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Abstract

We show that market discipline can be effective in resolving the moral hazard problem which arises when depositors do not know whether bankers are monitoring or not the projects they finance. Demandable debt, by allowing the possibility of bank runs, can induce bankers to monitor. However, market discipline comes at a cost. When depositors are not equally informed about the future value of bank assets, withdrawals caused by a liquidity shock may be confused with future insolvency and cause uninformed depositors to precipitate a run. Likewise, withdrawals due to upcoming insolvency may be confused with a liquidity shock and dissuade depositors from running. Bank runs are, therefore, costly and imperfect disciplinary devices for bankers. Our results offer a new perspective on the debate on market versus regulatory discipline of banks.

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1 Introduction

The safety and soundness of the banking system is an extremely valuable public good. Bank stability has always been a major concern for policymakers and a major topic of debate among economists. The issue is not purely academic, though, as many and recurrent bank runs and failures demonstrate. One cannot but notice the contrast between the variety of opinions expressed in the debate and the uniformity of policy stances. Since the devastating crises which undermined the stability of the US banking system in the 1930s, policymakers in industrialised countries have taken up a supervisory role and introduced deposit insurance. They have also chosen to offer a *de facto* complete insurance to the banking system by forbearing financially distressed banks and often bailing out insolvent ones.

This attitude, which has prevailed for the last half century, has been shaken by the many bank failures of the 1980s and 1990s. Systemic crises occurred both in developed and developing countries such as, for example, the United States, Finland, Japan, Chile, Argentina, Mexico, Indonesia, and Russia. Regulators in United Kingdom, Italy, Germany and France intervened to rescue individual banks in distress. According to most economists, the underlying cause of these crises was a problem of moral hazard. The *de facto* protection provided by regulators induced excessive risk-taking on part of banks.

These crises have renewed the debate on how to appropriately regulate the banking system. Several proposals have been put forth to reduce the distortions induced by the protective attitude of regulators. Most suggestions revolve around the ideas of strengthening supervision or increasing the price for bank protection by tightening capital adequacy ratios and deposit insurance premia.[1] Apart from problems of internal consistency of these possible solutions, it is striking that economists have only paid lip service to the possibility of relying on market discipline for overcoming bankers' moral hazard. It is here that our paper makes its contribution, by showing that the threat of bank runs, make possible by the use of demandable debt, can indeed pro-

proposals recently advanced by some policymakers, who have suggested to scale back deposit insurance coverage in order to restore market discipline.[2]

Few theoretical contributions have analysed these topics. The mainstream literature on bank runs does not consider issues of moral hazard, focusing instead on the role of banks in providing depositors with flexibility in the timing of consumption.[3] Diamond and Dybvig (1983), Jacklin and Bhattacharya (1988) and Chari and Jagannathan (1988), all build models where banks are equivalent to mutual funds and therefore there is no conflict of interest between depositors and bankers. These models provide different explanations for the occurrence of bank runs. Diamond and Dybvig show that runs are an unfortunate and undesirable side-effect of demandable debt and they happen as a 'sunspot' if depositors loose confidence in future bank solvency. Jacklin and Bhattacharya (1988) suggest, instead, that bank runs are information-based in that they are depositors' rational response to the arrival of negative information regarding the state of the bank's assets. Finally, Chari and Jagannathan (1988) argue that bank runs can be both information-induced and pure panics. The latter happen when depositors fear that some of them possess (superior) negative information about future bank returns.

To the best of our knowledge, the only paper which analyzes the incentive effects of demandable debt is Calomiris and Kahn (1991). They show that the threat of bank liquidation disciplines the banker when he can fraudulently divert resources ex post. Their analysis focuses on the issue of costly acquisition of information by depositors and gives a rationale for the imposition of the 'sequential service constraint' in the repayment of depositors. Calomiris and Kahn regard bank runs as always socially beneficial since they prevent fraud and allow the salvage of some of the bank's value.

Our approach provides a novel justification for the use of demandable debt as an incentive device for mitigating the moral hazard problem stemming from the banker's discretionary choice of whether to monitor projects or not. Unlike Calomiris and Kahn, this is done in a context where bank runs arise from the co-existence of liquidity, informed and uninformed depositors. This allows us to model both *(i)* how information is revealed to uninformed depositors by the withdrawal decisions of other depositors (as in Chari and Jagannathan) and *(ii)* how this feeds back to the withdrawal decisions of

[2] See, for example, Broaddus (1994), Chicago Fed Letter (1990) and Kaufmann (1994).

[3] For an overview of this literature, see Bhattacharya and Thakor (1993) and Freixas and Rochet (1998).

informed depositors. Therefore, we are able to explicitly model the costs and benefits of the incentive effects of demandable debt. The benefits consist of the incentive effects of demandable debt. The costs, instead, stem from the fact that, with demandable debt, inefficient liquidation (or continuation) may occur.

Debt demandability allows depositors to provide market discipline by watching the value of bank assets and triggering a run whenever they (rationally) expect this value to be low. Although it resolves moral hazard, market discipline comes at a cost. Since not all depositors are equally informed on the value of bank assets, it may happen that some commit errors in deciding when to run the bank. They may either leave their deposits at the bank when returns are in fact low, or they may withdraw their funds when returns are in fact high. The erroneous withdrawal decision of some depositors forces the others to precipitate a run. When this is the case, an ex post inefficient run has origin and a solvent bank is forced into liquidation. Therefore, the reliance on market discipline is a feasible incentive device, but an imperfect and costly one.

The rest of the paper is organized as follows. The model is described in section 2. The incentive effect of demandable debt is analysed in section 3. Section 4 concludes the paper.

2 The model

Consider an economy which lasts three periods (T = 0,1,2) and with two types of risk neutral agents: a bank and a continuum of depositors of measure one. The bank, which acts as a monopolist, can invest in a risky and illiquid project, which requires an outlay of one unit of capital at date 0. At date 2, the investment yields $x = H$ per unit invested if it succeeds and $x = 0$ in case it fails. Since the bank has no capital, it needs to raise funds from depositors. The bank can offer either a standard or a demandable deposit contract for different maturities, as specified below. Depositors are perfectly competitive and each endowed with one unit. The riskless interest rate is normalised to zero.

2.1 The bank

The probability of success of the project depends upon the behaviour of the banker: He can simply invest in the project or he can actively monitor it, increasing the probability of success. We denote the probability of success by p_b in the former case, and by p_g in the latter, with $p_g > p_b$. The subscripts b and g denote 'bad' (no monitoring) and 'good' (monitoring) behaviour on part of the banker. The project is economically viable only if the banker monitors: $p_g H > 1 > p_b H$. The banker may choose not to monitor in order to enjoy, at date 2, a non-trasferable private benefit B. The private benefit can be interpreted as the opportunity cost of not monitoring the project.

where B^S is defined as $B^S = (p_g - p_b)(H - R^S)$. In other words, B^S is the value of B which makes the banker indifferent between monitoring and not.

If condition (1) fails, the bank will be unable to raise funds with the standard debt contract because depositors anticipate that the banker will not monitor. Is there a way out to this problem? We now show that the use of a demandable debt contract can solve the moral hazard problem by inducing the banker to monitor the project.[5]

A *demandable debt contract* (D) is defined as a contract that requires one unit of investment at date 0 in exchange for the right to withdraw either *(i)* the initial unit of investment at date 1, or *(ii)* a repayment R^D at date 2. The face value of debt, R^D, is determined at date 0 so to guarantee depositors zero expected profits.

The bank pays off depositors who demand early withdrawal by liquidating the project. Liquidation is costly in the following sense. If only (relatively) few depositors ask for repayment at date 1, liquidation yields the initial unit of investment. If (relatively) many depositors withdraw at date 1, liquidation yields an amount ℓ which is less than the initial unit of investment. This assumption aims at capturing a notion of liquidity. Let LV represent the liquidation value of the project and let W be the amount of aggregate withdrawals of deposits at date 1. We assume:

$$LV = \begin{cases} 1 & \text{if } W \leq \overline{W} \\ \ell & \text{if } W > \overline{W} \end{cases}$$

where $\overline{W}$ and $\ell < 1$ are exogenously specified.

2.2 Depositors

There are two classes of depositors, liquidity depositors and strategic deposi-

depositors, $1-\widetilde{t}$, leave their funds at the bank until date 2.[6] Denote these two fractions 'early' and 'late' liquidity depositors, respectively. Without loss of generality, we assume that $\widetilde{t}$ can take three values, $0, t_1$ and t_2, with probabilities q_0, q_1 and q_2, respectively.[7]

Naturally, we also assume that the intermediate liquidity shock is more likely than the extreme ones: $q_1 > \frac{1}{2} > q_0, q_2$.

Strategic depositors, instead, compete for returns and behave strategically in order to maximise their utility, which is given by $U(c_1, c_2) = c_1 + c_2$. At date 0 they deposit their funds at the bank in exchange for a repayment $R^D > 1$ at date 2. At date 1, after the arrival of information on the future return of the project (as specified below), they decide whether to leave their deposits until date 2 or to withdraw prematurely.

All depositors withdrawing at date 1 submit their requests simultaneously. Depending on the value of aggregate withdrawals, W, each depositor receives either the initial deposit or a pro-rata share of the value of the bank's assets.[8] Similarly, depositors waiting until date 2 receive either the promised interest factor R^D or a pro-rata share of the value of the bank's assets. Without loss of generality, we simplify the analysis by assuming that depositors who do not withdraw at date 1 are not taken into account in the splitting of the value of the bank's assets.

2.3 Information

At date 1, a fraction α of strategic depositors receives a perfectly informative signal, $s \in \{H, 0\}$, on the future value of the bank's assets. The signal is the same for all informed strategic depositors. The remaining strategic depositors, $1-\alpha$, remains uninformed. At date 0, a strategic depositor does not know whether he will become informed or not.

[6] An analysis of the insurance provided to depositors by the bank goes beyond the scope of this paper, which concentrates on the incentive effects of demandable debt. By assuming risk neutrality, we avoid worry about the relationship between the shape of depositors' utility function and the project's liquidation value. On this issue, see Diamond and Dybvig (1983) and Jacklin and Bhattacharya (1988).

[7] A straightforward generalization to a continuous t would simply require its density function $f(t)$ to be strictly decreasing.

[8] Since we do not consider the issue of endogenous acquisition of information about project's future returns on part of depositors, we do not need to impose the sequential service constraint rule for depositors' repayment. On the role of the sequential service constraint, see Calomiris and Kahn (1991).

The realisation of $\widetilde{t}$ and $\widetilde{x}$ and the signal s received by informed strategic depositors are not observable by other agents in the economy. The only public information is the amount of aggregate withdrawals at date 1, W. In other words, what is observable is the total fraction of depositors who withdraw but not the reason behind their individual decisions.

Finally, we assume that $\widetilde{t}$ and $\widetilde{x}$ are independent of each other. Together, they describe the state of the world, $\theta \equiv (\widetilde{t}, \widetilde{x})$.

2.4 Parameter restrictions

In order for uninformed depositors to have a non-trivial signal extraction problem, we assume:

$$t_1 = \alpha \tag{2}$$

$$t_2 = t_1 + \alpha = 2t_1 \tag{3}$$

Condition (2) states that the fraction of informed depositors equals the intermediate fraction of early liquidity depositors. Condition (3) states that the largest fraction of early liquidity depositors equals the fraction of informed agents plus the intermediate fraction of early liquidity depositors.[9] Further, we assume:

$$\overline{W} = \frac{t_2}{2} \tag{4}$$

$$\ell = \frac{1 + t_1}{2} \tag{5}$$

Condition (4) fixes the threshold level of aggregate withdrawals beyond which the liquidation value of the project reduces to ℓ. Condition (5) specifies the liquidation value of the project when more than $t_2/2$ depositors withdraw at date 1.[10] Together these two conditions attempt to capture, in a reduced form, the determination of the asset's price in a secondary market. In the

[9] With these conditions in place, uninformed strategic depositors observe a noisy indicator of the bank's future asset returns from which they may be unable to infer θ. Hence, conditions (2) and (3) are neither restrictions on the structure of the economy, nor are they necessary for the existence of an equilibrium. Rather, they allow us to model confounding.

[10] From calculation available from the author, it can be shown that our results hold for a wide range of values of ℓ. Condition (5) is then imposed only for ease of simplicity.

spirit of Shleifer and Vishny (1992), condition (4) takes into account that the asset's price is determined by the asset's supply. Therefore, when the supply becomes large enough ($W > \overline{W}$), the price falls below the replacement value of capital. In the spirit of Akerlof (1970), condition (5) acknowledges the existence of a "lemons" problem which stems from the presence of asymmetric information about the asset's value. The secondary market prices the asset according to the only observable variable, W, which is correlated—albeit imperfectly—with the asset's value. When withdrawals exceed $\overline{W}$, the liquidation value falls, reflecting the market's expectation of a lower value of the asset.

2.5 Timing and notation

The time structure of the model is summarized in Figure 1. At date 0 the bank issues debt, investors deposit their funds, R^D is determined and the banker chooses whether to monitor the project or not. At the beginning of period 1, the fraction t of early liquidity depositors is realized and the signal s is observed by a fraction α of informed strategic depositors. Then, agents make their withdrawal decisions. If all strategic depositors withdraw at date 1, an *information-induced run* occurs: The bank liquidates the project and is closed down. If a run does not occur, at the beginning of period 2 the project's returns are realised and claims are settled. Conditional on the bank being solvent, each remaining depositor receives R^D and the bank retains the surplus.

T=0		T=1		T=2
investors deposit their funds; the banker chooses whether to monitor the project or not	fraction of early liquidity depositors realised; informed strategic depositors receive the signal	depositors make the withdrawal decision; the bank may liquidate the project	project returns are realised	depositors are repaid; the bank retains the surplus

Figure 1: Timing

Table 1 provides the list of notation which describes the model.

$\widetilde{x}$	= random return of the project at date 2 ($x = H, 0$)
$p_g(p_b)$	= success probability of the project when monitoring (no monitoring)
B	= private benefit
S	= standard debt
R^S	= face value of S
$\Pi_g^S(\Pi_b^S)$	= bank's expected profits when monitoring (no monitoring) with S
D	= demandable debt
R^D	= face value of D
$\Pi_g^D(\Pi_b^D)$	= bank's expected profits when monitoring (no monitoring) with D
W	= aggregate withdrawals
$\overline{W}$	= aggregate withdrawals beyond which $LV = \ell$
ℓ	= liquidation value when $\overline{W} \geqslant W$
$\widetilde{t}$	= fraction of 'early' liquidity depositors ($t = 0, t_1, t_2$)
q_i	= probability distribution of $\widetilde{t}$, $i = 0, 1, 2$
α	= fraction of informed strategic depositors

Table 1: Notation

3 The incentive effects of demandable debt

The equilibrium consists of three elements: the face value of debt R^D, the banker's monitoring choice at date 0, and depositors' withdrawal decisions at date 1. To find the equilibrium, we solve the model by backward induction. Given R^D and the banker's monitoring choice, we first analyse depositors' withdrawal decisions at date 1. Then we compute R^D and the banker's monitoring choice at date 0, taking into account depositors' withdrawal decisions.

3.1 Depositors' Withdrawal Decisions at date 1

At the beginning of period 1, the liquidity shock is realised and informed strategic depositors receive the signal s. Then, all agents choose simultaneously whether to withdraw or not, according to their type, to the available information and to others' decisions. We analyse the decision of each type of depositors in turn.

The decision of liquidity depositors is trivial: A fraction equal to the realisation of $\widetilde{t}$ withdraws deposits at date 1.

Informed strategic depositors make the withdrawal decision after observing s and W. Since $H \geqslant R^D > 1$, they would find it optimal to withdraw at date 1 when $s = 0$, irrespective of W. However, they choose to withdraw at date 1when they observe a 'long enough' W, irrespective of s. Indeed, when enough depositors withdraw at date 1, informed depositors know they will get less at date 2 if they did not withdraw. This is because the bank has to liquidate assets to satisfy withdrawals at date 1. Let $w^I(s, W)$ be the solution to informed strategic depositors' decision problem.

Uninformed strategic depositors make the withdrawal decision after observing W. They realise that W is correlated with s, although imperfectly. Indeed, W could be high either because the realisation of t is high or because informed agents have received a signal $s = 0$ concerning the value of assets at date 2. This confounding is crucial for the results. The decision problem faced by uninformed strategic depositors is then:

$$\max_{w^U(W)} \; c_1 + \int c_2 \, dF(\theta|W) \tag{6}$$

subject to:

$$c_1 = \begin{cases} w^U(W) & \text{if } W \leq \frac{1+t_1}{2} \\ \frac{\ell}{W} w^U(W) & \text{if } W > \frac{1+t_1}{2} \end{cases}$$

$$c_2 = \begin{cases} R^D(1 - w^U(W)) & \text{if } W \leq \frac{1+t_1}{2} \text{ and } x = H \\ 0 & \text{otherwise} \end{cases}$$

where $F(\theta|W)$ denotes the distribution of θ conditional on W. Let $w^U(W)$ be the solution to uninformed strategic depositors' decision problem.

The aggregate withdrawals demand, W_D

state	$\theta = (t, x)$	probability	W_D
1	$0, H$	$q_0 p_g$	$\frac{1}{2}[\alpha w^I(s, W) + (1-\alpha) w^U(W)]$
2	$0, 0$	$q_0(1-p_g)$	$\frac{1}{2}[\alpha w^I(s, W) + (1-\alpha) w^U(W)]$
3	t_1, H	$q_1 p_g$	$\frac{1}{2}[t_1 + \alpha w^I(s, W) + (1-\alpha) w^U(W)]$
4	$t_1, 0$	$q_1(1-p_g)$	$\frac{1}{2}[t_1 + \alpha w^I(s, W) + (1-\alpha) w^U(W)]$
5	t_2, H	$q_2 p_g$	$\frac{1}{2}[t_2 + \alpha w^I(s, W) + (1-\alpha) w^U(W)]$
6	$t_2, 0$	$q_2(1-p_g)$	$\frac{1}{2}[t_2 + \alpha w^I(s, W) + (1-\alpha) w^U(W)]$

Table 2: Aggregate withdrawals demand

A rational expectations Nash equilibrium for depositors' withdrawal decisions requires that agents make their optimal decision simultaneously, conditional on the information they have and taking into account the influence that their decision (and hence that of all depositors of their type) has on aggregate withdrawals. Formally, a rational expectations Nash equilibrium consists of:

(i) an aggregate withdrawal function $W(\theta)$ that specifies aggregate withdrawals for each state of nature θ, and

(ii) withdrawal demands $w^I(s, W(\theta))$ and $w^U(W(\theta))$ for informed and uninformed strategic depositors, such that:

(a) $W(\theta) = \frac{1}{2}[t + \alpha w^I(s, W(\theta)) + (1-\alpha) w^U(W(\theta))]$, for all θ

(b) $w^I(s, W(\theta))$ and $w^U(W(\theta))$ are the optimal solution to informed and uninformed depositors' decision problems

(c) if $W_D(\theta) = W_D(\theta')$, that is if $\frac{1}{2}[t+\alpha w^I(s, W(\theta))+(1-\alpha) w^U(W(\theta))] = \frac{1}{2}[t' + \alpha w^I(s, W(\theta')) + (1-\alpha) w^U(W(\theta'))]$, for any two states $\theta = (t, x)$ and $\theta' = (t', x')$, for all $w^I(s, W(\theta))$ and $w^U(W(\theta))$, then $W(\theta) = W(\theta')$.

A rational expectations Nash equilibrium is then characterized by the vector of aggregate withdrawals in each state of the world, $W = (W_1, W_2, W_3, W_4, W_5, W_6)$, which satisfies conditions (a), (b) and (c). Condition (a) resembles a market-clearing condition, which requires that aggregate withdrawals equal the sum of individual withdrawals. Condition (b) requires that depositors behave optimally. Condition (c) requires that if the aggregate withdrawals demand is the same for two states of the world, then the equilibrium outcome should also be the same. We now characterize the equilibrium.

Proposition 1 *: Under conditions (2) and (3), there exists a rational expectations Nash equilibrium* $W = (0, \frac{\alpha}{2}, \frac{t_1}{2}, \frac{1+t_1}{2}, \frac{1+t_2,}{2}, \frac{1+t_2}{2})$, *provided that:*

$$\frac{p_g q_1 R^D}{p_g q_1 + (1 - p_g) q_0} > 1 \tag{8}$$

$$\frac{p_g q_2 R^D}{p_g q_2 + (1 - p_g) q_1} < 1 \tag{9}$$

$$p_g R^D < \frac{1 + t_1}{1 + t_2} \tag{10}$$

Proof.

The proof consists of three steps:

Step (i)

We now go through each step in detail.

Step (i): the withdrawal decision of informed depositors conditional only on the signal s is:

$$w^I(s) = \begin{cases} 1 & \text{if } s = 0 \\ \\ 0 & \text{if } s = H \end{cases} \tag{11}$$

Given $w^I(s)$, the aggregate withdrawal demand at step (i), $W_D^{(i)}$, is shown in Table 4 for every state of the world.

The information partition of uninformed strategic depositors in the conjectured equilibrium $W^{(i)}$ (shown in Table 4) is:

$$\begin{array}{ll} W^{(i)} = 0 & \text{implies } \theta = \{1\} \\ W^{(i)} = \frac{t_1}{2} = \frac{\alpha}{2} & \text{implies } \theta = \{2,3\} \\ W^{(i)} = \frac{t_1+1}{2} = \frac{t_2+(1-\alpha)}{2} & \text{implies } \theta = \{4,5\} \\ W^{(i)} = \frac{t_2+1}{2} & \text{implies } \theta = \{6\} \end{array}$$

state	$\theta = (t,x)$	probability	$W_D^{(i)}$	$W^{(i)}$
1	$0, H$	$q_0 p_g$	$\frac{1}{2}(1-\alpha)w^U(W^{(i)})$	0
2	$0, 0$	$q_0(1-p_g)$	$\frac{1}{2}[\alpha + (1-\alpha)w^U(W^{(i)})]$	$\frac{\alpha}{2}$
3	t_1, H	$q_1 p_g$	$\frac{1}{2}[t_1 + (1-\alpha)w^U(W^{(i)})]$	$\frac{t_1}{2}$
4	$t_1, 0$	$q_1(1-p_g)$	$\frac{1}{2}[t_1 + \alpha + (1-\alpha)w^U(W^{(i)})]$	$\frac{t_1+1}{2}$
5	t_2, H	$q_2 p_g$	$\frac{1}{2}[t_2 + (1-\alpha)w^U(W^{(i)})]$	$\frac{t_2+(1-\alpha)}{2} = \frac{t_1+1}{2}$
6	$t_2, 0$	$q_2(1-p_g)$	$\frac{1}{2}[t_2 + \alpha + (1-\alpha)w^U(W^{(i)})]$	$\frac{t_2+1}{2}$

Table 4: Aggregate withdrawal demand and conjectured equilibrium in step (i)

Aggregate withdrawals are perfectly informative in states 1 and 6 but not in states 2, 3, 4 and 5.

Since $R^D > 1$, uninformed depositors find it optimal not to withdraw when $W^{(i)} = 0$, that is in state 1. Since $x = 0$, uninformed depositors find it optimal to withdraw when $W^{(i)} = \frac{t_2+1}{2}$, that is in state 6.

When $W^{(i)} = \frac{t_1}{2}$, uninformed depositors compute the expected utility from waiting until date 2 conditional on $\theta = \{2,3\}$, which is given by the left side of (8). Since this expected utility is greater than when withdrawing early, uninformed depositors find it optimal not to withdraw in states 2 and 3.

Finally, when $W^{(i)} = \frac{t_2+1}{2}$, uninformed depositors compute the expected utility from waiting until date 2 conditional on $\theta = \{4, 5\}$, which is given by the left side of (9). Since this expected utility is smaller than when withdrawing early, uninformed depositors find it optimal to withdraw.

The solution to uninformed depositors' decision problem in the conjectured equilibrium $W^{(i)}$, given $w^I(s)$, is then:

$$w^U(w^I(s)/W^{(i)}) = \begin{cases} 0 & \text{if } W^{(i)} = 0, \frac{\alpha}{2}, \frac{t_1}{2} \\ 1 & \text{if } W^{(i)} = \frac{t_1+1}{2}, \frac{t_2+1}{2} \end{cases}$$

Step (ii): Notice that $W^{(i)}$ is not an equilibrium since $w^I(s)$ is not a best response to $w^U(w^I(s)/W^{(i)})$. In state 5, in fact, informed depositors would get nothing from waiting until period 2, even if $s = H$. Given $W^{(i)} = \frac{1+t_1}{2} > \frac{t_2}{2}$ and $\ell = \frac{1+t_1}{2}$, the bank liquidates the project in order to pay off depositors withdrawing early. Informed strategic depositors then join the withdrawal queue so as to share the bank's resources at date 1. The solution to informed depositors' decision problem, given $w^U(w^I(s)/W^{(i)})$, is then:

$$w^I(s, W^{(ii)}) = \begin{cases} 1 & \text{if } s = 0 \text{ or } W^{(ii)} \geq \frac{1+t_1}{2} \\ 0 & \text{if } s = H \text{ and } W^{(ii)} < \frac{1+t_1}{2} \end{cases} \tag{12}$$

where $W^{(ii)}$ is the conjectured equilibrium at this stage.

Step (iii): We now verify that $w^U(w^I(s)/W^{(i)})$ constitutes uninformed depositors' best response to $w^I(s, W^{(ii)})$.

Table 5 gives the aggregate demand withdrawal, $W_D^{(ii)}$, for every state of the world, and given $w^I(s, W)$. $W_D^{(ii)}$ differs from $W_D^{(i)}$ only in state 5.

The information partition of uninformed depositors in the conjectured equilibrium $W^{(ii)}$ (shown in Table 5) is:

$$\begin{aligned} W^{(ii)} &= 0 && \text{implies } \theta = \{1\} \\ W^{(ii)} &= \tfrac{t_1}{2} && \text{implies } \theta = \{2, 3\} \\ W^{(ii)} &= \tfrac{t_1+1}{2} && \text{implies } \theta = \{4\} \\ W^{(ii)} &= \tfrac{t_2+1}{2} && \text{implies } \theta = \{5, 6\} \end{aligned}$$

state	$\theta = (t, x)$	probability	$W_D^{(ii)}$	$W^{(ii)}$	Run
1	$0, H$	$q_0 p_g$	$\frac{1}{2}(1-\alpha)w^U(W^{(ii)})$	0	no
2	$0, 0$	$q_0(1-p_g)$	$\frac{1}{2}[\alpha + (1-\alpha)w^U(W^{(ii)})]$	$\frac{\alpha}{2}$	no
3	t_1, H	$q_1 p_g$	$\frac{1}{2}[t_1 + (1-\alpha)w^U(W^{(ii)})]$	$\frac{t_1}{2}$	no
4	$t_1, 0$	$q_1(1-p_g)$	$\frac{1}{2}[t_1 + \alpha + (1-\alpha)w^U(W^{(ii)})]$	$\frac{t_1+1}{2}$	yes
5	t_2, H	$q_2 p_g$	$\frac{1}{2}[t_2 + \alpha + (1-\alpha)w^U(W^{(ii)})]$	$\frac{t_2+1}{2}$	yes
6	$t_2, 0$	$q_2(1-p_g)$	$\frac{1}{2}[t_2 + \alpha + (1-\alpha)w^U(W^{(ii)})]$	$\frac{t_2+1}{2}$	yes

Table 5: Aggregate withdrawals demand and conjectured equilibrium in step (ii)

Aggregate withdrawals are now perfectly informative only in states 1 and 4. As in step (i), uninformed depositors find it optimal not to withdraw in states 1, 2 and 3. Since $x = 0$, uninformed depositors find it optimal to withdraw when observing $W^{(ii)} = \frac{t_1+1}{2}$, that is in state 4.

When $W^{(ii)} = \frac{t_2+1}{2}$, uninformed depositors compute the expected utility from waiting until date 2 conditional on $\theta = \{5, 6\}$, which is given by the left side of (10). Since this expected utility is smaller than when withdrawing early, uninformed depositors find it optimal to withdraw in states 5 and 6.[12] Note that the ex ante and the ex post probabilities of success of the project coincide, since the realisation of t is the same in states 5 and 6:

$$pr(x = H/W^{(ii)} = \frac{1+t_2}{2}) = \frac{p_g q_2}{p_g q_2 + (1-p_g)q_2} = p_g$$

The solution to uninformed depositors' decision problem in the conjectured equilibrium $W^{(ii)}$ is then:

$$w^U(W^{(ii)}) = \begin{cases} 0 & \text{if } W^{(ii)} = 0, \frac{\alpha}{2}, \frac{t_1}{2} \\ 1 & \text{if } W^{(ii)} = \frac{t_1+1}{2}, \frac{t_2+1}{2} \end{cases} \tag{13}$$

Given $w^U(W^{(ii)})$, it is straightforward to verify $w^I(s, W^{(ii)})$ is the best response for informed strategic depositors. Therefore, the conjectured equilibrium $W^{(ii)}$ coincides with the actual equilibrium W. □

[12] Note that uninformed depositors only get $\frac{2\ell}{t_2+1} = \frac{t_1+1}{t_2+1}$ if they withdraw when observing $W^{(ii)} = \frac{t_2+1}{2}$, that is in states 5 and 6, because $l < 1$.

Proposition 1 implies that information-induced bank runs take place only in states 4, 5 and 6. Condition (8) assures that uninformed strategic depositors do not withdraw in states 2 and 3 since they expect to net more from leaving their funds than from withdrawing. Condition (9) and (10), instead, assures that uninformed strategic depositors withdraw in states 4,5 and 6 since they expect to net more from withdrawing than from leaving their funds.

Runs occurring in states 4 and 6 are efficient since they induce the liquidation of assets that would yield nothing if continued until period 2. The run occurring in state 5 is however inefficient, since it forces the liquidation of valuable assets. Likewise, continuation in state 2 is inefficient, since it would be optimal that withdrawals forced liquidation of the project in order to recover at least part of the investment.

Where do these inefficiencies come from? Both stem from the fact that uninformed depositors' inference problem is noisy: Conditional on the observation of aggregate withdrawals, uninformed depositors are not always able to infer the state of nature and, therefore, whether the bank is facing an insolvency or just a liquidity shock. Given this confounding, uninformed strategic depositors may make erroneous withdrawal decisions. They may withdraw when the project's returns are high (type I error) or leave their deposits until period 2, when the project's returns are low (type II error). Uninformed depositors realise that the magnitude of the aggregate withdrawal is positively correlated with the probability of the bank being insolvent. Therefore, they commit a type I error when aggregate withdrawals are large (state 5) and a type II error when aggregate withdrawals are low (state 2).[13]

Note that these two inefficiencies stem from 'rational' coordination problems among depositors, but that the coordination failure is different in each case. In state 2, inefficient continuation is due to the inability of uninformed depositors to realise that the queue consists only of informed depositors. In state 5, instead, the inefficient run is due to the inability of uninformed depositors to realise that the queue consists only of early liquidity depositors. In this latter case, the erroneous decision of uninformed depositors forces informed depositors to precipitate a run even if they know that the banks will be solvent.

[13]Since $q_1 > q_0$, q_2, when uninformed depositors observe high aggregate withdrawals they expect the bank being insolvent with a higher probability than when they observe low aggregate withdrawals.

This is different from both the coordination failure in Diamond and Dybvig (1983) and the panic equilibrium in Chari and Jagannathan (1988). Unlike these models, we always have information available to some depositors.

3.2 Determination of R^D and Banker's Monitoring Choice at T = 0

Let us now turn to date 0 when the bank offers the deposit contract and chooses between monitoring the project or not. The banker makes the decision about monitoring so as to maximise expected profits given that he must ensure zero expected returns to strategic depositors, and given aggregate withdrawals as in Proposition 1.

The face value of debt, R^D, is then determined by strategic depositors' participation constraint, taking into account that they do not know yet whether they will be informed or not at date 1. There is no participation constraint for liquidity depositors because they are not utility maximizers.[14] The value of R^D depends on the probability of each state of the world at date 1, shown in Table 6, and on equilibrium withdrawal decisions, $w^I(s, W)$ and $w^U(W)$.

state	probability	informed depositors' payoff

where:

i) the first two terms are the expected repayment for (informed and uninformed) strategic depositors at date 2, conditional on the bank being solvent and on no run occurring at date 1 (states 1 and 3);

ii) the third term is the expected repayment when informed depositors correctly withdraw their funds at date 1 after receiving a negative signal, while uninformed depositors erroneously wait until date 2 (state 2);

iii) the fourth term is the expected repayment for (informed and uninformed) strategic depositors when they correctly withdraw at date 1 and the bank has enough funds to repay them in full (state 4);[15]

iv) the fifth term is the expected repayment for both informed and uninformed strategic depositors when they withdraw at date 1 and get only a pro-rata share of bank's funds. It includes both the case of ex post inefficient run (state 5) and the case of efficient run with the highest realization of the liquidity shock (state 6).

The face value of debt, R^D, is then equal to:

$$R^D = \frac{1}{p_g(q_0+q_1)}\left[1-(1-p_g)(q_0\alpha+q_1)-q_2(\frac{1+t_1}{1+t_2})\right] \tag{14}$$

Note that condition (10) implies that $1 < R^D < R^S$. This is because $p_g R^S = 1$, while $p_g R^D < 1$. Depositors have different rights under the two types of contracts. With standard debt they must keep their money with the bank until date 2, and then get either R^S or 0. With demandable debt, instead, they can protect—albeit partially and sometimes erroneously—their investment by withdrawing at date 1. Therefore, they are ready to pay a 'price' for this right. This is the benefit of the 'discipline' function of demandable debt.[16]

It is worth pointing out that $R^D < R^S$ despite the fact that information is imperfect. Hence, with demandable debt, the larger payoffs received by strategic depositors who withdraw correctly (states 4 and 6) and by informed depositors in case of inefficient continuation (state 2) more than compensate (ex ante) the smaller payoff received by strategic depositors who incorrectly

[15] This is the case when all losses are borne by 'late' liquidity depositors ($\frac{1-t_1}{2}$) that receive nothing because they are not in the withdrawal queue at date 1 when the bank sells all its assets.

[16] Of course, R^D would be even lower had all strategic depositors perfect information on the future value of the bank's assets.

withdraw prematurely (state 5) and by uninformed depositors in case of inefficient continuation (state 2).

We now turn to the banker's monitoring choice. Table 7 shows the banker's payoffs when he monitors the project and when he does not, depending on the state of nature (and on depositors' withdrawal decisions as in Proposition 1).[17]

If the project is monitored, the bank makes positive profits only if there is no run and returns are high (states 1 and 3). If the project is not monitored, the bank makes positive profits whenever no run occurs. In particular, the bank gets the pecuniary payoff if there is no run and the project is successful (states 1 and 3) and the private benefit whenever it remains active until date 2, irrespective of the project's result (states 1, 2 and 3).

state	monitoring		no monitoring	
	probability	expected profits	probability	expected profits
1	$q_0 p_g$	$H - R^D$	$q_0 p_b$	$(H - R^D) + B$
2	$q_0(1 - p_g)$	0	$q_0(1 - p_b)$	$(1 - \frac{\alpha}{2})B$
3	$q_1 p_g$	$(1 - \frac{t_1}{2})(H - R^D)$	$q_1 p_b$	$(1 - \frac{t_1}{2})\left[H - R^D + B\right]$
4	$q_1(1 - p_g)$	0	$q_1(1 - p_b)$	0
5	$q_2 p_g$	0	$q_2 p_b$	0
6	$q_2(1 - p_g)$	0	$q_2(1 - p_b)$	0

Table 7: Bank's expected profits

The bank's expected profits are then given by:

$$\Pi_g^D = q_0 p_g (H - R^D) + q_1 p_g (1 - \frac{t_1}{2})(H - R^D) \tag{15}$$

when depositors correctly anticipate that the banker will monitor the project, and by:

$$\Pi_b^D = q_0 p_b \left[(H - R^D) + B\right] + q_0(1-p_b)(1-\frac{\alpha}{2})B + q_1 p_b (1-\frac{t_1}{2}) \left[(H - R^D) + B\right] \tag{16}$$

[17]In computing the bank's expected profits we take into account that, at date 2, the bank repays R^D to all depositors—both strategic and 'late' liquidity—because it cannot distinguish among them.

when depositors anticipate that the banker will monitor but he does not.[18] Clearly, if $\Pi_g^D > \Pi_b^D$, the banker finds it optimal to monitor the project, and the moral hazard problem is solved.

Proposition 2 *Given R^D and depositors' optimal withdrawal decisions, there exists a level of the private benefit, $\hat{B}$, such that demandable debt solves the banker's moral hazard problem for all $B \leq \hat{B}$.*

Proof. We define $\hat{B}$ as the value of B which makes the banker indifferent between monitoring and not, that is $\Pi_g^D = \Pi_b^D$. After substituting the expressions for the bank's expected profits given in (15) and (16), we obtain that:

$$\hat{B} = \frac{[q_0 + q_1(1 - \frac{t_1}{2})](p_g - p_b)(H - R^D)}{[q_0 + q_1(1 - \frac{t_1}{2}) - q_0\frac{t_1}{2}(1 - p_b)]} \tag{17}$$

It follows immediately that, for all $B \leq \hat{B}$, $\Pi_g^D \geq \Pi_b^D$, while for all $B > \hat{B}$, $\Pi_g^D < \Pi_b^D$. □

Proposition 2 states that market discipline is effective in resolving the banker's moral hazard problem, provided this is not too severe. The incentive effects of demandable debt depend on the different consequences of the threat of a bank run on the bank's expected profits. When the banker does not monitor, he is always penalized when a run takes place in that he loses his private benefits in states 4, 5 and 6—and his pecuniary profits in state 5. However, when he monitors, he is penalized less often, since he only loses his pecuniary profits (in state 5) when a run forces him to liquidate the (valuable) project. He does not loose anything when efficient runs take place (states 4 and 6). This is why the threat of bank runs is effective in inducing the banker to monitor the project.

Demandable debt, therefore, may constitute a solution to the consequences of asymmetric information. When credit markets do not work with standard debt, the introduction of demandable debt may be the solution:

[18] Note that the assumption $p_b H < 1$ implies that, if the banker does not monitor, rational depositors would not leave their funds with the bank because they would expect to make losses.

Proposition 3 *Since* $B^S < \hat{B}$, *for all* $B \in [B^S, \hat{B}]$, *demandable debt solve the banker's moral hazard problem but standard debt does not.*

Proof. By comparing expressions (17) and $B^S = (p_g - p_b)(H - R^S)$, it follows that $B^S < \hat{B}$. Therefore, for all $B \in [B^S, \hat{B}]$, it follows that $\Pi_g^D \geq \Pi_b^D$. This implies the second part of the claim. □

Proposition 3 shows that demandable debt is attractive because it allows depositors to react, although imperfectly, to the arrival of information, in the interim period, on the future value of the bank's assets.

4 Conclusion

In this paper we addressed two questions: (i) can bank runs discipline banker's moral hazard? (ii) what are the costs and benefits of demandable debt? With regard to the first question, we have shown that the threat of bank runs may constitute an effective incentive device. In particular, we have shown that demandable debt can induce bankers to monitor the projects they finance in situations when standard debt contract cannot. With regard to the second question, we have also shown that market discipline is costly. If some depositors are imperfectly informed on the value of bank assets, they may make mistakes when deciding whether to run on a bank or not: An insolvent bank may then be allowed to continue or a solvent bank may be erroneously forced into liquidation.

These results suggest a new perspective on bank regulation. Since market discipline works, but imperfectly, any sensible attempt to make it work should entail adequate regulatory measures aimed at eliminating the inefficiencies of market discipline. One possibility would be to increase the amount of information available to depositors. Should depositors be perfectly informed, market discipline would work seamlessly. The recent experience of Argentina, Chile and Mexico can be read in this perspective (Peria and Schmukler (1998)). Alternatively, regulators should secure the survival of solvent banks which are object of a run. The historical experiences of suspension of convertibility can be looked at from this angle. For instance, before the creation of the Federal Reserve system in 1914, the US relied on the existence of clearinghouses to reduce the probability of inefficient bank runs. Clearinghouses checked the solvency of member banks when a run occurred, acting as a delegated certifier on part of depositors and punishing banks which suspended convertibility without being solvent (Gorton (1985b)).

Recent empirical studies provide initial support for the efficacy of market discipline. Park and Peristiani (1998) and Peria and Schmukler (1998), among others, show that in both developed and developing economies depositors do react to the deterioration of banks' balance sheet. They find that depositors, whether small or large, punish risky banks by withdrawing their funds or by requiring higher interest rates.

Our framework could be extended in several directions. The first concerns the analysis of information. We have assumed that some depositors receive a costless signal on the value of bank assets. We could make the acquisition of information costly and endogenous. Also, we could study the channels through which information is disseminated. Second, we could examine depositors' risk aversion in order to assess the extent to which demandable debt can be successful in solving moral hazard, while at the same time being able to guarantee optimal risk sharing among depositors. Finally, we could extend our framework by introducing explicitly a role for a regulator. This would allow us to study formally the complementarity between market discipline and supervision, which arises from our results. This rich research agenda might help regulators achieve more informed and efficient decision making.

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