the equilibrium accuracy choice to any value $a \geq \underline{a}_H$.
Third, regulators should enforce capital requirements in absolute terms. Bank supervisors typically require banks to maintain a certain capital to assets ratio. Supporters of a macroprudential view of bank supervision argue that such requirement gives banks incentives to replenish their capital by shrinking assets rather than raising equity in the market. In our model, banks would prefer to downsize independently of regulator's funding costs if capital requirements are expressed in ratio terms.

1.7 Conclusions

This paper has examined the incentives of regulators to reveal information in crisis times. We have provided a positive analysis of information disclosure. We have taken as given the fact that regulators have conducted stress tests as a response to the recent financial crisis. Our analysis builds on the evidence that, in crisis times, banks are reluctant to raise capital in the market and information asymmetries get more severe.
Regulator's incentives to disclose information are crucial for market discipline. In our model, information disclosure ameliorates adverse selection, and prevents good banks from inefficiently downsizing. In a model where banks choose risk, information disclosure would also prevent excessive risk taking by making banks pay for the risk they take. Less risk taking would imply lower capital shortfalls, and would reinforce regulator's incentives to disclose information.
We have shown that, in our crisis environment, regulators will prefer less information to be disclosed if banks react by inefficiently downsizing. Unless the regulator can credibly threaten recapitalization at a dilution cost higher than the market, a bank will prefer to downsize rather than raise capital in order to fill the capital shortfall revealed by the stress test. Downsizing makes the bank solvent at the cost of a lower level of investment. If the foregone returns are greater than expected default costs, the regulator will minimize information disclosure. The regulator will reduce adverse selection to the point where the remaining banks prefer to keep investing rather than downsizing. By contrast, the regulator will have incentives to reveal information if its funding costs are low. Low funding costs make the recapitalization threat credible. Banks will prefer to raise capital and invest. The regulator will have incentives to reveal information also in case expected default costs are greater than the costs of downsizing. Downsizing is optimal given the regulator cannot credibly threaten recapitalization.
Our model links the favorable market reaction to the U.S. stress test to the implementation of a backstop mechanism (CAP) for weak banks. The lack of a EU-wide backstop mechanism, and the costs of downsizing for core EU members, are consistent with the skeptical market reaction to European stress tests.
Our model implies that the efficient resolution of banks' distress is crucial for the ef-

fectiveness of bank stress tests in times of crisis. This links our analysis to a number of well-debated issues in banking regulation. First, directly recapitalizing weak banks through the European Stability Mechanism would make stress tests more informative in Europe. The reason is that the costs of recapitalization would be borne by the ESM and not be added to the country's sovereign debt. Second, regulators should enforce capital requirements in absolute terms. If capital requirements are expressed in ratio terms, banks would prefer to downsize independently of regulator's funding costs .
In our model, downsizing allows banks to replenish their capital shortfall. This might not always be the case in reality. If banks' financial distress is more severe, restructuring banks' assets and/or liabilities might be necessary. Our model suggests that splitting ailing banks into a "good" and a "bad" bank, or swapping debt for equity, would give regulators stronger incentives to reveal capital shortfalls. The "good-bank/bad-bank" solution consists of taking bad assets and senior debt off the balance sheet of ailing banks, and transferring them to a "bad" bank. The "bad" bank would own the "good" bank[20]. Debt-for-equity swaps represent a form of debt renegotiation through which bank creditors accept to become equity holders. If bank's equity after restructuring is sufficiently large, these policies will guarantee solvency and the supply of credit at no cost for taxpayers. As creditors have incentives to free ride, renegotiating debt might be difficult. A better solution would be to require banks to hold contingent convertible bonds that would convert into equity once a contract defined trigger event occurs[21].

[20]The "good-bank/bad-bank" solution has been adopted in Ireland in 2009 and in Sweden in 1991.

[21]Switzerland will require its two largest banks a 19% capital requirement, of which 9% may be held in the form of contingent convertible debt. Contingent capital proposals are also currently under discussion within the Basel Committee, the Financial Stability Board (FSB), and the European Union.

Chapter 2

BANKS' OPTIMAL INFORMATION DISCLOSURE AND BANKS' OPACITY

2.1 Introduction

One of the main features of the recent financial crisis was the uncertainty about banks' solvency. According to a widespread view[1], investors lost the ability to assess the value of banks' capital after the subprime crisis erupted. Fearing information asymmetries, investors became more reluctant to lend and funding dried up for banks[2]. The same narrative also explains many of the bank run episodes in the US during the 19th and 20th century[3]. Public news about a shock to banks' solvency led depositors to indiscriminate withdrawals of funds because of the lack of information to sort out the solvent from the insolvent banks. Hence investors' inability to assess the value of banks' capital seems to be a common feature shared by financial crises.

It is well-known that asymmetric information might generate distortions. For example, it might inefficiently reduce the amount of trade in a market, and induce opportunistic behavior by agents. By contrast, the causes of asymmetric information and its variation over the business cycle are much less well-known. The existing literature either takes asymmetric information as an assumption or considers it as the result of an information acquisition choice by a fraction of market participants.

In this paper, we focus on the link between asymmetric information and banks' disclosure. We are interested in the interaction among the choice of risk, the incentives to disclose information, and the amount of information available in the market. In our

[1]See Gorton (2008), Dudley (2009) and Lewis (2008).

[2]Heider et al. (2009) describe the functioning of interbank markets during the recent financial crisis.

[3]See, for example, Calomiris and Mason (1997), Gorton (1988), and Park (1991).

model, information concerns the amount of bad loans that banks have in their portfolio. Bad loans are loans to borrowers that turn out to be insolvent and cannot pay back banks at the final date. We let banks choose the ex-ante distribution of bad loans, and recover part of their value by liquidating the insolvent borrowers at the interim date. We consider banks that have to rollover an outstanding amount of debt at the time they learn the amount of bad loans in their portfolio. As investors do not have this information, they decide whether to lend based on how many bad loans banks reveal by liquidating insolvent borrowers. The following trade-off arises for banks: Hiding bad loans determines the loss of their recovery value, but allows banks to signal lower losses and borrow at more favorable terms.

We demonstrate that information asymmetries arise in times of crisis because of a signaling externality. The logic of our argument is that weak banks have incentives to understate their bad loans in order to raise debt at a lower cost. While in normal times sounder banks can signal their better financial condition by disclosing less bad loans, signaling becomes impossible in crisis times. As investors would charge too high an interest rate to the banks they know to be weak, the incentives of weak banks to understate losses are so strong that sounder banks cannot signal themselves. Sounder banks would be able to reveal themselves only by disclosing a negative amount of bad loans, which is not feasible. Hence all banks disclose the same information in equilibrium. Anticipating that investors will not be able to assess their financial condition, banks have incentives to take excessive risk compared to the first best equilibrium allocation.

Two empirical predictions arise from our model. First, banks tend to overstate their financial condition in bad times. This is consistent with the practice of hiding loan losses by rolling over loans to insolvent firms, known as ”zombie” or forbearance lending[4], and with the literature on accounting discretion. Huizinga and Laeven (2009) document that banks used accounting discretion in the recent financial crisis in order to overstate the book value of their capital. Gunther and Moore (2003) find that the worse the financial condition, the more banks are likely to understate their financial losses. Second, the relation between banks' funding costs and balance sheet indicators of risk (non performing loans) is stronger in good times than in crisis times. This is consistent with the empirical literature on market discipline[5] and with Flannery et al. (2010) and Flannery et al. (2004), who find evidence of greater banks' opacity during the recent financial crisis but not in tranquil times. By contrast, Morgan (2002) and Iannotta (2006) find that banks are more opaque than other firms examining a period where no crisis occurred.

We highlight three main policy implications. First, bank regulation should be inspired by macroprudential principles. The traditional microprudential approach aims to guarantee that banks have enough capital to absorb losses and avoid taxpayers bailing banks

[4]This practice was quite common in Japan in the 90s (See Caballero et al. (2008) and Peek and Rosengren (2005)), and in Spain during the recent financial crisis (See ”Are Spanish Banks Hiding their Losses?”, FT Alphaville August 21, 2009).

[5]For example, see Levy-Yeyati et al. (2004) and Flannery (1998).

out. Regulators analyze banks in isolation and independently of other banks. By contrast, our results suggest that regulators should adopt a more systematic approach because banks exert a signaling externality when their financial condition deteriorates. Second, regulators should not consider market discipline and capital requirements in isolation. Regulators should set capital requirements taking into account that banks have stronger incentives to hide losses when they have little capital. Neglecting this link would imply understating the level of capital needed to prevent excessive risk taking. Regulators could allow banks to meet this higher capital requirements also requiring them to hold contingent convertible bonds (Cocos). Cocos are bonds that convert into equity once a contract defined trigger event occurs. If the trigger event occurs in crisis times, banks' capital will automatically be increased and hence the incentives to hide loan losses will be lower. Third, banks' supervision is crucial to identify and deal with ailing banks. For example, the disclosure of stress test results would remove information asymmetries and enhance market discipline in the context of our model. However, Spargoli (2012) shows that, if other frictions exist besides asymmetric information, regulators' incentives to reveal banks' capital shortfall depend on how efficiently banks' distress can be resolved. Regulators might prefer to hide some weak banks if they cannot count on efficient bank resolution policies.

Our paper is related to different strands of literature. Dang et al. (2012) show that having symmetric ignorance among agents is optimal because asymmetric information leads to an inefficiently low level of trade. In their model, information asymmetries arise because some agents are willing to bear an information acquisition cost when the benefit of being informed is large enough. Pagano and Volpin (2012) demonstrate that choosing not to release information about a security is optimal for an issuer who wants to maximize the issue price. The reason is that disclosure generates asymmetric information because only a fraction of buyers is sophisticated enough to understand its content. While in these papers information asymmetries arise from investors' choices or characteristics, our contribution is to focus on the role played by banks. We show that information asymmetries might arise even if investors are rational and cannot acquire private information. The reason is that banks' incentives to disclose information lead to an equilibrium where no information is produced.

Close to our paper is also the literature on endogenous liquidity[6]. This literature assumes asymmetric information and studies its social costs over the business cycle. This literature considers an environment where borrowers of different quality are hit by a liquidity shock and need to raise funds from uninformed investors. The prediction is that financial markets are more liquid in good times than in bad times because adverse selection is lower. In good times, that is when the return on investments is high, investments are more likely to be liquidated because of a liquidity shock rather than bad news about returns. The opposite happens in bad times. Differently from this literature, we do

[6]Eisfeldt (2004) is the pioneering contribution to this literature.

not assume asymmetric information. Our contribution is to explain why the degree of asymmetric information varies over the business cycle focussing on banks' information disclosure choice.

We take the incentives to disclose bad loans from Aghion et al. (1999) and Mitchell (2001). They build models where bank managers might want to overstate bank's financial condition in order to avoid regulator's intervention. The authors design bail out plans in a way to give the bank incentives to reveal its financial condition truthfully. By contrast, we consider the case where banks communicate information to investors.

Our paper is also related to the literature on macroprudential regulation. These papers identify externalities in individual banks' behavior and suggest policies to deal with them[7]. Our paper points out a further externality, as weak banks might make information about banks disappear. Finally, our paper is related to the literature about the optimal design of policies to elicit information disclosure from banks during financial crises [8]. Our results suggest policies that would prevent information asymmetries from arising rather than eliciting information disclosure.

The paper is structured as follows. Section 2 contains the model setup. Section 3 presents the complete information benchmark, while Section 4 describes the equilibrium under asymmetric information. In Section 5 we discuss some policy implications and in Section 6 we draw the conclusions.

2.2 The Model Setup

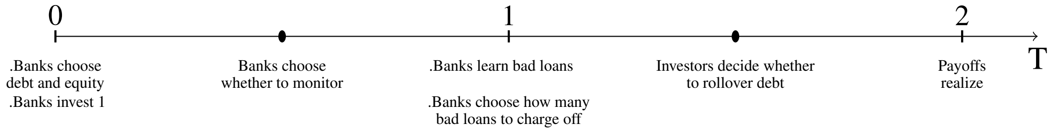
We consider a two periods game between a continuum of banks and investors. Investors are competitive, risk neutral and have a unit endowment. They require a net rate of return zero to invest in debt, and ρ to invest in equity. Figure 2.1 shows the timeline of the game. Banks have to raise funds to make a unit investment in a continuum of projects at time 0. They can finance the investment through short term debt or equity. After the financing choice, banks choose whether to monitor their investment. We assume that monitoring decreases the probability of failure of the investment ($\tilde{\theta}$). We assume that

$$\tilde{\theta}_s = \begin{cases} \theta_s & \text{if banks monitor} \\ \tilde{\tilde{\theta}}_s = \begin{cases} \theta_s & \text{w.p. } \frac{1}{2} \\ \gamma\theta_s & \text{w.p. } \frac{1}{2} \end{cases} & \text{if banks do not monitor} \end{cases}$$

[7] Examples are requiring banks to buy insurance against systemic crisis (Kashyap et al. (2008)), tying capital requirements to the correlation of bank risks rather than individual bank risks (Acharya (2009)), imposing charges on the gap between banks' current liquidity position and the Basel III norms (Perotti (2012)), penalizing banks on the basis of its systemic expected shortfall, that is banks' propensity of being undercapitalized when the system is undercapitalized (Acharya et al. (2009)).

[8] Bhattacharya and Nyborg (2010), Philippon and Schnabl (2009), Philippon and Skreta (2012), Bruche and Llobet (2012) and Tirole (2012).

Figure 2.1: Timeline



and that $\gamma > 1$. The index s stands for the state of the world, which we represent through the following distribution:

$$\theta_s = \begin{cases} \theta_C & \text{w.p. } p \\ \theta_N & \text{w.p. } 1-p \end{cases},$$

with $\theta_N > \theta_C$. We will call *crisis* the state of the world C, and *normal times* the state of the world N. Since banks invest in a continuum of projects, $\tilde{\theta}_s$ represents the fraction of projects that will fail. We define this fraction *bad loans* or *non performing loans*, and the complementary fraction *good loans*. Our assumption implies that banks will have θ_s bad loans if they monitor, whereas bad loans can be θ_s or $\gamma\theta_s$ with the same probability in case banks do not monitor. Since $\gamma > 1$ banks will have more bad loans in case they do not monitor independently of the state of the world. We assume that good loans yield a payoff $\tilde{Y}$ at time 2, and that

$$\tilde{Y} = \begin{cases} Y & \text{if } \tilde{\theta} = \theta \\ \tilde{\tilde{Y}} = \begin{cases} \overline{Y} & \text{w.p. } \alpha \\ \underline{Y} & \text{w.p. } 1-\alpha \end{cases} & \text{if } \tilde{\theta} = \gamma\theta \end{cases}$$

independently of the state of the world s. We assume that bad loans yield 0 at time 2 but, when banks learn which loans are bad, they can charge them off, invoke a bankruptcy procedure, and recover L per bad loan at time 1 [9].

The uncertainty about the state of the world s and the fraction of bad loans in case banks do not monitor realize at time 1. The state of the world is public information, whereas the fraction of bad loans is known to banks but not to investors. Since we assumed a continuum of banks, half of them have θ_s bad loans and the other half $\gamma\theta_s$ bad loans in case they have chosen not to monitor. At time 1, banks also have to decide how many bad loans to charge off the balance sheet. As the fraction of bad loans is private

[9] More generally, we could have assumed that the defaulting firm has some assets at the end of the period, but lower than the recovery value L. This is the case when the defaulting firm engages in opportunistic behaviors that dissipate the value of the assets. For example, the manager of the defaulting firm might undertake projects that yield private benefits but are not efficient for the firm, or sell firms' assets at very low prices to other firms where she has a stake.

information, banks may choose to hide some of their bad loans. However, banks cannot charge off more bad loans than what they have in the balance sheet. Banks' charge off choice serves as a signal to investors, who have to decide whether to rollover the debt taken up by banks at time 0. Banks can continue until time 2 and get the return on their investment if investors rollover the debt. If they do not, banks are liquidated at time 1 and shareholders get a 0 payoff.

This setup is intended to represent the effect of investors' lending choices in normal and crisis times on banks' risk taking. The assumption that banks differ in the fraction of bad loans in case they do not monitor, together with the information asymmetry about bad loans, generates a trade-off in the management of bad loans. As few bad loans implies a high value of assets and a low risk of default, banks have incentives to hide bad loans in order to borrow from investors at more favorable terms. However, this comes at the cost of giving up the recovery value L on the hidden bad loans. We will show that banks might be able to hide some of their bad loans in equilibrium, and demonstrate that this affects the monitoring choice.

In order to make banks' choice interesting, we need to assume a risk-return trade-off by imposing some structure on the projects' payoff. The payoff of the investment is the sum of the expected return on good loans ($1 - \mathbb{E}[\theta]$ or $1 - \gamma\mathbb{E}[\theta]$) and the recovery value on bad loans.

Assumption 7.

$$(1 - \mathbb{E}[\theta])Y + \mathbb{E}[\theta]L > (1 - \gamma\mathbb{E}[\theta])Y + \gamma\mathbb{E}[\theta]L$$

Assumption 8.

$$(1 - \theta_N)Y + \theta_N L < (1 - \gamma\theta_N)\mathbb{E}[Y] + \gamma\theta_N L$$

Assumption 9.

$$(1 - \theta_C)Y + \theta_C L > (1 - \gamma\theta_C)\mathbb{E}[Y] + \gamma\theta_C L$$

Assumption 10.

$$(1 - \gamma\theta_s)\overline{Y} + \gamma\theta_s L > (1 - \theta_s)Y + \theta_s L > (1 - \gamma\theta_s)\underline{Y} + \gamma\theta_s L \;\forall\; s$$

Assumption 7 means that monitoring is efficient, as in expectation it yields a higher payoff than not monitoring. Assumptions 8 and 9 state that the expected return in case of monitoring is greater than not monitoring in times of crisis, whereas it is lower in normal times. Assumption 10 means that, in both states of the world, the return in case of monitoring falls between the two possible return realizations in case of not monitoring. Taken together, Assumptions 8-10 imply that the risk-return trade-off has a within and an across states dimension: not monitoring yields more (less) than monitoring in the N (C) state in expectation, and if $\tilde{Y} = \overline{Y}$ ($\underline{Y}$) realizes in either state of the world.

We will impose two additional assumptions on parameters in order to streamline the presentation.

Assumption 11.

$$\gamma \in [1, 2]$$

Assumption 12.

$$(1-\alpha)\underline{Y}\frac{\gamma}{2} > L$$

Assumption 11 means that the difference in the fraction of bad loans among banks cannot be too large. Assumption 12 specifies an upper bound for the recovery value L. In the remainder of the paper, we will define *bad bank (B)* the bank with $\gamma\theta_s$ bad loans, and *good bank (G)* the bank with θ_s bad loans. We will denote $\hat{\theta}_{i,\,s}$, with $i = \{G,\ B\}$ and $s = \{C,\ N\}$, the fraction of bad loans charged off by the two types of banks in each of the two states of the world.

2.3 The Complete Information Benchmark

Let us start by describing the equilibrium of the game in case of no information asymmetry between banks and investors. As usual, we solve for the equilibrium of the game using backward induction. If investors know the fraction of bad loans banks have in their balance sheet, they will rollover the debt of both types of banks if

$$(1-\theta_s)Y + \hat{\theta}_{G,\,s}L \geq D, \tag{2.1}$$

and

$$(1-\gamma\theta_s)\mathbb{E}[Y] + \hat{\theta}_{B,\,s}L \geq D. \tag{2.2}$$

These inequalities mean that investors lend to the banks if their assets are worth more than their outstanding debt at time 1. As investors know the fraction of bad loans, banks' charge off choice is trivial. Banks charge off all their bad loans, that is $\hat{\theta}_{B,\,s} = \gamma\theta_s$ and $\hat{\theta}_{G,\,s} = \theta_s$, because hiding them only implies the loss of the recovery value L. In the remainder of the paper, we will focus on the parameter constellations defined in Case 1.

Case 1.

$$(1-\gamma\theta_C)\mathbb{E}[Y] \geq 1$$
$$(1-\gamma\theta_C)\underline{Y} + \gamma\theta_C L < 1$$

Case 1 defines an environment where investors are willing to rollover the debt of bad banks in a crisis even if they do not charge off any bad loan. However, investors require a risk premium if $D \in [(1-\gamma\theta_C)\underline{Y} + \gamma\theta_C L,\ 1]$. Case 1 also implies that good banks are solvent in both states, and bad banks are solvent in normal times independently of the realization of $\tilde{Y}$. In the asymmetric information case, the restrictions in Case 1, together

with the assumptions about payoffs, will give the bad bank a gain from mimicking good banks.
Banks choose whether to monitor in the stage before the uncertainty realizes. They will monitor their investment if

$$(1-p)\max\{(1-\theta_N)Y+\theta_N L-D,\,0\}+p\max\{(1-\theta_C)Y+\theta_C L-D,\,0\}\geq$$
$$(1-p)\max\{(1-\gamma\theta_N)\mathbb{E}[Y]+\gamma\theta_N L-D,\,0\}+p\max\{(1-\gamma\theta_C)\mathbb{E}[Y]+\gamma\theta_C L-D,\,0\},$$

that is if monitoring yields a higher expected payoff than not monitoring. Case 1 implies that the profits of both types of banks are positive in both states of the world. Hence banks choose to monitor because, in expectation, this yields more than not monitoring by Assumption 7.
At time 0, banks make the financing choice anticipating that they will choose to monitor their investment. They choose the debt-equity mix that solves the following optimization problem:

$$\max_D \Pi = (1-\mathbb{E}[\theta])Y+\mathbb{E}[\theta]L-D-(1+\rho)(1-D)$$

Banks will choose to finance their investment only with debt because debt is cheaper than equity. Investors are willing to lend $D = 1$ because they expect the bank to be solvent at time 2.
In our complete information benchmark case, banks make the efficient choice and no regulatory intervention is needed. We will now demonstrate that this might not be the case when banks have private information about the bad loans in their balance sheet.

2.4 The Equilibrium With Asymmetric Information

Asymmetric information makes the charge-off choice non trivial in case banks have decided not to monitor their investment in the first stage. The reason is that banks differ in terms of the bad loans they have in their portfolio in this case. Hiding bad loans yields a loss in terms of recovery value L, but allows the bad bank to mimic the good one and borrow at more favorable conditions at time 1. Hence banks and investors play a signaling game at time 1. Asymmetric information makes no difference in case banks have decided to monitor their investment in the first stage. The reason is that all banks have the same fraction of bad loans.
We will start describing the equilibria of the signaling game, and refer to the previous section for the equilibrium arising in case banks have decided to monitor in the first stage. We then proceed by finding the equilibrium in the first stage.

2.4.1 The Equilibria of the Signaling Game

Signaling games have typically a multiplicity of equilibria, depending on the specification of out of equilibrium beliefs. We will assume pessimistic out of equilibrium beliefs, that is investors believe a bank deviating from the equilibrium strategy to be of bad type. We will then use the Cho-Kreps intuitive criterion to refine out of equilibrium beliefs and narrow down the set of equilibria. This will lead us to find a continuum of separating equilibria and a pooling equilibrium, which are unique for a given parameter configuration. We will describe these equilibria in the next two subsections, and provide a graphical representation in the third.

Separating Equilibrium

In a separating equilibrium, investors learn whether banks are good or bad from their charge off choice. Investors rollover the debt of both types of banks if inequalities (2.1) and (2.2) hold. Given the restrictions in Case 1, investors will charge bad banks the interest rate

$$R_B(\hat{\theta}_{B,\,C}) = \begin{cases} 1 & \text{if } (1-\gamma\theta_C)\underline{Y} + \hat{\theta}_{B,\,C}L \geq D \\ \frac{D-(1-\alpha)\left[(1-\gamma\theta_C)\underline{Y}+\hat{\theta}_{B,\,C}L\right]}{\alpha D} & \text{if } D \in ((1-\gamma\theta_C)\underline{Y} + \hat{\theta}_{B,\,C}L,\ 1] \end{cases}$$

in a crisis. Investors will charge the risk free rate to bad banks in normal times and good banks in both states of the world. Note that $R_B(\hat{\theta}_{B,\,C})$ is decreasing in $\hat{\theta}_{B,\,C}$, as the higher the fraction of bad loans charged off, the higher the recovery value and hence the value of assets. Note also that $R_B(\hat{\theta}_{B,\,C})$ depends positively on debt. Debt is safe when its value is smaller than the lowest possible realization of the value of assets. When debt is larger, bad banks can default and investors charge a risk premium to make up for the expected loss given default.
Banks decide how many bad loans to charge off anticipating the interest rate required by investors. The couple $\hat{\theta}_{B,\,s},\ \hat{\theta}_{G,\,s}$ is an equilibrium if, in any state s, bad banks prefer charging off $\hat{\theta}_{B,\,s}$ bad loans and good banks $\hat{\theta}_{G,\,s}$ bad loans.

Proposition 2. *There exists a separating equilibrium with*

$$\hat{\theta}^{Sep}_{B,\,s} = \gamma\theta_s$$
$$\hat{\theta}^{Sep}_{G,\,s} = \gamma\theta_s - \frac{1-\alpha}{\alpha L}\left[D - (1-\gamma\theta_s)\underline{Y} - \gamma\theta_s L\right]$$

Proof. The couple $\hat{\theta}_{B,\,s},\ \hat{\theta}_{G,\,s}$ is an equilibrium charge off choice if the incentive constraints of both types of bank is satisfied. The incentive constraint of the bad bank is the following:

$$\max_{\hat{\theta}_{B,\,s}} \left[(1-\gamma\theta_s)\mathbb{E}[Y] + \hat{\theta}_{B,\,s}L - D\right] \geq \alpha \max\{(1-\gamma\theta_s)\overline{Y} + \hat{\theta}_{G,\,s}L - D,\ 0\} + \\ + (1-\alpha)\max\{(1-\gamma\theta_s)\underline{Y} + \hat{\theta}_{G,\,s}L - D,\ 0\}.$$

The left hand side is the equilibrium profit for the bad bank. Since investors infer that the bank is bad from $\hat{\theta}_{B,\,s}$, the bad bank chooses the charge off choice that maximizes its profits. The right hand side represents the profit from deviating to the charge off choice of good banks. This allows the bad bank to borrow at the risk free rate as we focused on the case where good banks is always solvent (Case 1). Given the profit-maximizing charge off choice for the bad bank is $\hat{\theta}_{B,\,s} = \gamma\theta_s$, the incentive constraint can be written as

$$(1-\gamma\theta_s)\mathbb{E}[Y] + \gamma\theta_s L - D \geq \alpha \max\{(1-\gamma\theta_s)\overline{Y} + \hat{\theta}_{G,\,s}L - D,\ 0\} + \\ + (1-\alpha)\max\{(1-\gamma\theta_s)\underline{Y} + \hat{\theta}_{G,\,s}L - D,\ 0\}.$$

It is easy to show that:

1. The incentive constraint is always satisfied if $(1-\gamma\theta_s)\underline{Y} + \hat{\theta}_{G,\,s}L \geq D$, as $\gamma\theta_s L > \hat{\theta}_{G,\,s}L$;
2. In case $(1-\gamma\theta_s)\underline{Y} + \hat{\theta}_{G,\,s}L < D$, the incentive constraint is satisfied if

$$\hat{\theta}_{G,\,s} \leq \gamma\theta_s - \frac{1-\alpha}{\alpha L}\left[D - (1-\gamma\theta_s)\underline{Y} - \gamma\theta_s L\right].$$

The incentive constraint of good banks is the following:

$$(1-\theta_s)Y + \hat{\theta}_{G,\,s}L - D \geq \max_{\hat{\theta}'_s} \left[(1-\theta_s)Y + \hat{\theta}'_s L - DR(\hat{\theta}'_s)_B\right].$$

The left hand side is the equilibrium profit for good banks, whereas the right hand side is the maximum profit the bad bank can obtain from a deviation. The optimal deviation $\hat{\theta}'_s$ is the one that maximizes the profits of good banks given investors' belief that the bank is bad. After some algebra, we get that the incentive constraint is satisfied if

$$\hat{\theta}_{G,\,s} \geq \theta_s - \frac{1-\alpha}{\alpha L}\left[D - (1-\gamma\theta_s)\underline{Y} - \gamma\theta_s L\right].$$

Note that there is a range of $\hat{\theta}_{G,\,s}$ for which the incentive constraint of both types of bank is satisfied because $\gamma\theta_s > \theta_s$. We can narrow down the set of equilibria using domination-based refinements. The intuition is that, if an action is dominant for some player, investors should believe that this action is taken by the player for which it is dominant. In our framework, hiding bad loans is costly because banks lose their recovery value. Since there is a range of $\hat{\theta}_{G,\,s}$ for which both incentive constraints are satisfied, the dominant action for good banks is to choose the largest $\hat{\theta}_{G,\,s}$ in the interval. As investors attribute this action to good banks, good banks actually finds it optimal to deviate. As a result, the only separating equilibrium left is the one described in Proposition 2.

□

Separation is an equilibrium when the incentive constraint of both good and bad banks is satisfied. Good banks must prefer the equilibrium charge off choice to charging off all bad loans and borrowing and the bad bank interest rate. Bad banks must prefer revealing their bad loans to mimicking good banks and borrowing at the risk free interest rate. The charge off choice in Proposition 2 is the one that satisfies the incentive constraints of both types of banks.

Bad banks find it optimal to charge off all their bad loans in equilibrium. The reason is that hiding bad loans would just yield a loss in the recovery value given that, in equilibrium, investors infer banks' type from the charge off choice. Any separating equilibrium with $\hat{\theta}_{B,\,s} < \gamma\theta_s$ would be dominated by the one with $\hat{\theta}^{Sep}_{B,\,s} = \gamma\theta_s$.

Good banks prefer to separate from bad banks by charging off a fraction $\hat{\theta}^{Sep}_{G,\,s}$ of bad loans. Note that $\hat{\theta}^{Sep}_{G,\,s}$ is decreasing in debt. Intuitively, the higher debt, the higher the interest rate bad banks have to pay, and hence the stronger the incentive of bad banks to mimic the good ones. As a result, good banks can separate only if they make mimicking more costly by hiding a sufficiently high fraction of bad loans. The relation between $\hat{\theta}^{Sep}_{G,\,s}$ and debt implies the following corollary to Proposition 2.

Corollary 1. *It holds that:*

1. $\hat{\theta}^{Sep}_{G,\,s} = \theta_s$ *if* $D = (1-\alpha)(1-\gamma\theta_s)\underline{Y} + \gamma\theta_s L + \frac{\alpha}{1-\alpha}(\gamma - 1)\theta_s L \equiv D_0$
2. $\hat{\theta}^{Sep}_{G,\,s} = 0$ *if* $D = (1-\alpha)(1-\gamma\theta_s)\underline{Y} + \gamma\theta_s L + \frac{\alpha}{1-\alpha}\gamma\theta_s L \equiv D_1$

Corollary 1 describes the two extreme cases in which good banks can separate from bad banks by charging off (case $\hat{\theta}^{Sep}_{G,\,s} = \theta_s$) and hiding (case $\hat{\theta}^{Sep}_{G,\,s} = 0$) all their bad loans. Good banks reveal themselves only by hiding all their bad loans when $D = D_1$, whereas they can separate from bad banks even by charging off all their bad loans if $D \leq D_0$. Note that $D_0 < D_1$. The intuition comes from the negative relation between $\hat{\theta}^{Sep}_{G,\,s}$ and debt. When $D \leq D_0$, separation is not costly for good banks because the debt repayment is so low that the gain from borrowing at the risk free rate is lower than the recovery value bad banks would lose mimicking good banks. By contrast, separation requires good banks to hide all their bad loans when $D = D_1$. The reason is that the debt repayment is so high that good banks can prevent bad banks from mimicking only

by giving up the recovery value on all their bad loans.
Proposition 2 defines two regimes. The first, which we define *perfect separation regime (PS)*, exists in the debt interval $D \in [0,\ D_0]$. In the PS regime, good banks reveal themselves by charging off all their bad loans. The charge off choice in this regime is the same as in the complete information benchmark, as both types of banks charge off all their bad loans. The second regime, which we define *costly separation regime (CS)*, exists in the debt interval $D \in (D_0,\ D_1]$. In the CS regime, good banks separates by hiding a fraction of bad loans which is increasing in the value of debt. This regime features an inefficiency, as good banks deplete the value of their assets by giving up the recovery value on part of their bad loans. Since $\hat{\theta}^{Sep}_{G,\,s}$ is decreasing in debt and must be non negative, separation will not always be feasible and an uninformative equilibrium might exist for large values of debt. Next section defines such a regime.

Pooling equilibrium

In a pooling equilibrium, good and bad banks charge off the same fraction of bad loans. We define $\hat{\theta}^P_s$ such a fraction. Note that $\hat{\theta}^P_s \leq \theta_s$ because good banks cannot charge off more bad loans than what they have in their balance sheet (θ_s). In a pooling equilibrium, good and bad banks are indistinguishable to investors at time 1. Knowing there is adverse selection among the pool of borrowers, and that half banks have θ_s bad loans and the other half $\gamma\theta_s$ bad loans, investors rollover banks' debt if

$$\frac{1}{2}\left[\alpha \min\{(1-\gamma\theta_s)\overline{Y} + \hat{\theta}^P_s L,\ D\} + (1-\alpha)\min\{(1-\gamma\theta_s)\underline{Y} + \hat{\theta}^P_s L,\ D\}\right] + \\ + \frac{1}{2}\min\{(1-\theta_s)Y + \hat{\theta}^P_s L,\ D\} = D.$$

This equation states that investors rollover banks' debt if they are indifferent between lending, and getting the expected return on the right hand side, and not lending and keeping D. Investors will charge the interest rate

$$R(\hat{\theta}^P_C) = \begin{cases} 1 & \text{if } (1-\gamma\theta_s)\underline{Y} + \hat{\theta}^P_s L \geq D \\ \frac{D - \frac{1-\alpha}{2}\left[(1-\gamma\theta_s) + \hat{\theta}^P_C\right]}{\frac{1+\alpha}{2}} & \text{if } D \in ((1-\gamma\theta_s)\underline{Y} + \hat{\theta}^P_s L,\ 1] \end{cases}$$

in the crisis state, and the risk free rate in normal times. Since we restricted the analysis to Case 1, in which $(1-\theta_C)Y > 1$ and $(1-\gamma\theta_C)\underline{Y} + \gamma\theta_C L < 1$, default risk only exists in the crisis state. Case 1 also implies that adverse selection does not lead to market unravelling, as investors are willing to rollover any amount of debt in the crisis state even if all banks are bad. As in the separating equilibrium case, the interest rate in the pooling equilibrium case is decreasing in the charge off choice ($\hat{\theta}^P_C$) and increasing in debt.

The interest rate charged by investors determines banks' profits in the pooling equilibrium. A pooling where both banks charge off $\hat{\theta}_s^P$ bad loans is an equilibrium if it yields profits larger than any other deviation. Proposition 3 states the conditions under which a pooling equilibrium exists.

Proposition 3. *There exists a pooling equilibrium with:*

1. $\hat{\theta}_C^P = \frac{1-\alpha}{2L}\left[D - (1-\gamma\theta_C)\underline{Y}\right] \equiv \theta_0$ *if* $D \in (D_1,\, D_2]$
2. $\hat{\theta}_C^P = \theta_s$ *if* $D \in (D_2,\, 1]$

It holds that $D_2 \equiv (1-\gamma\theta_C)\underline{Y} + \frac{2L}{1-\alpha}$.

Proof. There exists a pooling equilibrium with $\hat{\theta}_s^P$ if the equilibrium profits of both types of bank is larger than the profit from any deviation. The incentive constraint of the bad bank is the following:

$$\begin{aligned}&\alpha \max\{(1-\gamma\theta_s)\overline{Y} + \hat{\theta}_s^P L - DR(\hat{\theta}_s^P),\, 0\}+\\ &+(1-\alpha)\max\{(1-\gamma\theta_s)\underline{Y} + \hat{\theta}_s^P L - DR(\hat{\theta}_s^P),\, 0\} \geq\\ &\alpha \max\{(1-\gamma\theta_s)\overline{Y} + \hat{\theta}_s^{'} L - DR(\hat{\theta}_s^{'})_B,\, 0\}+\\ &+(1-\alpha)\max\{(1-\gamma\theta_s)\underline{Y} + \hat{\theta}_s^{'} L - DR(\hat{\theta}_s^{'})_B,\, 0\}.\end{aligned}$$

The left hand side is the equilibrium profit, while the right hand side is the profit from deviating to the charge off choice $\hat{\theta}_s^{'}$ given investors attribute this deviation to the bad type and charge the interest rate $R(\hat{\theta}_s^{'})_B$. Since $R(\hat{\theta}_s^{'})_B$ is decreasing in $\hat{\theta}_s^{'}$, and hiding bad loans is costly, the best deviation that the bad bank can do is $\hat{\theta}_s^{'} = \gamma\theta_s$. Hence the incentive constraint of the bad bank can be written as

$$\begin{aligned}&\alpha \max\{(1-\gamma\theta_s)\overline{Y} + \hat{\theta}_s^P L - DR(\hat{\theta}_s^P),\, 0\}+\\ &+(1-\alpha)\max\{(1-\gamma\theta_s)\underline{Y} + \hat{\theta}_s^P L - DR(\hat{\theta}_s^P),\, 0\} \geq \max\{(1-\gamma\theta_s)\mathbb{E}[Y] + \gamma\theta_s - D,\, 0\}.\end{aligned}$$

Note that the profit from the best deviation coincides with the equilibrium profit in the separating equilibrium. It can be easily shown that:

1. The incentive constraint is not satisfied if $R(\hat{\theta}_s^P) = 1$ because $\hat{\theta}_s^P \leq \theta_s < \gamma\theta_s$
2. If $R(\hat{\theta}_s^P) = \frac{D - \frac{1-\alpha}{2}\left[(1-\gamma\theta_s)+\hat{\theta}_C^P\right]}{\frac{1+\alpha}{2}}$, the incentive constraint is satisfied if

$$\hat{\theta}_s^P \geq \gamma\theta_s - \frac{1-\alpha}{2\alpha L}\left[D - (1-\gamma\theta_s)\underline{Y} - \gamma\theta_s L\right] \equiv \underline{\hat{\theta}}_s^P.$$

The incentive constraint of good banks is the following:

$$\max\{(1-\theta_s)Y + \hat{\theta}_s^P L - DR(\hat{\theta}_s^P),\, 0\} \geq \max\{(1-\theta_s)Y + \hat{\theta}_s' L - DR(\hat{\theta}_s')_B,\, 0\}).$$

By the same logic as the bad bank, the best deviation good banks can do given investors' beliefs is $\hat{\theta}_s' = \theta_s$. Hence the incentive constraint of good banks can be written as

$$\max\{(1-\theta_s)Y + \hat{\theta}_s^P L - DR(\hat{\theta}_s^P),\, 0\} \geq \max\{(1-\theta_s)Y + \theta_s L - DR(\theta_s)_B,\, 0\}).$$

It can be shown that the incentive constraint of good banks is satisfied if

$$\hat{\theta}_s^P \geq \theta_s - \frac{1-\alpha}{2\alpha L}\left[D - (1-\gamma\theta_s)\underline{Y} - \theta_s L\right] \equiv \underline{\underline{\hat{\theta}}}_s^P.$$

Since $\underline{\hat{\theta}}_s^P > \underline{\underline{\hat{\theta}}}_s^P$, the incentive constraint of both types of bank is satisfied if $\hat{\theta}_s^P > \underline{\hat{\theta}}_s^P$. Given good banks can charge off at most θ_s bad loans, there is a continuum of pooling equilibria with $\hat{\theta}_s^P \in \left[\underline{\hat{\theta}}_s^P,\, \theta_s\right]$. It can be shown that this interval is non-empty if

$$D \geq (1-\alpha)(1-\gamma\theta_s)\underline{Y} + \gamma\theta_s L + \frac{2\alpha}{1-\alpha}(\gamma-1)\theta_s L \equiv D_3.$$

The set of equilibria can be reduced applying the Cho-Kreps intuitive criterion. The intuition is that investors should attribute to good banks a deviation that the bad bank would not find it worth mimicking. The bad bank prefers not to mimic the deviations that yield a lower or equal payoff than the pooling equilibrium payoff. Hence there is no pooling equilibrium in case good banks prefer deviating to the charge off choice that makes the bad bank indifferent between pooling and mimicking. This charge off choice is such that

$$\begin{aligned}
&\alpha\left[(1-\gamma\theta_s)\overline{Y} + \hat{\theta}_s^P L - DR(\hat{\theta}_s^P)\right] = \\
&\alpha\left[(1-\gamma\theta_s)\overline{Y} + \hat{\theta}_s^* L - D\right] + (1-\alpha)\max\{(1-\gamma\theta_s)\underline{Y} + \hat{\theta}_s^* L - D,\, 0\}.
\end{aligned}$$

The left hand side is the equilibrium payoff, where we take into account the fact that pooling does not exist in case $R(\hat{\theta}_s^P) = 1$ and the bad bank is solvent in both states of the world. The right hand side is the payoff from deviating to $\hat{\theta}_s^*$ given investors attribute the deviation to good banks and hence charge the risk free rate. It can be shown that

$$\hat{\theta}_s^* = \frac{2}{(1+\alpha)L}\left[\hat{\theta}_s^P - \frac{1}{2}(1-\alpha)(D - (1-\gamma\theta_s)\underline{Y})\right],$$

and that good banks are indifferent between pooling and deviating to $\hat{\theta}_s^*$, in which case we assume that good banks prefer to deviate. Hence the pooling equilibrium with $\hat{\theta}_s^P$

does not exist if the corresponding $\hat{\theta}^*_s \geq 0$. The pooling equilibrium exists if $\hat{\theta}^*_s < 0$, as this deviation is not possible for good banks. It can be shown that $\hat{\theta}^*_s < 0$ if

$$\hat{\theta}^P_s < \frac{1-\alpha}{2L}\left[D - (1-\gamma\theta_s)\underline{Y}\right] \equiv \theta_0.$$

The range of pooling equilibria is reduced to those with $\hat{\theta}^P_C \in \left[\underline{\hat{\theta}}^P_C, \min\{\theta_0, \theta_C\}\right]$. It can be shown that $\theta_0 > \underline{\hat{\theta}}^P_C$ if $D > D_1$, which we have shown in Corollary 1. We further refine the set of equilibria noting that both banks prefer the equilibrium with the highest charge off choice. Hence investors should not attribute such a deviation to the worst type, but realize that it is profitable for both types. By this logic, the only pooling equilibrium left is the one with $\hat{\theta}^P_C = \min\{\theta_0, \theta_C\}$. It can be shown that $\theta_0 \leq \theta_C$ if $D \leq D_2$, and that $D_3 < D_1 < D_2$ by Assumption 11. □

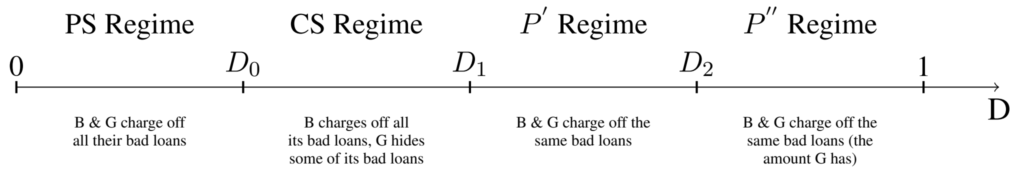
Note that a pooling equilibrium can only exist in the crisis state. The reason is that bad banks have incentives to pool when they risk defaulting, and default is possible only in the crisis state by Case 1. If bad banks could borrow at the risk free rate in a pooling equilibrium, they could borrow at the risk free rate also in a separating equilibrium. This is because bad banks deplete part of the value of their assets in a pooling equilibrium by hiding some bad loans. Hence it would be optimal for bad banks to deviate from the pooling equilibrium and charge off all their bad loans.
The existence of a pooling equilibrium requires that both types of bank do not have incentive to deviate to any other charge off choice. In the proof of Proposition 3 we show that this condition is satisfied for values of $\hat{\theta}^P_C \geq \underline{\hat{\theta}}^P_C$. The reason is that deviating from the equilibrium strategy is costly as investors attribute the deviation to bad banks. Hence even good banks prefer a pooling with a relatively low $\hat{\theta}^P_s$ in order to avoid borrowing at the interest rate that investors would charge to bad banks. However, the Cho-Kreps intuitive criterion suggests that investors should attribute a certain deviation to good banks if this deviation is equilibrium dominated for bad banks. Hence good banks would reveal themselves by doing such a deviation. The conditions in Proposition 3 guarantee that good banks cannot signal their type through the charge off choice. Recall that, by Corollary 1, good banks can separate by charging off 0 bad loans if $D = D_1$. Proposition 3 shows that a pooling equilibrium exists if $D > D_1$, that is in the range of debt values for which separation is not possible. The intuition is that the higher debt, the higher the debt repayment, and the stronger the incentive to mimic of bad banks. When $D > D_1$, bad banks would find the cost of mimicking greater than the gain if good banks were to charge off a negative fraction of bad loans, which is impossible.
The charge off choices θ_0 and θ_C are those such that good banks cannot reveal themselves. We show in the proof of Proposition 3 that both θ_0 and θ_C are greater than $\underline{\hat{\theta}}^P_C$, which is the lower bound of the interval in which the pooling equilibrium exists. As the interval $\hat{\theta}^P_C \in \left[\underline{\hat{\theta}}^P_C, \min\{\theta_0, \theta_C\}\right]$ is non-empty, there exists a continuum of pooling

equilibria even after applying the Cho-Kreps intuitive criterion. We further refine the set of pooling equilibria noting that the equilibrium with $\hat{\theta}_C^P = \min\{\theta_0, \theta_C\}$ is the one maximizing the profits of both types of banks. Hence investors should not attribute the deviation $\hat{\theta}_C^P = \min\{\theta_0, \theta_C\}$ to the bad type, but to both types with the prior probability. Hence both banks find this deviation optimal, and investors' belief are confirmed in equilibrium.
As a result, there exists a pooling equilibrium where banks charge off either θ_0 or θ_C bad loans. Proposition 3 states that the equilibrium charge off choice depends on the value of debt. In the range of debt values $D \in (D_1,\ D_2]$, the equilibrium charge off choice is the one such that separation would require a negative charge off choice ($\hat{\theta}_C^P = \theta_0$). Note that θ_0 is increasing in debt. The intuition is that the higher debt repayment, the stronger the incentive to mimic of bad banks, and the larger the range of $\hat{\theta}_C^P$ for which there exists a pooling ($\hat{\theta}_s^P \in \left[\underline{\hat{\theta}}_C^P,\ \theta_0\right]$). When the value of debt is larger than D_2, the fraction θ_0 becomes larger than θ_C. As good banks cannot charge off more bad loans than the true fraction, the charge off choice in the pooling equilibrium is $\hat{\theta}_C^P = \theta_C$.

Summary of the Equilibria

The trade-off between the gain in the debt repayment and the loss in the recovery value L drives the equilibrium charge off choice. In normal times, both types of banks charge off all their bad loans in equilibrium. The reason is that, by Case 1, bad banks do not risk defaulting and hence have no gain from mimicking good banks. By contrast, bad banks might default in the crisis state. In this state, the equilibrium of the signaling game is characterized by three regimes that can be defined in terms of debt values. Figure 2.2 shows a graphical representation of the equilibrium. When debt is lower than D_0,

Figure 2.2: The Equilibria of the Signaling Game in the Crisis State



the gain in the debt repayment is lower than the cost of hiding even a small fraction of bad loans. Hence both types of bank reveal all their bad loans (*perfect separation (PS) regime*). When the value of debt falls in the range between D_0 and D_1, the gain in the debt repayment is such that good banks have to hide some bad loans in order to prevent bad banks from mimicking. In equilibrium, bad banks reveal all their bad loans while good banks hide some of them (*costly separation (CS) regime*). When the value of debt is greater than D_1, the gain in the debt repayment is so large that bad banks would mimic any charge off choice by good banks. Banks reveal the same fraction of bad loans in equilibrium, and hence are not distinguishable by investors (*pooling (P) regime*). The value of the equilibrium charge off choice depends on the value of debt.

2.4.2 The Equilibrium of the Game in Stage 1

Having found the equilibrium of the signaling game, we proceed by solving for the choice of monitoring and debt at time 0. Banks anticipate that they will charge off all their bad loans in normal times, whereas in crisis times the equilibrium charge off choice will depend on the value of debt. Banks take the value of debt as given when choosing whether to monitor or not. Proposition 4 illustrates the optimal monitoring choice.

Proposition 4. *Banks monitor their investment in case:*

1. $D \leq D_1$
2. $D \in (D_1,\ D_2]$ *and*
$$\Gamma \leq p\theta_C L,$$
3. $D \in (D_2,\ 1]$ *and*
$$\Gamma \leq p\left[\theta_C L + \frac{1-\alpha}{1+\alpha}(D - D_2)\right]$$

where
$\Gamma \equiv \frac{p}{2}\left[(1-\gamma\theta_C)\overline{Y} - (1-\theta_C)Y\right] + \frac{1-p}{2}\left[(1-\gamma\theta_N)\mathbb{E}[Y] + \gamma\theta_N L - (1-\theta_N)Y - \theta_N L\right].$

Proof. Let us compare the profits from monitoring and not monitoring in the following ranges of debt values:

1. $D < D_0$: Banks monitor their investment because they anticipate that the charge off choice will be the same as in the full information benchmark. As a result, also the monitoring choice will be the same.
2. $D \in (D_0, D_1]$: Banks anticipate that the costly separation regime will arise in the crisis state. They will monitor if

$$\begin{aligned}&(1-p)\left[(1-\theta_N)Y + \theta_N L\right] + p\left[(1-\theta_C)Y + \theta_C L\right] \geq \\ &\frac{(1-p)}{2}\left[(1-\theta_N)Y + \theta_N L + (1-\gamma\theta_N)Y + \gamma\theta_N L\right] + \frac{p}{2}\left[(1-\gamma\theta_C)Y + \gamma\theta_C L\right] + \\ &+ \frac{p}{2}\left[(1-\theta_C)Y - \frac{1}{\alpha}(D - (1-\alpha)(1-\gamma\theta_C)\underline{Y} - \gamma\theta_C L)\right].\end{aligned}$$

The right hand side is the expected profit from not monitoring. In case the N state realizes, banks will reveal all their bad loans, and hence profits will be the same as in the full information benchmark. In case the C state realizes, only bad banks will charge off all their bad loans, while good banks will have to hide some of them. The last term on the right hand side of the inequality represents the equilibrium payoffs of good banks. The previous inequality can be rewritten as

$$\Delta_N^M - \Delta_C^M + p\left[D - (1-\gamma\theta_C)\underline{Y} - \gamma\theta_C L\right] \geq 0,$$

where $\Delta_C^M \equiv (1-\gamma\theta_C)\mathbb{E}[Y] + \gamma\theta_C L - (1-\theta_C)Y - \theta_C L$. Since the CS regime exists in the range of debt values $D \in (D_0, D_1]$, and $D_0 > (1-\gamma\theta_C)\underline{Y} + \gamma\theta_C L$, the previous inequality always holds and hence banks prefer to monitor in case $D \in (D_0, D_1]$.

3. $D \in (D_1, D_2]$: Banks anticipate that the pooling regime with $\hat{\theta}_C^P = \theta_0$ will arise in the crisis state. They will monitor if

$$\begin{aligned}&(1-p)\left[(1-\theta_N)Y + \theta_N L\right] + p\left[(1-\theta_C)Y + \theta_C L\right] \geq \\ &\frac{(1-p)}{2}\left[(1-\theta_N)Y + \theta_N L + (1-\gamma\theta_N)Y + \gamma\theta_N L\right] + \\ &+ \frac{p}{2}\left[(1-\gamma\theta_C)Y + (1-\theta_C)Y - 2D\right].\end{aligned}$$

The right hand side is the expected profit from not monitoring. In case the N state realizes, banks will reveal all their bad loans, and hence profits will be the same as in the full information benchmark. In case the C state realizes, both types of bank will charge off θ_0 bad loans. The last term on the right hand side of the inequality represents the expected equilibrium payoff of banks when the crisis state realizes. The condition in Proposition 4 follows from rearranging the previous inequality.

4. $D \in (D_1, 1]$: Banks anticipate that the pooling regime with $\hat{\theta}_C^P = \theta_C$ will arise in the crisis state. They will monitor if

$$\begin{aligned}&(1-p)\left[(1-\theta_N)Y + \theta_N L\right] + p\left[(1-\theta_C)Y + \theta_C L\right] \geq \\ &\frac{(1-p)}{2}\left[(1-\theta_N)Y + \theta_N L + (1-\gamma\theta_N)Y + \gamma\theta_N L\right] + \\ &\frac{p}{2}\left[(1-\gamma\theta_C)Y + (1-\theta_C)Y + \theta_C L - D - \frac{1-\alpha}{1+\alpha}(D - (1-\gamma\theta_C)\underline{Y} - \gamma\theta_C L)\right].\end{aligned}$$

The right hand side is the expected profit from not monitoring. In case the N state realizes, banks will reveal all their bad loans, and hence profits will be the same as in the full information benchmark. In case the C state realizes, both types of bank will charge off θ_C bad loans. The last term on the right hand side of the inequality represents the expected equilibrium payoff of banks when the crisis state realizes. The condition in Proposition 4 follows from rearranging the previous inequality.

□

Banks choose to monitor if they anticipate that the perfect separation ($D \leq D_0$) or costly separation regime ($D \in (D_0,\ D_1]$) will arise in the crisis state. In the case of perfect separation, the charge off choice of both types of bank is the same as in the complete information benchmark. As banks prefer to monitor in the complete information benchmark, it follows that banks will monitor also in the perfect separation regime. In the case of costly separation, banks anticipate that they will hide some bad loans in the crisis state in case they turn out to be of good type. In this case, the profit of good banks is lower than the profit they would get by choosing to monitor and getting θ_C bad loans for sure in the crisis state. Given this, and the fact that banks will have the same profits as if they monitor in case they turn out to be bad, the gain from monitoring is higher than in the perfect separation regime. Therefore banks have even stronger incentives to monitor in the costly separation regime. To understand the monitoring condition in the pooling regime, it is useful to show the optimality condition:

$$\frac{p}{2}\left[(1-\gamma\theta_C)\overline{Y}-(1-\theta_C)Y\right]+\frac{1-p}{2}\left[(1-\gamma\theta_N)\mathbb{E}[Y]+\gamma\theta_N L-(1-\theta_N)Y-\theta_N L\right]\leq$$
$$p\left[(\theta_C-\hat{\theta}_C^P)L+\frac{1-\alpha}{1+\alpha}(D-(1-\gamma\theta_c)\underline{Y}-\hat{\theta}_C^P)\right]. \tag{2.3}$$

The left hand side is the marginal gain banks obtain by not monitoring. While monitoring is efficient in the full information benchmark, it is not in case the pooling regime arises at time 1. The reason is that banks make profits only if $\tilde{Y}=\overline{Y}$ in case they turn out to be bad and the crisis state realizes. These profits are larger than in the case banks turn out to be good. Moreover, not monitoring yields a higher expected payoff in case the N state realizes. The right hand side represents the marginal cost of not monitoring. It is composed of two elements: The first is the loss in the recovery value on $\theta_C-\hat{\theta}_C^P$ bad loans that banks would have charged off in case they monitored, while the second is the risk premium that banks pay in a pooling equilibrium.
Hence banks choose not to monitor only if the marginal gain is larger than the cost. The thresholds in Proposition 4 follow from substituting the equilibrium charge off choice in equation (2.3). The marginal cost corresponding to the pooling with $\hat{\theta}_C^P=\theta_C$ is larger than the pooling with $\hat{\theta}_C^P=\theta_0$. Hence not monitoring in case $D\in(D_1,D_2]$ implies not monitoring in case $D\in(D_2,\ 1]$.
At time 0, banks choose the debt-equity mix anticipating the monitoring choice and the equilibrium of the signaling game at time 1. Proposition 5 illustrates the optimal choice of debt.

Proposition 5. *Banks choose*

$$D^*=\begin{cases}D_2 & \textit{if}\ \Gamma>p\theta_C L+\rho(1-D_2)\ \textit{and}\ \ \rho<p\frac{1-\alpha}{1+\alpha}\\ 1 & \textit{otw.}\end{cases},$$

where
$\Gamma \equiv \frac{p}{2}\left[(1-\gamma\theta_C)\overline{Y}-(1-\theta_C)Y\right]+\frac{1-p}{2}\left[(1-\gamma\theta_N)\mathbb{E}[Y]+\gamma\theta_N L-(1-\theta_N)Y-\theta_N L\right].$

Proof. We proceed by finding the optimal debt level in each debt interval, and then comparing the optimal profits across intervals.

1. $D \leq D_1$: As banks anticipate that they will monitor, the optimal value of debt solves the following problem

$$\begin{aligned} \underset{D}{\text{Max}} \quad & \Pi = (1-\mathbb{E}[\theta])Y + \mathbb{E}[\theta]L - D - (1+\rho)(1-D) \\ \text{s.t.} \quad & D \in [0,\ D_1] \end{aligned}$$

   The optimal value of debt is D_1 as $\rho > 0$.

2. $D \in (D_1,\ D_2]$: Banks will monitor if condition (2) in Proposition 4 is satisfied. The maximization problem in this case is similar to the previous one. By the same logic, the optimal value of debt is D_2. In case condition (2) is not satisfied, banks will not monitor and the optimal debt level solves the following problem:

$$\begin{aligned} \underset{D}{\text{Max}} \quad & \Pi = \frac{1-p}{2}\left[(1-\theta_N)Y + \theta_N L + (1-\gamma\theta_N)\mathbb{E}[Y] + \gamma\theta_N L\right] + \\ & + \frac{p}{2}\left[(1-\theta_C)Y + (1-\gamma\theta_C)\overline{Y}\right] - D - (1+\rho)(1-D) \\ \text{s.t.} \quad & D \in (D_1, D_2] \end{aligned}$$

   The optimal value of debt is D_2 as $\rho > 0$.

3. $D \in (D_2,\ 1]$: Banks will monitor if condition (3) in Proposition 4 is satisfied. The maximization problem in this case is similar to the previous one. By the same logic, the optimal value of debt is 1. In case condition (3) is not satisfied, banks will not monitor and the optimal debt level solves the following problem:

$$\begin{aligned} \underset{D}{\text{Max}} \quad & \Pi = \frac{1-p}{2}\left[(1-\theta_N)Y + \theta_N L + (1-\gamma\theta_N)\mathbb{E}[Y] + \gamma\theta_N L\right] + \\ & + p\left[\frac{1}{2}(1-\theta_C)Y + \frac{1}{2}(1-\gamma\theta_C)\overline{Y} + \theta_C L - \frac{1-\alpha}{1+\alpha}(D - (1-\gamma\theta_C)\underline{Y} - \theta_C L)\right] + \\ & - D - (1+\rho)(1-D) \\ \text{s.t.} \quad & D \in (D_2, 1] \end{aligned}$$

   The optimal value of debt is 1 if $\rho \geq p\frac{1-\alpha}{1+\alpha}$, while it takes the lowest possible value in the range if $\rho < p\frac{1-\alpha}{1+\alpha}$.

We will now compare the optimal profits across the 3 debt intervals. The following cases have to be considered:

1. Condition (2) and (3) in Proposition 4 hold: Banks know they will monitor independently of debt. The optimization problem becomes as in point (1), but without the restriction on debt. Hence the optimal solution is $D = 1$.

2. Condition (2) and (3) in Proposition 4 do not hold for any debt level: Banks know they will not monitor if $D > D_1$. The condition determining the choice of debt is the following:

$$\Pi^*(D \in (D_1,\ D_2]) \geq \begin{cases} \Pi^*(D \in (D_2,\ 1]) & \text{in case } \rho \geq p\frac{1-\alpha}{1+\alpha} \\ \Pi^*(D \in (D_2,\ 1]) & \text{in case } \rho < p\frac{1-\alpha}{1+\alpha} \end{cases}$$

   Banks will choose the optimal debt in the interval $D \in (D_1,\ D_2]$ if this yields higher profits than the optimal debt in the interval $D \in (D_2,\ 1]$. The optimal debt in the latter interval depends on the cost of capital ρ. It can be shown that the maximum profit is $\Pi^*(D \in (D_1,\ D_2])$ if $\rho < p\frac{1-\alpha}{1+\alpha}$ and $\Pi^*(D \in (D_2,\ 1])$ otherwise.

3. Condition (2) in Proposition 4 does not hold, while condition (3) holds only for some debt levels: This means that there is a $\overline{D}$ that falls into $D \in (D_2, 1]$ such that the bank monitors if $D \geq \overline{D}$ and does not otherwise. In this case, banks have to compare the following optimal profits: $\Pi^*(D \in (D_1,\ D_2])$, $\Pi^*(D \in (D_1,\ \overline{D})$ and $\Pi^*(D \in [\overline{D},\ 1)$. It can be shown that banks obtain the largest profits in the latter interval, as they monitor and can finance themselves only through debt. Therefore $D = 1$ is the optimal solution.

4. Condition (2) in Proposition 4 does not hold, while condition (3) holds only for all $D \in (D_2, 1]$: This means that banks will monitor in the range $D \in (D_2, 1]$ but not in the range $D \in (D_1, D_2]$. In this case, banks have to compare $\Pi^*(D \in (D_1, D_2])$ and $\Pi^*(D \in (D_2,\ 1])$. It holds that $\Pi^*(D \in (D_1,\ D_2]) \geq \Pi^*(D \in (D_2,\ 1])$ if

$$\rho(1 - D_2) \geq \frac{p}{2}\left[(1 - \gamma\theta_C)\overline{Y} - (1 - \theta_C)Y\right] + \frac{1-p}{2}\Delta_M - p\theta_C L$$

The conditions in Proposition 5 follow from rearranging the previous inequalities. □

The choice of the debt-equity mix depends on the cost of equity and on whether banks monitor their investment. Recall from Proposition 4 that banks' monitoring choice depends on which debt interval the value of debt falls in. Banks anticipate that they will monitor if they choose a value of debt in the interval $D \leq D_1$. Within this interval, the optimal choice is $D^*_M = D_1$. The reason is that debt is cheaper than equity when banks monitor because there is no risk of default. In the second and third intervals ($D \in (D_1,\ 1]$), the optimal choice of debt is not trivial because banks might not have incentives to monitor. When banks do not monitor, those that turn out to be bad in the crisis state might default. As the equilibrium interest rate contains a risk premium, equity is not necessarily more costly than debt. It turns out that the risk premium is always lower than ρ in the range $D \in (D_1,\ D_2]$, so that $D^*_{NM} = D_2$. In the range $D \in (D_2,\ 1]$, banks choose the highest level of debt ($D^*_{NM} = 1$) only if $\rho < p\frac{1-\alpha}{1+\alpha}$. In case $D \in (D_1,\ 1]$, and banks have incentives to monitor (conditions (2) and (3) in Proposition 4 hold), the optimal choice of debt will be the highest possible by the same argument as in the interval $D \in [0,\ D_1]$.

The optimal level of debt is the one that yields the largest profits among the optimal debt choices in each sub-interval. It is useful to write this optimality condition as follows:

$$
\begin{aligned}
&(1-\mathbb{E}[\theta])Y + \mathbb{E}[\theta]L - D^*_M - (1+\rho)(1-D^*_M) \geq \\
&\frac{1-p}{2}\left[(1-\theta_N)Y + \theta_N L + (1-\gamma\theta_N)\mathbb{E}[Y] + \gamma\theta_N L - D\right] + \\
&+ p\left[\frac{1}{2}(1-\theta_C)Y + \frac{1}{2}(1-\gamma\theta_C)\overline{Y} + \hat{\theta}^P_C L - \frac{1-\alpha}{1+\alpha}(D - (1-\gamma\theta_C)\underline{Y} - \hat{\theta}^P_C L)\right] + \\
&- D^*_{NM} - (1+\rho)(1-D^*_{NM}).
\end{aligned}
$$

The left (right) hand side is the profit corresponding to the optimal choice of debt in an interval where banks have (not) incentives to monitor. Hence banks will choose a level of debt such that they can commit to monitoring if

$$
\Gamma - \left[(\theta_C - \hat{\theta}^P_C)L + \frac{1-\alpha}{1+\alpha}(D - (1-\gamma\theta_c)\underline{Y} - \hat{\theta}^P_C)\right] \leq \rho[(1-D^*_{NM}) - (1-D^*_M)]. \tag{2.4}
$$

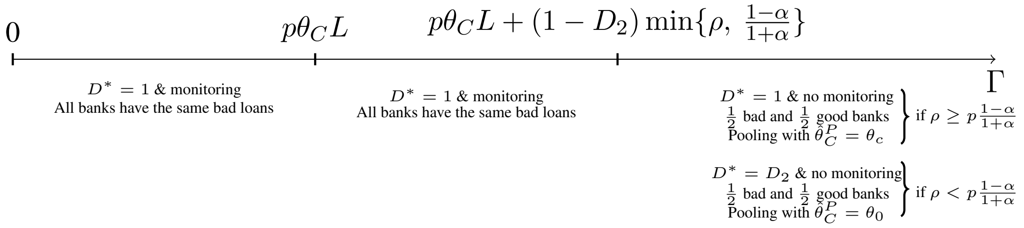
Recall from equation (2.3) that the left hand side represents the marginal profit from not monitoring conditional on a given value of debt. Equation (2.4) states that the banks will choose a level of debt such that they have incentives to monitor if the marginal profit from not monitoring is lower than the marginal cost. The marginal cost depends on the difference in the capital that banks need to have in case they monitor or not.

Note first that equation (2.4) is defined only if there exists a debt interval in which banks do not monitor. By Proposition 4, this is the case when the left hand side is positive, that is when the marginal profit from not monitoring is positive. This marginal profit has to be compared with the marginal cost of capital. Consider first the case in which banks do not monitor and choose $D^*_{NM} = D_2$. If banks can commit to monitor only with a lower amount of debt ($D^*_M = D_1$), equation (2.4) never holds. Not monitoring yields a higher expected return and allows banks to save on the cost of capital. If banks can commit to monitor with a higher level of debt than D^*_{NM} (because condition 3 in Proposition 4 holds, but condition 2 does not), a trade-off arises for banks. Not monitoring yields a higher expected return, but requires more capital. Banks will choose not to monitor when the cost of capital is low enough (case $D^* = D_2$ in Proposition 5). In the opposite case, banks will choose a level of debt such that they can commit to monitor. Finally, in case the optimal choice is not to monitor when $D = 1$, banks will optimally choose $D^*_{NM} = 1$ in order to save on the cost of capital.

2.4.3 Overview of the Equilibrium under Asymmetric Information

Figure 2.3 describes the equilibrium of the game under asymmetric information. Recall

Figure 2.3: Overview of the Equilibria under Asymmetric Information



that Γ represents the additional expected return from not monitoring in the states of the world where banks do not default. By our assumptions about payoffs, not monitoring yields more than monitoring in normal times and in crisis times if the return realization is good, but leads banks to default in crisis times if the return realization is bad. If $\Gamma \leq p\theta_C L$, that is condition (2) and (3) in Proposition 4 hold, banks have incentives to monitor independently of the value of debt. As banks never default in case they monitor, debt is cheaper than equity and hence banks finance themselves only through debt. Monitoring also implies that information asymmetries do not arise at time 1 because all banks have the same fraction of bad loans in both states of the world.
The same outcome is obtained in the case $\Gamma \in \big(p\theta_C L,\ p\theta_C L + (1 - D_2)\min\{\rho,\ \frac{1-\alpha}{1+\alpha}\}\big]$. By Proposition 4, banks do not have incentives to monitor if $D \in (D_1,\ D_2]$, but they do if $D = 1$. As not monitoring requires raising $1 - D_2$ of equity, and Γ does not offset this additional cost, banks prefer to monitor and finance themselves only with debt.
The outcome in the case $\Gamma > p\theta_C L + (1 - D_2)\min\{\rho,\ \frac{1-\alpha}{1+\alpha}\}$ depends on the cost of equity. Note first that, by Proposition 4, banks prefer not to monitor for any value of debt $D > D_1$. As banks can raise less equity than if they wanted to commit to monitoring ($D = D_1$), banks prefer a level of debt such that they do not have incentives to monitor. The actual level of debt depends on the cost of equity: Banks finance themselves only with debt if the cost of capital is large enough. Not monitoring makes banks different in terms of bad loans if the crisis state realizes at time 1. A pooling equilibrium in which banks reveal the same bad loans will arise at time 1 for these level of debt. The reason

is that bad banks prefer to charge off the same amount of bad loans as good banks, independently of how small is this amount, in order to borrow at the pooling interest rate and save on the debt repayment. Whether banks choose $D = 1$ or $D = D_2$ affects only the equilibrium charge off choice.

2.5 Policy Implications

The existence of an equilibrium in which bad banks pool with good banks generates two inefficiencies: The loss in the recovery value of the bad loans that banks hide in equilibrium, and the choice not to monitor. We will now explore which policies a welfare-maximizing regulator could implement in order to restore the first best allocation.

The first set of policies we consider are policies subsidizing bad banks. The rationale for these policies is that a pooling equilibrium exists when bad banks prefer to charge off the same amount of bad loans as good banks in order to borrow at the pooling interest rate and save on the debt repayment. Hence subsidies in the form of a higher recovery value of bad loans or a lower debt repayment would restore banks' incentives to charge off all their bad loans. Examples of these policies are asset purchase programs like TARP, in which the regulator pays a subsidized price for bad loans, or debt guarantees, in which the regulator provides investors insurance against banks' default. As both policies require the use of taxpayers' money, a trade-off between the dead weight losses from taxation and the gain from restoring the incentives to disclose information arises at time 1. Subsidizing bad banks also strengthens the incentives not to monitor at time 0. Hence policies subsidizing bad banks can only implement a second best allocation.

In the setup we are considering, other policies can be used to implement the first best allocation. The first is increasing capital requirements. While in the complete information benchmark banks monitor even if they finance themselves only with debt, in case there are information asymmetries banks might choose not to monitor if they raise no equity. The reason is that banks do not pay for the risk they have taken if a pooling equilibrium arises at time 1, and therefore choose not to monitor if the risk-return trade-off is favorable enough for them (Γ large enough). In this case, Proposition 4 states that banks have incentives to monitor their investment if $D \leq D_1$. Hence requiring banks to raise $1 - D_1$ of equity would restore banks' incentives to monitor and suffice to implement the first best allocation in the setup we have considered. This is a novel result, which suggests that capital requirements and market discipline, that is the first and third pillar of Basel II, should not be considered in isolation. Not only capital requirements represent a buffer against losses, but also give banks incentives to reveal information and hence enable investors to discipline banks. It should be noted that, in reality, raising capital requirements could lead banks to shrink their size as equity is more costly than debt. A trade-off would arise between the costs of a smaller banks' size and the gain of having banks monitoring their investment.

The social costs of a smaller banks' size could be mitigated by allowing banks to raise $1 - D_1$ in contingent convertible bonds (cocos) rather than equity. Cocos are debt securities that convert into equity once a contract defined trigger event occurs. If the trigger event consists in the realization of the crisis state, the fraction $1 - D_1$ of banks' debt would be converted into equity and banks would have incentives to reveal their type. The advantage of cocos compared to equity is that their cost is lower because investors become equity holders only with some probability. Hence the incentives to downsize would be lower than in the case banks have to raise equity. The drawback of cocos is that, in reality, it might be difficult to define the trigger event.
The third policy is conducting stress tests and disclosing the results. If the regulator was able to conduct stress test that perfectly identify banks' type, it would be optimal to remove information asymmetries and avoid banks' signaling externalities. Banks would prefer to monitor their investment at time 0 anticipating that the regulator will reveal the amount of their bad loans at time 1. This result depends crucially on the fact that asymmetric information is the only friction in our model. In a model with multiple frictions, as Spargoli (2012), disclosing information does not necessarily lead to the first best allocation. Spargoli (2012) shows that the regulator prefers to limit information disclosure if it anticipates that banks will reduce their credit supply as a reaction. In a setup where full information disclosure is not optimal, stress tests would not necessarily implement the first best allocation. The reason is that banks anticipate that they will have a chance to pool with the better type, and hence they might still have incentives not to monitor.

2.6 Conclusion

Our paper provides a theoretical model explaining why investors' ability to assess banks' solvency becomes impaired in times of crisis. We demonstrate that an equilibrium where no information is available in the market arises in times of crisis because weak banks exert a signaling externality on sound banks. Banks choose how many bad loans to reveal solving a trade-off between recovering part of the value of their bad loans and borrowing at more favorable terms. We show that, for weak banks, the gain in terms of lower debt repayment dominates the loss of the recovery value in times of crisis. Hence sound banks cannot signal themselves because this would require revealing a negative amount of bad loans. By contrast, sound banks can reveal themselves in normal times because even weak banks can borrow at relatively low risk premium. Hence an equilibrium where all banks reveal the same information arises in times of crisis but not in normal times. We demonstrate that banks have incentive to take excessive risk anticipating that investors will not be able to assess their solvency in times of crisis.
The predictions of our model are consistent with the empirical literature. First, banks have stronger incentives to overstate their financial condition in bad times, as found by Huizinga and Laeven (2009) and Gunter and Moore (2003). Second, the relation be-

tween indicators of risk and interest rates are stronger in normal times than in crisis times, which is a result documented by the vast literature on market discipline.

Our results have implications for bank regulation. Among them, we highlight that regulators should take into account the link between banks' capital and banks' incentives to disclose information. Neglecting this link would lead regulators to understate capital requirements, as banks would take excessive risk anticipating that an uninformative equilibrium will arise in times of crisis.

Chapter 3

FINANCIAL LIBERALIZATION AND BANK FAILURES: THE UNITED STATES FREE BANKING EXPERIENCE (JOINT WITH P. AGER)

3.1 Introduction

In the last three decades many financial crises occurred after countries liberalized their financial system. This is not a new phenomenon. Between 1837 and 1863 several U.S. states experienced a period of bank entry and failure after introducing a free banking system. With the introduction of free banking, governments gave up their control powers over bank entry and made the banking business more responsive to market rather than political forces.[1] Under the free banking law any individual could establish a bank provided that certain capital and circulation requirements defined by the law were satisfied.[2] We exploit the state-year variation in the introduction of free banking laws to test whether the relaxation of entry restrictions leads to more bank failures.

The existing literature about financial crises has found a systematic negative relation between financial liberalization and financial stability (see e.g. Demirguc-Kunt and Detragiache (1998) and Kaminsky and Reinhart (1999)). Using cross-country panels,

[1]During the free banking era, that is the period between the closing of the Second Bank of the United States in 1836 and the passage of the National Banking Act in 1863, the regulation of banks was in the responsibility of individual states free from federal intervention.

[2]Typical requirements were a minimum level of capital and a bond-secured banknote circulation (see e.g. Rockoff (1972) and Hasan (1987)). See Section 2 for a more detailed description of banking regulation in antebellum U.S.

these papers cannot control for unobservable or difficult-to-measure omitted variables that might confound the relation between liberalization and financial stability. For example, financial crises might be caused by severe economic downturns, or excessive risk taking fueled by state implicit guarantees, rather than liberalization.

Our contribution to the financial stability literature is twofold. First, we focus on an institutional setup where banks could not count on any state implicit guarantee, as opposed to studies based on contemporary data. Between 1837 and 1863, the US did not have any central bank that could act as a lender of last resort. Deposits and banknotes were uninsured, and governments never bailed any bank out. Focusing on the 1837-1863 US allows us to rule out the hypothesis that implicit state guarantees, rather than liberalization, drive our results. Second, the federal structure of the U.S. allows us to use a regression discontinuity setup where we can exploit within-country across states, rather than across country variation in financial liberalization. Our identification strategy compares contiguous counties lying on the border of states that passed a free banking law at different points in time[3]. The main advantage of our approach is to use geographically close counties that are more likely to have similar growth paths and face similar shocks. In contrast to a traditional cross-county panel approach, we would not base our inference on the comparison of heterogeneous treatment and control groups like comparing counties of Wisconsin and Alabama. This makes the threat that unobservable variables drive the results less credible.

On the historical front, the existing literature links the frequent bank failures in the US between 1837 and 1863 to the characteristics of banks chartered under the free banking law[4]. We take a more systemic approach and investigate how the introduction of free banking affected the stability of the county banking system as a whole. We consider also the traditionally chartered banks in free banking states as a potential source of financial instability since they could coexist with banks chartered under the free banking law in most of the states. However, we do not claim that the introduction of free banking laws caused the many financial panics that occurred in the 1837-1863 US.

We use Warren Weber (2011a)'s antebellum balance sheet and bank census data. Weber's census of banks lists every entry and exit of chartered banks during the antebellum period. For most of these banks, Weber provides yearly balance sheets that we aggregate up at the county level. Our main finding is that the fraction of failed banks increased roughly by 2 percent in counties where the state government switched to a free banking system. To link our result more closely to the existing literature on the instability of

[3]Our study is not the first one in the finance literature which exploits policy discontinuities at the state border to investigate how regulatory changes affect bank performance. Huang (2008) uses contiguous county-pairs separated by state borders to investigate the local economic effects of relaxing bank-branching restrictions in the US between 1975 and 1990. Further studies using policy discontinuities at state borders are among others Holmes (1998) and Dube et al. (2010).

[4]See, for example, Rockoff (1972); Rolnick and Weber (1984, 1985); Economopoulos (1990) and Hasan and Dwyer (1994).

the free banking era, we complement our analysis by examining the instability of free and state banks at the individual bank level. Consistent with the existing literature we find that the probability of failure of free banks is significantly higher than for banks in states that did not introduce a free banking law.[5] We also find that the probability of failure of traditionally chartered banks in states which switched to free banking is relatively higher than their counterparts in states without free banking laws. We consider our results at the individual level as suggestive evidence that the financial instability of the free banking era cannot be entirely explained by the fragility of free banks.

The theoretical banking literature considers competition as an important channel through which financial liberalization affects financial stability. Banking theory has, however, conflicting views on how competition affects financial stability. The competition-fragility view suggests that liberalization leads to fiercer competition, which erodes banks' charter value and provides incentives to take excessive risk (Marcus (1984), Chan et al. (1986) and Keeley (1990)). In a more competitive environment banks reduce their effort to screen borrowers properly, because they earn fewer informational rents (Allen and Gale (2000a)). Models supporting the competition-fragility view predict that liberalization measures facilitating entry and increasing bank competition lead to more financial instability. The competition-stability view developed by Boyd and DeNicolo (2005) suggests that banks with greater market power charge higher interest rates which in turn induces borrower to choose riskier projects. Recently, both views were tested empirically, with ambiguous results.[6] We consider the introduction of the free banking law as a measure increasing bank competition in two ways. First, free banking gave any individual the possibility to open up a bank in profitable markets where the incumbent enjoyed monopoly rents. Second, free banking could make incumbent - traditionally chartered – banks act in a more competitive manner in order to prevent bank entry.

From a historical perspective, our paper contributes also to a strand of literature that investigates the effect of free banking on entry. Historians generally consider the free banking as a system facilitating entry, but the empirical literature provides conflicting interpretations. Ng (1988) finds that bank assets in states enacting free banking did not grow relative to regional or national trends. This means that free banking did not lead to more entry. After controlling for a number of factors likely to influence bank entry, Bodenhorn (1993) finds that free banking had little influence on entry into six antebel-

[5]Our individual level estimates for free banks are in line with the recent study of Jaremski (2010), which uses Warren Weber's dataset to test the two main hypotheses for free banks failure: falling asset prices (Rolnick and Weber (1984, 1985)) and under-diversification of bank portfolios (Economopoulos (1990)). Jaremski results are in favor of the falling asset prices hypothesis, where free banks failed, because they were exposed to systemic risk. Jaremski also shows that free banks were significantly more likely to fail than traditionally chartered banks, but in contrast to our approach he does not distinguish between state banks in free banking vs. non-deregulated states.

[6]Examples of recent empirical studies are Berger et al. (2009) and Anginer et al. (2012). See also the surveys of Beck (2008) and Vives (2010) and the references therein for further information on relation between competition and financial stability.

lum urban markets. Economopoulos and O'Neill (1995), however, find in their study of ten free banking states that growth in bank capital and net entry was more responsive to underlying economic influences in free banking states than in states that retained legislative chartering. Bodenhorn (2008) shows that free banking led to a consistent increase in bank entry using county level data of New York, Massachusetts and Pennsylvania. Compared to these studies we have the advantage of having a comprehensive dataset about the free banking era at hand. Our contribution is to provide a rigorous empirical investigation of the competition channel, both in terms of identification and sample coverage. We find that the entry rate increased approximately by 6 percent in counties where the state government switched to a free banking system. When looking at incumbent banks, our results support the view that competition affected also traditionally chartered banks. We find that incumbent state banks significantly reduced their market share after free banking was introduced. This evidence, together with the evidence about bank failures, is consistent with the hypothesis that the introduction of free banking led to fiercer bank competition and, in turn, to more risk taking by both traditionally chartered and free banks.[7]

The reminder of our paper is organized as follows. Section 2 provides a brief overview of the free banking era. Section 3 describes our data and how we construct our samples. Section 4 explains the estimation strategy. Section 5 presents our main results. Section 6 discusses further robustness checks. The last section concludes.

3.2 The Free Banking Era (1837-1863)

The antebellum US was an emerging economy with sustained output growth and rapid capital accumulation, but also prone to financial crises.[8] While historians usually viewed banks as the root of instability, Bodenhorn (2000) emphasizes their role in the economic development of the antebellum US. Bodenhorn points out the importance of banks in the provision of means of payments, in the accumulation of savings and in their effi-

[7] A paper in a similar spirit, but investigating the effect branch banking had on competition and financial stability is the work of Carlson and Mitchener (2006). The authors show that the increased competition by branch banking in the 1920s and 1930s drives weak banks out of the banking market. This consolidation, Carlson and Mitchener argue, increases financial stability. The effect of lifting branch banking restrictions in the U.S. starting in the 1970s was the center of Jayaratne and Strahan (1996, 1998) work. Using U.S. state-level panel data, Jayaratne and Strahan find that the relaxation of bank branch restrictions increased bank efficiency and spurred economic growth after the branching reforms. Huang (2008), by using a more sophisticated identification strategy, finds in contrast to Jayaratne and Strahan (1996) only minor effects for the local economy after statewide branching restrictions are lifted.

[8] Many regional and four nationwide panics (in 1833, 1837, 1839 and 1857) happened during the antebellum period. Jalil (2012) identifies regional and nationwide panics in the US and provides explanations of their causes. Studies by Calomiris and Schweikart (1991), O'Grada and White (2003), Kelly and O'Grada (2000) and Temin (1969) focus on specific panic episodes.

cient allocation. This is important for the purpose of our study as it highlights that the function of banks at that time was similar to modern banks. Still, they differed in some important aspects. First, banknotes were not issued by a central bank but by individual banks. Banknotes were the most common means of payment.[9] They entitled the holder to demand redemption in specie at any time. Banknotes were liabilities for antebellum banks as deposits are for banks nowadays. Second, banks lent mainly short term (typically at three months) to finance trading transactions by firms. As Bodenhorn (2000) claims, this practice did not reflect individual banks' preferences, but rather the financing needs of firms.

All US states had their own system of bank regulation in the antebellum period.[10] Before 1837, states exerted their control over banks mainly through bank chartering.[11] In order to open up a bank, the aspiring banker had to apply for a bank charter. The state government decided whether to grant the charter and, in case it did, it set the requirements the bank had to satisfy. Requirements differed from bank to bank, but generally consisted of an initial capital level and constraints on the allocation of funds.[12] It was usually difficult to obtain a bank charter, because states wanted to limit the number of banks in order to protect the interests of incumbents.[13] This policy constrained supply in an economy that needed bank credit to finance its development. Starting from Michigan in 1837, New York and Georgia in 1838, US states responded to economy's needs and introduced free banking laws (see Figure 3.1). Free banking laws allowed any individual to open up a bank subject to the requirements defined by the law. Banks must have a minimum amount of capital and the banknote circulation must have been fully backed by government bonds or mortgages (see e.g. Rockoff (1972), Hasan (1987) and Jaremski (2010)). In some states free banking laws also defined shareholders' liability and constrained circulation to specie. Nowhere they imposed constraints on the allocation of credit.

The regulatory system had implications for the activities of banks. Figure 3.2 compares the balance sheet of an average bank in states that introduced a free banking law with states sticking to the traditional charter policy. We choose to report the aggregate rather than the individual balance sheet of an average free and state bank, because of two reasons. First, the focus of our analysis is on aggregate outcomes. Second, using state

[9]Bodenhorn (2000) argues that banknotes widely circulated within the US, and that there was an active market for banknote discounts (see also Gorton (1996) and Jaremski (2011)).

[10]See Bodenhorn (2002), Hammond (1957) and Schweikart (1987) for a description of banking in the antebellum US.

[11]Few states had general banking laws. Banking laws were usually defining managers and shareholders liability and tying banknote circulation to bank capital or specie. In no state the law allowed individuals to open a bank without a charter. See Dewey (1910), Knox (1903), and Hendrickson (2011) for banking regulation in the 19th century US.

[12]Some charters required banks to lend to companies involved in the construction of railroads or canals, or to invest in state bonds (see e.g. Knox (1903).

[13]See Bodenhorn (2006, 2008).

averages rather than bank averages allows us to capture the effect that competition could have on the liability structure of banks.[14] On the asset side, public bond holdings were larger in states that passed a free banking law by almost a factor of 10. This is not surprising since free banks were required to back their banknotes with public bonds. The higher fraction of public bonds was compensated mainly by a lower fraction of loans. On the liability side, the capital of banks in states that introduced a free banking law was 10 percent lower, whereas deposits were 5 percent larger. The evidence about capital is consistent with the findings in Hanson et al. (2010).[15] The higher ratio of deposits to assets suggests that free banks had to issue deposits in order to lever up, because their banknote circulation had to be fully backed by bonds.

3.3 Data and Sample Construction

3.3.1 Data

Our analysis builds on the individual balance sheets and the census of banks in the antebellum U.S. collected by Weber (2011a).[16] Starting from 1789, the census of state banks contains the location, name, the beginning and ending dates for all banks that existed in the United States prior to 1861. Weber provides also information on the charter type of the bank, i.e. whether a bank was traditionally chartered or established under the free banking law, and whether the bank failed, closed or still existed in 1861. The bank balance sheet dataset contains detailed information about banks' assets and liabilities that U.S. antebellum banks had to report to the state banking authorities. We merge the census of state banks with the individual bank balance sheet data.

According to Bodenhorn (2008) banking in the free banking era was generally a local affair both in legal and economic terms. Bodenhorn uses county-level data to study bank entry in nineteenth century New York, Massachusetts and Pennsylvania. In general, when studying local banking markets it has been a convention in the banking literature to use a county as the unit of analysis (see e.g. Berger et al. (2009); Black and Strahan (2002) and Huang (2008)). Many researchers use county level data to study the impact of bank activities on economic output (Ashcraft (2005); Calomiris and Mason (2003) and Gilber and Kochin (1998)). Following Bodenhorn's argumentation, we take the county as the appropriate unit of analysis to study the effect of free banking on financial stability. We match the location of each bank to its respective county and aggregate our dataset at the county level.

[14] Hanson et al. (2010) argues that competition leads banks to decrease their capital holdings in order to save on funding costs.

[15] See footnote 14.

[16] Both datasets are publicly available at Warren Weber's data archive: http://www.minneapolisfed.org/research/economists/wewproj.html.

The focus of our empirical analysis is on the period from 1833 to 1860.[17] We choose 1833 as starting year, i.e. four years before the first state – Michigan – introduced a free banking system, in order to have a sufficiently large pre-treatment window to implement a difference in difference (DID) estimation. With 1833 as starting point we avoid also measurement error due to data availability problems of earlier years.[18] Our empirical analysis ends in 1860 right before the outbreak of the U.S. Civil War. The 1861-1865 Civil War was an atypically large, negative shock to the US economy. This event could have affected the banking sector in an unusual way.

3.3.2 Sample Construction

We analyze the effect of introducing a system of free banking on county banking markets using the DID method on a sample of contiguous counties sharing the same state border. We compare outcomes in counties where the state introduced a free banking law, i.e. the treatment group, versus outcomes in counties where the state retained the traditional chartering policy, i.e. the control group. We restrict our analysis to a pre and post treatment period. In the pre-treatment period both states did not introduce a system of free banking. We define the pre-treatment period as the 5-year interval before one of the two bordering states adopted the free banking law. The post-treatment period is the time interval in which one of the bordering states has a free banking law while the other still sticks to a traditional charter policy. Following Huang (2008), we select a county as control group only if it belongs to a state that introduced free banking at least three years after its bordering state. Once both states have adopted a free banking law, we drop the corresponding counties from our analysis.

We use the 1860 census boundary file map downloaded from the National Historical Geographic Information System (NHGIS) to identify all U.S. counties that straddle a state border. ArcGIS is used to find the set of antebellum counties lying on state boundaries. We assign a unique border segment identifier to any contiguous border county.[19] Our sample consists only of border segments for which we have at least five years of observations for any county on each side of the state border. We believe that using contiguous border counties is a well suited method to estimate the impact of deregulation effects if we have enough border segments with a different regulatory status and there is substantial variation in financial instability between treatment and control group over the period of interest.

[17] We exclude Washington D.C. from our sample, since it was a federal district.

[18] During the free banking era banks sent annual reports to the state authorities, and the problem of missing data is less problematic. Despite the comprehensive data availability, there are a few cases where balance sheet information is missing for certain years. In these cases we imputed the missing values of these banks. We describe our imputation method in detail in a supplementary appendix available upon request.

[19] Note that a border county can be in multiple border segments.

The advantage of comparing only contiguous border counties is their similarity in observable and unobservable characteristics such as underlying growth trends. Traditional cross-state panel studies like Jayaratne and Strahan (1996, 1998) implicitly assume that a randomly chosen U.S. county is a good control independently of the state in which the treatment occurs. We compare in Section 3.5 our proposed method with the traditional approach where we consider all U.S. counties to highlight potential differences in the estimated coefficients. Figure 3.3 provides the summary statistics for both samples.

3.4 Estimation Strategy

For the traditional approach we estimate the effect of introducing free banking on financial stability as follows:

$$y_{csr,t} = \lambda_c + \lambda_{r,t} + \beta TE_{s,t} + \gamma FBEXP_{s,t} + \Gamma' X_{csr,t} + \epsilon_{csr,t}. \tag{3.1}$$

Our variable of interest, $y_{csr,t}$, is the failure rate of banks. The failure rate of banks is constructed as the number of banks that failed in county c of state s and region r at time t, normalized by the total number of banks in c at time t. The county fixed effects, λ_c, capture time-invariant factors such as geography and any other determinants of the county steady state. We include regional time period fixed effects, $\lambda_{r,t}$, that control for the variation between U.S. census regions.[20] Hence, our estimates are based only on the variation within each macro-region. The treatment effect, $TE_{s,t}$ is a binary variable which takes the value one for all years t since a state decided to switch to a free banking system. We use a state specific linear trend starting from the liberalization year, $FBEXP_{s,t}$, to take into account the experience of states with the free banking system. The matrix, $X_{csr,t}$, includes time varying county-specific control variables. We cluster the error term, $\epsilon_{csr,t}$, at the state level to ensure that the computed standard errors of our estimates are robust to arbitrary correlation across counties in each US state.
Our identification strategy, which we call border-county approach, follows closely the regression discontinuity design of Black (1999) and Fack and Grenet (2010). Our preferred estimation equation is:

$$y_{cbs,t} = \alpha + \lambda_{b,t} + \beta TE_{s,t} + \gamma FBEXP_{s,t} + \Gamma' X_{cbs,t} + \epsilon_{cbs,t}. \tag{3.2}$$

The important difference to equation (3.1) is the inclusion of border segment time period fixed effects, $\lambda_{b,t}$. The border segment time period fixed effects control for any common observable and unobservable factors varying across state borders which would otherwise bias our findings. Equation (3.2) pools the estimates by exploiting the within-border segment variation across all border segments. Our identifying assumption is

[20] The U.S. census regions in our sample are: New England, Mid-Atlantic, Midwest and the South.

that any within-border segment difference in the treatment effect is uncorrelated to the within-border segment difference in the error term, that is $E(TE_{s,t}, \epsilon_{cbs,t}) = 0$. Following Huang (2008), we do not consider any time-invariant factor in our preferred estimation equation (3.2) since our objective is to choose our set of variables as parsimoniously as possible. If there are any time-invariant observable or unobservable factors that affect financial instability, they should not bias the point estimate of the difference-in-difference treatment effect. If a certain time-invariant county-specific factor affects financial stability, it should affect the treatment and control group in the pre and post treatment period in the same way and hence not confound our results.

We use two-dimensional clustering to account for within-state over time and within border segment over time correlations. Hence, our estimates are robust to arbitrary correlation across counties in each US state and across counties in each border segment. The two-dimensional clustering accounts also for the mechanical correlation induced by the presence of a single county in multiple border segments.

To complement our analysis we examine the instability of free and traditionally chartered banks at the individual bank level. We compare the probability of failure of free banks and traditionally chartered banks in liberalized states relative to traditionally chartered banks in non-liberalized states by using the following linear probability model:

$$y_{isr,t} = \lambda_s + \lambda_{r,t} + \lambda_i t + \beta FB_i + \gamma TE_{s,t} \times TB_i + \Gamma' X_{isr,t-1} + \epsilon_{isr,t}. \qquad (3.3)$$

The probability of failure, $y_{isr,t}$, is a binary variable which takes the value one in case a bank fails at time t. The parameters λ_s, $\lambda_{r,t}$ and $\lambda_i t$ denote state fixed effects, regional time period fixed effects and a trend for bank i, respectively. We do not control for individual fixed effects, because we are interested in the effect of both types of charters, which is usually time-invariant.[21] The variable FB_i is a dummy variable taking the value one if a bank is a free bank.[22] The interaction term, $TE_{s,t} \times TB_i$, captures the effects of being a traditionally chartered bank (TB) after a state switched to free banking. The omitted category is the group of traditionally chartered banks in non-liberalized states. The matrix, $X_{isr,t-1}$, includes lagged time varying individual balance-sheet controls.

Since we are also interested in how incumbent banks respond to removals of entry barriers, we employ the following DID estimation:

$$y_{isr,t} = \lambda_i + \lambda_{r,t} + \beta TE_{s,t} + \Gamma' X_{isr,t-1} + \epsilon_{isr,t}. \qquad (3.4)$$

[21] In three states the free banking law was repealed (Michigan, 1838; Connecticut, 1855 and Tennessee, 1858). The banks in these states who were initially chartered under the free banking law continued their business under the traditional system, given they did not fail before. In some rare cases, state banks continued their business under a free banking charter after their original charter expired (New York). We exclude the very few banks that switched their charter from our analysis.

[22] Note, that we are not able to use a DID estimation here, since free banks only existed after a state introduced free banking.

We use the market share of incumbents defined as the fraction of own assets over total assets in a county as dependent variable. Individual, time-invariant, bank characteristics are absorbed by the inclusion of individual fixed effects, λ_i.[23] Our variable of interest is the treatment effect, $TE_{s,t}$, which takes the value one after a state introduced a free banking system.

3.5 Results

3.5.1 Financial Instability

Table 3.1 reports the treatment effect for the failure rate of banks. Column (1) shows the estimates of the traditional approach using equation (1). In the first specification we only control for county fixed effects, regional time period fixed effects and states experience with free banking. In column (2), we add to the regression controls for county-specific differences in the banking sector, such as, the ratios of loans to assets, specie to assets, capital to assets, public bonds to assets and the average asset size. The failure rate of banks in counties which were exposed to treatment is approximately 1.2 percent higher and significant at the 5 percent significance level.[24] We are aware that the results of the traditional approach might suffer from omitted variables bias and that the inclusion of the county-specific bank controls further exacerbates endogeneity problems. The potential bias introduced by the inclusion of the county-specific bank controls in column (2) seems, however, not very large and might by therefore only a minor concern.
With the border-county approach, we try to tackle the endogeneity issues inherent in the traditional approach. Columns (3)-(6) present our main results using equation (2). Column (3) reports the estimates when controlling for border segment time period fixed effects and states experience with free banking. In column(4), we restrict the relevant variation even further and also include regional time period fixed effects in the regression to wipe out any heterogeneous trends at the regional-level which could still confound our results. In column (5) we include the same county-specific bank controls as in column (2). One advantage of our border-county approach is to obtain coefficients for control variables using out-of sample information, that is, we can also exploit information about counties of border segments where none of the states adopted a free banking system.[25] The out-of sample method solves the problem of having potentially biased coefficients of the bank controls due to the introduction of free banking. That is, if we

[23]In contrast to equation (3), we are able to apply a DID estimation, since we are only looking at incumbent banks, i.e. banks which are in the sample during the whole period, 1833-1860.

[24]Note, that there is a drop of observations, because we do not have information on the balance sheet controls for all counties at hand. This drop in observations does not change our result, qualitatively.

[25]We provide a detailed explanation how we used the out-of sample method to obtain point estimates for the bank controls which are not contaminated by (in-)sample-selection problems in the supplementary appendix available upon request.

include bank controls in-sample, one does not consider how bank controls normally affect financial stability, since the coefficient on the bank controls could be contaminated by the deregulation itself.[26] In the final column, we adopt the out-of sample method proposed by Huang (2008) and use the out-of sample coefficients for the county-specific bank controls to obtain an unbiased estimate of our treatment effect. Our coefficient of interest in column (6) shows the treatment effect after we subtracted the bank controls – using the estimated out-of sample coefficient – from the dependent variable. The failure rate estimates using the border-county approach all range between 1.5 and 2.6 percent and all estimates are at least significant at 10 percent significance level. In general the treatment effect in the border-county approach is larger, which implies that the traditional approach yields to downward biased estimated coefficients.
Table 3.2 shows the bank-level results for the probability of failure of free and state banks.[27] Column (1) shows the estimates controlling for state fixed effects and regional time period fixed effects. In column (2), we add a bank specific trend and the lagged asset size of a bank as control to avoid problems of reverse causality. In the last column we add further lagged bank-specific control variables, such as, the ratios of loans to assets, specie to assets, capital to assets, public bonds to assets and deposits to assets. We find that free banks had a probability of failure approximately 3.5 percent higher than traditionally charted banks in non-liberalized states. This result is significant at the 1 percent significance level. Our findings are consistent with the evidence in the free banking literature that (e.g. Rolnick and Weber (1984, 1985), Economopoulos (1990), and Jaremski (2010)) free banks had a significantly higher probability of failure than traditionally chartered banks. The individual dataset also allows us to examine whether the traditionally chartered banks in liberalized states were more likely to fail than their counterpart in non-liberalized states. We find that traditionally chartered banks in liberalized states had a significantly higher likelihood of failure. Our results show that not only free banks, but also the traditionally chartered banks were a source of instability in the liberalized states.

3.5.2 Competition

Table 3.3 reports the treatment effect for the entry rate of banks. Similar to the failure rate, the entry rate of banks is constructed as the number of banks that entered in a county in a given year normalized by the total number of banks in the county. We use the same specifications as in Table 3.1, except that we control only for the asset size of banks in columns (2), (5) and (6) since it is unlikely that the balance sheet ratios affect the entry decision of banks. We find that liberalization leads to significantly higher entry rates. The entry rate estimates all range between 6 and 11.2 percent and are significant

[26] We refer to Huang (2008) for more details about the out-of sample method.
[27] The specification is equation (3).

at the 1 percent significance level using the traditional approach and at least significant at the 10 percent significance level using the border-county approach. Our estimates confirm the results of Economopoulos and O'Neill (1995) and Bodenhorn (2008) that free banking led to more bank entry.

The Herfindahl-Hirschman-Index (HHI) is a standard measure used in the banking literature to measure the degree of concentration in the banking sector. Table 3.4 shows the results using the HHI on deposits as dependent variable. Columns (1)-(2) report the results for the traditional approach.[28] In both specifications we find a negative and statistically significant association between the introduction of free banking and the HHI on deposits. Our estimates turn insignificant once we use the border-county approach.[29]

We use the turnover rate as further evidence that free banking increased competition. We believe that the turnover rate is a good measure to capture the dynamics of the banking sector. We expect a competitive banking system to have higher bank entry and failures than a regulated banking system. We define the turnover rate as the sum of new and failed banks over the total number of banks in a county in a given year. In Table 3.5, using the same specifications as in Table 3.3, we show that the turnover ratio was significantly higher in free banking states.

Since we are also interested in how incumbent banks reacted to increased banking competition in free banking states, we analyze the adjustments of incumbent's market share. The incumbent's market share is defined as the fraction of the incumbent's asset relative to the total assets of a county. We use equation (3.4) to estimate the treatment effect. In the first specification we only control for individual fixed effects and regional time period fixed effects. In column (2), we add to the regression a bank-specific linear trend and the lagged asset size. In Column (3) we add additional lagged variables to control for bank-specific differences, such as, the ratios of loans to assets, specie to assets, capital to assets ratio, public bonds to assets and deposits to assets. The results of columns (1)-(3) in Table 3.6 are in line with our macro level findings. Traditionally chartered banks experienced a significant drop of about 3% in their asset share after a state switched to a free banking system.[30] We consider our findings as substantive evidence that free banking led to more banking competition and that competition also affected incumbent banks. Overall, our results on competition and financial stability are consistent with the hypothesis that the introduction of free banking led to fiercer bank competition and, in turn, to more risk taking by both traditionally chartered and free banks.

[28]In columns (2), (5) and (6) we add the asset size and the average ratio of deposits to assets in a county as further controls.

[29]Results are qualitatively similar for the HHI loans and are available upon request.

[30]Using estimation equation (3.3), we also find that free and traditionally chartered banks in free banking states had significantly lower market shares than banks in non-liberalized states. These results are provided in the supplementary appendix and available upon request.

3.6 Robustness

A major concern when using a DID approach is that anticipation effects drive the results. If banks anticipate the deregulation event before the actual introduction they might adjust their behavior in advance. We include leads of the treatment effect up to three years in equation (3.2) and test the significance of their cumulative sum in order to examine whether anticipation effects contaminate our findings. In the supplementary appendix we report the results for the failure and entry rate. Neither the failure rate nor the entry rate displays any significant anticipation effect. For both cases the cumulative effect is not significant until the introduction of the free banking system in time t. The insignificance of the cumulate effect indicates that our results are not driven by any anticipation effects.

Spurious effects at the state border constitute a further threat to the internal validity of our border-county approach. We construct a placebo sample to address this concern. We match the border counties of the deregulated states with adjacent – hinterland – counties of the same state and assume that the hinterland counties are counterfactually not affected by the free banking law.[31] We re-run equation (3.2) for our main variables of interest (failure and entry rate) using the constructed placebo sample. If spurious effects are not a concern, the treatment effect in these regressions should be insignificant. We report the results of the placebo sample in the supplementary appendix. None of the specifications show a statistically significant treatment effect, indicating that spurious effects at the state border are not contaminating our border-county estimates.

A potential threat to our border-county design consist in financial instability spillovers, since treatment and control counties are only separated by state borders. Theory suggests various channels through which shocks to few banks propagate to the whole banking system. In an incomplete information setup, a bank run in a region might signal problems at banks in another region. The arrival of bad news might cause self-fulfilling expectations of a bank run in the other region.[32] Contagion might also occur through interbank claims, as the default of a bank in the network might cause the default of its creditor banks[33]. In our case, the presence of contagion attenuates the coefficient of the treatment effect towards zero, so that we can consider our estimates for the failure rate of banks as a lower bound.

Other potential confounders for our identification strategy are state-year varying legislation correlated with the introduction of the free banking system. During the 19th century, U.S. states used usury laws to regulate the maximum legal interest rate a bank can charge on a loan. More financially liberal states might not only switch to a free banking system, but also lift restrictions on the maximum legal interest rate. A laxer

[31] We refer to counties contiguous to border counties in the same state as hinterland counties, if they do not share any border with another state.

[32] As in Diamond and Dybvig (1983).

[33] See for example Allen and Gale (2000c) and Freixas et al. (2000).

usury law increases the potential pool of borrowers thereby making bank entry more attractive, but it also increases risk taking, because it allows banks to lend to riskier borrowers.[34] We collected data on usury laws from Holmes (1892) to test whether the presence of state-year varying usury laws might contaminate our findings. Columns (1) and (2) of Table 3.7 report the results for the failure rate (Panel A) and the entry rate (Panel B) when we control for state usury laws. Including state usury laws does not alter our main results, in both cases the coefficient remains positive and statistically significant.[35]

Similar to the traditional banking charter policy, state governments authorized the formation of non-financial incorporations by special charters. The evolution of the charter policy for non-financial corporations resembles the charter policy of the banking sector. During the 19th century, U.S. states gradually lifted barriers to entry for non-financial corporations by introducing general incorporation laws. When states liberalized their charter policy, new firms established under general incorporation laws could potentially spur the demand for external finance thereby making entry in the banking sector more profitable. Granting the privilege of limited liability, incorporation laws could encourage risk-taking by the new firms thereby increasing the probability of failure of banks. Hence, the introduction of general incorporation laws and not free banking could drive our results. To address these concerns, we exploit the state-year variation in the adoption of general incorporation laws reported in Evans (1948). Columns (3) and (4) of Table 3.7 provide the results for the failure and entry rate. In both cases the sign of treatment effect coefficient is positive and remains statistically significant.

State-specific liability insurance systems, clearing arrangements and branch-banking laws impose a further threat to the identification strategy, since they affect the probability of bank failure. Our evidence might not be driven by the introduction of free banking laws, but whether states adopted those arrangements. In New England, most of the banks joined the Suffolk Banking System (1827-1858), a privately organized banknotes clearing system. By clearing notes for New England banks, the Suffolk Banking System objective was to prevent bank failures and to act as lenders of last resort.[36] Since the Suffolk Banking System was a regional clearing system operating only in New England, we can control for it by including region time varying fixed effects. Six states, New York, Vermont, Indiana, Michigan, Ohio and Iowa established state-specific liability insurance systems during the antebellum period with the objective to reimburse creditors of insolvent banks. We collect information about the period of time a liabil-

[34] Rockoff (2003) provides a detailed examination of the economic history of usury laws in the United States. For a study of the political economy of U.S. state usury laws we refer to Benmelech and Moskowitz (2010).

[35] Columns (1) and (2) display the results for the traditional and the border-county approach, respectively.

[36] See Hammond (1957) for an early interpretation of the Suffolk Banking System. More recent studies are Mullineaux (1987) and Calomiris and Kahn (1996).

ity insurance system existed in these states from Weber (2011b) and Klebaner (2005) to test whether state-year variation in liability insurance systems contaminate our results.[37] The coefficient of the treatment effect reported in columns (5) and (6) of Table 3.7 remains qualitatively unaffected when controlling for liability insurance systems. Calomiris and Schweikart (1991) argue that branch-banking states in the South were better able to cope with the financial panic in 1857 and experienced low bank failure rates, because of cooperative planning. In Columns (7) and (8) of Table 3.7 we add a binary variable which equals one if branch banking existed in a state at time t to the list of controls.[38] Including a dummy for branching does not change our results.
The decision to suspend the convertibility of banknotes during a crisis period could also confound our results lowering the probability of bank failure. If states that did not adopt a free banking system suspended convertibility in crisis periods, our evidence might not be driven by the introduction of free banking laws. We identify statewide bank suspensions by using the information on national-wide and local panics from Jalil (2012). The last two columns of Table 3.7 report the results. We do not find any evidence that statewide bank suspensions affect our results.[39]

3.7 Conclusion

Eighteen US states introduced free banking laws between 1837 and 1860. Free banking laws subtracted the constitution of banks from the discretion of governments and allowed any individual to establish a bank subject to the requirements defined by the law. We exploit these historical events to investigate the relation between liberalization and financial instability. The fact that the liberalization measure varies over time and across states allows us to use an identification strategy relying on the variation across contiguous counties separated by state borders. The similarity of shocks and trends among bordering counties mitigates the threat that unobservable variables correlated to liberalization confound the result.
In line with the existing evidence, our results support the hypothesis that liberalization leads to financial instability. We find that the introduction of free banking laws caused the failure of a significantly larger fraction of banks. In line with the antebellum history literature, we provide evidence that free banks were more likely to fail than other banks.

[37]We construct a binary variable which equals one if a state had a liability insurance system in time t. Note that in some states only certain types of banks (e.g. in Ohio and Indiana state banks and their branches) were members of the insurance system, other states (e.g. Vermont) required new chartered banks to join the system, but decided later on to base membership on a voluntarily basis. We refer to Weber (2011b) for more details about the antebellum liability insurance systems.

[38]We use the information on branch banking from Weber (2011a)'s database.

[39]Jalil (2012) lists among other things the emergence of bank suspensions as requirement to identify financial crises. A financial crisis in his series is only defined if there were bank suspensions in a given month (year).

More interestingly, we show that free banking also increased the individual probability of failure of incumbent banks. As suggested by banking theory, we consider increased bank competition as a possible explanation for our results. We find that free banking led to more bank entry and eroded the market share of incumbent banks. These results suggest that bank competition causes more risk taking.

Tables and Figures

Figure 3.1: The Eighteen US Free Banking States

MICHIGAN	1837;1857	(a)
NEW YORK	1838	
GEORGIA	1838	
ALABAMA	1849	
NEW JERSEY	1850	
MASSACHUSETTS	1851	
VERMONT	1851	
OHIO	1851	
ILLINOIS	1851	
CONNECTICUT	1852	(b)
INDIANA	1852	
WISCONSIN	1852	
TENNESSEE	1852	(c)
FLORIDA	1853	
LOUISIANA	1853	
MINNESOTA	1858	
IOWA	1858	
PENNSYLVANIA	1860	

(a) Michigan suspended the free banking law in 1838 and reenacted it in 1857. Source: Rockoff (1972).
(b) Connecticut repealed the free banking law in 1855. Source: Rockoff (1972).
(c) Tennessee repealed free banking in 1858. Source: Schweikart (1987).

Figure 3.2: Comparison of Balance Sheet Items

Asset Side

Items	*Free Banking States*	*Traditional Banking States*
Loans	0.70	0.75
Cash	0.06	0.07
Due from banks	0.09	0.08
Notes other banks	0.03	0.03
Real Estate	0.03	0.02
Public Bonds	0.06	0.01
Other Assets	0.04	0.04

Liability Side

Items	*Free Banking States*	*Traditional Banking States*
Capital	0.41	0.50
Circulation	0.31	0.29
Deposits	0.18	0.13
Due to banks	0.03	0.03
Profits*	0.03	0.02
Other Liabilities	0.04	0.03

Figure 3.3: Summary Statistics

PART A		***TRADITIONAL APPROACH***			
VARIABLES	*OBS*	*Mean*	*Sd*	*Min*	*Max*
Entry Rate	9089	0.07	0.22	0.00	1.00
Failure Rate	9089	0.01	0.10	0.00	1.00
Turnover Rate	9089	0.11	0.27	0.00	2.00
HHI (Deposits)	7199	0.65	0.33	0.03	1.00
Treatment Effect (TE)	9089	0.34	0.47	0.00	1.00
Loans to Assets	7397	0.67	0.20	0.00	1.00
Deposits to Assets	7397	0.13	0.10	0.00	0.84
Public Bonds to Assets	7397	0.05	0.13	0.00	1.00
Capital to Assets	7397	0.41	0.14	0.00	1.00
Cash to Assets	7397	0.08	0.07	0.00	0.69
Log (Assets)	7397	8.84	1.32	4.38	14.36
Experience Free Banking	9089	2.91	5.38	0.00	24.00

PART B		***BORDER-COUNTY APPROACH***			
VARIABLES	OBS	Mean	Sd	Min	Max
Entry Rate	2683	0.07	0.22	0.00	1.00
Failure Rate	2683	0.01	0.09	0.00	1.00
Turnover Rate	2683	0.10	0.26	0.00	2.00
HHI (Deposits)	2182	0.65	0.34	0.03	1.00
Treatment Effect (TE)	2683	0.29	0.45	0.00	1.00
Loans to Assets	2245	0.68	0.19	0.00	1.00
Deposits to Assets	2245	0.13	0.09	0.00	0.84
Public Bonds to Assets	2245	0.04	0.11	0.00	0.84
Capital to Assets	2245	0.40	0.13	0.00	0.99
Cash to Assets	2245	0.07	0.06	0.00	0.56
Log (Assets)	2245	8.71	1.10	5.20	12.32
Experience Free Banking	2683	2.10	4.21	0.00	22.00

Table 3.1: Free Banking and Financial Stability: County Level Analysis

	FAILURE RATE					
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment Effect (TE)	0.0128**	0.0121**	0.0148***	0.0260***	0.0144*	0.0211***
	(0.00579)	(0.00440)	(0.00521)	(0.00351)	(0.00817)	(0.00723)
Observations	9089	7397	2601	2601	2186	2163
R^2	0.098	0.079	0.006	0.008	0.031	0.012
Experience Free Banking	yes	yes	yes	yes	yes	yes
County FE	yes	yes	no	no	no	no
Region Time FE	yes	yes	no	yes	yes	yes
Border Segment Time FE	no	no	yes	yes	yes	yes
Balance Sheet Controls	no	yes	no	no	yes	yes*

Columns (1)-(2) report the results for the traditional approach. Robust standard errors clustered at the county level in parentheses. We report in columns (3)-(6) the results for the border-county approach. Standard errors clustered at the state and border segment in parentheses: *** $p<0.01$, ** $p<0.05$, * $p<0.1$. In columns, (2), (5) and (6), we include the following balance sheet controls: the ratio of loans to assets, specie to assets, capital to assets, public bonds to assets and the average asset size (estimates not reported in the table). We provide a detailed description of the control variables included in the supplementary online appendix. *In column (6), we control for the balance-sheet variables out-of sample. See Section (5) for further details.

Table 3.2: Free Banking and Instability: Bank Level Analysis

	FAILURE RATE		
	(1)	(2)	(3)
Free Banks	0.0351***	0.0286***	0.0302***
	(0.00709)	(0.00773)	(0.00797)
$TE \times TraditionalBanks$	0.00924**	0.00719*	0.00698*
	(0.00399)	(0.00383)	(0.00379)
Observations	25807	21422	21376
R^2	0.118	0.095	0.098
State FE	yes	yes	yes
Region Time FE	yes	yes	yes
Bank Specific Trend	no	yes	yes
Balance Sheet Controls	no	yes	yes

Robust standard errors clustered at the county level in parentheses: *** p<0.01, ** p<0.05, * p<0.1. In column (2) we include the following balance sheet control: the lagged asset size. In column (3) we add to the regression: the ratio of loans to assets, specie to assets, capital to assets, public bonds to assets and deposits to assets (estimates not reported in the table). Traditional banks are the omitted category. See Section (5) for further details.

Table 3.3: Free Banking and Competition: County Level Analysis

	ENTRY RATE					
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment Effect (TE)	0.0601***	0.0611***	0.0666*	0.112***	0.0682**	0.0603**
	(0.0189)	(0.0177)	(0.0342)	(0.0416)	(0.0280)	(0.0257)
Observations	9089	7397	2601	2601	2186	2163
R^2	0.103	0.127	0.005	0.010	0.012	0.004
Experience Free Banking	yes	yes	yes	yes	yes	yes
County FE	yes	yes	no	no	no	no
Region Time FE	yes	yes	no	yes	yes	yes
Border Segment Time FE	no	no	yes	yes	yes	yes
Balance Sheet Controls	no	yes	no	no	yes	yes*

Columns (1)-(2) report the results for the traditional approach. Robust standard errors clustered at the county level in parentheses. We report in columns (3)-(6) the results for the border-county approach. Standard errors clustered at the state and border segment in parentheses: *** $p<0.01$, ** $p<0.05$, * $p<0.1$. In columns, (2), (5) and (6), we include the following balance sheet control: the average asset size (estimate not reported in the table). We provide a detailed description of the control variables included in the supplementary online appendix. *In column (6), we control for the balance-sheet variables out-of sample. See Section (5) for further details.

Table 3.4: Free Banking and Competition: County Level Analysis

	HERFINDAHL-HIRSCHMAN-INDEX (DEPOSITS)					
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment Effect (TE)	-0.0605**	-0.0612**	0.0823	-0.0540	0.00911	0.0179
	(0.0290)	(0.0246)	(0.0835)	(0.0619)	(0.0496)	(0.0623)
Observations	7084	7084	2114	2114	2114	2114
R^2	0.248	0.444	0.024	0.065	0.576	0.031
Experience Free Banking	yes	yes	yes	yes	yes	yes
County FE	yes	yes	no	no	no	no
Region Time FE	yes	yes	no	yes	yes	yes
Border Segment Time FE	no	no	yes	yes	yes	yes
Balance Sheet Controls	no	yes	no	no	yes	yes*

Columns (1)-(2) report the results for the traditional approach. Robust standard errors clustered at the county level in parentheses. We report in columns (3)-(6) the results for the border-county approach. Standard errors clustered at the state and border segment in parentheses: *** p<0.01, ** p<0.05, * p<0.1. In columns, (2), (5) and (6), we include the following balance sheet controls: the average asset size and the ratio of deposit to assets (estimates not reported in the table). We provide a detailed description of the control variables included in the supplementary online appendix. *In column (6), we control for the balance-sheet variables out-of sample. See Section (5) for further details.

Table 3.5: Free Banking and Competition: County Level Analysis

	TURNOVER RATE					
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment Effect (TE)	0.0753***	0.0747***	0.0983**	0.156***	0.0995***	0.0889***
	(0.0260)	(0.0238)	(0.0442)	(0.0571)	(0.0351)	(0.0300)
Observations	9089	7397	2601	2601	2186	2163
R^2	0.078	0.089	0.007	0.013	0.014	0.006
Experience Free Banking	yes	yes	yes	yes	yes	yes
County FE	yes	yes	no	no	no	no
Region Time FE	yes	yes	no	yes	yes	yes
Border Segment Time FE	no	no	yes	yes	yes	yes
Balance Sheet Controls	no	yes	no	no	yes	yes*

Columns (1)-(2) report the results for the traditional approach. Robust standard errors clustered at the county level in parentheses. We report in columns (3)-(6) the results for the border-county approach. Standard errors clustered at the state and border segment in parentheses: *** $p<0.01$, ** $p<0.05$, * $p<0.1$. In columns, (2), (5) and (6), we include the following balance sheet control: the average asset size (estimate not reported in the table). We provide a detailed description of the control variables included in the supplementary online appendix. *In column (6), we control for the balance-sheet variables out-of sample. See Section (5) for further details.

Table 3.6: Free Banking and Competition: Bank Level Analysis

INCUMBENTS MARKET SHARE			
	(1)	(2)	(3)
Treatment Effect (TE)	-0.0339*	-0.0314*	-0.0339**
	(0.0179)	(0.0174)	(0.0165)
Observations	9546	9181	9181
R^2	0.152	0.163	0.183
Individual Bank FE	yes	yes	yes
Region Time FE	yes	yes	yes
Bank Specific Trend	no	yes	yes
Balance Sheet Controls	no	yes	yes

Robust standard errors clustered at the county level in parentheses: *** p<0.01, ** p<0.05, * p<0.1. In column (2) we include the following balance sheet control: the lagged asset size. In column (3) we add to the regression: the ratio of loans to assets, specie to assets, capital to assets, public bonds to assets and deposits to assets (estimates not reported in the table). Traditional banks are the omitted category. See Section (5) for further details.

Table 3.7: Robustness Checks

	Usury Laws		Incorporation Laws		Insurance Systems		Branches		Suspensions	
PANEL A: FAILURE RATE	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Treatment Effect (TE)	0.0120**	0.0246***	0.0109**	0.0192**	0.0129**	0.0269***	0.0108**	0.0255***	0.0124***	0.0252***
	(0.00871)	(0.00439)	(0.00280)	(0.00432)	(0.00502)	(0.00484)	(0.00449)	(0.00431)	(0.00448)	(0.00471)
PANEL B: ENTRY RATE	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Treatment Effect (TE)	0.0611***	0.0577**	0.0608***	0.0627**	0.0583***	0.0608**	0.0597***	0.0535**	0.0621***	0.0585**
	(0.0179)	(0.0264)	(0.0196)	(0.0273)	(0.0159)	(0.0298)	(0.0189)	(0.0240)	(0.0178)	(0.0278)
Observations	7397	2163	7397	2163	7397	2163	7397	2163	7397	2163
R^2 (PANEL A)	0.079	0.018	0.079	0.012	0.080	0.014	0.079	0.013	0.079	0.013
R^2 (PANEL B)	0.127	0.004	0.127	0.004	0.129	0.004	0.127	0.005	0.127	0.004
Sample	Traditional	Border	Traditional	Border	Traditional	Border	Traditional	Border	Traditional	Border

Columns (1), (3), (5), (7) and (9) report the results for the traditional approach. Robust standard errors clustered at the county level in parentheses. We report in columns (2), (4), (6), (8) and (10) the results for the border-county approach. Standard errors clustered at the state and border segment in parentheses: *** $p<0.01$, ** $p<0.05$, * $p<0.1$. For the traditional approach we use for panel A specification (2) of table IV (see page 24) and specification (2) of table VI (see page 26) for panel B. For the border-county approach we use for panel A specification (6) of table IV (see page 24) and specification (6) of table VI (see page 26) for panel B.

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