Collective Strategic Defaults: Bailouts and Repayment Incentives

Razvan Vlahu*
University of Amsterdam

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Abstract

I show that under a global games approach banks may be subject to risk of failure even when fundamentals are strong due to a coordination problem among debtors. As a result of collective strategic default a financially sound firm may claim inability to repay if it expects a sufficient number of other firms to do so as well, thus reducing bank's enforcement ability. This occurs in particular when financial environment is characterized by inadequate bankruptcy laws and poor disclosure rules. I study a model in which participants take simultaneous actions on the basis of imprecise private signals about the ratio of bad loans in bank portfolio. The model has a unique equilibrium in which an attack against the bank occurs when its fundamentals are above some threshold level. The model also helps us understand the role of the Central Bank as a Lender of Last Resort under opportunistic behavior from borrowers. While an ex-post bailout policy is often believed to reduce bank incentives, in this case it induces commercial banks to affect loan quality, which indirectly reduces incentives for strategic default. I find that the marginal cost of intervention incurred by Central Bank has a double-edge effect. While a higher cost helps to mitigate the moral hazard problem at the bank level by determining it to exert maximum of effort even when fundamentals are stronger, it also increase the probability of bank failure by lowering the threshold in fundamentals that triggers collective strategic default. I also show that high expected profitability is indispensable for banks to protect themselves against collective strategic default from debtor firms.

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1 Introduction

This paper looks at the possibility of collective strategic default, leading to bank collapse. There is much anecdotal evidence of coordinated non repayment in emerging markets, such as Eastern European countries during transition, and banking crises in Mexico and East Asia. In many cases penalties for delaying repayments were usually lower than the cost of borrowing. This occurred in particular when bailouts were funded by monetary creation, leading to a massive inflation and thus devaluation of loan repayments. Moreover, the delays in the legal procedure to recover the loans were huge. Very often the governments in these countries decided to clear debtor firms obligations in order to avoid tough and unpopular social measures as in Romania (1994) and Russia (1992, 1994). While analyzing the strategies and policies implemented by Mexico to resolve their 1994 banking crisis, De Luna-Martinez (2000) identifies the reluctance of borrowers to repay their loans as one of the causes that exarcebated the crisis. A large part of borrowers faced not only the lack of capability, but also the lack of incentives to repay their loans. Hence, as evidence suggests, in circumstances when financial environment is characterized by inadequate bankruptcy laws and poor disclosure rules, potentially solvent firms would have a strong incentive to mimic the behavior of a distressed firm. They understand that the lending bank will be able to fully pursue non paying solvent firms only if it survives. Therefore, solvent firms action may depend on its beliefs about other firms actions and not only on the information regarding how strong the bank fundamentals are. This behavior may be a different determinant for low level of credit and high interest rate differential between deposit and loan rates in emerging economies beside the known factors that are studied in banking literature such as poor corporate sector, low competition in banking, poor law enforcement or political favors in lending[1].

Although the claim in strict form predicts that many severe banking crises episodes have been exarcerbated by the strategic default of solvent firms, particularly in those emerging economies where poor supervision and regulation of banking system were in place, I would still expect that this non repayment tendency to be met in developed western economies too. In a recent article in Financial Times discussing the subprime meltdown, Martin Feldstein, the president of National Bureau of Economic Research, is suggesting that structured finance and securitization has created a coordination failure among borrowers which might cause the deepest and longest recession in the US in the last decades. Due to the fact that commercial banks, acting like lenders, have no recourse to the house's owner beyond the value of the house, and given that more and more people see the value of their mortgages exceding the value of their homes, individuals with negative equity, most of them real

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

estate speculators, have a strong incentive to default. This temptation to turn in the keys and walk away is aggravated by the difficulty in voluntary negociations between creditors and borrowers, because most of these mortgages have been securitised and a renegociation with the mortgage originator proves impossible. Anecdotal evidence is also provided by the interbank payment system. Kahn and Roberds (1998) examine the effects of settlement rules on banks' tendencies to honor interbank commitments rather than default. They found that default probability and the costs associated with potential defaults is higher when net settlement system is in place, while gross settlement increases the costs associated with holding reserves. Banks with large net debt position relative to their capital find tempting to default or to delay the sending of payment messages to other banks, these decisions being exacerbated by the imperfect monitoring by the managers of the payment network or governmental regulators. As we have seen in March 2008, when the US Fed decided to bailout Bear Stearns, regulators have a crucial role in solving the conflict between the interests of an individual bank and the social interest of the payment network.

The main goal of this paper is to evaluate the effect of Central Bank intervention policy as a Lender of Last Resort under opportunistic behavior from borrowers. The Central Bank should, on one hand, to try to minimize the ex-ante moral hazard problem for all parties involved and, on the other hand, to minimize the cost of intervention when it acts as a Lender of Last Resort (LOLR). Secondly, I identify conditions under which an active Central Bank reduces moral hazard for all parties involved (commercial banks and debtor firms). I consider a Central Bank as being active when it might step in once a commercial bank is in trouble and provide help under some specific market conditions. Alternatively, a Central Bank is inactive if its ex-ante stated decision of non intervention is consistent with its ex-post adopted policy. Finally, I investigate how the ex-ante probability of failure of a commercial bank is influenced by different factors such as unconditional commercial bank fundamentals or intervention cost incurred by the Central Bank.

This paper derives the probability of a run by bank borrowers[2], while depositors are passive players. Since banking sector problems and specially bank runs represent a threat in both emerging and developed economies[3], a huge literature is dedicated to this topic. Nevertheless, the existing literature is centered around the traditional models build by Diamond and Dybvig (1983), Chari and Jagannathan (1988), Calomiris and Kahn (1991),

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

[3] Lindgren, Garia and Saal (1996) identifie 133 countries facing banking problems between 1980 and 1996. Gorton (1988) analyzes panics during US National Banking Era from 1865 to 1914. Caprio and Klingebiel (1996), Lindgren et. al.(1999), Hoggarth, Reis and Saporta (2001) documented the costs of these banking problems.

Allen and Gale (1998), in which the focus is on the liabilities side of bank balance sheet[4].

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

My results suggest that an active Central Bank can mitigate the strategic behavior of debtor firms. It allows commercial banks to survive more often when they face opportunistic behavior from borrowers. Debtor firms will behave strategically only when bank fundamentals are very poor, because in that case Central Bank intervention will be very costly and thus improbable while bankrupt banks do not pursue failed debtors. Secondly, the cost of intervention faced by the Central Bank has a double-edge effect. On one hand it reduces the moral hazard problem at the commercial bank level, but on the other hand it can precipitate bank failure by lowering the threshold of fundamentals that triggers collective strategic default. Thirdly, I provide a different explanation for the high interest rate differential between deposit and loan rates in emerging economies. I show that high expected profitability is indispensable for banks to protect themselves against collective strategic default from debtor firms.

To my knowledge there are few formal models that are trying to determine the probability of a bank failure due to strategic coordination of its borrowers. Bond and Rai (2005) analyze the effect of borrower run in microfinance, for an environment where the threat of credit denial is an important source of repayment incentives. My approach is different than theirs in the sense that their work is focused only on the relation between lenders and borrowers and tries to identify the best lending policies which allow lenders to survive borrower run. My purpose is to understand the role of the Central Bank as a LOLR under opportunistic behavior from borrowers. There are also papers which endogenize the asset side of the bank balance sheet. Naqvi (2006) develops a bank run model by endogenizing the asset side of the bank balance sheet. He shows that the presence of a perfectly informed LOLR can avoid costly liquidations and thus it is Pareto improvement. Rochet and Vives (2004) model coordination failure on the interbank market. These papers are different from mine because they ignore the moral hazard problem between the borrowers and the bank. The main novelty in my paper relative to these papers is that it focuses on the borrowers collective strategic default, while depositors are passive players.

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

Related Literature

Strategic default as an individual borrower strategy has been studied in many papers in the finance literature. Townsend (1979) and Gale and Hellwig (1985) show that firms behave strategically under asymmetric information on firm profits by using cash diversion[5]. The cash diversion problem may be severe when contracts are incomplete in the sense that cash flows are not verifiable (Hart and Moore 1988, 1994, and Bolton and Scharfstein, 1990)[6]. A documented path for cash diversion is the tunneling transfer which is described by Akerlof and Romer (1993) and by Johnson, La Porta, Lopez-de-Silanes and Shleifer (2000).

Existing banking literature analyzes many aspects of banking crises. One of the most documented is the regulators' choices between rescuing and closing troubled banks. Goodhart and Huang (2003) show that the Central Bank should act as a LOLR to avoid contagion during a banking crisis. By using a 'too big to fail' approach Freixas (1999) argues that the LOLR should bail out an insolvent bank, while solvent banks are assumed to be bailed out by the interbank market. My approach is based on the reporting and disclosure channel. Commercial banks have to inform the Central Bank about their non-performing loans, and, by using this information, the Central Bank will decide if its role as LOLR is requested. A similar approach was used by Mitchell (1995). She found that bank managers have incentives to underestimate the size of non-performing loans under a tough intervention policy and show that this will lead to inefficient liquidation of bad loans. Aghion, Bolton and Fries (1999) analyze both tough and soft recapitalization policies, arguing that soft intervention mechanism will induce bank managers to exaggerate the recapitalization needs. They also suggest that bank's incentives to misreport can be mitigated by an efficient bailout scheme which is conditional on the liquidation of firms in default.

I form the model in the context of the global games methodology first introduced by Carlsson and van Damme (1993) and later refined by Morris and Shin (1998). This realistic approach does not depend on common knowledge and helps to resolve the issue of multiple equilibria. Common knowledge, introduced in theoretical models through a perfect public information, can create self-fulfilling belief equilibria which might destabilize an economy. Sudden crises without any fundamental reason can arise in such unstable economy due to changes in beliefs of market participants. The presence of multiple equilibria in many macroeconomic models[7] makes any policy analysis very difficult because is problematic to

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

[6] Bolton and Scharfstein (1990) show that when the returns of the borrower's investment are not verifiable by a third party (and thus are noncontractible) the threat of termination (not to lend in the future) provides the incentive to repay.

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

attach probabilities to different outcomes. The central assumption of the global games methodology is that individual actions are strategic complements: an agent's incentive to take a particular action increases as more and more agents take the same action[8]. In this approach, a small amount of noise in fundamentals can be stabilizing and can pin down a unique equilibrium with agents playing threshold strategies. By using an iterated deletion of strictly dominated strategies, the unique Nash equilibrium can be derived for games with incomplete information. The theory of global games has been useful in modeling various economic applications[9]. Fukao (1994) and Morris and Shin (1998) use this approach in modeling speculative currency attacks in the presence of identical speculators. Morris and Shin (2004) examine pricing of debt. Corsetti et al.(2004) and Peydro-Alcalde (2005) show how the presence of a large player influences the coordination problem in forex market and in a creditor's decision to renew its credit, respectively. Shin (1996) studies asset trading. Postlewaite and Vives (1987), Goldstein (1999), Morris and Shin (2000), Rochet and Vives (2004), Dasgupta (2004), Iyer and Peydro-Alcalde (2004), and Goldstein and Pauzner (2005) applied the theory of global games to model bank runs and to examine contagion in the interbank market. Morris and Shin (2003) and Corsetti, Guimaraes and Roubini (2004) use global games to study the impact an international LOLR has on adjustment policies of borrower countries. Morris et al. (1995) study asset prices. Atkeson (2000) and Edmond (2004) employ this method for explaining riots and political change. More advanced models allow not only for noisy private signals about fundamentals, but also for public signals and discuss these signals' impact on the unique equilibrium[10].

The paper is organized as follows. Section 2 describes the basic model, the agents and their payoffs. Section 3 discusses the equilibrium and the thresholds derivation under imperfect information. Section 4 examines the comparative statics and the predictions of the model. Finally, Section 5 concludes and provides some directions for further research. The Appendix contains the mathematical detailed solutions of my main results.

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balance-of-payments crisis.

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

[9]Morris and Shin (2003) is a comprehensive review of the literature on global games. See also Vives (2004) for a review of recent applications to finance, macroeconomics and industrial organization.

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

2 Model

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

2.1 Agents

2.1.1 Commercial Bank

The bank finances itself at date 0 by taking uninsured deposits for a total amount q, which mature at date 1. Focusing on uninsured deposits avoids the moral hazard problem from any deposit insurance scheme with respect to bank incentives[11]. The bank has no cash or other reserves. The nominal value of deposits at date 1 is $Q > q$. As I focus on the assets side of the bank's balance sheet, I model depositors as passive players without alternative investment opportunities besides costless storage. I assume that depositors participation constraint is always satisfied ($\frac{Q}{q} * P(BankSurvives) \geq 1$).

Let the riskless interest rate be 0. The bank invests at date 0 the total amount of its funds q in a continuum of identical risky loans of size 1 each, granted to risk-neutral firms. Each loan matures in the next period and the returns on these loans at date 1 is $D > 1$. For the reminder of the paper I normalize the nominal value of deposits Q such that $Q < 1$. The bank's balance sheet at date 0 will be the following:

No cash	No Equity
$\sum$Loans $= q$	$\sum$Deposits $= q$

Table 1. Bank's balance sheet at date 0.

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

Before granting risky loans at date 0 the bank will set up its loan collection strategy. Specifically, the bank has to implement a costly effort e to assure repayment by its borrowers. The effort lies in the interval $[0, 1]$. These measures represent activities such as extensively screening loans applications, hiring better loan agents or writing better contracts that can be easily enforced in a court. I assume the cost function is quadratic in effort and proportional to the returns on the loans, $c(e) = \frac{e^2}{2}D$. Once e has been chosen, it is common knowledge among all agents.

The value of the bank's fundamentals depends on d, the ratio of firms that are in genuine financial distress and can not repay their loan. This random variable is normally distributed with mean $(\mu - e)$ and variance $1/\alpha$ (precision α) and it lies in the interval $[0, 1]$. Here μ stands for unconditional bank fundamentals. Thus higher the effort e exerted by the commercial bank, better will be the lending policies and risk measures at the bank level. The bank fundamentals d are not common knowledge among market participants. From these insolvent d firms the bank can not extract any liquidation value, whatever its effort.

Debtor firms have no information about bank value. Alternatively, the bank may not be listed on a stock exchange[12]. Usually, financial environment of emerging economies is characterized by poor capital markets. There is no other source of financing for the bank in the short run (e.g. the bank has no access to interbank loans). A motive could be that fear of contagion might lead to low level of liquidity in the interbank system (Dasgupta 2004, Iyer and Peydro-Alcalde 2004, Allen and Gale 2000, Calomiris and Mason 2003)[13].

I assume that the bank is most efficient at extracting cash from the debtor firms due to its collection skills (Diamond and Rajan 1998, 2001). Thus its loans are not tradeable and selling the entire loans portfolio to other financial agents is not optimal. The bank can not insure itself against the costs of forcing a defaulting firm to repay.

2.1.2 Firms

Each firm which expects a positive cash flow C in period 1 higher than its duty to the bank D (henceforth, a good firm) may take one of two actions. It may decide *not to repay* its loan, thus mimicking the situation of a firm in real financial distress. Alternatively it may decide *to repay* it in full. I assume that insolvent firms d (henceforth, a firm in genuine financial distress, or a bad firm) have zero cash, thus they have no option to repay. The

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

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

critical question is whether the $(1-d)$ potentially solvent firms will choose to repay. They understand that the lending bank will be able to fully pursue non paying solvent firms only if it survives. Therefore, solvent firms action may depend on its beliefs about other firms' actions and not only on the information regarding how strong the bank fundamentals are. I assume that a good firm which is indifferent between attacking and not will choose not to attack.

2.1.3 The Central Bank

The Central Bank decides on its intervention policy based on the total number of non-performing loans it reports. Henceforth I make the assumption that the commercial bank can not misreport the non-performing loans volume (the Central Bank can verify at zero cost this reported number). Note that the real number of non paying firms include all distressed firms plus those good firms mimicking the behavior of a distressed one. I analyze two different cases. In the first case I assume no Central Bank intervention. This case corresponds to an inactive Central Bank. The Central Bank declares ex-ante that it will not bailout commercial bank if it faces trouble and it will be consistent ex-post with this decision. Then I consider the case of an active Central Bank. An active Central Bank might step in and provide additional funds if necessary by lending at a zero interest rate, in order to avoid the bank default. The Central Bank decides on the *optimal BailOut Amount* (BOA) by balancing the cost of a successful intervention against the social cost of doing nothing. The bailout amount is unknown ex-ante to firms and commercial bankers and since the Central Bank itself can not differentiate between bad firms and good firms that are not repaying, it will choose between 2 possible actions: full bailout or no bailout. This uncertainty may induce the bank to take costly effort to reduce the incidence of strategic default by debtor firms. I assume that if the active Central Bank is indifferent between helping the decapitalized bank and not, it will choose to bailout the bank.

I will now describe the payoff functions for these market participants and the structure of the game they play.

2.2 Payoff Functions

2.2.1 Firms' Payoffs

The payoff structure for a debtor firm is as follows. If a healthy financial firm doesn't repay its loan and the bank fails, then it saves the repayment, producing a positive payoff of D, minus an amount X representing the positive value that the Central Bank can extract ex-post from non repaying good firm. This difference $D - X$ is positive and it indicates that the original lender is the most efficient at extracting any hidden cash from borrower firms. If a good firm does not repay and the bank survives, the bank can force at no cost repayment D and also can force a contractual fine $F > 0$[14]. This contractual fine represents penalties for non repaying or delaying the repayment. If a good firm decides to repay its loan, it will get either 0 if the bank fails or $V > D$ otherwise, where V represents the present value of future long term relation between the firm and the bank[15]. The payoff structure for a good firm is illustrated in the next table.

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

Table 2. Good firm's payoff.

2.2.2 Default Conditions

For both financially distressed and healthy firms, a default is triggered by non repayment at date 1. I introduce here the function $z(d) = (1 - d)n(d)$, a function of d representing *the necessary fraction of firms which should choose not to repay their loans such that the bank will fail.* I will show later that this function is strictly decreasing in d. The bank will become insolvent if the value of its liabilities Q is higher than the value of its assets:

$$[1 - d - \underbrace{(1 - d)n(d)}_{z(d)}] * D < Q \tag{1}$$

At date 1 the bank's assets are influenced by the ratio of firms in genuine financial distress (d) and also by the ratio of mimicking firms ($(1 - d)n(d)$). The function $n(d)$ indexes

[14] Limited liability is introduced by assuming the following relation between the cash flow C generated by a good firm, the repayment D and the fine F: $D + F \leq C$.

Alternatively, the fine F might represent a non monetary cost. Firms which decide to behave strategically will suffer public blame once bank survives and is able to point out to 'strategic' borrowers. The main predictions of our model would remain unchanged if we follow this path. The only difference will be that F should be taken out from commercial bank payoff.

[15] Diamond (1991) shows that firms that have been successful in the past are able to obtain better credit terms, since they are more likely to be successful in the future. According to Mayer (1988) firms and financial intermediaries develop long-term relationships.

the fraction of good firms which chooses the action *not repay*. I denote by $z'_d(d)$ the first derivative of $z(d)$ with respect to bank fundamentals d. Thus $z'_d(d) < 0$, meaning that higher the number of firms in real financial distress, the lower is the threshold number of mimicking good firms which should not repay such that the bank fails. Let denote by $\overline{d}$ the point at which $z(d) = 0$ and by $\underline{d}$ the point at which $z(d) = 1$. The intuition for the solution of the model *if we assume* common knowledge about bank fundamentals is as follows. The state of bank fundamentals affects the degree of coordination among good firms and thus the payoff from successful collective default. If the bank fundamentals are strong, only a high degree of coordination can undermine the bank capacity to collect unpaid loans. Therefore all good firms will repay their loans in time. On the other hand, when bank fundamentals are very poor, few firms which do not repay their loan can trigger the bank failure. In this situation the dominant strategy for all firms will be non repaying because this strategy will generate a positive payoff. While in these two regions there is one pure Nash equilibrium, in the intermediate region the model has multiple equilibria under a common knowledge assumption. With self-fulfilling beliefs two pure strategy equilibria will coexist: a 'bad' equilibria in which all firms decides not to repay because each one believes in bank's failure, and the 'good' equilibria in which all firms decides to repay because each one believes in bank's strength[16]. To summarize, under common knowledge the classification of fundamentals will be:

- for $0 \leq d \leq \underline{d}$ we have $z(d) > z(\underline{d}) = 1$. In this case all good firms will repay because the bank will survive even if all borrowers default.
- for $\overline{d} \leq d \leq 1$ we have $z(d) < z(\overline{d}) = 0$. In this case all good firms will not repay because the bank will go bankrupt even if no firm will default.
- for $\underline{d} < d < \overline{d}$ we have multiple equilibria. The outcome depends on firms' expectations of what other firms will do, and not on the underlying bank's fundamentals.

Given the commercial bank insolvency condition (1) which relates the nominal value of deposits (Q) and the nominal value of loans (D) with bank fundamentals (d) and with the necessary fraction of firms which should behave strategically to trigger bank's default ($z(d)$), we can find the thresholds $\underline{d}$ and $\overline{d}$. By definition the random variable d lies in the interval $[0, 1]$. The only values satisfying both inequation (1) and also the classification of fundamentals under common knowledge are $\underline{d} = 0$ and $\overline{d} = 1 - \frac{Q}{D}$. Thus, we can conclude that under common knowledge, for this specific form of game in which the number of

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

agents who might coordinate is dependent of fundamentals, there is one region with one pure Nash equilibrium, and another region where the model has multiple equilibria.

- for $0 \leq d < \overline{d}$ we have multiple equilibria. The outcome depends on firms' expectations of what other firms will do, and not on the underlying bank's fundamentals.
- for $\overline{d} \leq d \leq 1$ we have $z(d) < z(\overline{d}) = 0$. In this case all good firms will not repay because the bank will go bankrupt even if no firm will default.

The next sections assumes no common knowledge about fundamentals. The debtor firms hold common prior beliefs about the state of fundamentals d and receive private signals about its realization $x_i = d + \epsilon_i$, where ϵ_i is normally distributed with mean 0 and variance $1/\beta$ (precision β). Moreover, ϵ_i is independent of d and identically and independently distributed across firms. Borrowers can calculate under these circumstances a conditional distribution based on their private signal.

2.2.3 Commercial Bank's Payoff

I assume that upon bankruptcy, the bank can no longer enforce contracts and thus it can not extract the available cash from good firms. This gives to the Central Bank some incentive to keep the commercial bank alive. As there are no other source of financing for the bank at date 1, only Central Bank's intervention can allow it to meet its obligations. Insolvency condition is captured by (1). The commercial bank becomes insolvent if the value of its liabilities Q is higher than the value of its assets.

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

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

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

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

2.2.4 The Central Bank's Payoff

The Central Bank values the long term relation between good firms and their bank, as all good firms which repay their loans will lose a positive known value V if the bank fails. The Central Bank will try to minimize the social cost induced by the failure of the bank, trading it off against the cost of full intervention. Let γ be the Central Bank's marginal cost of intervention. We can interpret this cost from two different perspectives. The most straightforward interpretation is to consider the intervention cost as being the fiscal cost of providing funds to the falling bank. Using this approach, this cost can be linked either with the negative effects of tax increases required to fund the bailout, or with the similar effect of government deficits on other macro variables such as exchange rate. An alternative interpretation is to consider the intervention cost as a proxy for Central Bank's independence and its commitment to maintain price stability.

The concept of independence means that, once appointed, the central banker is able to set policy without interference or restriction of the political authorities (Rogoff 1985). For industrialized economies a large literature has investigated the finding that measures of Central Bank independence are negatively correlated with average inflation, suggesting that, highly independent Central Banks are presumed to place more weight on achieving low inflation[17]. Nevertheless, Central Banks are of two types: those concerned with both inflation and economic growth, and those targeting only inflation rate. Two of the most important Central Banks in the world, the US Federal Reserve (Fed) and the European Central Bank (ECB), fall one in the first category and the other one in the second. While the ECB has a single mandate - mantaining price stability by controlling inflation - and is not concerned with maximizing economic growth, the Fed has two mandates - to preserve the value of the US dollar and to maintain full employment - the two being incompatible. To exemplify the distinction between these two Central Banks we can analyze their policies adopted during 2007/2008 credit crisis. On one hand, the ECB was reluctant to cut interest rates because inflation was consistently above its target. On the other hand, Fed governors chose to try to boost up the economy and let the inflation surge and they also bailed out Bear Stearns, a primary broker which was not under direct supervision of the Fed. Following this approach and considering the intervention cost γ as a proxy for Central Bank's independence and its commitment to maintain price stability, we can assume that an independent Central Bank, which is committed to deal with inflationary pressures, will have a higher γ. According to the previous example, the ECB, which places a higher weight on inflation objectives, will have a higher γ than the Fed, which was concerned during the credit crisis about economic contraction mainly.

Further, I assume common knowledge about γ. It is a positive constant and a higher

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

γ means higher cost of intervention. The expected cost if the Central Bank decides to intervene and to bailout the commercial bank is

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

while the expected social cost if the Central Bank allows the bank to go bankrupt is

$$-V * \underbrace{(1-d) * (1-n(d))}_{\text{ratio of repaying firms}}.$$

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

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

If the Central Bank decides to step in, it will provide all the necessary funds to recapitalize the bank (an amount $Q - D(1-d)(1-n(d))$. Otherwise, it will provide no money, allowing the bank to fail.

The set of available information the Central Bank has is different than the one possessed by the commercial bank. While the commercial bank has information only about the prior distribution of its fundamentals d, the Central Bank will have some more information on top of this, namely the ratio of reported non-performing loans $d + (1-d) * n(d)$.

The extensive form of the game is the following:

- At date 0 the bank collects the uninsured deposits, the level of costly effort e is chosen and becomes common knowledge, and the investment is made.
- Nature draws the bank fundamentals d according to the prior normal distribution; d is not common knowledge. Each debtor firm receives a private noisy signal x_i.
- At date 1, based on their signals, the debtor firms update their beliefs about the bank fundamentals d and simultaneously decide to repay their loans or not. Since the signals allow debtor firms to infer the beliefs of the others, observing a high signal induces them to believe that other firms also received a high signal. Hence they will assign a high probability to an attack on the bank, while a low signal suggests exactly the opposite.

- At date 2, based on the information on the reported number of non-performing loans, the Central Bank decides on the optimal bailout amount. If the bank remains solvent, it collects D and also F for all good firms which do not repay at date 1. If not, defaulted loans are collected by Central Bank from mimicking firms and yield X, with $X < D$.
- Finally, the payoffs of the game are revealed and distributed.

3 Equilibrium and thresholds derivation

I now derive the probability of a run by bank borrowers, measuring a collective strategic default. Hence, since a firm's signal provides information not only about bank fundamentals, but also about other firms' signals, it allows some inference regarding their actions. Observing a high signal induces a debtor firm to believe that other firms also received high signal. Thus it will assign a high probability to an attack on the bank, while a low signal suggests exactly the opposite.

Solving the game requires solving backwards for the intervention policy of the Central Bank, then analyzing the behavior of debtor firms, and finally solve the effort decision for the commercial bank.

In solving the game and deriving the unique equilibrium, I use the global games methodology first introduced by Carlsson and van Damme (1993) and later refined by Morris and Shin (1998). I first assume no Central Bank intervention policy, then I consider the case of an active Central Bank.

3.1 Inactive Central Bank Case

3.1.1 Firms repayment incentives

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

$$\begin{aligned} P(BankSurvives \mid x_i) * (-F) + P(BankFails \mid x_i) * (D - X) > \\ P(BankSurvives \mid x_i) * V + P(BankFails \mid x_i) * 0 \end{aligned} \tag{2}$$

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

The value for X, the amount that the Central Bank can extract ex-post from a non repaying good firm, is strictly positive in (2) because although the Central Bank is inactive in this economy, it will step in if bank's default materializes and it will extract this amount from mimicking good firms.

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

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

These equilibrium thresholds d^* and x^* are the following:

$$x^* = \frac{\alpha + \beta}{\beta} d^* - \frac{\alpha}{\beta}(\mu - e) - \frac{\sqrt{\alpha + \beta}}{\beta} \Phi^{-1}(\frac{D - X}{V + F + D - X}), \tag{3}$$

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

$$d^* + \frac{Q}{D} = \Phi(\frac{\alpha}{\sqrt{\beta}}(d^* - (\mu - e) - \frac{\sqrt{\alpha + \beta}}{\alpha} \Phi^{-1}(\frac{D - X}{V + F + D - X}))), \tag{4}$$

where d^* is the threshold value for commercial bank fundamentals above which the bank fails when the Central Bank is not active. Φ represents the cumulative distribution function of the standard normal distribution. The solution to equation (4) should belong to the region of fundamentals which is characterized by multiple equilibria under common knowledge assumption. Thus, d^* should lie in $[0, \overline{d}]$.

The right side of equation (4) is a cumulative normal distribution

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

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

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

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

$$\frac{\alpha}{\sqrt{\beta}} \leq \sqrt{2\pi} \tag{5}$$

Proposition 1 *When the precision of the private signal of debtor firms (β) is large enough relative to prior precision (α) so as to satisfy (5), there is a unique d^* defined in (4) such that, in any equilibrium of the game with imperfect information, the bank fails if and only if $d > d^*$.*

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

This result implies that removing the assumptions of common knowledge eliminates multiple equilibria only if the precision of private signals is large relative to the precision of the prior (β large when compared to α). This condition is sufficient for uniqueness of equilibrium because only this equilibrium survives iterated deletion of strictly dominated strategies (see Morris and Shin 2000, 2003).

In order to keep model tractable and to derive closed form results I will analyze the equilibrium values under the assumption that the private signal's precision is very high ($\beta \to \infty$).

This approach is standard in the literature of symmetric binary global games. Importantly, Morris and Shin (2003) show that this limiting assumption will not restore common knowledge. They prove that strategic uncertainty regarding the actions of other agents is higher for $\beta \to \infty$ and that limiting behavior can be identified independently of the prior beliefs and the shape of noise. As information concerning fundamentals become more precise and the noise smaller, the actions in equilibrium resemble the behavior when the uncertainty regarding the actions of other agents become more diffuse. With respect to my model, a good debtor firm believes that the ratio of good debtor firms choosing the action not repay is a uniform distributed random variable over $[0, 1]$. Under this assumption equation (4) becomes:

$$d^* + \frac{Q}{D} = \frac{V+F}{V+F+D-X} \tag{6}$$

This result shows us that deposit-to-assets ratio plays an important role in preventing a strategic behavior of debtor firms, even if the Central Bank is inactive. A lower deposit-to-assets ratio for the bank ($\frac{Q}{D}$) implies a higher threshold above which the bank will fail when facing collective strategic default. Nevertheless, this result holds always when the decrease in this ratio is due to a decrease in Q, the nominal value of deposits at date 1. The impact of D, the returns on loans at date 1, on equilibrium threshold is ambiguous. Differentiating (6) with respect to D yields the following result:

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

If the difference in the right side of the above equation is positive, then keeping all other factors constant an increase in returns on loans will imply a stronger position for the commercial bank facing strategic behavior from debtor firms, which is characterized by a higher value for the equilibrium threshold d^* above which the bank fails. A restrictive condition which will support this result is that $Q \geq V+F > X$. Otherwise, if the difference is negative, the increase in returns on loans will have the opposite effect, weakening bank position in front of a strategic attack of debtor firms.

3.1.2 Bank optimal effort

Taking as given the optimal strategy for debtor firms, the bank will choose its optimal effort by maximizing its expected payoff, conditional on the available information. An increase in exerted effort e implies a lower value for average weakness of bank fundamentals ($\mu - e$). Thus, by extensively screening loans applications, hiring better loan agents or writing better contracts that can be easily enforced in a court, the bank might reduce the ratio of non-performing loans, making in this way a strategic attack from debtor firms less likely. This happens because by lowering the average weakness of its fundamentals the bank actually increases the probability of lower signals received by debtor firms. The expected payoff for bank is given by:

$$
\begin{gathered}
P(BankSurvives \mid d) * D * E_d[(1-d) * (1-n(d))] + \\
+ P(BankSurvives \mid d) * (F + D) * E_d[(1-d) * n(d)] + \\
+ P(BankSurvives \mid d) * (-Q - c(e)) + \\
+ P(BankFails \mid d) * (-c(e))
\end{gathered} \tag{7}
$$

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

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

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

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

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

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

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

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

$$\begin{aligned}&\Phi(\sqrt{\alpha}(d^* - (\mu - e))) * D * [H(x^*) - (\mu - e)] + \\&+\Phi(\sqrt{\alpha}(d^* - (\mu - e))) * (F + D) * [1 - H(x^*)] \\&+\Phi(\sqrt{\alpha}(d^* - (\mu - e))) * (-Q - c(e)) + \\&+(1 - \Phi(\sqrt{\alpha}(d^* - (\mu - e)))) * (-c(e))\end{aligned} \tag{8}$$

In order to have an explicit solution I assume that the information about prior distribution of fundamentals is precise enough, hence $\alpha \to \infty$. Hence, we take firstly limit with respect to β, and afterwards with respect to α. A very precise prior translates in less noise regarding the bank's fundamentals. The optimal choice of effort will be:

$$e^* = \begin{cases} 1, & -1 \leq \frac{V+F}{V+F+D-X} - \frac{Q}{D} - \mu \leq 0 \\ 0, & otherwise \end{cases} \tag{9}$$

See the Appendix for detailed derivations.

According to (9), the commercial bank exerts *no effort* when its unconditional fundamentals (μ) are below $\frac{V+F}{V+F+D-X} - \frac{Q}{D}$, in which case a strategic attack from debtor firm is not likely, or when the unconditional fundamentals are very high (above $1 + \frac{V+F}{V+F+D-X} - \frac{Q}{D}$). A poor loan quality level characterized by a high average weakness of bank fundamentals $\mu - e$ will increase the probability for a successful strategic attack from debtor firms, more than proportionally. I will analyze this in depth in Section 4.

3.2 Active Central Bank Case

3.2.1 Central Bank intervention decision

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

The Central Bank will compare the cost implied by a full intervention

$$-\gamma[Q - D * (1 - d)(1 - n(d))]$$

with the social cost expected if the bank goes bankrupt, which is

$$-V * (1 - d) * (1 - n(d))$$

Thus, the Central Bank is more likely to intervene under high social cost caused by the bank closure, and is more likely to allow bank failure in the case of high intervention costs. Let us denote the ratio of non-performing loans by $NPL(d) = d + (1 - d)n(d)$. Following from the bank's default condition (equation (1)) the Central Bank's expected cost function is given by:

$$C(NPL(d)) = min \{V * (1 - d) * (1 - n(d)),\ \gamma[Q - D * (1 - d)(1 - n(d))]\} \tag{10}$$

The firms know ex-ante the Central Bank's preference (γ is common knowledge) between helping the bank and letting it go. Although the cost of intervention γ is common knowledge for all the players, ex-post intervention policy is affected by the degree of coordination between debtor firms. A high degree of coordination will increase the cost of intervention while decreasing the social cost caused by the bank closure. Hence, the Central Bank decision to bailout or not is not known ex-ante. By implementing such a bailout policy which is focused on the above objective function, Central Bank introduces uncertainty regarding the bailout amount. Hence, its final decision induces the commercial bank to exert maximum of effort ex-ante and also helps to mitigate the strategic behavior of debtor firms. With respect to its cost function, the Central Bank will decide for a full bailout when the social cost is higher than inflationary cost generated by the amount BOA injected in the insolvent bank. Alternatively, it chooses no intervention:

$$BOA \in \{0, Q - D * [1 - NPL(d))]\} \tag{11}$$

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

$$NPL^* \leq \frac{V + \gamma D - \gamma Q}{V + \gamma D} \tag{12}$$

This expression is decreasing in γ. A higher cost of intervention implies a lower probability for a full bailout. The Central Bank will step in and provide the necessary amount only for a reduced ratio of non-performing loans reported, given the higher cost of intervention γ.We can also see that the threshold in non-performing loans reported by the commercial bank below which the Central Bank intervenes is decreasing in Q and increasing in D. This result shows us that deposit-to-assets ratio plays an important role in preventing a strategic behavior of debtor firms, also in the case of an active Central Bank. A high expected profitability will increase the threshold NPL^* below which the Central Bank intervention will allow commercial bank to avoid failure.

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

3.2.2 Firms repayment incentives

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

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

If the ratio of non-performing loans is below the threshold accepted by the Central Bank, then the commercial bank will be bailed out (if necessary) and a strategic attack from debtor firms will be contained. I will start by deriving the equilibrium in threshold strategies. Let suppose as before that there is a threshold x^{**} such that all the firms which see a signal $x > x^{**}$ will not repay their loans to bank. Given NPL^* derived at the last stage of the game (in section 3.2.1.) and following the same reasoning as when the Central Bank was inactive, we may derive the new thresholds x^{**}, the threshold signal at which a good firm is indifferent between repaying his loan or not, and d^{**}, the threshold value for commercial bank fundamentals above which the bank fails when Central Bank is active as:

$$x^{**} = NPL^* \frac{\alpha + C}{C} - \frac{\alpha(1 - d^{**} + \mu - e)}{C} - \sqrt{\frac{\alpha + C}{C\beta}} \Phi^{-1}\left(\frac{D - X}{V + F + D - X}\right), \tag{13}$$

$$d^{**}+\frac{Q}{D} = \Phi(\sqrt{\beta}\frac{\alpha - C}{C}(d^{**}+NPL^{*}\frac{\alpha + C}{\alpha - C}-\frac{\alpha(1+\mu-e)}{\alpha - C}-\frac{C}{\alpha - C}\sqrt{\frac{\alpha + C}{C\beta}}\Phi^{-1}(\frac{D-X}{V+F+D-X}))), \tag{14}$$

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

The right side of equation (14) is a cumulative normal distribution:

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

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

$$\begin{aligned} &\frac{\sqrt{\beta}}{\alpha+\beta+2\rho\sqrt{\alpha\beta}}(-\beta - 2\rho\sqrt{\alpha\beta}) \leq \sqrt{2\pi} \\ &\rho < 0 \\ &0 < \beta \leq -2\rho\sqrt{\alpha\beta} \\ &\alpha > -\beta - 2\rho\sqrt{\alpha\beta} \end{aligned} \tag{15}$$

Proposition 2 *When the precision of the private signal of debtor firms (β) and the prior precision (α) satisfy the conditions described by (15), there is a unique d^{**} defined in (14) such that, in any equilibrium of the game with imperfect information, the bank fails if and only if $d > d^{**}$.*

Proof. *See the Appendix.* ■

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

$$d^{**} = 1 - \frac{Q}{D}. \tag{16}$$

Proposition 3 *The threshold d^{**} above which the bank fails even if the Central Bank is active is always larger than d^{*}, the threshold above which the bank fails if Central Bank is inactive. Both fundamentals thresholds are lower than the ratio of non-performing loans NPL^{*} for which an active Central Bank is indifferent between saving the bank and not.*

Proof. *See the Appendix.* ■

The result suggests that an active Central Bank can mitigate strategic default behavior of debtor firms, as it allows commercial banks to survive more often, preserving its loan enforcement capacity so that firms choose to repay more often. Debtor firms will behave strategically only when commercial bank fundamentals are very poor, in which case they assign a low probability for an intervention by the Central Bank as it would be very expensive.

Deposit-to-assets ratio plays an important role in preventing a strategic behavior of debtor firms in this case too. A lower deposit-to-assets ratio for the bank ($\frac{Q}{D}$) implies a higher threshold above which the bank will fail when facing collective strategic default. This result holds always both for a decrease in Q, the nominal value of deposits at date 1, and for an increase in D, returns on loans at date 1.

3.2.3 Bank optimal effort

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

$$\begin{gathered} P(BankSurvives \mid d) * D * E_d[(1-d)*(1-n(d))]+ \\ +P(BankSurvives \mid d) * (F+D) * E_d[(1-d)*n(d)]+ \\ +P(BankSurvives \mid d) * (-Q-c(e))+ \\ +P(BankFails \mid d) * (-c(e)) \end{gathered}$$

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

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

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

The optimal choice of effort when the information about prior distribution of fundamentals is precise enough ($\alpha \to \infty$) will be:

$$e^{**} = \begin{cases} 1, & -1 \leq 1 - \frac{\gamma Q}{V+\gamma D} - \frac{Q}{D} - \mu \leq 0 \\ 0, & otherwise \end{cases} \tag{17}$$

The optimal results for bank's effort suggest that bank's behavior is influenced in this case by its unconditional fundamentals (μ) and by the Central Bank cost of intervention (γ). From (17), the commercial bank will exert *no effort* when its unconditional fundamentals (μ) are below $1 - \frac{Q}{D} - \frac{\gamma Q}{V+\gamma D}$, in which case a strategic attack from debtor firm is not likely, or when the unconditional fundamentals is very high (above $2 - \frac{Q}{D} - \frac{\gamma Q}{V+\gamma D}$). A poor loan quality level will increase the probability for a successful strategic attack from debtor firms.

Proposition 4 *The optimal effort e^{**} has the same values as in the case with an inactive Central Bank, namely $e = e^* = e^{**}$.*

Proof. *Following from (9) and (17), this is a direct result of my limiting assumptions.* ■

However, the Central Bank intervention changes the thresholds in unconditional bank fundamentals which trigger collective strategic default. As we will see, from the point of view of moral hazard induced at the commercial bank level, for some values for γ the presence of Central Bank is beneficial.

When the Central Bank is not active, the possibility of a collective strategic default will induce the commercial bank to exert maximum optimal effort $e = 1$ sooner (when unconditional fundamentals are lower). This will happen only for low values of γ ($\gamma < \gamma^*$), where $\gamma^* = \frac{V(D-X)}{Q(V+F)+(D-X)(Q-D)}$. In this case, we will have the following classification for the unconditional bank fundamentals:

$$\underset{(\mu_1)}{\frac{V+F}{V+F+D-X} - \frac{Q}{D}} < \underset{(\mu_2)}{1 - \frac{Q}{D} - \frac{\gamma Q}{V+\gamma D}} < \underset{(\mu_3)}{1 + \frac{V+F}{V+F+D-X} - \frac{Q}{D}} < \underset{(\mu_4)}{2 - \frac{Q}{D} - \frac{\gamma Q}{V+\gamma D}}$$

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

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

Figure 1 shows the level of effort exerted by commercial bank for different values of its unconditional fundamentals when cost of intervention is low.

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

$$\underset{(\mu_2)}{1 - \frac{Q}{D} - \frac{\gamma Q}{V+\gamma D}} < \underset{(\mu_1)}{\frac{V+F}{V+F+D-X} - \frac{Q}{D}} < \underset{(\mu_4)}{2 - \frac{Q}{D} - \frac{\gamma Q}{V+\gamma D}} < \underset{(\mu_3)}{1 + \frac{V+F}{V+F+D-X} - \frac{Q}{D}}$$

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

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

Figure 2 shows the level of effort exerted by commercial bank for different values of its unconditional fundamentals when cost of intervention is high.

I summarize these findings in the following three propositions.

Proposition 5 *For low cost of intervention ($\gamma < \gamma^*$), an active Central Bank will induce moral hazard in commercial bank behavior. When Central Bank is not active, the commercial bank will decide to exert optimal effort* $e = 1$ *when its unconditional fundamentals are stronger ($\mu_1 \leq \mu \leq \mu_2$) than when Central Bank is active. When the Central Bank is active the commercial bank exerts effort only when the unconditional bank fundamentals are above μ_2.*

Proposition 6 *When cost of intervention is low enough ($\gamma < \gamma^*$), an active Central Bank will induce the commercial bank to exert maximum of effort even if its unconditional fundamentals are very poor ($\mu_3 < \mu \leq \mu_4$).*

Proposition 7 *A high enough cost of intervention ($\gamma > \gamma^*$) mitigates the moral hazard problem introduced by an active Central Bank when commercial bank unconditional fundamentals are strong enough ($\mu_2 \leq \mu \leq \mu_1$).*

Proof. *See the Appendix.* ■

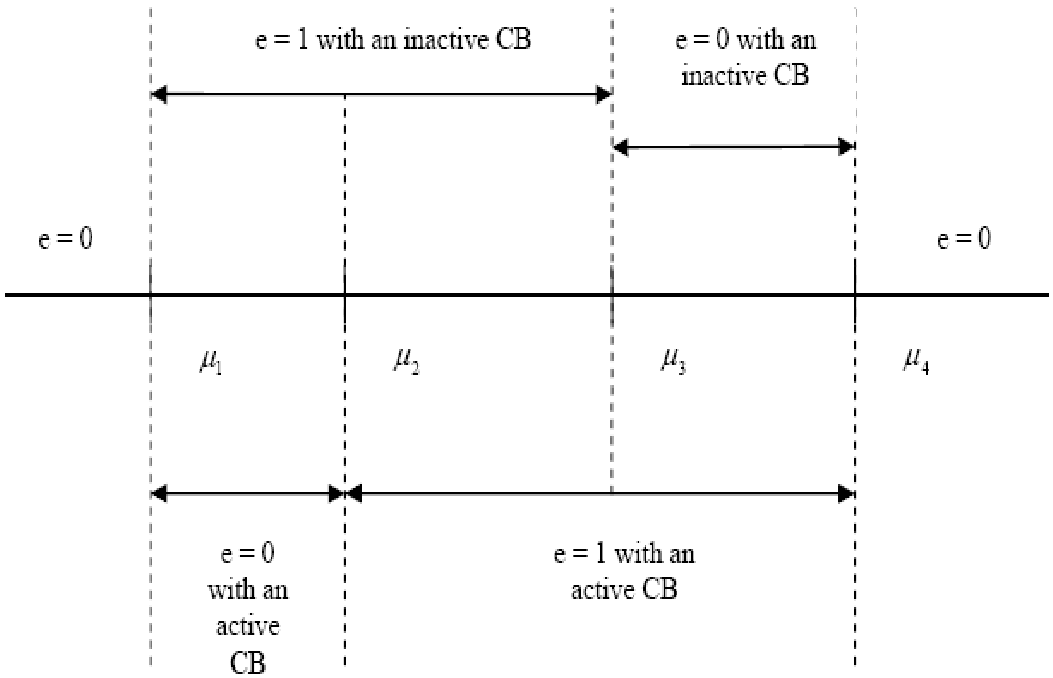

Figure 1. Optimal effort for low cost of intervention.

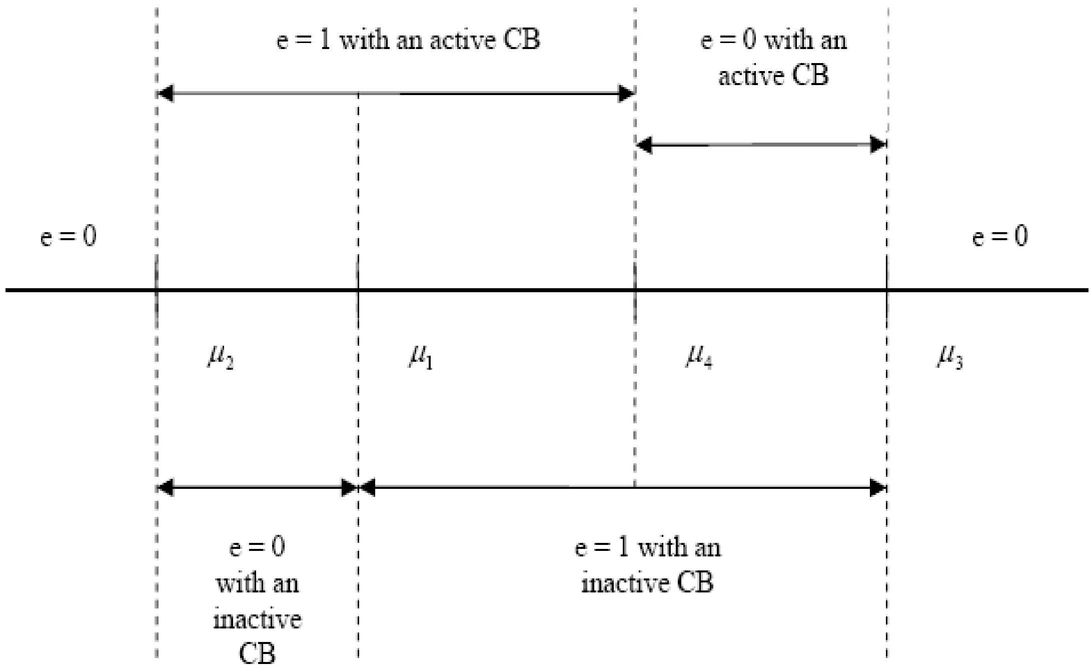

Figure 2. Optimal effort for high cost of intervention.

4 Comparative statics

4.1 Changes in unconditional bank fundamentals

The effort exerted by the bank in period 0 will have a direct impact on the prior unconditional fundamentals. An increase in effort e implies a lower value for average weakness of bank fundamentals $(\mu - e)$. A higher average weakness of bank fundamentals caused either by a lower effort e exerted by the bank, or by a higher unconditional bank fundamentals μ, will have a double impact. Firstly I examine the changes in the exogenous variable μ, when effort e is given.

On one hand, an increase in μ will lower the equilibrium threshold in bank fundamentals (d^* or d^{**}) below which the bank survives when facing a strategic attack of debtor firms. This result comes from differentiating (4) and (14), respectively. Hence, $\frac{\partial d^*}{\partial \mu} < 0$ and $\frac{\partial d^{**}}{\partial \mu} < 0$. These results suggest that when the unconditional fundamentals become worse, commercial banks may be subject to risk of failure more often due to a coordination problem among debtors.

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

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

Differentiating the above probability with respect to μ yields

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

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

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

$$P(BankFails \mid prior\ d) = P(NPL > NPL^*) =$$

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

Differentiating the above probability with respect to μ yields

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

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

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

Figures 3 to 5 illustrates what happens for a specific set of parameters by plotting the equilibrium thresholds in bank fundamentals and the probability of default as a function of unconditional fundamentals. The case of an inactive Central Bank is captured in Figure 3 for $\frac{Q}{D} = 0.05$, $\Phi^{-1}(\frac{D-X}{V+F+D-X}) = 1.293$, $\alpha = 9$,and $\beta = 160$, while for the case of an active Central Bank parameters are $\frac{Q}{D} = 0.05$, $\Phi^{-1}(\frac{D-X}{V+F+D-X}) = 1.293$, $\alpha = 10$, $\beta = 0.3$ and $\rho = -0.1$. Figure 4 illustrates a scenario with a low cost of intervention γ which translates in a higher threshold in non-performing loans below which the Central Bank intervenes ($NPL^* = 0.8$). Figure 5 illustrates a scenario with a high cost of intervention γ which translates in a lower threshold in non-performing loans below which the Central Bank intervenes ($NPL^* = 0.2$).

I also examine the impact that an increase in unconditional fundamentals μ will have on the incidence of collective strategic default, measured here by $(1-d)n(d)$. Firstly I examine the changes in the exogenous variable μ, when effort e is given and afterwards I examine the case when effort e is the optimal effort. When the unconditional bank fundamentals increases, keeping the effort exerted by the commercial bank constant, the probability that good firms will receive a higher signal increases, implying that more solvent firms will choose the action not repay. As we have seen previously, the unconditional bank fundamentals have a negative impact on the equilibrium thresholds. Intuition suggests that, due to the fact that bank will fail for lower levels of fundamentals, the necessary number of good firms which should choose the action non repay such that the bank fails should increase. The result holds true in both cases we have analyzed. The derivative $\frac{\partial(1-d)n(d)}{\partial\mu}$ is positive for the case of an inactive/active Central Bank. Complete derivations can be found in Appendix.

When effort e is the optimal effort, and thus a change in unconditional bank fundamentals will trigger a change of strategy from commercial bank, the effects described above remain the same when all agents play their optimal strategies. As we have seen before, due to the fact that the optimal effort e is not a continuous variable, we meet jumps in the incidence of collective strategic default. For the case of an inactive Central Bank I illustrate this in figure 6 via simulation by setting $\frac{Q}{D} = 0.05$, $\Phi^{-1}(\frac{D-X}{V+F+D-X}) = 1.293$, $\alpha = 9$,and $\beta = 160$, and varying μ from 0 to 1. The case of an active Central Bank is captured in figure 7 for $\frac{Q}{D} = 0.05$, $\Phi^{-1}(\frac{D-X}{V+F+D-X}) = 1.293$, $\alpha = 10$, $\beta = 0.3$, $\rho = -0.1$ and $NPL^* = 0.8$. An interesting feature of strategic behavior for debtor firms is captured in figures 6b and 7b. The simulation suggests that in both cases, when we compute the necessary ratio of good firms which should behave strategically in order to trigger bank's default with respect to total number of debtor firms and also with respect to total numbers of *good* firms, this ratios are increasing with respect to bank unconditional fundamentals. We may conclude that higher values for unconditional bank fundamentals increase the ratio of good firms in equilibrium due to the negative impact on equilibrium thresholds d^* and d^{**}, while they increase also the required degree of coordination among these good firms that can lead to bank failure.

The above results suggest that the economic environment has a very serious impact on the ability that commercial banks have to survive when facing strategic default. The unconditional bank fundamentals (μ) might represent a measure for development of corporate sector. A high μ, can be interpreted as weak corporate sector with poor performance (poor asset quality). Alternatively, we may interpret a high μ as an indicator for a weak judiciary system. The commercial banks can not influence directly this macro variable. Thus, in countries where financial environment is characterized by poor quality of corporate sector and/or poor law enforcement, commercial banks are very exposed to the risk of collective strategic default.

4.2 Effect changes in the intervention cost

When the cost of intervention (γ) increases, the threshold values for unconditional bank fundamentals at which the commercial bank chooses to exert maximum effort diminish. This result comes directly from Proposition 7 which captures the switch between thresholds μ_1 and μ_2. Higher cost of intervention will have a negative impact for the value of μ_2. This result suggests that moral hazard introduced by the Central Bank as a Lender of Last Resort is mitigated by a higher cost of intervention. Thus countries in which the Central Bank faces a shortage of reserves and the cost of foreign capital is high, or countries in which monetary authorities are concerned by the high inflationary costs induced by printing money, will induce incentives for banks to anticipate collective strategic default and to exert maximum of effort.

Another effect of intervention cost is on the thresholds in fundamentals above which the bank will fail. By differentiating (14), we obtain a negative value for $\frac{\partial d^{**}}{\partial \gamma}$. This implies a lower threshold below which the bank survives. Thus, an increase in marginal cost of intervention translates into a lower equilibrium value for commercial bank fundamentals above which the bank will fail.

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

Figure 8 illustrates what happens for a specific set of parameters by plotting the equilibrium thresholds in bank fundamentals and the probability of default as a function of unconditional fundamentals for different values in cost of intervention. The cost of intervention γ

and the ratio of non-performing loans NPL^* changes from 0.1 to 0.2 and from 0.4 to 0.2, respectively, while other parameters are kept constant: $\frac{Q}{D} = 0.05$, $\Phi^{-1}(\frac{D-X}{V+F+D-X}) = 1.67$, $\alpha = 10$, $\beta = 0.3$, and $\rho = -0.1$.

Thus, we may conclude that higher cost of intervention has a double-edge effect: on one hand it helps in reducing moral hazard by commercial banks due to the fact that commercial bank will have stronger incentive to exert maximum of effort when unconditional bank fundamentals are stronger, on the other hand it lowers the threshold of fundamentals that triggers collective strategic default and thus precipitate bank failure.

5 Conclusion and further research

In this model I examine the role of the Central Bank as a Lender of Last Resort under opportunistic behavior from borrowers. While an ex-post bailout policy is often believed to reduce bank incentives, I show that under specific market conditions it induces commercial banks to affect loan quality, which indirectly reduces incentives for strategic default.

I form my model in the context of the global games methodology. Under this approach, banks may be subject to risk of failure even when fundamentals are strong due to a co-ordination problem among debtors. As a result of collective strategic default a financially sound firm may claim inability to repay if it expects a sufficient number of other firms to do so as well, thus reducing bank's enforcement ability. This occurs in particular when financial environment is characterized by inadequate bankruptcy laws and poor disclosure rules.

My results suggest that an active Central Bank can mitigate the strategic behavior of debtor firms. It allows commercial banks to survive more often when they face opportunistic behavior from borrowers. Debtor firms will behave strategically only when bank fundamentals are very poor, because in that case Central Bank intervention will be very costly and thus improbable. Secondly, the cost of intervention faced by the Central Bank has a double-edge effect. On one hand it reduces moral hazard problem at the commercial bank level, but on the other hand it can precipitate bank failure by lowering the threshold in fundamentals that triggers collective strategic default. Thirdly, I show that high expected profitability is indispensable for banks to protect themselves against collective strategic default from debtor firms. As a measure of expected profitability I use the deposit-to-asset ratio. I prove that this ratio plays an important role in preventing a strategic behavior of debtor firms, even if the Central Bank never intervenes to bailout a defaulting bank. A lower deposit-to-assets ratio for the bank implies a higher threshold above which the bank will fail when facing collective strategic default. This result supports the economic intuition that in developing economies high interest rate differential between deposit and loan rates can be interpreted as a risk management mechanism which helps commercial banks to protect themselves against a collective strategic default from debtor firms.

Nevertheless, I derive my results under the assumption that all market participants know ex-ante the Central Bank's preference between helping the bank and letting it go. I leave for further research the alternative case in which Central Bank's preference is not common knowledge. Further research should also focus on empirical tests of the implications of my analysis. To implement the tests, however, more detailed data are required than are available from sources such as anecdotal evidence.

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7 Appendix

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

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

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

$$P(x \leq x^* \mid d) = \Phi(\sqrt{\beta}(x^* - d)), \tag{18}$$

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

This is a straightforward result of the following variable transformation:

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

This means that a critical fraction of good firms should attack the bank in order to cause the bank's failure. This value is given by the cumulative mass of good firms who have seen a signal above the threshold signal x^*. One of the main assumptions I made was that a good firm which is indifferent between attacking and not will choose not to attack. Thus:

$$P(x > x^* \mid d) = z(d) = (1 - d)n(d) \tag{19}$$

By plugging the distribution of signals x_i across firms conditional on the realization of fundamentals d^* and the ratio of good firms which choose not to repay (in 18 and 1, respectively), one obtains the main equilibrium condition:

$$\Phi(\sqrt{\beta}(x^* - d^*)) = \frac{Q}{D} + d^* \tag{20}$$

Following from (1), the bank default will be triggered for

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

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

Applying Bayesian inference under a normal distribution conditional on another normal distribution, we may derive the posterior distribution over bank's fundamentals d for a firm who has seen a signal x, as the following cdf: $P(d \leq d^* \mid x)$[18]. This function is decreasing

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

in x, positive and continuous for any values of d^*. The higher x, the lower the probability that fundamentals d lies below any threshold d^*:

$$P(d \leq d^* \mid x) = \Phi(\sqrt{\alpha+\beta}(d^* - \frac{\alpha(\mu-e)+\beta x}{\alpha+\beta})) \tag{21}$$

This result is derived using the same method of variable transformation. As a result of Bayesian inference, each borrower firm who sees signal x has a posterior distribution over d that is normal with mean $\frac{\alpha(\mu-e)+\beta x}{\alpha+\beta}$ and variance $\frac{1}{\alpha+\beta}$. The main difference between the classical and Bayesian approaches to inference is that unknown model parameters are treated as random variables in Bayesian inference and not as constants as is the case in classical inference. The next Appendix derives the posterior distribution over bank's fundamentals d for a firm who has seen a signal x.

By replacing in (2) the probability of bank survival with the value we have found in (21), we may built the second main equilibrium condition:

$$d^* - \frac{\alpha(\mu-e)+\beta x^*}{\alpha+\beta} = \frac{1}{\sqrt{\alpha+\beta}}\Phi^{-1}(\frac{D-X}{V+F+D-X}) \tag{22}$$

By solving the system of equations formed by (20) and (22), equilibrium thresholds d^* and x^*can be found. Solving (22) for x^*, we obtain the threshold signal at which a good firm is indifferent between repaying his loan or not:

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

Solving now (20) for d^* and using the value we have just derived above for equilibrium signal x^*, gives the threshold value for bank's fundamentals above which the bank fails:

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

The right side of above equation is a cumulative normal distribution

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

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

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

Posterior distribution over bank's fundamentals d for a firm who has seen a signal x. Bayesian inference.

Our task is to compute the posterior distribution of d. From the private signals definition we can immediately infer that for a given d the distribution of signal x will be normal with mean d and variance $\frac{1}{\beta}$, where d has a prior normal distribution with mean $\mu - e$ and variance $\frac{1}{\alpha}$. According to this Bayesian model just described we can write the likelihood function:

$$f(x \mid d) = \frac{1}{\sqrt{2\pi}\sqrt{\frac{1}{\beta}}}\exp(-\frac{1}{2}\frac{(x-d)^2}{\frac{1}{\beta}}).$$

We also know the prior density function for variable d:

$$f(d) = \frac{1}{\sqrt{2\pi}\sqrt{\frac{1}{\alpha}}}\exp(-\frac{1}{2}\frac{(d-(\mu-e))^2}{\frac{1}{\alpha}}).$$

We may conclude that the posterior density of d is:

$$f(d \mid x) = f(d) * f(x \mid d) =$$

$$= \frac{1}{\sqrt{2\pi}\sqrt{\frac{1}{\alpha}}}\exp(-\frac{1}{2}\frac{(d-(\mu-e))^2}{\frac{1}{\alpha}}) * \frac{1}{\sqrt{2\pi}\sqrt{\frac{1}{\beta}}}\exp(-\frac{1}{2}\frac{(x-d)^2}{\frac{1}{\beta}}) =$$

$$= const * \exp(-\frac{1}{2}\frac{(d-(\mu-e))^2}{\frac{1}{\alpha}} - \frac{1}{2}\frac{(x-d)^2}{\frac{1}{\beta}}),$$

where *const* stands for a constant.

We can easily see that $f(d \mid x) = f(d) * f(x \mid d) = const * \exp(-G/2)$, where

$$G = \frac{1}{\frac{1}{\alpha}}(d^2 - 2d(\mu - e) + (\mu - e)^2) + \frac{1}{\frac{1}{\beta}}(x^2 - 2xd + d^2) =$$

$$= d^2(\frac{1}{\frac{1}{\alpha}} + \frac{1}{\frac{1}{\beta}}) - 2d(\frac{\mu - e}{\frac{1}{\alpha}} + \frac{x}{\frac{1}{\beta}}) + c,$$

where c stands for a constant. We may rewrite this value as:

$$G = h_1[d^2 - 2d(\frac{h_2}{h_1}) + (\frac{h_2}{h_1})^2] + c = h_1(d - \frac{h_2}{h_1})^2 + c,$$

where $h_1 = \frac{1}{\frac{1}{\alpha}} + \frac{1}{\frac{1}{\beta}}$ and $h_2 = \frac{\mu - e}{\frac{1}{\alpha}} + \frac{x}{\frac{1}{\beta}}$.

Thus, we may conclude that

$$f(d \mid x) = const * \exp\left\{-\frac{1}{2}\left[h_1(d - \frac{h_2}{h_1})^2 + c\right]\right\} = const * \exp\left\{-\frac{1}{2\frac{1}{h_1}}\left[(d - \frac{h_2}{h_1})^2\right]\right\} \sim$$

$$\sim N(\frac{h_2}{h_1}, \frac{1}{h_1}),$$

where $\frac{h_2}{h_1} = \frac{\alpha(\mu - e) + \beta x}{\alpha + \beta}$ and $\frac{1}{h_1} = \frac{1}{\alpha + \beta}$.

Proof of Proposition 1: To be added

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

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

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

$$= 1 - E_d[\Phi(\sqrt{\beta}(x^* - d)]$$

Recall that d is normally distributed and it belongs to $[0, 1]$ and that Φ is the cumulative density function of the standard normal distribution. I denote by f the general density function and by F the general cumulative density function. Hence:

$$E_d[\Phi(\sqrt{\beta}(x^* - d)] = \int_0^1 F(x^* \mid d) * f\ (d)\ dd =$$

$$= \int_0^1 (\int_{-\infty}^{x^*} f(y \mid d) dy) * f\ (d)\ dd = \int_0^1 \int_{-\infty}^{x^*} \underbrace{f(y \mid d) * f(d)}_{f(y,d)}\ dy\ dd =$$

$$\underset{by\ changing\ limits}{=} \int_{-\infty}^{x^*} \int_0^1 f(y, d)\ dd\ dy = \int_{-\infty}^{x^*} f(y)\ dy = H(x^*),$$

where $H(x^*)$ is the cumulative distribution function for signals x. Thus, we can conclude that: $E_d[(1-d) * n(d)] = 1 - H(x^*)$.

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

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

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

Bank optimal effort derivation. The case of inactive Central Bank

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

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

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

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

$$\underset{e}{max}\ \{-D * (\mu - e) + D * H(x^*) + (F + D) - (F + D) * H(x^*) - Q - c(e)\}$$

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

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

$$\underset{e}{max}\ \{-c(e)\}$$

with solution $e = 0$.

Combining the last two results,

$$e^* = \begin{cases} 1, & \mu - e < d^* \\ 0, & otherwise \end{cases} \Leftrightarrow e^* = \begin{cases} 1, & -1 \leq d^* - \mu \leq 0 \\ 0, & otherwise \end{cases} \Leftrightarrow$$

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

Optimal strategy for an active Central Bank

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

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

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

$$V*(1-d)*(1-n(d)) \geq \gamma[Q - D*(1-d)(1-n(d))] \Leftrightarrow$$

$$\Leftrightarrow V*(1-NPL(d)) \geq \gamma[Q - D*(1-NPL(d))] \Leftrightarrow$$

$$\Leftrightarrow V + \gamma D - \gamma Q \geq V*NPL(d) + \gamma D*NPL(d) \Leftrightarrow$$

$$\Leftrightarrow NPL(d) \leq \frac{V+\gamma D-\gamma Q}{V+\gamma D}$$

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

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

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

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

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

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

$$P(x \leq x^{**} \mid d) = \Phi(\sqrt{\beta}(x^{**} - d)), \tag{23}$$

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

We can derive now the cumulative mass of good firms who have seen a signal above the threshold signal x^{**}. One of the main assumptions I made was that a good firm which is indifferent between attacking and not will choose not to attack. Thus:

$$P(x > x^{**} \mid d) = z(d) = (1-d)n(d) \tag{24}$$

By plugging the distribution of signals x_i across firms conditional on the realization of fundamentals d^{**} and the ratio of good firms which choose not to repay (in 23 and 1, respectively), one obtains the main equilibrium condition:

$$\Phi(\sqrt{\beta}(x^{**} - d^{**})) = \frac{Q}{D} + d^{**} \tag{25}$$

Following from (1), the bank default will be triggered for

$$[1 - d^{**} - (1 - d^{**})n(d^{**})] * D = Q,$$

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

Given the fundamentals distribution (d is $N(\mu - e, \frac{1}{\alpha})$) and the distribution for the ratio of good firms who have seen a signal higher than x^{**} (from (23) we can infer that $(1-d)n(d)$ is $N(1-d, \frac{1}{\beta})$), the distribution of $NPL(d)$ can be computed as a normal one with mean $(\mu - e + 1 - d)$ and variance $(\frac{1}{\alpha} + \frac{1}{\beta} + \frac{2\rho}{\alpha\beta})$, where ρ is the correlation coefficient between random variables d and $(1-d)n(d)$.

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

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

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

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

$$P(NPL(d) \leq NPL^* \mid x) = \Phi(\sqrt{\frac{\beta(\alpha + C)}{C}}(NPL^* - \frac{\alpha(1 - d + \mu - e) + xC}{\alpha + C})), \qquad (26)$$

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

Given NPL^* derived at the last stage of the game (in section 3.1.2.) and following the same rationament we have used in the previous case when we have studied an economy in which Central Bank was inactive, we may derive the new thresholds x^{**} and d^{**} following the next steps:

By replacing in (2) the probability of bank survival with the value we have found in (26), we may built the second main equilibrium condition:

$$\frac{C}{C + \alpha}x = NPL^* - \frac{\alpha(\mu - e + 1 - d)}{C + \alpha} - \sqrt{\frac{C}{\beta(C + \alpha)}}\Phi^{-1}(\frac{D - X}{V + F + D - X}) \qquad (27)$$

By solving the system of equations formed by (25) and (27), equilibrium thresholds d^{**} and x^{**}can be found. Solving (27) for x^{**}, we obtain the threshold signal at which a good firm is indifferent between repaying his loan or not:

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

Solving now (25) for d^{**} and using the value we have just derived above for equilibrium signal x^{**}, gives the threshold value for bank's fundamentals above which the bank fails:

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

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

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

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

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

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

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

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

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

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

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

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

Proof of Proposition 2: To be added

Fundamentals threshold for precise private signal. The case of an active Central Bank

Threshold equilibria for bank fundamentals is

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

By taking limit with respect to β, we may find that $d^{**}+\frac{Q}{D} = \Phi(+\infty*(-1)*(d^{**}-NPL^{*}))$. We have to analyze the value for this cumulative standard normal function. If $d^{**} > NPL^{*}$, then $d^{**} = -\frac{Q}{D} < 0$, which contradicts the definition for d which lies in $[0,1]$. If $d^{**} < NPL^{*}$, then $d^{**} = 1-\frac{Q}{D} > 0$. We have to check if $1-\frac{Q}{D} < \frac{V+\gamma D-\gamma Q}{V+\gamma D}$, the right side being the equilibrium value NPL^{*}.

$$1-\frac{Q}{D} < \frac{V+\gamma D-\gamma Q}{V+\gamma D} \Leftrightarrow 1-\frac{Q}{D} < 1-\frac{\gamma Q}{V+\gamma D} \Leftrightarrow$$

$$\Leftrightarrow \frac{Q}{D} > \frac{\gamma Q}{V+\gamma D} \Leftrightarrow \frac{1}{D} > \frac{\gamma}{V+\gamma D} \Leftrightarrow V+\gamma D > \gamma D \Leftrightarrow V > 0 \ (TRUE)$$

Proof. of Proposition 3: This proposition states two results. The first result states that the threshold d^{**} above which the bank fails even if the Central Bank is active is always larger than d^{*}, the threshold above which the bank fails if Central Bank is inactive. The second result states that both d^{*} and d^{**} are lower than NPL^{*}. Recall that when $\beta \to \infty$, $d^{*} = \frac{V+F}{V+F+D-X} - \frac{Q}{D}$ and $d^{**} = 1 - \frac{Q}{D}$, with both $d^{*}$and d^{**} in $[0,1]$. Because $D - X > 0$, we can imply that $1 > \frac{V+F}{V+F+D-X}$. Further we can say that $1 - \frac{Q}{D} > \frac{V+F}{V+F+D-X} - \frac{Q}{D}$. The proof for the second result was given previously while computing the value for d^{**} under the limiting case ($\beta \to \infty$). ■

Bank optimal effort derivation. The case of active Central Bank

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

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

$$\Phi(\sqrt{\frac{\alpha\beta}{\alpha+\beta+2\rho\sqrt{\alpha\beta}}}(NPL^* - (\mu - e + 1 - d^{**}))) * D * [H(x^{**}) - (\mu - e)] +$$

$$+\Phi(\sqrt{\frac{\alpha\beta}{\alpha+\beta+2\rho\sqrt{\alpha\beta}}}(NPL^* - (\mu - e + 1 - d^{**}))) * (F + D) * [1 - H(x^{**})]$$

$$+\Phi(\sqrt{\frac{\alpha\beta}{\alpha+\beta+2\rho\sqrt{\alpha\beta}}}(NPL^* - (\mu - e + 1 - d^{**}))) * (-Q - c(e)) +$$

$$+(1 - \Phi(\sqrt{\frac{\alpha\beta}{\alpha+\beta+2\rho\sqrt{\alpha\beta}}}(NPL^* - (\mu - e + 1 - d^{**}))) * (-c(e))$$

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

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

$$\underset{e}{max}\ \{-D * (\mu - e) + D * H(x^{**}) + (F + D) - (F + D) * H(x^{**}) - Q - c(e)\}$$

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

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

$$\underset{e}{max}\ \{-c(e)\}$$

with solution $e = 0$.

Combining the last two results,

$$e^{**} = \begin{cases} 1, & \mu - e + 1 - d^{**} < NPL^* \\ 0, & otherwise \end{cases} \Leftrightarrow$$

$$\Leftrightarrow e^{**} = \begin{cases} 1, & -1 \leq NPL^* + d^{**} - \mu - 1 \leq 0 \\ 0, & otherwise \end{cases} \Leftrightarrow$$

$$\Leftrightarrow e^{**} = \begin{cases} 1, & -1 \leq \frac{V+\gamma D-\gamma Q}{V+\gamma D} - \frac{Q}{D} - \mu \leq 0 \\ 0, & otherwise \end{cases} \Leftrightarrow$$

$$\Leftrightarrow e^{**} = \begin{cases} 1, & -1 \leq 1 - \frac{Q}{D} - \mu - \frac{\gamma Q}{V+\gamma D} \leq 0 \\ 0, & otherwise \end{cases}$$

Proof. of Proposition 5: This proposition states that when cost of intervention is low ($\gamma < \gamma^* = \frac{V(D-X)}{Q(V+F)+(D-X)(Q-D)}$), an active Central Bank will induce moral hazard in commercial bank behavior. When Central Bank is not active, the commercial bank will decide to exert optimal effort $e = 1$ when its unconditional fundamentals are stronger ($\mu_1 \leq \mu \leq \mu_2$) than when Central Bank is active. When the Central Bank is active the commercial bank exerts effort only when the unconditional bank fundamentals are above μ_2. The thresholds in unconditional bank fundamentals μ_1 and μ_2 are given by $\frac{V+F}{V+F+D-X} - \frac{Q}{D}$ and $1 - \frac{Q}{D} - \frac{\gamma Q}{V+\gamma D}$, respectively. Given the fact that commercial bank will exert effort when the Central Bank is inactive only for values of unconditional fundamentals higher than μ_1, while it will exerts effort when the Central Bank is active for values of unconditional fundamentals higher than μ_2, the proof reduces to show that $\frac{V+F}{V+F+D-X} - \frac{Q}{D} < 1 - \frac{Q}{D} - \frac{\gamma Q}{V+\gamma D}$ holds true for $\gamma < \gamma^*$.

$\frac{V+F}{V+F+D-X} - \frac{Q}{D} < 1 - \frac{Q}{D} - \frac{\gamma Q}{V+\gamma D} \Leftrightarrow \gamma Q(V + F + D - X) < (V + \gamma D)(V + F + D - X) - (V + F)(V + \gamma D) \Leftrightarrow$

$\Leftrightarrow \gamma < \frac{V(D-X)}{Q(V+F)+(D-X)(Q-D)}$.

Given the fact that γ is a positive constant, $Q(V + F)$ should be higher that $(D - X)(Q - D)$.But by assumption we know that $V > D$. So we can write $Q(V + F) > Q(D + F)$. In order to finish our proof we have to show that

$Q(D + F) > (D - X)(Q - D) \Leftrightarrow QF > -D^2 - X * (Q - D) \Leftrightarrow Q(F + X) > D(X - D)$,

which is true because right side is negative. ■

Proof. of Proposition 6: This proposition states that when cost of intervention is low enough ($\gamma < \gamma^*$), an active Central Bank will induce the commercial bank to exert maximum of effort even if its unconditional fundamentals are very poor ($\mu_3 < \mu \leq \mu_4$). The thresholds in unconditional bank fundamentals μ_3 and μ_4 are given by $1+\frac{V+F}{V+F+D-X}-\frac{Q}{D}$ and $2-\frac{Q}{D}-\frac{\gamma Q}{V+\gamma D}$, respectively. Given the fact that commercial bank will exert effort when the Central Bank is inactive only for values of unconditional fundamentals lower than μ_3, while it will exerts effort when the Central Bank is active for values of unconditional fundamentals lower than μ_4, the proof reduces to show that $1+\frac{V+F}{V+F+D-X}-\frac{Q}{D}<2-\frac{Q}{D}-\frac{\gamma Q}{V+\gamma D}$ holds true for $\gamma<\gamma^*$.

$1+\frac{V+F}{V+F+D-X}-\frac{Q}{D}<2-\frac{Q}{D}-\frac{\gamma Q}{V+\gamma D} \Leftrightarrow 1-\frac{D-X}{V+F+D-X}<1-\frac{\gamma Q}{V+\gamma D} \Leftrightarrow$

$\frac{\gamma Q}{V+\gamma D}<\frac{D-X}{V+F+D-X} \Leftrightarrow \gamma<\frac{V(D-X)}{Q(V+F)+(D-X)(Q-D)}$. ■

Proof. of Proposition 7: This proposition states that a high enough cost of intervention ($\gamma>\gamma^*$) mitigates the moral hazard problem introduced by an active Central Bank when commercial bank unconditional fundamentals are strong enough ($\mu_2\leq\mu\leq\mu_1$). The proof follows the lines of the proof given for Proposition 5. The only difference consists in the fact that we have to show that $\frac{V+F}{V+F+D-X}-\frac{Q}{D}>1-\frac{Q}{D}-\frac{\gamma Q}{V+\gamma D}$ holds true for $\gamma>\gamma^*$. ■

Derivation for changes in unconditional bank fundamentals

Differentiating with respect to μ (4) and (14), respectively, when effort e is given, yields:

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

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

which is less than 0 given (5), and

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

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

which is less than 0 given (15).

When Central Bank is not active $(1-d^*)n(d)=P(x>x^*\mid d^*)=1-\Phi(\sqrt{\beta}(x^*-d^*))$, where x* and d* are equilibrium values described in (3) and (4). Thus, we can imply that, when effort e is constant,

$$(1-d^*)n(d) = 1-\Phi(\sqrt{\beta}(\frac{\alpha}{\beta}d^* - \frac{\alpha}{\beta}(\mu - e) - \frac{\sqrt{\alpha+\beta}}{\beta}\Phi^{-1}(\frac{D-X}{V+F+D-X}))) \underset{\text{by differentiating wrt to } \mu}{\Rightarrow}$$

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

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

The case when the Central Bank is active is analogous:

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

where x** and d** are equilibrium values described in (13) and (14). Thus, we can imply that

$$(1-d^{**})n(d) =$$
$$1-\Phi(\sqrt{\beta}(NPL^*\frac{\alpha+C}{C} - \frac{\alpha(1-d^{**}+\mu-e)}{C} - \sqrt{\frac{\alpha+C}{C\beta}}\Phi^{-1}(\frac{D-X}{V+F+D-X}) - d^{**})) \underset{\text{by differentiating wrt to } \mu}{\Rightarrow}$$

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

$$= \phi(.) * \frac{\sqrt{\beta}}{C} * (\alpha + \frac{\partial d^{**}}{\partial\mu} * (\beta + 2\rho\sqrt{\alpha\beta}))$$

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

Derivation for changes in intervention cost

Differentiating with respect to γ (14), when effort e is given, yields:

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

$$\frac{\partial d^{**}}{\partial\gamma} = \phi(.) * \sqrt{\beta}\frac{\alpha-C}{C}(\frac{\partial d^{**}}{\partial\gamma} - \frac{\alpha+C}{\alpha-C}\frac{QV}{(V+\gamma D)^2}) \Rightarrow$$

$$\frac{\partial d^{**}}{\partial\gamma} = \frac{\sqrt{\beta}\frac{C-\alpha}{C}\phi(.)\frac{\alpha+C}{\alpha-C}\frac{QV}{(V+\gamma D)^2}}{1-\sqrt{\beta}\frac{\alpha-C}{C}\phi(.)},$$

which is less than 0 given (15). Then, we can imply that:

$$(1-d^{**})n(d) =$$
$$1-\Phi(\sqrt{\beta}(NPL^{*}\tfrac{\alpha+C}{C}-\tfrac{\alpha(1-d^{**}+\mu-e)}{C}-\sqrt{\tfrac{\alpha+C}{C\beta}}\Phi^{-1}(\tfrac{D-X}{V+F+D-X})-d^{**})) \underset{\text{by differentiating wrt to } \gamma}{\Rightarrow}$$

$$\tfrac{\partial(1-d^{**})n(d)}{\partial\gamma} = -\phi(.)\tfrac{\sqrt{\beta}}{C} * [\underbrace{(\alpha+C)\frac{-QV}{(V+\gamma D)^2}}_{\text{negative}} + \underbrace{\frac{\partial d^{**}}{\partial\gamma}}_{\text{negative}} * \underbrace{(-\beta-2\rho\sqrt{\alpha\beta})}_{\text{positive}}] > 0$$

Derivation for changes in fundamentals

When Central Bank is not active $(1-d)n(d) = P(x > x^{*} \mid d) = 1-\Phi(\sqrt{\beta}(x^{*}-d))$, where x^{*} is equilibrium value described in (3). Thus, we can imply that

$$(1-d)n(d) = 1-\Phi(\sqrt{\beta}(\tfrac{\alpha}{\beta}d-\tfrac{\alpha}{\beta}(\mu-e)-\tfrac{\sqrt{\alpha+\beta}}{\beta}\Phi^{-1}(\tfrac{D-X}{V+F+D-X}))) \underset{\text{by differentiating wrt to } d}{\Rightarrow}$$

$$\tfrac{\partial(1-d)n(d)}{\partial d} = -\phi(\sqrt{\beta}(\tfrac{\alpha}{\beta}d-\tfrac{\alpha}{\beta}(\mu-e)-\tfrac{\sqrt{\alpha+\beta}}{\beta}\Phi^{-1}(\tfrac{D}{V+F+D}))) * \tfrac{\alpha}{\sqrt{\beta}}$$

which is negative.

The case when the Central Bank is active is analogous:

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

where x^{**} is equilibrium value described in (13). Thus, we can imply that

$$(1-d)n(d) =$$
$$1-\Phi(\sqrt{\beta}(NPL^{*}\tfrac{\alpha+C}{C}-\tfrac{\alpha(1-d+\mu-e)}{C}-\sqrt{\tfrac{\alpha+C}{C\beta}}\Phi^{-1}(\tfrac{D-X}{V+F+D-X})-d)) \underset{\text{by differentiating wrt to } d}{\Rightarrow}$$

$$\tfrac{\partial(1-d)n(d)}{\partial d} = -\phi(\sqrt{\beta}(NPL^{*}\tfrac{\alpha+C}{C}-\tfrac{\alpha(1-d+\mu-e)}{C}-\sqrt{\tfrac{\alpha+C}{C\beta}}\Phi^{-1}(\tfrac{D-X}{V+F+D-X})-d)) * \tfrac{-\beta-2\rho\sqrt{\alpha\beta}}{C}$$

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

Figure 3a. Chance of collective strategic default when CB is inactive

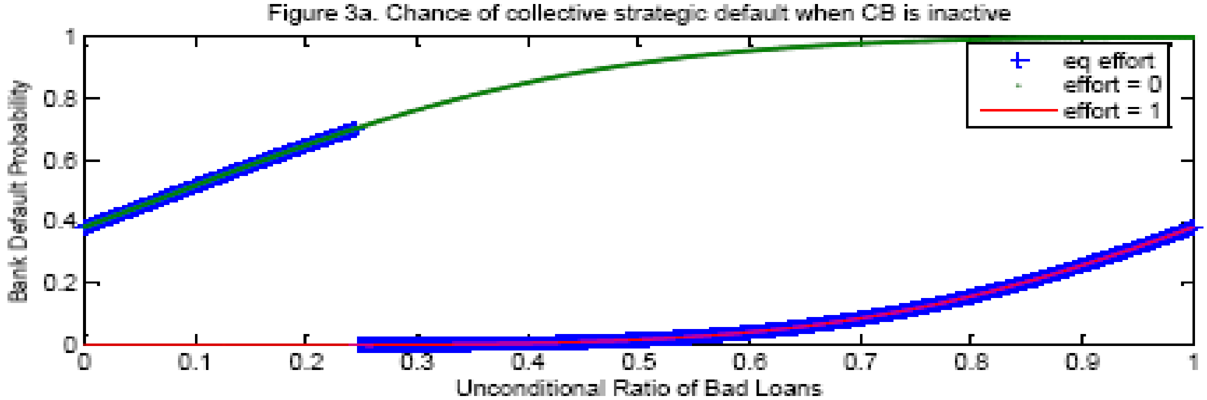


Figure 3b. Threshold for Collective Strategic Default when CB is Inactive

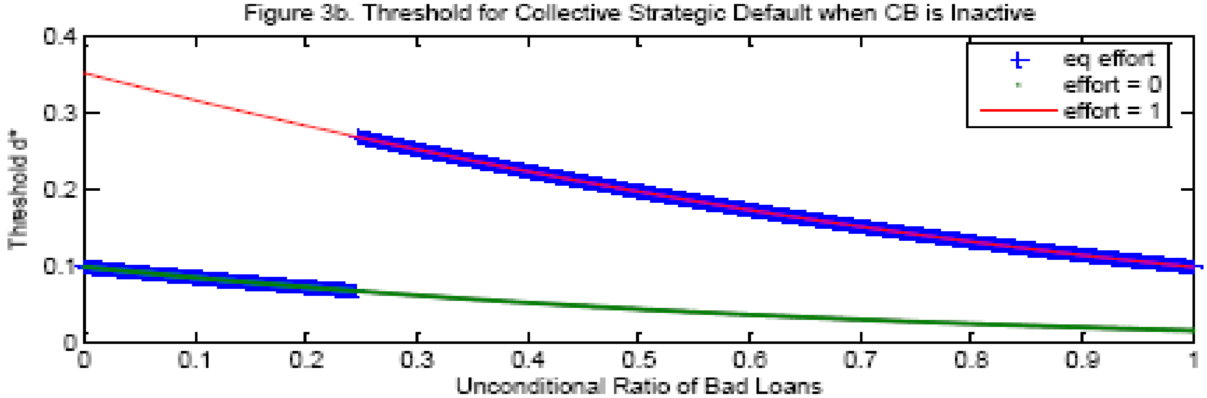


Figure 4a. Chance of collective strategic default when CB is Active.
Cost of intervention is low. NPL* = 0.8

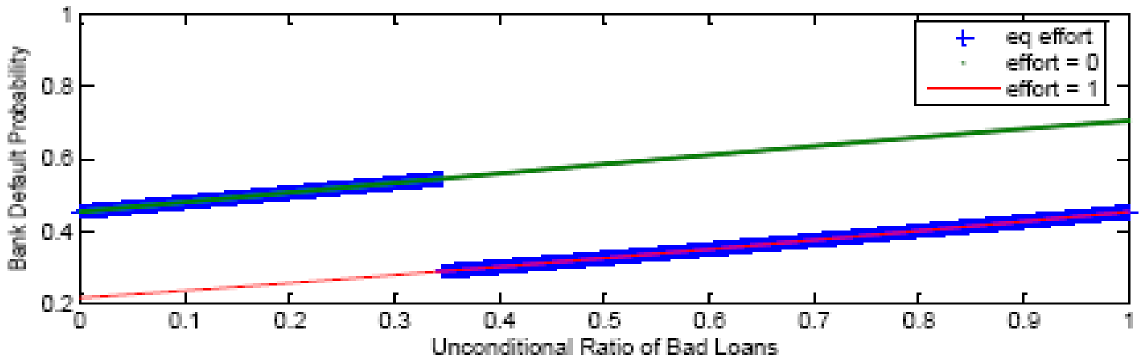


Figure 4b. Threshold for Collective Strategic Default when CB is Active.
Cost of intervention is low. NPL* = 0.8

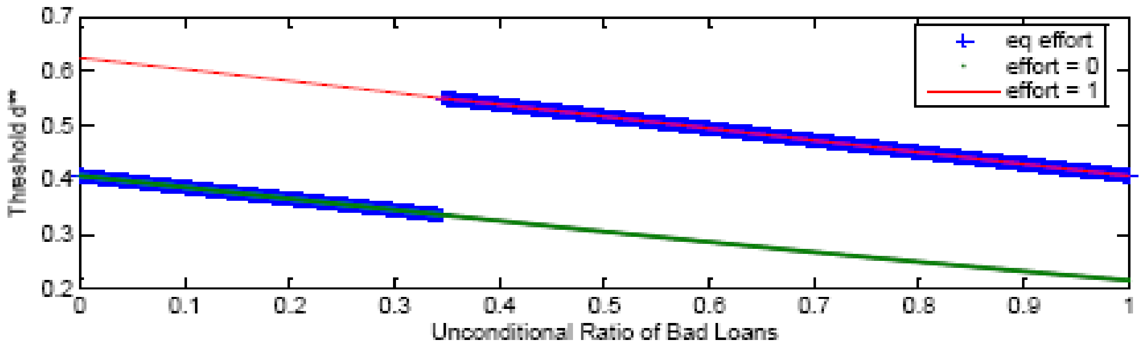


Figure 5a. Chance of collective strategic default when CB is Active.
Cost of intervention is high. NPL* = 0.2

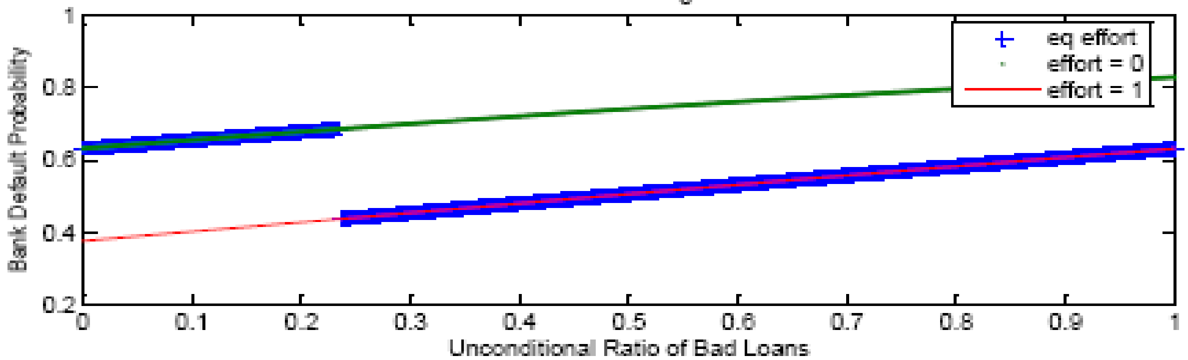


Figure 5b. Threshold for Collective Strategic Default when CB is Active.
Cost of intervention is high. NPL* = 0.2

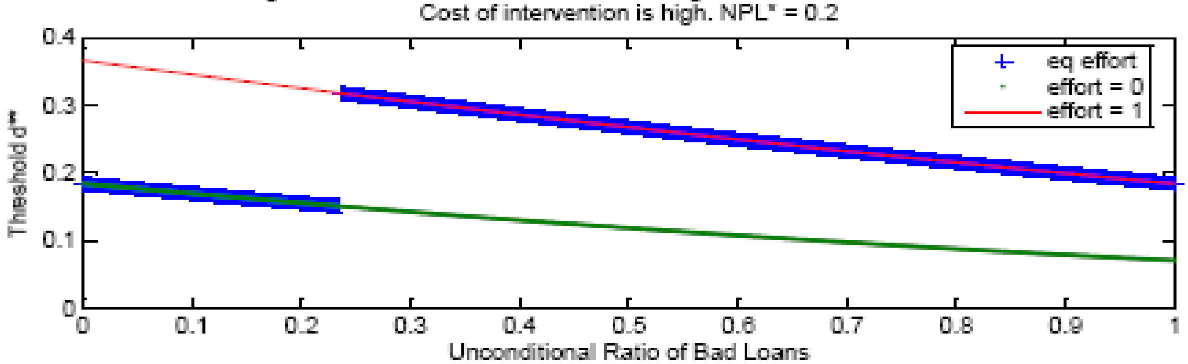


Figure 6a. Required Ratio for Succesfull Collective Strategic Default when CB is Inactive
The Ratio is out of Total No of Firms

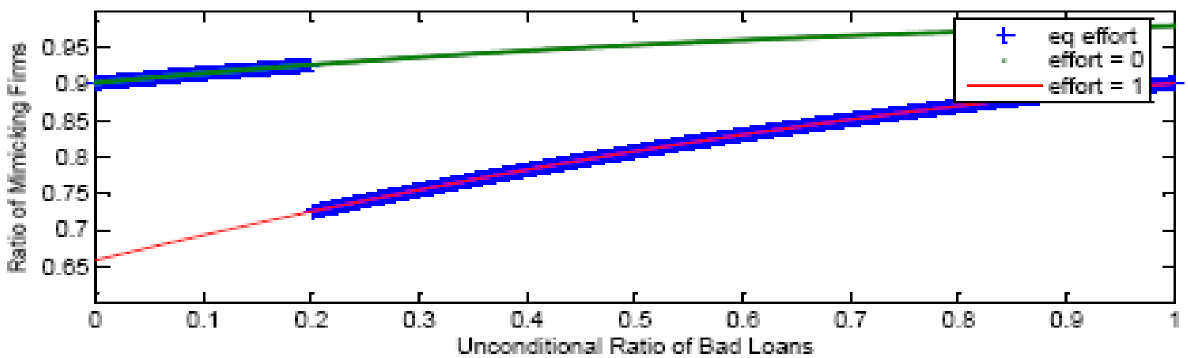
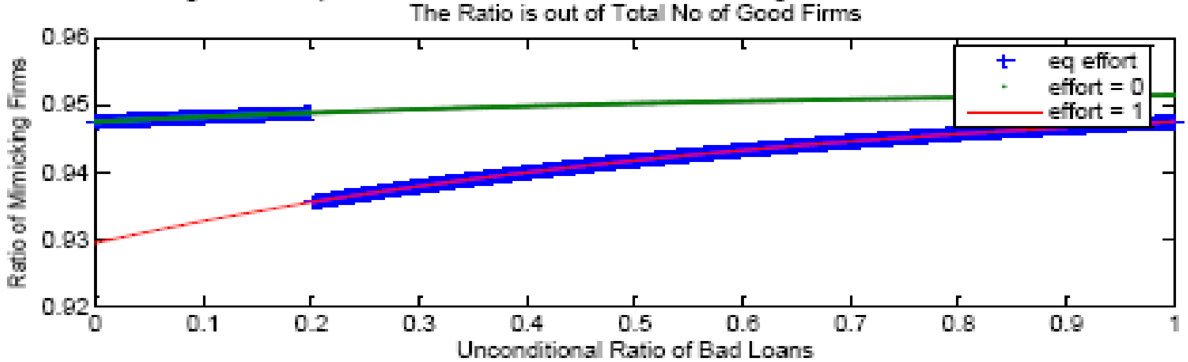


Figure 6b. Required Ratio for Succesfull Collective Strategic Default when CB is Inactive
The Ratio is out of Total No of Good Firms



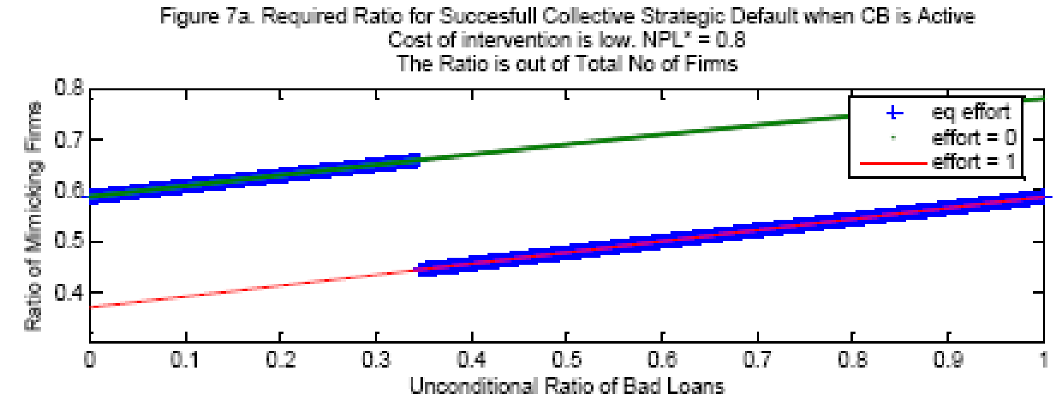


Figure 7a. Required Ratio for Succesfull Collective Strategic Default when CB is Active
Cost of intervention is low. NPL* = 0.8
The Ratio is out of Total No of Firms
Ratio of Mimicking Firms
Unconditional Ratio of Bad Loans
eq effort
effort = 0
effort = 1
0.8
0.7
0.6
0.5
0.4
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

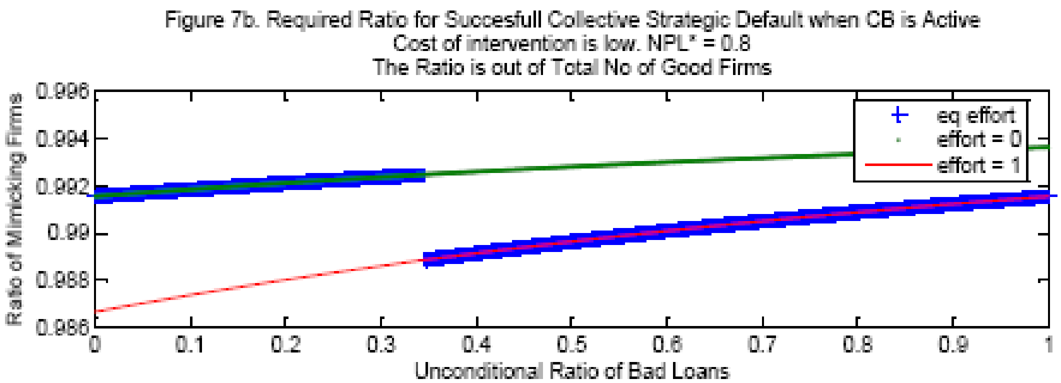


Figure 7b. Required Ratio for Succesfull Collective Strategic Default when CB is Active
Cost of intervention is low. NPL* = 0.8
The Ratio is out of Total No of Good Firms
Ratio of Mimicking Firms
Unconditional Ratio of Bad Loans
eq effort
effort = 0
effort = 1
0.996
0.994
0.992
0.99
0.988
0.986
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

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

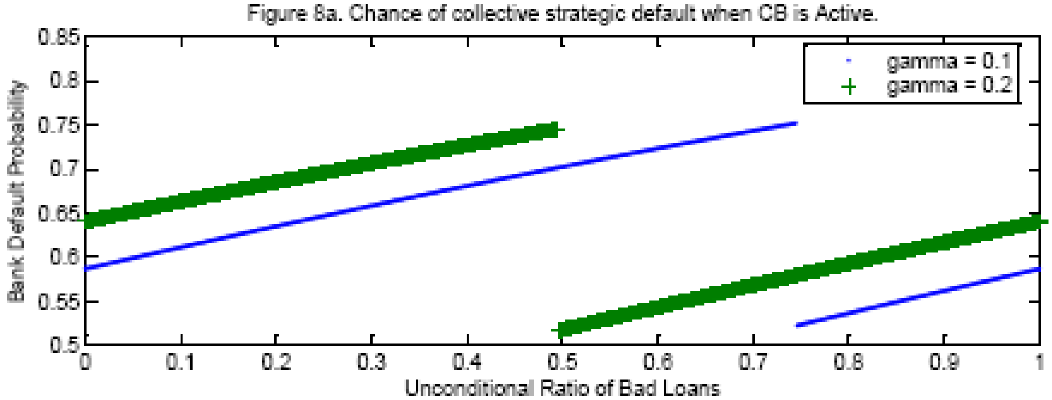


Figure 8b. Threshold for Collective Strategic Default when CB is Active