Centralization versus Decentralization of the Lender of Last Resort

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Abstract

This paper develops a game theory model to analyze the optimal structure of the Lender of Last Resort in Europe. When depositors are imperfectly informed, the indifference to international transmission displayed by national authorities has value. A centralized authority is at a signalling disadvantage because it internalizes externalities: pooling equilibria arise in which depositors cannot disentangle its motivation to act. The optimum is achieved by delegation: the central authority decides when to retain control and when to delegate to the national authorities. However, when investment in bank supervision is endogenized, decentralization can dominate both centralization and delegation.

Keywords: Lender of Last Resort, Supervision, Bailout, Delegation, Contagion, Centralization

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1 Introduction

The current financial crisis has witnessed bank bailouts at an unprecedented scale. As a consequence, the design of the institutions that govern bailouts has moved to the forefront of the political debate. In Europe the proper degree of centralized intervention has been the focus of the discussion. Though the European Central Bank is involved in crisis management through aggregate liquidity interventions, bailout decisions are still at taken the national level. Even before the crisis many authors questioned the wisdom of assigning the responsibility for financial stability to national authorities, as determined by the Maastricht Treaty.[1] Goodhart (2000) synthesizes the core of their argument as follows:

> " [...] the likelihood of increasing externalities (overspills), as financial interpenetration within the EU gathers pace, suggests greater centralization."

Proponents of continuing the decentralized institutional arrangement point to the informational advantages of local regulators (Schoenmaker, 2000) and to the political (burden-sharing) difficulties inherent in centralizing intervention (Goodhart, 2000).

This paper instead sheds a new light on this trade-off from the perspective of asymmetric information and uncertainty. It shows that the key advantage of centralization - the internalization of externalities - can turn into a disadvantage in some states of the world. Because national authorities have more limited objective functions, they have a signalling advantage. Their indifference to transmission effects can be an asset when the public is uncertain. The modelled mechanism works as follows. Depositors are uncertain about bank health, and their withdrawal decisions depend on their perceptions of bank fundamentals. Those perceptions are formed on the basis of two elements. Firstly, depositors receive an imprecise signal on the state of banks, through for instance reports in the financial press. Secondly, they learn about this state from the actions of regulators. Regulators, through their bank supervision, possess superior information. It is this informational advantage that implies that their actions have

[1] See Aglietta (2000), Prati and Schinasi (2000), Lastra (2000), Bini Smaghi (2000), Vives (2001), Steiger (2004), Kahn and Santos (2004) and Boot (2006).

signalling effects to depositors.

Consider that there is one bank per country and that the failure of a bank has international spillover effects. These spillovers are not taken into account by a national authority. Rather, such an authority follows a Bagehotian doctrine: it only saves a local bank that is illiquid, but solvent (Bagehot, 1873). A central authority would save such a bank too. But because it internalizes contagion effects, it also bails out an insolvent bank whose failure is too costly from an international perspective. This brings the game between a central authority and imperfectly informed depositors to a pooling equilibrium. Depositors cannot disentangle its motivation to act. Instead, a national authority's response leads to a separating equilibrium, in which depositors update beliefs. When depositors' view is more negative than reality, national authorities have an advantage at preventing the spread of a scare. This intuition is shown to hold both when banks are subject to a common shock and when they are subject to idiosyncratic shocks. The highest welfare is achieved by a mixed institutional form: delegation. The central authority delegates control to national authorities when their signalling benefit outweighs its internalization benefit.

This is only true when the regulator possesses perfect information, however. When instead regulators must invest in bank supervision in order to acquire information, results emerge that run counter to intuition. In particular, decentralization can dominate both delegation and centralization. The value of acquiring information depends on the equilibrium of the game between authorities and the public. In spite of externalities national authorities endogenously supervise more intensely than a central authority. Thus, even though a delegating central authority can make use of both its internalization benefit and the signalling advantage of national authorities, it can be inferior to pure decentralization. The reason is that the optimality of the delegation decision itself depends on the precision of acquired information. This contrasts the standard view in the debate on pan-European bank supervision that externalities necessarily plead for greater centralization.

The modelling takes the form of a sequential game in which subgame-perfect equilibria are derived through backward induction. However, for some parameter values non-equilibria arise. These non-equilibria are the result of an insoluble cycle between depositor beliefs and authorities' optimal response. No mutually consistent set of beliefs and actions exists in these cases. In deriving our results, we focus on parameter values for which non-equilibria are excluded.

Although the paper is written in terms of "traditional" depositor-instigated runs, nothing would formally change if depositors would be replaced by interbank partners. Several authors have argued that currently the gravest liquidity threat to a bank is a lack of creditworthiness on the interbank market (i.e. Freixas (2003)). This indeed seems to have been the case for many banks in the current financial crisis. As long as the informational advantage of regulators remains in tact, however, modelling and results are not affected by the choice between depositors and interbank participants as players in the game.

Depositor runs in the game are purely fundamentals based: runs occur because of negative signals about bank health, not because of fear that other depositors are also running. The microfoundations consider a representative depositor for each bank, in fact. Focussing on the interaction between intervention and depositor perceptions, we thus choose to abstract from self-fulfilling aspects of depositor behavior. There is a sizeable literature on the relationship between bank fundamentals and runs. Many empirical studies conclude that bank runs are triggered by bad news about fundamentals.[2] And several authors formally model this relationship (Chari and Jagannathan (1988), Allen and Gale (1998), Gorton and Huang (2002b), Goldstein and Pauzner (2005) and Chen and Hasan (2008)).[3]

Several studies have considered aspects of centralizing the Lender of Last Resort (LOLR) or bank supervision. Kahn and Santos (2004) analyze the optimal sequence of centralization. They show that centralizing supervision first is optimal, as LOLR centralization reduces a decentralized supervisor's incentive to monitor. In Dell'Arriccia and Marquez (2006) national

[2] See the references in Chen and Hasan (2008, p.1), Gorton and Huang (2002a, pp. 5-6) and Hasan and Dwyer (1994).

[3] See Corsetti et al. (2006) and Rochet and Vives (2004) for models in which runs occur in response to a mixture of bad fundamentals and self fulfilling prophecies. See also Corsetti et al. (2004) for a model in which signalling effects between agents in conjunction with fundamentals determine whether or not a run is triggered.

regulators are heterogeneous in the weights they put on banks' profits in their objective functions. Endogenous centralization only happens when regulators' preferences are sufficiently similar. Calzolari (2004) models the lobbying of nonbenevolent regulators. Lack of coordination among separate regulators makes lobbying actions less effective than in a centralized regime. Holthausen and Rønde (2004) use a cheap-talk game to analyze cooperation between national authorities. Divergent interests among regulators lead the host-country supervisor of a multinational bank to withhold information from the home-country supervisor. Coordination cannot replicate centralization, therefore. These papers differ from ours in that they focus on politically-biased authorities and do not explicitly model depositor beliefs.

Repullo (2000) considers a different institutional trade-off: should a central bank or a deposit insurer be appointed as LOLR. The deposit insurer faces a fixed cost in replacing insured deposits, while the central bank's cost of intervention increases in the size of the loan. Repullo shows that for small liquidity needs the central bank is the optimal LOLR and for larger needs the deposit insurer.[4] Our paper abstracts from the issue which of these institutions acts as LOLR (it could also be a national government, in fact). It also abstracts from the implications of LOLR safety nets for banks' risk profiles (Goodhart and Huang (2005) and Cordella and Yeyati (2003)). Finally, it does not consider the possibility of an efficient interbank market taking over the role of a LOLR, as proposed by Goodfriend and King (1988), Kaufman (1991) and Schwarz (1992). Several authors present formal counterarguments to this view by modelling interbank inefficiences that LOLRs can improve upon (Freixas et al. (2000, 2004), Rochet and Vives (2004), Rochet and Tirole (1996) and Flannery (1996)).

The next section presents the basic game and its results. Section 3 introduces endogenous bank supervision. Section 4 then analyzes several alternative specifications. It derives results for bank-specific states (as opposed to the common state analyzed in the basic game). Furthermore, the section shows that results hold if public uncertainty is about the extent of contagion rather than about a separate state. It also investigates the effects of verbal com-

[4]Kahn and Santos (2005) build on Repullo's framework to analyze whether deposit insurance and lending of last resort are best carried out separately or by a single institution.

munication by authorities to the public and of politically-motivated national authorities. The final section summarizes the main results and discusses their applicability to the policy debate on the International Lender of Last Resort. Proofs and microfoundations can be found in the Appendices.

2 The Basic Game

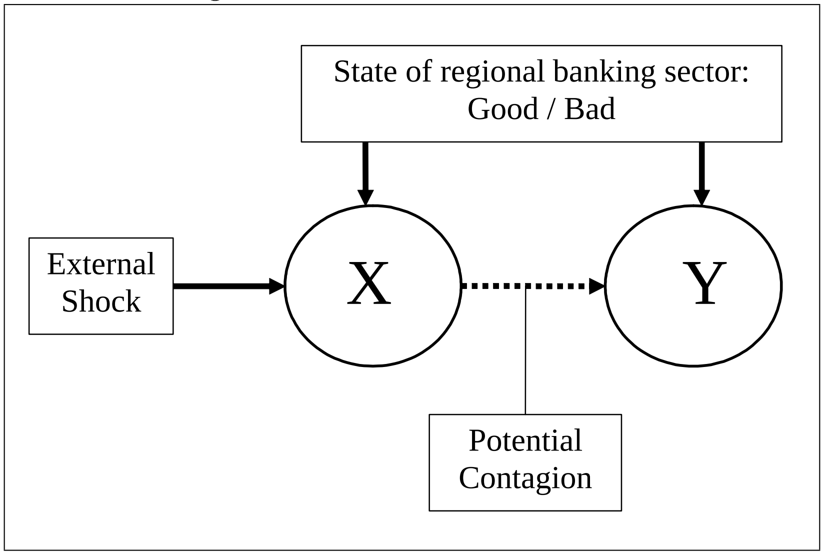
In this section we present our basic game. There are two countries X and Y. Those countries are assumed to be within one "region". One could think of them as two countries within the euro area. We will consider two institutional setups. Under decentralization each country has its own national authority: NA_X for country X and NA_Y for country Y. The NA could be either a central bank or a national government. Under centralization there is a single LOLR for the entire region, which we call the CA (Central Authority).

A Banks

In each country there is one bank. We refer to these as Bank_X and Bank_Y. The banks do not themselves take any decisions in the game. Rather, depending on the state of the banking sector (to be defined below), and on the actions of depositors and of LOLRs, banks simply either fail or do not fail. Initially, the banks' financial position is as follows. Firstly, the entire regional banking sector is subject to a state, which can be either Good or Bad. Secondly, Bank_X has been hit by an external shock, which may be transmitted to Bank_Y. This is depicted in Figure 1, and is explained below.

The state of all banks in the region is assumed to be the same. That is, Bank_X and Bank_Y are either both in the Good state or in the Bad state. This is the simplest setting in which to derive our main results, because it clearly distinguishes between the two elements that we require for our results: an uncertain state and transmission effects. However, the two can also be blended together: section 4C shows that all results go through when the uncertainty is about the depth of contagion between banks, rather than the state that they are in. Moreover, results are robust to having bank-specific states rather than a common state.[5]

Figure 1: The banks' environment



In addition to the common state, Bank_X has been hit by a shock. We call this shock a foreign contagion effect. For example, Bank_X could have had links to a US bank that failed (such as interbank loans, or asset holdings).[6] This shock is publicly known and is not a random variable. The potential for the transmission of the shock (further contagion) comes into the model through Bank_Y's links to Bank_X. We can conceive of Bank_Y as having an interbank loan to Bank_X. If Bank_X fails, Bank_Y suffers losses.

The relationship between the market value of a bank, the state, and contagion effects is as follows:

$$V_+^G > V_-^G > V_+^B > 0 > V_-^B \tag{1}$$

Here V represents the market value of assets minus liabilities, superscripts refer to the state of the banking sector (G is Good, B is Bad), and subscripts denote whether a bank has been hit by a contagion effect or not ($-$ meaning that it has been hit, and $+$ that it has not). Hence, V_+^G is the value of a bank when the state is Good and it has not been subject to contagion.

Given that Bank_X is always victim to the external contagion effect, its value can be only V_-^G or V_-^B, depending on the state of the banking sector. Bank_Y, instead, can have any of

[5] See the discussion in Section 4C.

[6] For models with contagion through interbank loans see Allen and Gale (2000) and Dasgupta (2004).

the four values above, depending on both the state, and whether it is subject to contagion emanating from Bank_X's failure. The above relationship implies that a bank is only insolvent when it is both in the bad state and hit by contagion. In all other cases, its market value is still positive. The issue of solvency will be of importance when we consider LOLRs' cost functions.

B Depositors

The timing of the game between depositors and LOLRs is as follows:

Table 1: Timing of the Game

1. State of regional banking sector drawn: Good / Bad
2. Depositors receive signal on state: Correct / Incorrect
3. Depositor_X decides: Run / No run
4. NA_X or CA acts in X: Intervention / No intervention
5. Depositor_Y decides: Run / No run
6. NA_Y or CA acts in Y: Intervention / No intervention

The true state is thus determined in stage 1. We let p denote the probability that the state is Good.

Stage 2 concerns depositors' signal. Each bank has its own representative depositor: Depositor_X for Bank_X and Depositor_Y for Bank_Y. Each of these can be seen as representing a group of identical depositors of a bank. Depositor_X holds no deposits in Bank_Y, and vice versa.[7] The depositors are informationally identical. They receive the same, publicly observable signal about the state of the banking sector. This is stage 2 in the game.

Formally, we term the signal Φ and the true state of the banking sector S, where $S = G, B$ means that the state is Good/Bad. Likewise, $\Phi = G, B$ means that depositors receive a signal that, respectively, the state is Good and the state is Bad. The probability that depositors

[7] This keeps the decision of Depositor_X separate from the impact it has on Bank_Y and Depositor_Y. It is possible to prove that even if the two groups of depositors would be one, our results would be the same. Nonetheless, it is both conceptually and formally simpler to keep the banks' depositors distinct.

receive the correct signal is $\frac{1}{2} < q < 1$. The probability q thus represents the precision of the signal that depositors receive, with $q \to 1$ and $q \to \frac{1}{2}$ the limit cases of, respectively, perfectly informed depositors and completely uninformative signals.[8] Signals are the first source through which depositors receive information about the state of the regional banking sector. The second source, discussed below, is the actions taken by LOLRs and observed by depositors.

At his respective decision stage, a depositor can either withdraw his deposits, or do nothing. When a depositor withdraws his deposits we say that he "runs". In our basic game we do not explicitly model the motivation behind a run. We simply assume that whenever a depositor's view of the state of the banking sector is sufficiently negative (defined below), he instigates a run. In Appendix B we extend to an explicit modelling of depositors' motivation to run.

Depositors instigate a run on their bank whenever the following two conditions are met:

1. At stage 2 the signal is negative: $\Phi = B$.

2. LOLR actions have provided no new information suggesting that this signal is wrong.

Note that the second condition is only of relevance to Depositor_Y. Depositor_X takes his decision before any LOLR action has taken place. It is the interaction between the action of the LOLR in country X and the inference by Depositor_Y that underlies the signalling effects of the model.

When a run occurs, a bank fails unless it receives assistance from the LOLR. The social cost of bank failure is C_F. This can represent direct losses to depositors, or losses of bank-specific relationships, or wider country-specific ramifications of the bank's failure. It is the cost imposed on society by the bankruptcy.

In the basic game we focus on runs as the only cause of bank failure. Insolvent banks can continue to operate if the public does not know about their financial position, that is. This simplification is relaxed in uB and is shown not to affect the results.

[8] The structure of signalling is the same as in Chen and Hasan (2008).

C LOLRs

The LOLR possesses superior information about the state. It has a key informational advantage over depositors, and observes S. In the basic game the LOLR is thus assumed to have perfect information. Section 3 generalizes to endogenous information acquisition: the LOLR can only obtain superior information by investing in bank supervision. In addition to the state, the LOLR also observes Φ, the public signal to depositors. The rationale is that a public signal like media coverage is as easily observable to the LOLR as it is to depositors.

The decision that a LOLR takes is whether or not to intervene. Intervention is the provision of financial assistance to a bank in distress. This can be liquidity provision to a solvent bank. But if the bank is actually insolvent, the LOLR may also provide funds to bail it out. All we assume in this respect is that, firstly, intervention is always costly and, secondly, it is more costly if it is done to save an insolvent bank.[9]

LOLRs play their role in stages 4 and 6 of the game depicted in Table 1. In a decentralized setup, NA_X acts in stage 4 and NA_Y in stage 6. In a centralized setup, instead, it is the CA that acts in both stages.

Let C_I be the cost to the LOLR of any intervention, and C_S the additional cost of bailing out an insolvent bank. That is, assistance costs $C_I + C_S$ when a bank's value is V_-^B. The LOLR fully internalizes the social cost of bank failure, C_F. It aims to minimize costs. Hence, the trade-off that it faces is between the cost of intervention (C_I or $C_I + C_S$, depending on solvency) and the cost of non-intervention (C_F or 0, depending on whether failure occurs in the absence of support).

We specify three relations between the cost parameters. The first two are:

$$C_I < C_F \tag{2}$$

and

$$C_I + C_S > C_F \tag{3}$$

[9]This assumption is also found in Goodhart and Huang (2005) and in Kahn and Santos (2004).

These relations (2) and (3) are simply a reproduction of the Bagehotian doctrine that only illiquid, but solvent banks should qualify for LOLR intervention (Bagehot (1873)). Finally, however:

$$2C_I + C_S < 2C_F \tag{4}$$

Literally, relationship (4) says that it is better to save one insolvent bank ($C_I + C_S$) and one solvent bank (C_I) than to let both fail ($2C_F$). This relationship is necessary from both a technical and an intuitive respect. Technically, in the absence of relationship (4) a solution to the CA's optimization problem does not exist. This is proven below, in Lemma 2. When it does not hold, no mutually consistent set of depositor beliefs and LOLR actions exists. Any policy by the CA leads to inference by depositors that makes another strategy optimal for the CA, which leads to different inference by depositors, and so on (see the Proof of Lemma 2).

But one can also give an intuitive explanation of what this condition means. Essentially, relationship (4) implies that in the presence of contagion bailing out an insolvent bank can sometimes be optimal. This type of assumption is not new to the literature (Goodhart and Huang (2005), Freixas (2003, p.104), Prati and Schinasi (2000, p.92)). Suppose that both Depositor$_X$ and Depositor$_Y$ run. Saving both banks costs $2C_I + C_S$ ($C_I + C_S$ for Bank$_X$ and C_I for Bank$_Y$). Letting both banks fail costs $2C_F$. Saving Bank$_X$ is then best for regional welfare, but not for country X considered by itself, as $C_I + C_S < C_F$. Relationship (4) thus creates the potential for an internalization by the CA of transmission externalities not taken into account by a NA.

Finally, we assume that depositors can only observe *whether* a LOLR has intervened, but not *how costly* that intervention is. Though a fairly strong assumption, we also believe that it is quite plausible. The crucial point in this assumption is that the public cannot infer from seeing a LOLR act, whether the bank at stake is insolvent or only illiquid. In practice, the degree of distress of a bank is often impossible to determine for outsiders. Even when the size of the LOLR's assistance package is publicly known, without precise knowledge of the bank's exposures the general public can hardly make inferences about whether the intervention is for restoring liquidity or solvency. Overall, the informational setup can be summarized as follows:

Player	**Information**
Depositor$_X$	Signal Φ
Depositor$_Y$	Signal Φ; whether Bank$_X$ failed; whether LOLR in X intervened
LOLR in X	State S; signal Φ; run on Bank$_X$
LOLR in Y	State S; signal Φ; whether Bank$_X$ failed; run on Bank$_Y$

D Results

We first describe the outcomes for pure centralization and decentralization, and subsequently consider delegation.

Centralization and decentralization

It is easiest to present the results in a case-by-case manner. In particular, we can identify four cases relating to the state of the banking sector and the signal received by depositors:

Case I:	Bad State, Correct Signal ($S = B \wedge \Phi = B$)
Case II:	Bad State, Incorrect Signal ($S = B \wedge \Phi = G$)
Case III:	Good State, Correct Signal ($S = G \wedge \Phi = G$)
Case IV:	Good State, Incorrect Signal ($S = G \wedge \Phi = B$)

The interesting Cases are I and IV. In the following Lemma we prove that in Cases II and III the behavior of centralized and decentralized Lenders of Last Resort are the same (proof in the Appendix):

Lemma 1 *In Case II and Case III neither the NAs nor the CA ever intervene. Centralization and decentralization are thus equivalent in these Cases.*

Hence, there is no trade-off to be analyzed for these cases, and we choose to focus our attention on Cases I and IV. We will refer to these as the Crisis Case and the Scare Case, respectively, since in the former the state is truly bad, while in the latter depositors incorrectly believe it is. The following two Propositions establish the key results of our paper (proofs in the Appendix):

Proposition 1 *When $\Phi = B$ the CA provides assistance to both banks, regardless of the true state. That is, in both the Crisis Case and the Scare Case a centralized authority intervenes everywhere.*

Proposition 2 *NAs let both banks fail in the Crisis Case. In the Scare Case, instead, NA_X provides assistance to $Bank_X$, which through depositor updating also saves $Bank_Y$, without further action by NA_Y.*

Taking together Propositions 1 and 2, we can see that the Crisis Case represents the benefit of centralization and the Scare Case the benefit of decentralization. In the Crisis Case NAs let both banks fail. NA_X does not take into account the externality that the failure of Bank_X imposes on Bank_Y. From NA_X's perspective only the direct effect on country X counts, and saving Bank_X is not worthwhile. Because of the contagion, leading to the insolvency of Bank_Y, NA_Y subsequently lets Bank_Y fail too. The CA, instead, properly internalizes the international transmission, and maximizes regional welfare by saving both banks.

However, it is *because* the CA cares about contagion in the Crisis Case, that in the Scare Case decentralization is better. Depositors know that when they have received a negative signal and run, NA_X will only respond if the true state is Good. That is, NA_X only intervenes when depositors' beliefs are incorrect. In this case Bank_X is actually solvent but would fail in the absence of liquidity assistance. NA_X's action then provides depositors with credible information about the true state of the banking sector.

When instead the CA intervenes in stage 4, depositors obtain no new information. They know that, no matter what the true state, the CA always intervenes when they receive a negative signal. That is, depositors cannot disentangle whether the CA is responding because Bank_X is solvent and worth saving in its own right, or because the CA wants to prevent contagion. Thus, they have no basis on which to update their beliefs. If, as in the Scare Case, the true state is actually Good, the CA will have to provide assistance to two solvent banks. First to Bank_X and then, because depositors still follow their negative signal, also to Bank_Y.

The very fact that the CA cares about contagion when there really is a crisis, implies that it needs to intervene more when there is only a scare. NA_X, by being indifferent to transmission, imposes a positive externality on NA_Y in the Scare Case. Through its intervention, depositors know that the problem is local. No additional intervention by NA_Y is then required.

Looking at comparative statics, centralization becomes more attractive for a higher frequency of crises (lower p) and better informed depositors (lower q). The expected benefit of central decision making is:

$$E\left[W_{CA} - W_{NAs}\right] = (1-p)\,q\,(2C_F - (2C_I + C_S)) - p\,(1-q)\,C_I \tag{5}$$

where $W_{CA} - W_{NAs}$ means "regional welfare under centralization" minus "regional welfare under decentralization". Here $(1-p)\,q$ and $p\,(1-q)$ are the probabilities associated to the Crisis and Scare Cases, respectively. Hence, $\frac{\partial}{\partial p}E\left[W_{CA} - W_{NAs}\right] < 0$ and $\frac{\partial}{\partial q}E\left[W_{CA} - W_{NAs}\right] > 0$.

Finally, we prove the necessity of relationship (4) (proof in the Appendix):

Lemma 2 *The CA's problem can only be solved if relationship (4) holds.*

The first-best solution

The trade-off between centralization and decentralization can be resolved through delegation. This requires a structure in which both a centralized authority and national authorities are in place. The CA is first to decide. It can choose to retain control and decide on intervention by itself. Instead, it can also choose to delegate the decision on intervention to a national authority. Depositors can observe who it is that intervenes. The timing of the game becomes as follows:

Table 2: Timing including delegation

1. State of regional banking sector drawn: Good / Bad
2. Depositors receive signal on state: Correct / Incorrect
3. CA decides who to appoint as LOLR (itself or NAs)
4. Depositor$_X$ decides: Run / No run
5. Appointed authority acts in X: Intervention / No intervention
6. Depositor$_Y$ decides: Run / No run
7. Appointed authority acts in Y: Intervention / No intervention

The following Proposition shows that the optimum is achieved by state-dependent delegation: the CA delegates authority to the NAs in Case IV and retains authority otherwise (proof in the Appendix).

Proposition 3 *State-dependent delegation by the CA achieves the highest possible welfare. It dominates both pure centralization and pure decentralization.*

Delegation thus allows the benefits of internalizing externalities and of signalling to be simultaneously reaped. This is only true when bank supervision is exogenous, however, as shown in section 3.

3 Endogenous bank supervision

Till now it has been assumed that LOLRs possess perfect information about the state. This section relaxes that assumption: LOLRs are allowed to endogenously invest in bank supervision. It is this supervision that yields superior knowledge. Endogenous information acquisition turns out to have surprising implications.

Assume that, instead of knowing the state with certainty, a LOLR receives a signal on it, just as the public does. That signal is correct with probability $h(m)$. Here m is the amount invested in supervision by the LOLR. We assume that in the absence of investment in supervision ($m = 0$) LOLRs know as much as the public: $h(0) = q$. In particular, we choose the following functional form

$$h(m) = q + (1 - q)\sqrt{m} \tag{6}$$

and normalize $m \in [0, 1]$ so that $h(1) = 1$. Here, $\sqrt{m}$ implies a decreasing marginal benefit to investment in supervision. This ensures interiority of the solution to optimal investment.

Starting from the basic game as depicted in Table 1, a stage "zero" is added at which LOLRs decide how much to invest in supervision. The same can be done for the delegation game in Table 2. Given the outcomes of the subsequent stages (from Propositions 1-3), the results for this stage 0 can be derived by backward induction. Call m^* optimal investment. Then (proofs in the Appendix):

Proposition 4 *Investment in supervision is smallest under pure centralization. Depending on parameter values, investment can be largest under pure decentralization or under delegation.*

Corollary 1 *Welfare under decentralization can be higher than under delegation. Centralization is always dominated by delegation, moreover.*

Counterintuitively, therefore, decentralization can be better than both delegation and centralization. The dominance over delegation is especially surprising, since the delegation structure includes access to national authorities. The reason is somewhat subtle. It is the possibility of making mistakes - basing actions on incorrect information - that drives authorities' investment in supervision. The delegating CA is concerned with different types of mistakes than decentralized authorities, however. For instance, it worries that it might retain control when it should have delegated (depositors run when the state is actually Good, but the authority receives the same incorrect signal as depositors). A national authority, instead, wants to avoid accidentally bailing out an insolvent institution, or letting a healthy bank fail because of a false signal.

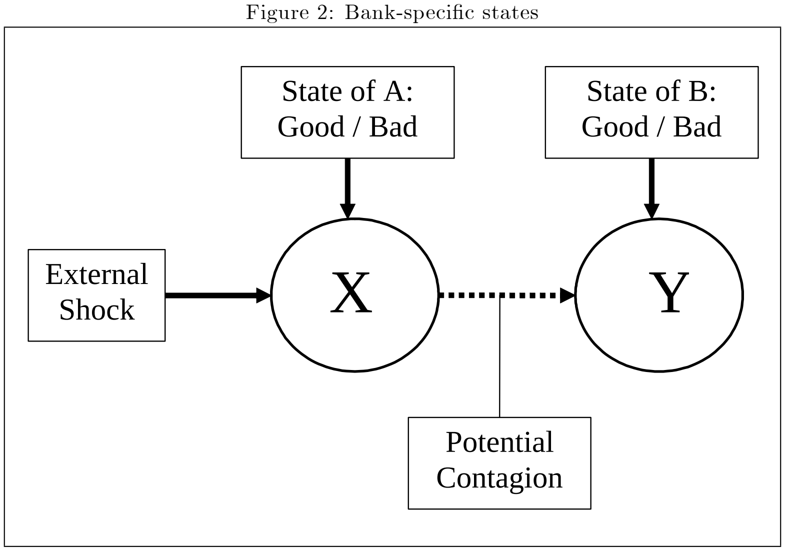
Overall, the delegating CA, because of the delegating structure, makes less costly mistakes. For example, when all authorities incorrectly believe that the state is Good, while depositors run, the CA will incorrectly delegate. But this mistake is at no cost to it, since national authorities will bail out (a mistake from their own perspective, but optimal for the CA). Since decentralization leads to costlier mistakes, investment to avoid those mistakes can be larger. Bank supervision can be more intense, that is. With endogenously more information at their disposal, decentralized authorities can achieve a higher social welfare than a delegating CA.

4 Alternative environments

A Bank-specific states (in progress)

The basic game considered a common state for banks, as depicted in Figure 1. Results do not depend on the commonality of the state, however. This section shows that the main intuitions hold when there are bank-speficic states. This alternative environment is depicted in Figure 2.

Figure 2: Bank-specific states



Instead of a single state S, there are now two states, S_X and S_Y, for, respectively, Bank_X and Bank_Y. Moreover, each depositor now receives a signal on the state of his own bank only. Depositor_X gets signal Φ_X and Depositor_Y receives Φ_Y. Note that since depositors care only about the health of their own bank it is innocuous to assume that the do not observe the other depositor's signal (as it does not affect their action).

B Bank failures without runs

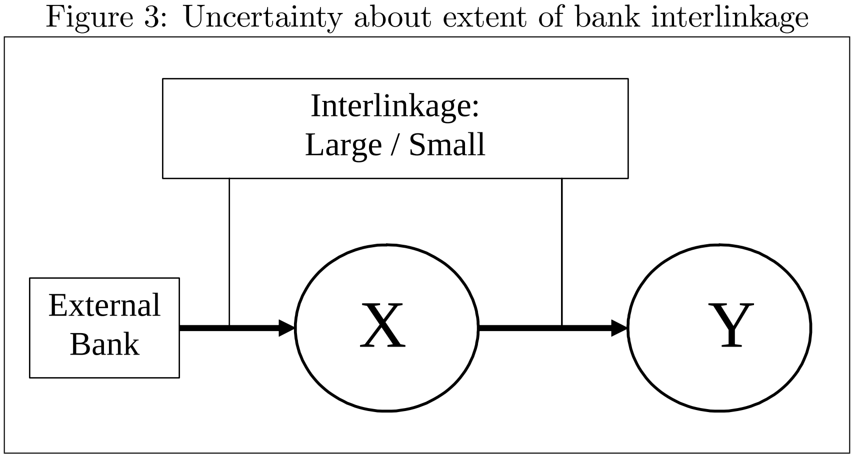
In our basic game banks only fail when a run on their deposits occurs. That is, even insolvent banks can continue to operate (indefinitely) in the absence of a run. This section shows, however, that this implicit assumption is not crucial. Assume that there is a post-game stage in which insolvent banks that have not previously received assistance (at stage 4 for Bank$_X$ and stage 6 for Bank$_Y$) are declared bankrupt. That is, any bank whose value is V_{-}^{B} and has not been bailed out, fails. This imposes the same social cost of bank failure, C_F, as before. We abstract from any time discounting. Hence, to a LOLR the failure of a bank in the post-game stage is as costly as failure during the game (stage 4 and 6). The following Corollary summarizes the effects of having insolvent banks that always fail (proof in the Appendix):

Corollary 2 *With post-game failure of insolvent banks Lemma 1 is only valid for NAs. For $\Phi = G$ and $S = B$ the CA now bails out both banks. Nonetheless, Propositions 1, 2 and 3 remain valid without alterations.*

C Uncertainty about interlinkage

The environment depicted in Figure 1 is not key for the results. Figure 3 depicts an alternative environment for which the main results go through:

Figure 3: Uncertainty about extent of bank interlinkage



In this setup there is uncertainty about the degree to which banks are linked. It is publicly known that there are transmission effects between banks, but not how large these are. In Figure 2 an external bank with linkages to Bank_X fails. Contagion effects occur. The same is true between Bank_X and Bank_Y. Some contagion always takes place. But if the extent of interlinkage between banks is large, contagion is more damaging. Assistance by LOLRs affects the damage done by contagion. When the interlinkage is large and Bank_X does not receive assistance, we have that Bank_Y is worth V_-^B. Whereas, if Bank_X does receive assistance in this case, Bank_Y is worth V_+^B. When, instead, the interlinkage between the banks is small the value of Bank_Y is V_+^G and V_-^G, respectively, when assistance is and is not provided to Bank_X. Bank_X is worth V_-^G when its linkage to the external bank is small and V_-^B when it is large.[10]

Compared to our initial setup, this is purely a terminological difference. The payoff structure is unaltered, as are the problems of depositors and LOLRs. Thus, it directly follows that the results are unchanged:

Corollary 3 *Propositions 1, 2 and 3 remain valid when uncertainty is about the extent of contagion rather than about the state.*

D Verbal communication

Our main results depend on LOLRs' ability to communicate through their actions. In reality authorities have more direct ways of communicating to the public, however, such as press statements. In this section we consider whether allowing for verbal communication affects our results. We adjust the basic game in the following way. At its respective decision stage(s), a LOLR is allowed to issue a statement, which is costless to it, and which concerns the true state. Thus, say, at stage 4 of the game, NA_X can choose to make a statement about S (i.e.: it can say $S = G$ or $S = B$). It can also choose not to issue a statement. The outcome is as follows (proof in the Appendix):

[10] An extension that is not considered here is to endogenize contagion: the extent of bank interlinkage can depend on the institutional framework. This type of endogeneity is considered by Fecht et al. (2008).

Proposition 5 *The results in Propositions 1, 2 and 3 are unaffected by the possibility of verbal communication.*

The reason for this result is quite simple. Under decentralization the true state is already revealed by NA_X's action and the possibility of verbal communications adds nothing. Under centralization, instead, verbal communication is not credible, because the CA always has the incentive to say that the state is Good. It suffers from a time-inconsistency problem in that ex-ante it would be better off publicly committing to a policy of thruthful revelation. But it has no commitment device, and when the Bad state occurs it would deviate from such a policy.

E Politically motivated NAs

It is often argued that national authorities overweigh the interests of their domestic financial institutions (Giovannini, 1993). This section analyzes the consequences of such behavior on our results. Biased NAs essentially associate a greater cost to the failure of a domestic bank. We introduce a factor C_P which represents the political cost to a NA of a local bank's failure. The total cost of the bank failure that the NA considers in its decision is then $C_F + C_P$. That is, the social cost of failure plus the political cost. The case of biased national regulators only becomes interesting when C_P is sufficiently large: $C_I + C_S < C_F + C_P$. NAs are willing to save insolvent domestic institutions. When this is the case, the following Proposition applies (proof in the Appendix):

Proposition 6 *When $C_I + C_S < C_F + C_P$ holds, centralization and decentralization are equivalent.*

National authorities' bias makes them to bail out too often. But the fact that they do not internalize the international externalities of domestic bank failure makes them underprovide bailouts. The two effects cancel each other out. Nonetheless, authorities' political bias imposes social costs. Considering the outcomes of section 3 decentralization can dominate other forms of LOLR. Political bias undoes this potential, as signalling advantages vanish.

F Multiple banks per country

The setup in our model is one of a single bank per country. This is why the national authorities follow a Bagehotian doctrine without considering contagion effects. But when there are several banks per country, internal contagion effects imply that national authorities too can optimally bailout an insolvent bank. The important principle remains, however, that as long as there are also international contagion effects associated with domestic bank failure, there will be underprovision of bailouts. Uninternalized externalities and their interaction with signalling effects are still present. But capturing the main intuitions would require a more complex framework, either with more states or with numerical values for investment in bailouts. The binary structure of the basic game is too limited to cope with multiple banks per country.

5 Conclusions

The theory that this paper has presented cautions against fully centralized crisis management. The very fact that a central authority internalizes cross-border externalities, implies that its actions are associated with more negative signalling. In an environment of public uncertainty, transmission indifference can have value. A mixed solution in which decisions can also be delegated to national authorities improves upon pure centralization. Nonetheless, when endogenous bank supervision is considered, decentralization can even improve upon this mixed solution.

These results are not only of relevance to institutional design in the euro area. There has recently been a lively debate on the desirability of an Asian Monetary Fund (AMF), which could act as an International Lender of Last Resort (ILOLR) within its region.[11] In this role, it would be a competitor to the IMF. If we translate our model such that banks are countries and depositors are foreign investors, we can use it to shed light on this issue. Countries "fail"

[11] See Rajan (2000), Sakakibara (2001), Narine (2003) and Lipscy (2003). And for press coverage of recent stepts taken towards the possible formation of an AMF: (http://www.feer.com/economics/2008/june/an-asian-monetary-fund-second-try); (http://english.ohmynews.com/articleview/article_view.asp?at_code=409447); (http://www.aseansec.org/afp/115.htm); (http://www.asiapacificbusiness.ca/apbn/pdfs/bulletin208.pdf).

when they find themselves unable to repay foreign denominated debt. Of the two countries in the model, one would fall under AMF authority and the other would not. Alternatively, the IMF would be the ILOLR to both. Our theory would then predict that the AMF would be best in place to respond to a currency crisis when a country's true fundamentals are good. An example would be South Korea during the Asian crisis. This would minimize negative signalling, and thereby the risk of further contagion abroad. When fundamentals are bad, however, the IMF would prove more effective.[12]

Overall, we believe that in the upcoming policy debate on restructuring the international financial architecture, signalling effects are a factor that is worth taking into account. This paper has aimed at providing a simple framework to think about their consequences.

Appendix A: Proofs

Proof of Lemma 1. In both Case II and Case III depositors' stage 2 signal is $\Phi = G$. First, we assume that depositors do not change their beliefs about S after stage 4. We will subsequently prove that this is indeed their optimal behavior, regardless of whether $S = G$ or $S = B$ in stage 1.

Given $\Phi = G$ and our assumption that depositors' beliefs do no change after stage 4, Depositor$_Y$ does not run in stage 5. Hence, at stage 6 NA$_Y$ will face the following decision problem:

$$\begin{array}{ll}
\text{if value of Bank}_Y \text{ is } V_+^G \text{ then:} & \min_{I,N}\{C_I, 0\} \\
\text{if value of Bank}_Y \text{ is } V_+^B \text{ then:} & \min_{I,N}\{C_I, 0\} \\
\text{if value of Bank}_Y \text{ is } V_-^G \text{ then:} & \min_{I,N}\{C_I, 0\} \\
\text{if value of Bank}_Y \text{ is } V_-^B \text{ then:} & \min_{I,N}\{C_I + C_S, 0\}
\end{array}$$

where $\min_{I,N}$ means minimize over intervention (I) and non-intervention (N), and the first entry in the brackets represents the LOLR's costs of intervention and the second entry those of non-intervention. Therefore, NA$_Y$'s optimal strategy is never to intervene: regardless of S and of whether contagion from X has occurred, non-intervention is optimal.

[12] For a study on the signalling effects of IMF intervention see Zwart (2007).

Similarly, the stage 4 decision of NA_X is based on

$$\begin{aligned} \text{if } S &= G \text{ then } \min_{I,N} \{C_I, 0\} \\ \text{if } S &= B \text{ then } \min_{I,N} \{C_I + C_S, 0\} \end{aligned}$$

and, thus, non-intervention is always optimal.

And, if the CA is the LOLR, its decision problem can be written as:

$$\begin{aligned} \text{if } S &= G \text{ then } \min_{I-I,I-N,N-I,N-N} \{2C_I, C_I, C_I, 0\} \\ \text{if } S &= B \text{ then } \min_{I-I,I-N,N-I,N-N} \{(2C_I + C_S), (C_I + C_S), (C_I + C_S), 0\} \end{aligned}$$

where $I - I$ means intervene in both stages 4 and 6, $I - N$ intervene only in stage 4, $N - I$ intervene only in stage 6, and $N - N$ never intervene. Thus, the CA chooses non-intervention in both stages 4 and 6.

Under both decentralization and centralization, therefore, non-intervention at stages 4 and 6 is always optimal for the LOLR(s). Irrespective of the true state S drawn at stage 1, that is.

So when $\Phi = G$, depositors' observation of non-intervention by the LOLR in stage 4, provides them with no additional information about the S drawn in stage 1. Hence, they have no basis on which to update their beliefs.

Overall, therefore, neither the NAs or the CA will intervene at any stage when in Cases II and III. ■

Proof of Proposition 1. Like in Lemma 1, we first assume that the CA's stage 4 decision provides depositors with no information about stage 1. Subsequently, we prove that this is indeed the case.

Given $\Phi = B$ and no change in the beliefs of depositors (following from the assumption in the above paragraph), at stage 5 Depositor_Y runs on Bank_Y whenever the CA does not intervene in stage 4. At stage 3 Depositor_X always runs. Therefore, the CA's optimization problem is as follows:

$$\begin{aligned} \text{if } S &= G \text{ then } \min_{I-I,I-N,N-I,N-N} \{2C_I, (C_I + C_F), (C_I + C_F), 2C_F\} \\ \text{if } S &= B \text{ then } \min_{I-I,I-N,N-I,N-N} \{(2C_I + C_S), (C_I + C_S + C_F), (C_I + C_S + C_F), 2C_F\} \end{aligned}$$

Now, given

$$C_I < C_F < C_I + C_S$$

and

$$2C_I + C_S < 2C_F$$

we have that

$$2C_I < C_I + C_F < 2C_F$$

and when $S = G$ the CA's optimal choice of actions is $I - I$. It intervenes at both stages 4 and 6.

But we also have that

$$2C_I + C_S < 2C_F < C_I + C_S + C_F$$

and when $S = B$ the CA's optimal choice of actions is $I - I$.

Therefore, regardless of whether the true state is Good or Bad, whenever $\Phi = B$ the CA intervenes in both countries. And, given that the it does so, depositors indeed gain no additional information about S from the CA's actions in stage 4. ■

Proof of Proposition 2. Now consider first NA_X's decision at stage 4, when depositors have received a signal that the banking sector is weak[13], $\Phi = B$:

$$\begin{aligned} \text{if } S &= G \text{ then } \min_{I,N} \{C_I, C_F\} \\ \text{if } S &= B \text{ then } \min_{I,N} \{C_I + C_S, C_F\} \end{aligned}$$

which by $C_I < C_F < C_I + C_S$ implies that it is optimal for NA_X to intervene only if the state is Good, $S = G$. If $S = B$, instead, NA_X chooses non-intervention. NA_X's action thus perfectly informs depositors about the state. That is, whenever $\Phi = B$ at stage 2, then through the NA's decision at stage 4 depositors know with certainty which state prevailed at stage 1.

Because of depositors' knowledge after stage 4, NA_Y's decision can now be described as follows

$$\begin{aligned} \text{if } S &= G \text{ then } \min_{I,N} \{C_I, 0\} \\ \text{if } S &= B \text{ then } \min_{I,N} \{C_I + C_S, C_F\} \end{aligned}$$

Since $C_I > 0$ and $C_I + C_S > C_F$, non-intervention is always optimal for NA_Y at stage 6. Summarizing the case of decentralization with $\Phi = B$, then, when $S = B$ non-intervention is optimal for both NA_X and NA_Y, so that both Bank_X and Bank_Y fail. When, instead, $S = G$, NA_X bails out Bank_X and, through depositors' updating, also Bank_Y is saved, without further intervention in country Y. ■

Proof of Lemma 2. Consider $2C_I + C_S > 2C_F$ and the setting of Proposition 1 ($\Phi = B$). As in the proof of that Proposition, first assume that depositors do not update their beliefs after stage 3. Then the CA's problem is:

$$\begin{aligned} \text{if } S &= G \text{ then } \min_{I-I, I-N, N-I, N-N} \{2C_I, (C_I + C_F), (C_I + C_F), 2C_F\} \\ \text{if } S &= B \text{ then } \min_{I-I, I-N, N-I, N-N} \{(2C_I + C_S), (C_I + C_S + C_F), (C_I + C_S + C_F), 2C_F\} \end{aligned}$$

so that by $C_I < C_F$ its optimal policy is $I - I$ when $S = G$. But by $2C_I + C_S > 2C_F$ its optimal policy is $N - N$ when $S = B$. This implies that the initial assumption that depositors do not update their beliefs is false: the CA's stage 3 action directly reveals S to them.

[13] Notice that the Proof of Proposition 2 does not make use of induction from Stage 6 backwards. Rather, because NCB_A and Depositor_A do not internalize the effects of their Stage 3/4 actions on Stages 5 and 6, we can solve for Stage 3/4 actions first, and subsequently take them as given for Stage 5/6 decisions.

Now assume, therefore, that depositors update their beliefs to $S = G$ after stage 3 when they observe policy I. Then the CA's problem is:

$$\begin{aligned}
\text{if } S &= G \text{ then } \min_{I-I,I-N,N-I,N-N} \{2C_I, C_I, (C_I + C_F), 2C_F\} \\
\text{if } S &= B \text{ then } \min_{I-I,I-N,N-I,N-N} \{(2C_I + C_S), (C_I + C_S), (C_I + C_S + C_F), 2C_F\}
\end{aligned}$$

so that for the CA's best policy is $I - N$ for all S. But given that this is its optimal policy regardless of the state, then its stage 3 decision carries no information about S. Thus, the assumption that depositors update their beliefs after stage 3 is false. There does not exist a consistent combination of optimal depositor behavior and an optimal strategy of the CA, therefore. Any policy by the CA leads to inference by depositors that makes another strategy optimal for the CA, which leads to different inference by depositors, and so on. ∎

Proof of Proposition 3. Consider the following play by the CA. When $(S, \Phi) = (G, B)$ he delegates decision-making authority to the NAs at stage 3. Otherwise he retains control. We show that this is the optimal strategy for the CA. By the Proof of Proposition 2, NA_X chooses action I at stage 5, after which Depositor_Y does not run, and NA_Y chooses action N. Depositor behavior is unchanged under delegation: NAs objective functions are as before, and thus its choice of I credibly signal that $S = G$. In all other state-signal combinations (S, Φ), the CA's payoff is at least as high under its own action as under that of the NAs. Formally, term Del the decision to delegate and $NoDel$ the decision to retain control. As a tie-breaking assumption assume that the CA retains control when indifferent about delegation. The CA's choice at stage 3 is

$$\begin{aligned}
\text{if } (S, \Phi) &= (G, G): \min_{Del,NoDel} \{0, 0\} \\
\text{if } (S, \Phi) &= (B, G): \min_{Del,NoDel} \{0, 0\} \\
\text{if } (S, \Phi) &= (G, B): \min_{Del,NoDel} \{C_I, 2C_I\} \\
\text{if } (S, \Phi) &= (B, B): \min_{Del,NoDel} \{2C_F, 2C_I + C_S\}
\end{aligned}$$

so that Del is optimal for $(S, \Phi) = (G, B)$ and $NoDel$ otherwise.

It follows from applying equation (5):

$$\begin{aligned}
E[W_{DEL} - W_{NAs}] &= (1 - p)\, q\, (2C_F - (2C_I + C_S)) \\
E[W_{DEL} - W_{CA}] &= p\,(1 - q)\, C_I
\end{aligned}$$

that state-dependent delegation welfare dominates both pure centralization and pure decentralization. ∎

Proof of Proposition 4. First note that depositors still optimally discard their signal when there is any information content to the action of the LOLR. For any $m \geq 0$ depositors realize that the LOLRs signal is at least as precise as their own. Moreover, as the cost structures and the post-zero stages of the game are all unchanged, depositors make the same inferences from LOLR actions as before. The fact that it responds to a more precise signal rather than certain knowledge of the state makes no difference.

First we consider investment under delegation. An implicit assumption is that all parts of the LOLR have same information here. That is, the joint (CA+NA) LOLR is treated as a single entity in terms of the precision of the signal receives (as there is also only one joint investment decision). Whenever the signal received by the LOLR is correct, it implements the first-best (Proposition 3). Thus, costs only arise when, with probability $1 - h(m)$, it receives an incorrect signal and takes a decision that ex-post turns out to be wrong. This, as we show, matters only in the Scare Case: the CA should delegate but incorrectly retains control. The associated expected cost is

$$[1 - h(m)]\, p(1-q)\, C_I$$

In Cases II and III Lemma 1 still applies: regardless of the LOLRs own signal, it knows that depositors think the state is Good, and thus has no incentive to act. In the Crisis Case, instead, a wrong signal to the LOLR (it believes the state is Good) implies incorrect delegation to NAs. As NAs have the same beliefs, however, they intervene. Thus, NAs (inadvertently) implement the social optimum, and no cost arises. Thus, the LOLR's problem under delegation is:

$$\min_m \left\{ \left[1 - \left(q + (1-q)\sqrt{m}\right)\right] p(1-q)\, C_I + m \right\}$$

which yields

$$m^*_{del} = \frac{(1-q)^2}{4} \left[p(1-q)\, C_I\right]^2$$

Under pure centralization there can be no benefit to investment in supervision. This follows directly from the fact that its actions - by Proposition 1 - do not depend on the state. Rather, they follow the signal of depositors, Φ. As there is no benefit, but only a cost to increasing m it is immediate that $m^*_{ca} = 0$.

Under pure decentralization, the problem of NA_X is:

$$\min_m \left\{ \left[1 - \left(q + (1-q)\sqrt{m}\right)\right] \left[p(1-q)(C_F - C_I) + (1-p)\, q\, (C_I + C_S - C_F)\right] + m \right\}$$

That is, when the signal it has is incorrect, it treats the Scare Case as the Crisis Case and lets Bank_X fail when it should have been saved (costing $(C_F - C_I)$). Moreover, the opposite can also happen: the Scare Case is incorrectly treated as the Crisis Case, which costs the NA $C_I + C_S - C_F$ (the cost of saving an insolvent bank, instead of letting it fail). Thus:

$$m^*_x = \frac{(1-q)^2}{4} \left[p(1-q)(C_F - C_I) + (1-p)\, q\, (C_I + C_S - C_F)\right]^2$$

Notice that as the action of NA_X perfectly reveals its signal, NA_Y can free ride on NA_X's investment. With zero investment it can get a signal as precise as that of NA_X. As NA_Y's marginal benefit of information acquisition can never be larger than NA_X's (when no run occurs in X, NA_Y has no need to know the state at all). Therefore, NA_Y always chooses to free ride and invest zero, $m^*_y = 0$ (but its associated probability of having the correct signal is still $h(m^*_x)$)

Now, comparing decentralization and delegation

$$\begin{aligned} & m_x^* - m_{del}^* \\ = \; & p(1-q)(C_F - C_I) + (1-p)q(C_I + C_S - C_F) - p(1-q)C_I \\ = \; & C_F - 2C_I + \frac{(1-p)q}{p(1-q)}(C_I + C_S - C_F) \end{aligned}$$

This can be either greater or smaller than zero: for $p \to 0$ we have that $(m_x^* - m_{del}^*) > 0$ and for $p \to 1$ $(m_x^* - m_{del}^*) \to (C_F - 2C_I) < 0$. ■

Proof of Corollary 1. The welfare comparison between delegation and decentralization is given by

$$\begin{aligned} E[W_{DEL} - W_{NAs}] = \; & -[1 - h(m_{del}^*)]p(1-q)C_I \\ & + h(m_x^*)(1-p)q(2C_F - (2C_I + C_S)) \\ & - [1 - h(m_x^*)](1-p)q(2C_F - (2C_I + C_S)) \\ & + [1 - h(m_x^*)]p(1-q)[2C_F - 2C_I] \end{aligned}$$

Take limit case of $h(m_{del}^*) = h(m_x^*) = q \to \frac{1}{2}$ and $C_F \to C_I$. It then directly follows that $E[W_{DEL} - W_{NAs}] < 0$. Thus, decentralization can dominate delegation.

Delegation always (weakly) dominates centralization, moreover, as:

$$\begin{aligned} E[W_{DEL} - W_{CA}] & = -[1 - h(m_{del}^*)]p(1-q)C_I + [1 - h(m_{ca}^*)]p(1-q)C_I \\ & = h(m_{del}^*) - h(m_{ca}^*) \geq 0 \end{aligned}$$

■

Proof of Corollary 2. We first prove the first sentence of the Corollary. Recall that Lemma 1 is concerned with Cases II and III. For both of these, $\Phi = G$. NA$_X$ now faces the following choice:

$$\begin{aligned} \text{if } S & = G \text{ then } \min_{I,N} \{C_I, 0\} \\ \text{if } S & = B \text{ then } \min_{I,N} \{C_I + C_S, C_F\} \end{aligned}$$

where the C_F in the last operator is new compared to Lemma 1, and is a consequence of the assumption that a bank with value $\underline{V}^B$ now also fails in the absence of a run. Nonetheless, by $C_I > 0$ and $C_I + C_S > C_F$ NA$_X$ chooses non-intervention regardless of S. Subsequently, NA$_Y$ finds itself in the exact same position as NA$_X$ and thus makes the same choice. The outcome of Cases II and III for NAs is equivalent to Lemma 1, therefore.

For the CA, instead, the problem can be written as:

$$\begin{aligned} \text{if } S & = G \text{ then } \min_{I-I, I-N, N-I, N-N} \{2C_I, C_I, C_I, 0\} \\ \text{if } S & = B \text{ then } \min_{I-I, I-N, N-I, N-N} \{(2C_I + C_S), (C_I + C_S + C_F), (C_I + C_S + C_F), 2C_F\} \end{aligned}$$

which means that it still chooses $N-N$ when $S=G$, but, contrary to Lemma 1, now chooses $I-I$ when $S=B$. This proves the second sentence of the Corollary.

However, all values of the CA's problem in the Proof of Proposition 1 and of the NAs' problems in the Proof of Proposition 2 remain unchanged. Hence, the Propositions remain valid. The reason that the values are unaffected is that these Propositions are concerned with Case I and Case IV, in both of which $\Phi = B$. As can be seen from the two proofs, the only time that non-intervention would then not lead to bank failure through a run is NA_Y in Case IV. Whenever non-intervention does lead to failure through a run, post-game failure is irrelevant (since it is preceded by the run). And for NA_Y in Case IV post-game failure is irrelevant too, because Bank_Y is solvent.

Finally, Proposition 3 is unaffected. The only change in the strategies of the CA and NAs is that the CA now prefers $I-I$ to $N-N$ in Case II. In this Case, in Proposition 3, it retains control. It still does so now, since it prefers its own actions $I-I$, to those of the NA, $N-N$. ■

Proof of Proposition 5. We first show that verbal communication is irrelevant for outcomes under centralization. We prove by contradiction that depositors attach no value to the statements of the CA. Suppose that depositors believe the statements of the CA.

First notice that the stage 6 statement of the CA is irrelevant as it comes at the end of the game and cannot influence depositors' actions. We thus focus on the stage 4 statement decision. Call the statement λ, where $\lambda \in \{G, B, \varnothing\}$. Here, $\lambda = G, B$ refers to the statement that $S=G$ and $S=B$, respectively, while $\lambda = \varnothing$ means no statement is issued. Now we can write down the CA's optimization problem for the different statements, for each of the cases covered by Propositions 1 and 2. In Case I:

$$\begin{aligned}
\text{if } \lambda &= G \text{ then } \min_{I-I,I-N,N-I,N-N} \{(2C_I + C_S), (C_I + C_S), (C_I + C_S + C_F), C_F\} \\
\text{if } \lambda &= B \text{ then } \min_{I-I,I-N,N-I,N-N} \{(2C_I + C_S), (C_I + C_S + C_F), (C_I + C_S + C_F), 2C_F\} \\
\text{if } \lambda &= \varnothing \text{ then } \min_{I-I,I-N,N-I,N-N} \{(2C_I + C_S), (C_I + C_S + C_F), (C_I + C_S + C_F), 2C_F\}
\end{aligned}$$

so that the lowest cost outcome is achieved by $\lambda = G$ and actions $N-N$.

In Case IV:

$$\begin{aligned}
\text{if } \lambda &= G \text{ then } \min_{I-I,I-N,N-I,N-N} \{2C_I, C_I, (C_I + C_F), C_F\} \\
\text{if } \lambda &= B \text{ then } \min_{I-I,I-N,N-I,N-N} \{2C_I, (C_I + C_F), (C_I + C_F), 2C_F\} \\
\text{if } \lambda &= \varnothing \text{ then } \min_{I-I,I-N,N-I,N-N} \{2C_I, (C_I + C_F), (C_I + C_F), 2C_F\}
\end{aligned}$$

so that the lowest cost outcome is achieved by $\lambda = G$ and actions $N-I$.

Hence, regardless of the true state, the CA always chooses $\lambda = G$. But then its statements have no informational content. Therefore, it cannot be true that depositors believe the CA's statement.

Given that depositors attach no value to the statements of the CA, its optimization problem becomes completely independent of λ. Verbal communication then has no effect on the decisions that the CA takes.

For NAs the proof is straightforward. At stage 4 NA_X is indifferent about which statement to make, as it does not consider the subsequent stages. Any statement NA_X makes is in any case irrelevant, moreover, since depositors know the true state from its action, as shown in the Proof of Proposition 2. Depositors thus attach no additional value to the statement of NA_X, and verbal communication does not affect the outcomes under decentralization either. Finally, as verbal communication does not change the behavior of either CA or NAs, Proposition 3 is also unaffected. ■

Proof of Proposition 6. First note that for the cases covered by Lemma 1 (namely II and III), NAs' behavior is also unaltered by the political cost. This follows from the Proof of Lemma 1, in which C_F does not appear, and thus the adjusted cost of bank failure, $C_F + C_P$, does not matter.

For the CA the setting is precisely as in section 2, and thus it behaves as in Lemma 1 and Proposition 1. Thus, for the cases covered by Lemma 1 (those with $\Phi = G$) it already follows that CA and NA behavior are equivalent. Now for the cases with $\Phi = B$ we can follow the same solution structure as in the Proof of Proposition 2. NA_X's problem becomes:

$$\begin{aligned} \text{if } S &= G \text{ then } \min_{I,N} \{C_I, C_F + C_P\} \\ \text{if } S &= B \text{ then } \min_{I,N} \{C_I + C_S, C_F + C_P\} \end{aligned}$$

so that by $C_I < C_I + C_S < C_F + C_P$ it is optimal for NA_X to intervene for all S. As no depositor updating can take place when LOLRs' response is independent of the state, Depositor_Y behaves as Depositor_X and NA_Y solves the same problem as NA_X. Therefore, when $\Phi = B$ NAs intervene for all S, as does the CA by Proposition 1. Hence, centralization and decentralization are equivalent. ■

Appendix B: Microfoundations

Here we provide simple microfoundations for depositors' assumed behavior. In particular, we model depositors' decision to run whenever they receive a negative signal (absent updating on the basis of LOLR actions). As discussed in the introduction, there exist several papers that model bank runs resulting from adverse information. These are generally much more complicated than what is required for our purposes. In the seminal model of Chari and Jagannathan (1988), for instance, informed depositors either withdraw funds because of liquidity needs or because they run in response to adverse information. Uniformed depositors may then instigate a run when they observe informed depositors withdrawing. This can happen even when the informed depositors actually received no adverse information, and their liquidity needs just happened to be high.

In our case, instead, all depositors are informed (all receive the signal). We only need to model the fact that informed depositors run in response to a negative signal. A simple way to do this is as follows. Depositor_X has holds an amount of D as deposits in Bank_X, and Depositor_Y has the same amount of deposits in Bank_Y. In the Good state the return on the deposits is $R_G > 1$. Thus, when $S = G$, $R_G D$ is paid to the depositor by his respective bank.

This payment occurs after the six stages of the game in Table 1 have been completed (i.e. in a post-game stage). When, instead, the state is Bad, the depositor receives $R_B D$ where $R_B \in [0,1)$. That is, the depositor suffers a loss on his deposit. For simplicity, we can set $R_B = 0$.

Instead of waiting till the post-game stage, the depositor can also make an early withdrawal (instigate a run) during his decision stage in the game (stage 3 for Depositor$_X$ and stage 5 for Depositor$_Y$). Then, his return is γD with $\gamma \in (0,1]$. Here γ represents the fact that due to bank failure less than the entire deposit may be returned. Without loss of generality we can set $\gamma = 1$, however. We abstract from any time discounting and assume that depositors are risk neutral.

Defining $R \in \{R_G, R_B\}$, we can write down the depositor's expected return if he does not run as $E[R]$. Here:

$$E[R] = \begin{cases} qR_G \text{ if } \Phi = G \\ (1-q) R_G \text{ if } \Phi = B \end{cases}$$

Recall that $q \in \left(\frac{1}{2}, 1\right)$: if the depositor receives a positive signal ($\Phi = G$), his expected return is higher than when he receives a negative signal ($\Phi = B$).

To obtain the result that a depositor runs if and only if he receives a negative signal, it must be that:

$$(qR_G > 1 \wedge (1-q) R_G < 1) \Leftrightarrow q > \frac{1}{R_G} \max\{1, (R_G - 1)\}$$

That is, the microfoundations work as long as the signals that depositors receive are sufficiently precise. Coupled with $q \in \left(\frac{1}{2}, 1\right)$ we can write the condition as:

$$q \in \left(\max\left\{ \frac{1}{2}, \left[\frac{1}{R_G} \max\{1, (R_G - 1)\} \right] \right\}, 1 \right)$$

The reason for this condition is intuitive. Running only for $\Phi = B$ means "following" the signal. That is, the depositor should believe the signal enough so that he chooses not to withdraw when it is positive, and not to take the risk of staying when it is negative. As long as depositor information is not too imprecise, therefore, the behavior assumed in section 2 can be microfounded.

Note that we have abstracted from deposit insurance. This can be justified in three ways. Firstly, as discussed before, depositors could be seen as interbank participants, whose loans are unguaranteed. Secondly, depositors could be seen as "large", such that their deposits are not fully covered by the insurance scheme. Finally, however, the current crisis has shown us that small depositors who are covered by insurance can nonetheless withdraw their funds (Fortis in Belgium, for instance). One reason may be the waiting times they need to incur until receiving the payment from the deposit insurance corporation.

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