What Institutional Structure for 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, because it internalizes externalities, faces a pooling equilibrium. It cannot effectively signal the motivation behind its interventions. This leads to unnecessary depositor scares. The first-best is achieved by delegation: the central authority decides when to retain control and when to delegate to the national authorities. Central coordination dominates pure centralization.

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

JEL Classification: D82, G21, G28

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, in particular, 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 argues that neither pure centralization nor pure decentralization are optimal. Rather, a structure in which the central authority can delegate some decisions to national authorities achieves the highest welfare. The reason is 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. An optimal institutional structure makes use of both the internalization benefit of a central authority and the signalling benefit of national authorities.

The modelled mechanism works as follows. Depositors are uncertain about bank health, and their withdrawal decisions depend on their perceptions of bank fundamentals. Those

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

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 signalling effects to depositors.

The failure of a bank has international spillover effects that 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. A central authority would also save such a bank. 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. The central authority's actions carry no information on the state. Instead, a national authority's response leads to a separating equilibrium, in which depositors know why it responded. When depositors' view is more negative than reality, national authorities have an advantage at preventing the spread of a scare. When depositors' negative beliefs are correct, however, decentralization leads to lower social welfare because of the underprovision of bailouts. Only state-dependent delegation achieves the optimum: the central authority delegates control to national authorities when their signalling benefit outweighs its internalization benefit. Otherwise, it intervenes itself. Alternatively, an outside central body, such as the Commission in the European context, can decide on delegation.

The modelling takes the form of a sequential game. There are two countries and one bank in each country. The banks are linked through interbank loans. First, depositors decide whether they run on the bank in one country, and the authority in charge decides whether to save that bank. Subsequently, the same decisions are taken in the second country. Banks in both countries are subject to a common state, on which depositors receive an initial signal. Authorities observe both the state and the signal. When depositors in the first country run due to an incorrect negative signal, the response of a national authority to save the illiquid local bank immediately convinces depositors in the other country that their signal was

wrong. In this manner, national authorities can impose positive externalities on each other by being indifferent to international contagion. The same mechanism holds when banks face idiosyncratic shocks. The central authority can respond for different reasons. Either it wants to save a solvent local bank, or it knows that the state of the bank in the second country is sufficiently precarious that it merits saving the insolvent bank in the first country. Depositors cannot disentangle its motivation, so that the central authority's intervention is associated with negative signalling.

The delegation structure is modelled by introducing a separate stage in the game at which the central authority decides whether or not to retain control. Solving the game in this structure, an expression can be derived for the ex-ante probability that a central authority decides to intervene itself. The higher the likelihood of a genuine crisis, the more interlinked the banks and the better informed depositors are, the more often a central authority will retain control.

This paper does not explicitly consider the role of bank supervision. It is simply assumed that the Lender of Last Resort (LOLR) in charge is also the supervisor. A companion paper, Agur (2009b), separately considers the issue of centralizing or decentralizing bank supervision. Note also that 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 the LOLR 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 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 (2002), Goldstein and Pauzner (2005) and Chen and Hasan (2008)).[3]

The optimal design of the LOLR suggested in this paper is closely related to the literature on delegation. We refer to the review of the literature in Agur (2009a). That paper generalizes this paper's basic results on optimal transmission indifference and state-dependent delegation. It allows for multiple states and multiple actions in a principal-agent framework that includes an imperfectly informed outsider.

The next section reviews the related literature on the LOLR. Section 3 presents the basic game and its results. Section 4 analyzes robustness to alternative specifications, while sections 5 and 6 investigate the effects of cheap-talk communication and 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   Literature on LOLR

To our knowledge this paper provides the first formalization of a trade-off between centralizing and decentralizing the LOLR. Kahn and Santos (2004) do formally analyze the issue of centralization. But their analysis centers on the optimal sequence of centralizing the LOLR and banking supervision. They assume that regulators overweigh the local banks' interests. Centralization reduces this forbearance, since all banks in the region become "local" to the regulator. There is no benefit to decentralization. But centralizing the LOLR first reduces a decentralized supervisor's incentive to monitor (because bad local banks receive less support),

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[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.

while centralizing the supervisor first has no effects on a decentralized LOLR's incentives. Hence centralizing supervision first is optimal. Kahn and Santos do not explicitly model depositors' beliefs. This is the reason that are no signalling effects and no advantages to decentralization like in our paper.

There have been several other formal analyses of LOLR functions in general (unrelated to centralization).[4] In the model of Goodhart and Huang (2005) welfare losses from bank failure increase quadratically in bank size. This represents the increased risks of financial contagion when larger banks fail. When a bank turns to the LOLR for assistance, the LOLR does not know whether it is illiquid or insolvent. Bailing out an insolvent bank imposes a welfare cost. This cost increases only linearly in size, however. Thus, there is a threshold bank size above which the LOLR chooses to bail out, which rationalizes a "too big to fail" policy. Modelling dynamically, moreover, Goodhart and Huang identify the main trade-off of LOLR intervention as stemming contagion versus raising banks' moral hazard.

Cordella and Yeyati (2003) argue, instead, that LOLR intervention need not cause a rise in banks' risk profiles. The reason is that a bailout scheme increases a bank's probability of survival, which raises the charter value at stake in case of failure. With higher incentives to protect that value, banks choose chose safer investments. The authors find that there is always a policy for which this value effect unambiguously dominates moral hazard from the LOLR's safety net. An ex-ante LOLR commitment to bailout can thus *reduce* excessive risk-taking by banks.

Repullo (2000) analyzes who can best be designated as LOLR: the Central Bank or the Deposit Insurance Corporation. The latter always faces costs if a bank fails, but its costs do not increase in the size of its loan, which replaces insured deposits. The Central Bank's intervention costs, instead, do rise for larger loans. For any liquidity shocks the deposit insurer is slightly too tough a LOLR, whereas Central Bank toughness rises in the size of the shock. Thus, for small liquidity needs the Central Bank is the optimal LOLR and for larger needs

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[4]The policy discussions surrounding LOLR intervention, and the current applicability of traditional arguments going back to Bahegot (1873) and Thornton (1802), are reviewed by Humphrey (1975), Bordo (1990), Goodhart (1999) and Freixas et al. (1999).

the deposit insurer.[5]

In contrast to the above literature, however, several authors have argued that direct lending to banks by a LOLR serves no purpose at all in the presence of an efficient interbank market (Goodfriend and King (1988), Kaufman (1991) and Schwarz (1992)). In their view, a LOLR should only stabilize aggregate liquidity through Open Market Operations (OMO) and leave the rest to the market. However, several authors have provided formal counter-arguments to this view by questioning the efficiency of the interbank market.

Freixas et al. (2004) model banks that face both liquidity and solvency shocks. Interbank loans may be subject to moral hazard in screening or in monitoring. When screening loan applicants is the main source of moral hazard, the LOLR should lend to individual banks at a penalty rate, which discourages insolvent banks from borrowing as if they are only illiquid.

Rochet and Vives (2004) instead assume that the LOLR has superior information at its disposal from banking supervision. The interbank market inefficiency arises through adverse selection: banks require a premium to lend because they do not know if the borrower is motivated by liquidity or solvency concerns. The interbank market can get gridlocked even when all banks are solvent.[6] The LOLR, able to distinguish illiquidity from insolvency, can successfully intervene. In such cases OMO cannot replace lending to individual institutions.[7]

3   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

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[5]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.

[6]Freixas et al. (2000) also model the potential for interbank gridlock, arising through depositors' uncertainty about where they will consume. The LOLR need not explicitly intervene, but instead prevents gridlock by acting as guarantor of interbank credit lines. For more on the role of intervention in the interbank market see also Rochet and Tirole (1996).

[7]Flannery (1996) reaches the same conclusion. On the basis of empirical findings, he assumes that identifying borrower solvency becomes more difficult in times of crisis. This prevents private lenders from effectively redistributing aggregate liquidity when most needed.

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). After deriving the results for pure centralization and pure decentralization we will show that a mixed institutional form - delegation - dominates both.

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.

Figure 1: The banks' environment
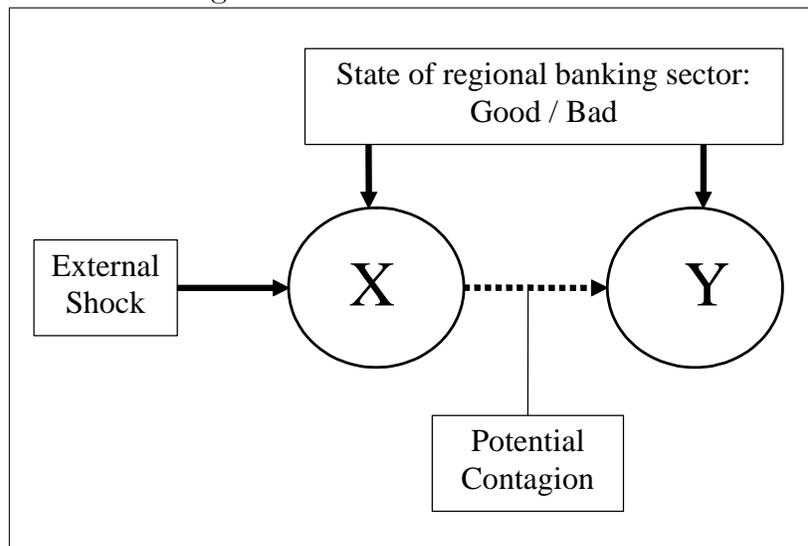
The state of all banks in the region is assumed to be the same. That is, Bank_X and Bank_Y are either both in the Good state or in the Bad state. This is the simplest setting in which to derive our main results, because it clearly distinguishes between the two elements that we require for our results: an uncertain state and transmission effects. However, the two can

also be blended together: Section 4B shows that all results go through when the uncertainty is about the extent of interlinkage between the banks, rather than the state they are in. Moreover, results are robust to having bank-specific states rather than a common state.[8]

To help conceptualize the setting in the current Section, consider the following example. In a major country outside of the region, a financial crisis has occurred. We can think of the recent crisis in the US subprime market. This crisis affects all banks in the region. Exposure to the foreign crisis can be either high or low (such as exposure to mortgage-backed securities). If exposure is high, the regional banking sector is said to be in a Bad state. If exposure is low, the banking sector is said to be in a Good state. The degree of exposure is not known with certainty by the public. It can observe imprecise signals based on, for instance, reports in the press.

The financial positions of Bank_X and Bank_Y are not identical. In addition to the common state, Bank_X has been hit by 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). This foreign shock to which Bank_X is subject is publicly known. It is not a random variable. Bank_Y has links to Bank_X. It is here that the potential for transmission of shocks comes into the model. We can conceive of Bank_Y as having an interbank loan to Bank_X. If Bank_X fails, Bank_Y suffers losses. Thus, there can be contagion: the bank-specific foreign shock that Bank_X suffers, could lead to losses for Bank_Y.

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.

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[8]See the discussion in Section 4.C.

Given that Bank$_X$ is always victim to the external contagion shock, 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 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:

<div align="center">

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

</div>

The true state is thus determined in Stage 1. We let p denote the probability that the state is Good (and thus with probability $(1-p)$ it is Bad). The subsequent Stages are described below.[9]

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.[10] The depositors are informationally

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[9]Note that this is a sequential game without repetition (in each country each player acts only once). A setting without repetition is clearly simpler, and proves sufficient to expose the main analytical results. Furthermore, financial crises and bailouts tend to be rather rare and unpredictable events, which are perhaps not best modelled in a repeated game setting.

[10]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.

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 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.[11] Signals are the first source through which depositors receive information about the state of the regional banking sector. The second source, discussed in Subsection C, 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.

When a run does occur, the 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. Bank runs are the only possible cause of bank failure in our basic game. This allows us to focus on our main results in the simplest way. We relax this assumption in Section 4A.

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

C LOLRs

Through its banking supervision a LOLR possesses superior information about the state. It has a key informational advantage over depositors, and observes S. 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.[12]

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.[13] 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 $C_I + C$, 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

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

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

[13]We restrict the LOLR to always pay the complete cost of intervention: it cannot choose to pay less (only C_I) when assisting an insolvent bank.

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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 on 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 (1999, p.92)). Imagine that depositors receive a negative signal, and that no LOLR action can convince them that their beliefs are wrong. That is, both Depositor$_X$ and Depositor$_Y$ will run. Initially the value of Bank$_X$ is V_-^B: it is insolvent. Now, saving it costs the LOLR $C_I + C_S$. Given that by saving Bank$_X$, Bank$_Y$ remains solvent (V_+^B), saving Bank$_Y$ from Depositor$_Y$'s run costs C_I. Hence, the overall cost of intervention is $2C_I + C_S$, which is less than letting both banks fail, $2C_F$. Saving Bank$_X$ is optimal from the perspective of regional welfare, but not for country X considered by itself, as $C_I + C_S < C_F$. The condition 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. As discussed in the introduction, it is the very fact that the public does not know the exact reason that a centralized authority is responding - to save a bank that is really solvent or to prevent contagion - that creates the potential benefit of decentralization.

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,

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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.

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 1: 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.*

Within the European context this institutional structure seems feasible. The European System of Central Banks (ESCB) could provide a structure similar to what is described, with the European Central Bank at its head, which can delegate decision to national central banks if needed. To the public it is clearly observable who it is that provides bailouts to a given bank. Thus, the benefits of internalizing externalities and of signalling can be simultaneously reaped.

E   Comparative statics

We perform comparative statics to analyze how the relative benefit of centralized decision making is affected by different factors. This relative benefit can be interpreted both in terms of the trade-off between pure centralization and decentralization (Propositions 1 and 2) and in terms of the delegation structure. In the latter when centralized decision making becomes more beneficial, the CA will choose to retain control more often. We consider the following three factors:

1. The frequency of financial crises.

2. The precision of depositor information.

3. The degree of international interlinkage between banks.

Comparative statics can be analyzed using an expression for the expected benefit of central decision making. The probability that the Crisis Case occurs is $(1-p)\,q$. When it occurs the associated benefit of having the CA in charge is $(2C_I + C_S - 2C_F)$ - the value of saving both banks instead of letting both fail. The probability that the Scare Case occurs is $p\,(1-q)$. And the associated cost of CA decision control is C_I - the cost of providing assistance to Bank$_Y$ that would have been avoided under decentralization. Overall, then, the expected benefit of

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central decision making is:

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

where $W_{CA} - W_{NAs}$ means "regional welfare under centralization" minus "regional welfare under decentralization".

From the above expression we obtain the following derivatives:

$$\frac{\partial}{\partial p}E\left[W_{CA} - W_{NAs}\right] = -\left[q\left(2C_F - (2C_I + C_S)\right) + (1-q)C_I\right] < 0 \tag{6}$$

$$\frac{\partial}{\partial q}E\left[W_{CA} - W_{NAs}\right] = (1-p)\left(2C_F - (2C_I + C_S)\right) + pC_I > 0 \tag{7}$$

When the Bad state occurs more frequently (lower p) the internalization benefit of central decision making matters more often. Likewise, the better informed depositors are (higher q), the smaller the importance of the signalling benefit that decentralized authorities possess. Thus, the more frequently financial crises occur and the better informed depositors are, the more beneficial centralized decision making becomes. In the delegation structure the CA will retain control more often for a lower p and a higher q, therefore.

Finally, as witnessed by the quote from Goodhart (2000) in the introduction, it is generally thought that increased financial interpenetration in the EU favors centralization. Our theory "roughly" agrees with that view. Roughly, because it contains no direct measure of interpenetration. We can argue, however, that greater interlinkage implies that potential contagion is larger. Bank$_Y$ could have more interbank loans to Bank$_X$, for instance. If so, this would lower the value of Bank$_Y$ by more when it is subject to contagion. The costs of Bank$_Y$'s failure would then be higher (it has fewer assets per creditor left). Given that contagion to and insolvency of Bank$_Y$ are avoided under centralization (the Crisis Case), greater interlinkage would raise the expected benefit of having the CA as LOLR.

4 Robustness to alternative setups

A 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 assumption is not crucial. The main results of the paper go through even when insolvent banks do always fail.

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 1 *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, both Propositions 1, 2 and 3 remain valid without alterations.*

B Uncertainty about interlinkage

The environment depicted in Figure 1 is not key for the results. Figure 2 depicts an alternative environment for which the main results go through:

Figure 2: Uncertainty about extent of bank interlinkage
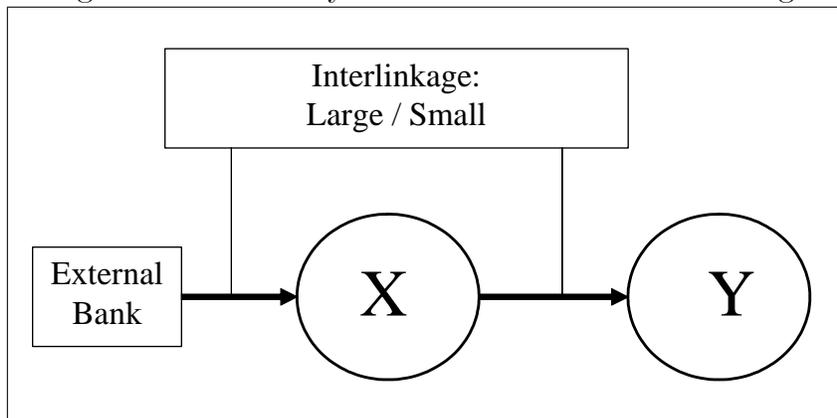
In this setup there is uncertainty about the degree to which banks are linked. It is publicly known that there are transmission effects between banks, but not how large these are. In Figure 2 an external bank with linkages to Bank_X fails. Contagion effects occur. The same is true between Bank_X and Bank_Y. Some transmission 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 V_-^B when it is large.

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

C   Separate states

In Figure 2 there is a common degree of interlinkage. That is, either interlinkage between both the external bank and Bank_X and between Bank_X and Bank_Y is large, or both linkages are

small. Likewise, in the basic game either both banks are in a Good state or both are in a Bad state. The existence of a common state is not a necessary feature of the model. There can be bank-specific states. There will still be a signalling advantage to decentralized authorities. The CA's knowledge of the state in Y affects its behavior in X, while for the NAs this is not true. The CA still faces pooling equilibria. This is proven at a general modelling level by Agur (2009a).

5   Verbal communication

Our main results depend on LOLRs' ability to communicate through their actions. The argument that NAs are more effective at this communication is the reason that there is a cost to centralization. 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):

Proposition 4 *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.

6 Politically motivated NAs

"National authorities have a political stake in the economic viability of domestic financial institutions" Giovannini (1993, p.224).

So far this paper has abstracted from any kind of political motivations among regulators. National authorities are benevolent, they just do not internalize cross-border externalities. It has often been argued, however, that national authorities overweigh the interests of domestic institutions because of political motivations. This section analyzes how such behavior would affect 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.

As long as $C_I + C_S > C_F + C_P$ holds, however, political costs are small enough that they do not affect any of our results (qualitatively). This follows directly from the fact that

$$C_I < C_F \Rightarrow C_I < C_F + C_P$$

which, in conjunction with $C_I + C_S > C_F + C_P$ implies that NAs still only save solvent but illiquid domestic banks. Their behavior, and therefore the inferences of depositors, are the same.

The case of politically-motivated NAs only becomes interesting when NAs' political cost of bank failure is large enough that $C_I + C_S < C_F + C_P$ holds. Now, NAs are willing to save insolvent domestic institutions. When this is the case, the following Proposition applies (proof in the Appendix):

Proposition 5 *If $C_I + C_S < C_F + C_P$ then centralization and decentralization are equivalent.*

This seems quite counter-intuitive. The reason for this result is that NAs are so sensitive to domestic bank failure that they always intervene when depositors run. The transmission-

internalization of the CA then leads to the same behavior as the "always-respond" rule of the NAs. Essentially, NAs' bias to protect domestic institutions would lead them to bail out too often. But the fact that they do not internalize the externalities that domestic bank failure imposes on other countries leads them to underprovide bailouts. Here, the two effects cancel each other out, and the NAs intervene just as often as the CA.

If we would let go of relationship (4) and assume that $2C_I + C_S > 2C_F$ then we could have NAs that bailout too much from a welfare perspective. Even when they should let domestic institutions fail, they do not. But of course by Lemma 2 the CA's problem becomes insoluble in this case, so that no comparison can be made between centralization and decentralization.

Interestingly, however, even when $2C_I + C_S < 2C_F$ and Proposition 4 applies, political motivations of NAs can be detrimental to welfare. It would seem as though NAs' political bias is a second-best solution to the fact that they do not internalize international externalities. But by becoming equivalent to centralized authorities, NAs then also lose the welfare benefits of decentralization. That is, they can no longer effectively prevent the spread of scares as in Proposition 2. The reason is that their intervention no longer conveys information about the uncertain state.

7   Conclusions

The theory that this paper has presented cautions against completely centralized crisis management. On the one hand, a centralized authority internalizes cross-border externalities more effectively. But, on the other hand, the very fact that it does so implies that its actions are associated with more negative signalling. In an environment of public uncertainty, transmission indifference can have value. This is why a mixed solution in which decisions can also be delegated to national authorities improves upon pure centralization.

This is 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.[14] 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" 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.

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:

$$\text{if value of Bank}_Y \text{ is } V_+^G \text{ then:} \quad \min_{I,N} \{C_I, 0\}$$

$$\text{if value of Bank}_Y \text{ is } V_+^B \text{ then:} \quad \min_{I,N} \{C_I, 0\}$$

$$\text{if value of Bank}_Y \text{ is } V_-^G \text{ then:} \quad \min_{I,N} \{C_I, 0\}$$

$$\text{if value of Bank}_Y \text{ is } V_-^B \text{ then:} \quad \min_{I,N} \{C_I + C_S, 0\}$$

---

[14]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).

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.

Similarly, the Stage 4 decision of NA_X is based on

$$\text{if } S = G \text{ then } \min_{I,N}\{C_I, 0\}$$

$$\text{if } S = B \text{ then } \min_{I,N}\{C_I + C_S, 0\}$$

and, thus, non-intervention is always optimal.

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

$$\text{if } S = G \text{ then } \min_{I-I, I-N, N-I, N-N}\{2C_I, C_I, C_I, 0\}$$

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

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:

$$\text{if } S = G \text{ then } \min_{I-I, I-N, N-I, N-N}\{2C_I, (C_I + C_F), (C_I + C_F), 2C_F\}$$

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

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[15], $\Phi = B$:

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

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

---

[15]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.

after Stage 3. Then the CA's problem is:

if $S = G$ then $\min\limits_{I-I,I-N,N-I,N-N} \{2C_I, (C_I + C_F), (C_I + C_F), 2C_F\}$

if $S = B$ then $\min\limits_{I-I,I-N,N-I,N-N} \{(2C_I + C_S), (C_I + C_S + C_F), (C_I + C_S + C_F), 2C_F\}$

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.

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:

if $S = G$ then $\min\limits_{I-I,I-N,N-I,N-N} \{2C_I, C_I, (C_I + C_F), 2C_F\}$

if $S = B$ then $\min\limits_{I-I,I-N,N-I,N-N} \{(2C_I + C_S), (C_I + C_S), (C_I + C_S + C_F), 2C_F\}$

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

$$\text{if } (S, \Phi) = (G, G): \min\limits_{Del, NoDel} \{0, 0\}$$
$$\text{if } (S, \Phi) = (B, G): \min\limits_{Del, NoDel} \{0, 0\}$$
$$\text{if } (S, \Phi) = (G, B): \min\limits_{Del, NoDel} \{C_I, 2C_I\}$$
$$\text{if } (S, \Phi) = (B, B): \min\limits_{Del, NoDel} \{2C_F, 2C_I + C_S\}$$

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

It follows from applying equation (5):

$$E[W_{DEL} - W_{NAs}] = (1 - p)q(2C_F - (2C_I + C_S))$$
$$E[W_{DEL} - W_{CA}] = p(1 - q)C_I$$

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

Proof of Corollary 1. 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 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 4. 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:

$$\text{if } \lambda = G \text{ then } \min_{I-I,I-N,N-I,N-N} \{(2C_I + C_S), (C_I + C_S), (C_I + C_S + C_F), C_F\}$$

$$\text{if } \lambda = B \text{ then } \min_{I-I,I-N,N-I,N-N} \{(2C_I + C_S), (C_I + C_S + C_F), (C_I + C_S + C_F), 2C_F\}$$

$$\text{if } \lambda = \varnothing \text{ then } \min_{I-I,I-N,N-I,N-N} \{(2C_I + C_S), (C_I + C_S + C_F), (C_I + C_S + C_F), 2C_F\}$$

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

In Case IV:

$$\text{if } \lambda = G \text{ then } \min_{I-I,I-N,N-I,N-N} \{2C_I, C_I, (C_I + C_F), C_F\}$$

$$\text{if } \lambda = B \text{ then } \min_{I-I,I-N,N-I,N-N} \{2C_I, (C_I + C_F), (C_I + C_F), 2C_F\}$$

$$\text{if } \lambda = \varnothing \text{ then } \min_{I-I,I-N,N-I,N-N} \{2C_I, (C_I + C_F), (C_I + C_F), 2C_F\}$$

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 5. 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 3, 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:

$$\text{if } S = G \text{ then } \min_{I,N} \{C_I, C_F + C_P\}$$

$$\text{if } S = B \text{ then } \min_{I,N} \{C_I + C_S, C_F + C_P\}$$

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:

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

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 3 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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