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Do Social Networks Prevent Bank Runs?

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Abstract

We report experimental evidence on the effect of observability of actions on bank runs. We model depositors' decision-making in a sequential framework, with three depositors located at the nodes of a network. Depositors observe the other depositors' actions only if connected by the network. A sufficient condition to prevent bank runs is that the second depositor to act is able to observe the first one's action (no matter what is observed). Experimentally, we find that observability of actions affects the likelihood of bank runs, but depositors' choice is highly influenced by the particular action that is being observed. This finding suggests a new source for the ocurrence of bank runs. Observability of actions can provoke runs that cannot be explained neither by coordination nor by fundamental problems, the two main culprits identified by the literature.

Keywords: bank runs, social networks, coordination failures, experimental evidence.

JEL Classification: C70, C91; D80; D85; G21

"I recently asked a group of colleagues -and myself- to identify the single most important development to emerge from America's financial crisis. Most of us had a common answer: The age of the bank run has returned." Tyler Cowen, The New York Times (March 24, 2012)

1 Introduction

During the Great Depression, much economic loss was directly caused by bank runs (Bernanke, 1983). More recently, in 2007, the bank run on Northern Rock in the UK heralded the oncoming economic crisis. Since then, several banks in other developed countries have experienced runs, such as the Bank of East Asia in Hong Kong and Washington Mutual in the US. Run-like phenomena have also occurred in other institutions and markets such as money-market, hedge and pension funds (Baba, McCauley and Ramaswamy, 2009; Duffie, 2010), the repo market (Ennis, 2012; Gorton and Metrick, 2011) and even in bank lending (Ivashina and Scharfstein, 2010). Recent examples of massive withdrawals in these markets and institutions include the collapse of Bear Stearns, the Lehman experience and the depositors run on Bankia, one of the biggest Spanish banks.

One of the leading explanations for the occurrence of bank runs concerns the existence of coordination failure by depositors (e.g., self-fulfilling prophecy). Depositors might rush to withdraw their money from a bank without fundamental problems if they think that other depositors will do it as well.[1] Diamond and Dybvig (1983) provide the seminal model of coordination problems among depositors. They represent the depositor coordination problem as a simultaneous-move game in which multiple equilibria emerge, one of which has depositors participating in a bank run. Although many researchers have continued to use and build on this seminal model of depositor coordination, descriptions of real-world bank runs (Sprague, 1910; Wicker, 2001) and statistical data (Starr and Yilmaz 2007) make clear that depositors' decisions are not entirely simultaneous but partially sequential. Many depositors have information about what other depositors have done and react to this information when making their decisions (Iyer and Puri, 2011; Kelly and O Grada, 2000). As it is shown in Kiss, Rodriguez-Lara and Rosa-Garcia (2012), the information flow among depositors might have policy implications (e.g., for the optimal design of deposit insurance); therefore

[1] The degradation of market and bank fundamentals (e.g. macroeconomic shocks, specific industrial conditions, worsening quality of the management) is the other main explanation for the occurrence of bank runs (see for instance Allen and Gale, 1998; Calomiris and Gorton, 1991; Calomiris and Mason, 2003; Gorton, 1988). Ennis (2003) cites examples of bank runs that occured in absence of economic recession and convincingly argues that although historically bank runs have been strongly correlated with deteriorating economic fundamentals, the coordination failure explanation cannot be discarded as a source of bank runs. Gorton and Winton (2003) provide a comprehensive survey on financial intermediation dealing in depth with banking panics.

understanding how observability of actions influences the emergence of bank runs is of first order importance.

This paper attempts to capture the effects of observability as a determinant of bank runs, an issue that has mostly been disregarded by the literature. We use a sequential model in the tradition of Diamond and Dybvig (1983), with three depositors located at the nodes of a network.[2] Our model builds on the assumption that links enable observability. Hence, a link connecting two depositors implies that the depositor who acts later can observe the other depositor's action. Likewise, the depositor who acts earlier knows that her action is being observed. These features allow the connected depositors to play a sequential game, while the depositors who are not linked play a simultaneous game. The social network structure determines then the type of strategic interaction (simultaneous or sequential) and the information flow among depositors.[3]

Depositors decide in sequence whether to withdraw their deposit or to wait.[4] In the spirit of Diamond and Dybvig (1983), we do not consider any aggregate uncertainty. It is common knowledge that there is an impatient depositor who has an immediate need for funds and always withdraws her deposit, regardless of the available information. The other two depositors, who are called patient depositors, do not need their money urgently and decide whether to withdraw their funds from the bank or keep them deposited.

If both patient depositors decide to keep the money in the bank, they receive the highest possible payoff. Withdrawal yields a lower but still relatively high payoff to the first two depositors who decide to withdraw. Waiting alone yields a lower payoff, and the worst payoff is received by the depositor who withdraws after other depositors have made two withdrawals. Given these payoffs, a patient depositor prefers to wait if the other patient depositor does so as well, but the possibility of observing a waiting (if a patient depositor decided to wait) is restricted by the network structure and the position in the sequence of decision.

We study the impact of different network structures on equilibria in a model of local information. A bank run occurs, according to our definition, if at least one of the patient depositors withdraws. We show that if the link between the first two depositors to decide (henceforth, link 12) is in place, no bank run arises in equilibrium. This result implies that when the link 12 is in place, patient depositors should wait, regardless of their position and what they observe. The link 12 (and not the information it transmits) thus represents a sufficient condition to prevent bank runs. If the link 12 does not exist, bank runs may occur in equilibrium because of a coordination failure (i.e., patient depositors might coordinate on the bank run equilibrium).

[2] We consider a small number of depositors so that our model could be interpreted as the possibility of a run in the wholesale market with big creditors. Models involving few depositors are often analyzed in the literature that focuses on bank runs (Ennis and Keister, 2009b; Green and Lin, 2000; Peck and Shell, 2003).

[3] We follow the standard convention in game theory, so even though decisions are made at different points in time, the game is simultaneous if players decide without knowing the actions chosen by others. By contrast, sequentiality implies that previous decisions are known.

[4] We will use "to keep the money in the bank" and "to wait" in an interchangeable manner.

Hence, non-observability of initial decisions make banks fragile (multiple equilibria).

To the best of our knowledge, our analysis is the first to use a network to model information flow among depositors in the classic bank-run problem. One of the advantages of our modeling choice is that it allows for the representation of both simultaneous and sequential moves in the same framework, and is the first model in the bank run literature to do so. Moreover, the use of networks reveals the importance of the information structure in determining whether the no-run equilibrium is unique or bank runs may arise.[5]

The idea of the link 12 as a sufficient condition to prevent bank runs represents a clear-cut prediction to be tested in a controlled laboratory experiment. We thus designed an experiment to mimic the theoretical setup described above. We matched subjects in pairs to form banks of three depositors, letting the computer act as the impatient depositor. Subjects and the computer were randomly set in a network structure. Subjects were asked to decide between waiting or withdrawing. They knew that the computer was programmed to always withdraw and were aware of the possible payoffs. The game was played for 15 rounds, and a different scenario was faced each time (i.e., a different network structure or/and a different position in the sequence of decision).[6]

In line with our theoretical prediction, we find that those network structures that have the link 12 produce the smallest probability of bank runs and are the most efficient ones (i.e., generate the highest payoffs). We also provide evidence that non-observability of decisions make banks fragile (bank runs are more frequent) but show that observability of decisions affects bank runs in a history-dependent way (i.e., observing early withdrawals triggers runs). At the depositors' level statistical tests do partially confirm the theoretical prediction and some interesting results arise. In those networks in which the link 12 exists, depositor 1's withdrawal rate is significantly lower than in those without this link. We also see that with respect to the case in which depositor 1 has no links, the link 13 has a considerable effect in reducing depositor 1's withdrawal rate. We interpret that depositor 1's behavior is driven by the fact that her action is observed. By waiting, depositor 1 can induce the other patient depositor to follow suit.

Regarding depositor 2, the experimental data confirm that the link 12 affects her withdrawal rate. We see that when depositor 2 observes a waiting, it decreases the likelihood of withdrawal, which is in line with our prediction. If depositor 2 observes a withdrawal, then she is likelier to withdraw; a finding that is at odds

[5] Diamond and Dybvig (1983) and Peck and Shell (2003) are examples of models with multiple equilibria. Goldstein and Pauzner (2005) show in a global games setup that both run and no run are possible equilibria but the fundamentals determine unambigously which one occurs. Green and Lin (2003) show that a bank can offer a complex contract that uniquely implements the efficient outcome. In our model, observability determines whether unique or multiple equilibria are expected.

[6] The network and the position in the line were exogenously determined so that we leave aside issues of network formation and endogenous positions while focusing on the impact of observability.

with our prediction. We also observe that depositor 3's choice is partially influenced by what she observes. Depositor 3 tends to wait upon observing that predecessors did the same, but observing withdrawals does not affect her likelihood of withdrawal. Although this behavior also contradicts (up to some extent) our theoretical prediction, it is worth noting that the depositor 2 and 3's departures from equilibrium behavior point out the importance of observability of decisions. In particular, we find that observing a waiting makes the strategic uncertainty disappear and fosters the equilibrium without bank runs, whereas the observation of a withdrawal sparks bank runs. A bounded-rationality model that assumes that each depositor has a specific cognitive level (representing the degree to which she can reason about other depositors) reconciles with our data. In particular, a level-k model explains bank runs that occur in the presence of the link 12, which cannot be explained in our model if depositors are fully rational.[7]

This finding suggests a new source for the occurrence of bank runs. We find that observability of actions can provoke runs in scenarios in which theoretically it is not possible to have them because of fundamental problems or coordination on the bank run equilibrium. Hence, our results differ from models in which bank runs are the outcome of the usual coordination failures (e.g. Schotter and Yorulmazer, 2009, or Garratt and Keister, 2009). Interestingly, our results emerge in a context with no aggregate uncertainty about the number of patient and impatient depositors. The observability of withdrawals triggers runs even in the absence of credit risk and asymmetric information about the health of the bank and these bank runs occur in a context of imperfect and incomplete information, which are intrinsic characteristics of the financial intermediation and financial markets, as well as many other real-life situations. This makes our model different from others in which successful coordination obtains due to perfect or less than perfect information (e.g. Choi, Gale and Kariv, 2008; Choi et al., 2011).

Overall, the results gleaned from our experiment complement our theoretical prediction by suggesting that the existence of a link at the beginning of the sequence can prevent the emergence of bank runs, but only under certain conditions. If depositor 1 is patient and her action is observed, bank runs occur less often than in the case in which no actions are observable. However, if a withdrawal is observed at the beginning, then bank runs may be even more frequent than in the case without observability. This finding suggests a new source for the occurrence of bank runs. We find that observability of actions can provoke runs in scenarios in which theoretically it is not possible to have them because of fundamental problems or coordination on the bank run equilibrium. Interestingly, our results emerge in a context with no aggregate uncertainty about the

[7] Crawford, Costa-Gomes and Iriberri (2012) and Klos and Strater (2010) provide a level-k explanation to bank runs using the basic coordination problem with simultaneous decisions and a global game that involves uncertainty about the fundamentals of the bank, respectively.

number of patient and impatient depositors. Hence, our results differ from models in which bank runs result from coordination failures (e.g. Schotter and Yorulmazer, 2009, or Garratt and Keister, 2009) and from models in which successful coordination obtains due to perfect or less than perfect information (e.g. Choi, Gale and Kariv, 2008; Choi et al., 2011). The observability of withdrawals trigger runs even in the absence of credit risk and asymmetric information about the health of the bank and these bank runs occur in a context of imperfect and incomplete information, which are intrinsic characteristics of the financial intermediation and financial markets, as well as many other real-life situations.

In Section 1, we review the literature and relate it with our findings. In Section 2 we detail our experimental design and present our theoretical framework. In Section 3, we analyze the experimental results. We discuss how a level-k model explains anomalies seen in the data in Section 4. Section 5 concludes.

Literature Review

Two strands of work are related to our paper: the literature on bank runs and the experimental literature on coordination.

A sizable part of the literature on bank runs follows the work of Diamond and Dybvig (1983) and models depositor behavior as a coordination problem that involves simultaneous decisions. Observability of past actions has received scarce attention in the theoretical literature but has been investigated in laboratory experiments.[8] Schotter and Yorulmazer (2009) generate conditions in the lab that lead to bank runs and investigate how different factors (e.g. asymmetric information, deposit insurance) affect how quickly depositors withdraw.[9] Theoretically, subjects' behavior should be invariant to the form of the game, but Schotter and Yorulmazer (2009) find that more information about other depositors' decisions (by observing how many people withdrew and their payoffs in previous rounds) leads to later withdrawals under some conditions. Although our approach is also concerned with the importance of information, our analysis departs from this study which assumes that a bank run is already underway, whereas we address how the bank runs emerge.

The novelty in Garratt and Keister (2009) is that in some treatments subjects were given up to three opportunities of withdrawal and sometimes faced forced withdrawals. When subjects were given multiple opportunities to withdraw, they were informed about the total number of withdrawals in their bank after each opportunity. Forced withdrawals occurred with some probability as some subjects were not allowed to

[8] Observability plays a central role in the theoretical model of Gu (2011), but the scope of her paper is very different. She considers that patient depositors withdraw only if they expect the bank to perform poorly, so she focuses on a signal extraction problem while leaving coordination problems aside.

[9] Kiss, Rodriguez-Lara and Rosa-Garcia (2012) and Madies (2006) also investigate the efficiency of deposit insurance to curb bank runs by means of laboratory experiments.

decide on their own but were forced to withdraw; thus, the other subjects observed these forced withdrawals. Garratt and Keister (2009) find that uncertain withdrawal demand when subjects have multiple opportunities to withdraw lead to frequent bank runs, while these factors alone do not result in a high number of bank runs. They claim that more information about other depositors' decisions may be harmful for coordination when there are still opportunities to withdraw. Similarly to Garratt and Keister (2009), our experimental evidence highlights that when a withdrawal is observed, bank runs are more likely to emerge. As a result, the impatient depositor (i.e., the computer) in the first position may increase the likelihood of bank runs. However, if depositor 1 is patient, the link 12 enforces coordination and helps to prevent bank runs in equilibrium. Our papers diverge also in the experimental design. Unlike Garratt and Keister (2009), we do not consider multiple possibilities of withdrawal or force individuals to withdraw. Instead, withdrawal demand in our experimental design is certain and due to the computer (i.e., it is programmed into the simulation software), so that there is no aggregate uncertainty in our model.[10] This is a key feature as we show that even with known withdrawal demand the frequency of bank runs varies substantially depending on the network structure and on the observed decisions (i.e., even in the absence of aggregate uncertainty bank runs may occur frequently).

There are further important differences between our work and these experimental papers on bank runs. First, observability of actions in previous papers allow multiple opportunities to withdraw so as to compare the simultaneous and the sequential setup. In our design, the simultaneous setup is characterized by the empty network and the fully sequential one by the complete network, but we also investigate network structures that involve partial information. Second, our approach is an attempt to study how differences in the information structure influence whether bank runs occur. We indeed test conditions that ensure a unique equilibrium without bank runs. The idea of the link 12 as a sufficient condition to prevent bank runs makes our paper divert from the other experimental papers (e.g., Arifovic, Jiang and Xu, 2011), which do not identify conditions that lead to a unique equilibrium with no bank run.

Our paper is also related to the large literature on coordination games in experimental economics. More specifically, the spirit of our experiment is very much related to coordination problems in networks.[11] The closest paper to ours is Choi et al. (2011) who analyze how the network structure affects coordination in a public-good game and find that observability leads to higher cooperation in some network structures while

[10] In Schotter and Yorulmazer (2009) uncertainty involves the fundamentals of the bank, since banks have different quality that is generally unobservable to depositors. Chari and Jagganathan (1988) show theoretically how a heightened withdrawal demand may be perceived incorrectly as a signal that the bank's quality is poor.

[11] See Devetag and Ortmann (2007) for a comprehensive discussion of coordination games in experiments. Kosfeld (2004) provides a special survey on network experiments.

it is detrimental in others. In their model, the network structure is known. Given the nature of bank runs, it seems reasonable to consider the assumption of imperfect and incomplete information in our case. Despite other obvious differences in the model (e.g., there are no incentives to free-ride in our model) there is a striking similarity in the results. They call strategic commitment the tendency to make contributions early in the game to encourage others to contribute. This commitment is of strategic value only if it is observed by others. Our finding that depositor 1 is more likely to wait when observed by any of the subsequent depositors can be seen as a case of strategic commitment. Similar results are obtained by Brandts and Cooper (2006), who focus on the importance of observability in the context of coordination in organizations.

2 The Setup

Experimental Design

A total of 48 students reporting no previous experience in laboratory experiments were recruited among the undergraduate population of the Universidad de Alicante. Students had no (or very little) prior exposure to game theory and were invited to participate in the experiment in December 2008. We conducted two sessions at the Laboratory of Theoretical and Experimental Economics (LaTEx). The laboratory consists of 24 computers in separate cubicles. The experiment was programmed and conducted using the *z-Tree* software (Fischbacher, 2007). Instructions were read aloud with each subject in front of his or her computer. We let subjects ask about any doubts they may have had before starting the experiment.[12] The average length of each session was 45 minutes. Subjects received on average 12 Euros for participating, including the show-up fee.

In both sessions, subjects were divided into two matching groups of 12. Subjects from different matching groups never interacted with each other throughout the session. Subjects within the same matching group were randomly and anonymously matched in pairs at the end of each round. Each of these pairs was assigned a third depositor, simulated by the computer so as to create a three-depositor bank. Subjects played a coordination problem for 15 rounds. Subjects knew that one of the depositors in the bank was simulated by the computer. In the spirit of the bank-run literature, we refer to the computer as the impatient depositor because it was programmed to always withdraw. The other two depositors in the bank were members of the subject pool. We refer to them as patient depositors.

In each round, subjects were asked to choose between withdrawing or waiting. Before making their decisions, subjects were informed about their position in the line. They knew that this position ($i = 1, 2, 3$)

[12] This paper contains supplementary material. The instructions are in the Appendix A.

was randomly and exogenously assigned and that it was subjects' private information. Furthermore, they knew that positions were equiprobable and independent of previous rounds (e.g., the computer was not more probable to be at the beginning of the sequence).

Before proceeding to explain the network structures that determine the information flow among depositors, we mention a few noteworthy aspects of the experimental design. First, types (patient or impatient) were not publicly observed in our experiment, but there was not aggregate uncertainty about the number of patient and impatient depositors. This feature of our design is in line with the original model of Diamond and Dybvig (1983) and makes our model divert from other experiments in which the number of depositors who are forced to withdraw is unknown (e.g., Garratt and Keister, 2009). Second, a random position in the decision-making sequence was assigned to each participant because our theoretical model relies upon the assumption that positions are known (as is the case in Andolfatto, Nosal and Wallace, 2007; Ennis and Keister, 2009b; Green and Lin, 2000). The aim of our experiment is to investigate the depositors' behavior in all possible scenarios. By assigning subjects a random position in the line (instead of allowing them to decide), we control for this feature and collect information about depositors' behavior in many different environments.[13]

The Network Structure

We model the information flow among depositors through a network. A network (Γ) is the set of existing links among the depositors. Two depositors are neighbors if a link connects them. A link is represented by a pair of numbers ij for $i, j \in \{1, 2, 3\}$, $i < j$. For instance, 12 denotes that depositor 1 and depositor 2 are linked; therefore, depositor 1 knows that depositor 2 will observe her action and that depositor 2 chooses after observing depositor 1's action. Then, when depositor i has to decide, she knows: (a) the actions of neighbors who acted earlier, and (b) whether her action would be observed by neighbors deciding later. Depositor i does also know her own type and her position in the line. The network structure, however, was not commonly known, meaning that information was local and thus no depositor knew whether the other two depositors were connected.[14]

Links were independent of types, so depositors of the same type were not more likely to be linked, nor

[13] The optimal decision on when to go to the bank has not been studied in the theoretical models of bank runs, thus we study all the possible sequences. We note that if we allowed subjects to decide *when* to go to the bank, we might lack observations for instance with the computer at the beginning of the sequence.

[14] We note that the network allows the depositors to obtain information about what happened in their bank in each round, but subjects in the experiment do not get any information about the history (e.g., they never know what their neighbors have done in previous rounds or the networks that their neighbors have played in).

was there any relationship between types and the number of links. Subjects were aware of these features and knew that the information structure was exogenously given (i.e., it was not the depositor's choice to decide her position in the line or the number of links). Finally, it was commonly known that position in the line, the network structure, or both changed in each round.

We considered all of the possible networks: $(12, 23, 13)$, $(12, 23)$, $(12, 13)$, $(13, 23)$, (12), (13), (23), $(\emptyset)$, where $(\emptyset)$ stands for the empty network, which has no links at all, whereas the structure $(12, 23, 13)$ contains all the possible links and is called the complete network. The empty network can be interpreted as a simultaneous-move game where depositors have no information about other depositors' actions, as in Diamond and Dybvig (1983). On the other hand, the complete network represents a fully sequential setup, meaning that depositors observe predecessors' actions.

The Underlying Model

Here we describe the underlying model that is played in each round.

Consider that each of the three depositors in the sequence deposits her endowment of $e > 0$ monetary units in the bank at $t = 0$ and signs a contract that specifies the depositors' payoffs depending on two factors: (a) depositors' choice at $t = 1$, and (b) the available funds of the bank.

At the end of $t = 0$, depositors learn their types, their links and their position in the sequence of decision ($i = 1, 2, 3$). Private types and equiprobable positions imply that only the conditional probability of the type sequence was known. For instance, if depositor 1 is patient, then both type sequences (patient, patient, impatient) and (patient, impatient, patient) have probability $1/2$. The impatient depositor only cares about immediate consumption, so she always withdraws at $t = 1$. The other two depositors derive utility from consumption at any period, so as they are called to decide at $t = 1$, they may either keep the money in the bank or withdraw it. Depositors cannot trade directly and they decide once, according to their position in the sequence.[15]

Notationally, $y^i \in \{0, 1\}$ for $i = 1, 2, 3$ stands for depositor i's decision, where 0 denotes keeping the money, whereas 1 indicates withdrawal. We define as $y^{-i} \in Y^{-i}$ the unordered decisions of the other depositors, where $Y^{-i} = (\{1, 1\}, \{1, 0\}, \{0, 0\})$. We denote as c_1^i depositor i's payoff upon withdrawal at $t = 1$ and c_0^i the payoff if she waits at $t = 1$ for $i = 1, 2, 3$. We assume that the utility functions are strictly

[15] The importance of trade possibilities among depositors is discussed in Jacklin and Bhattacharya (1988). The absence of trade possibilities is a standard assumption in bank-run models (e.g., Ennis and Keister, 2009a, Green and Lin, 2003, Peck and Shell, 2003). In these models, it is also assumed that depositors learn their types after signing the contract and before making their choices. We assume that all decisions are made at t=1 as in the literature. At t=1, we can think of three stages, with each depositor deciding in one of these stages.

increasing and strictly concave.

Payoffs

We now detail the payoffs in the experiment. Depositors have an endowment of $e = 40$ pesetas in each round.[16] This amount was deposited in their common bank. The contract $\gamma = (c_{00}, c_1, c_{01}, c_{11}) = (70, 50, 30, 20)$ resembles the *ex ante* optimal contract in Diamond and Dybvig (1983) and it allows for coordination problems, satisfying the following relations[17]:

$$c_{00} > c_1 > e > c_{01} > c_{11} \tag{1}$$

If a depositor decides to withdraw at $t = 1$, then she immediately receives the money from the bank. Payoff upon withdrawal is $c_1^i = c_1 = 50$ for $i \in \{1, 2\}$, and for $i = 3$ it is

$$c_1^3 = \begin{cases} c_1 = 50 \text{ if } y^{-3} \in \{\{1,0\}, \{0,0\}\} \\ c_{11} = 20 \text{ if } y^{-3} = \{1,1\} \end{cases} .$$

In words, the bank commits to pay $c_1 = 50$ to the first two withdrawing depositors. This amount corresponds to the depositor's initial endowment ($e = 40$) plus an interest rate of 10 monetary units. Note that depositor 3 may be the first or second withdrawing depositor and that in this case she receives $c_1 = 50$. If depositor 3 withdraws after two withdrawals, then she gets the remaining funds in the bank ($c_{11} = 3e - 2c_1 = 20$), which amount to less than her initial endowment $e = 40$.

If at least one of the depositors waits, the amount of funds the bank has at the end of period 1 is either $E_1 = 3e - c_1 = 70$ or $E_2 = 3e - 2c_1 = 20$. We assume that this amount earns a return and then is

[16] We used Spanish pesetas in our experiment, as this practice is standard for all experiments run in Alicante. The reason for this design choice is twofold. First, it mitigates integer problems, compared with other currencies (USD or Euros, for example). On the other hand, although Spanish pesetas are no longer in use, Spanish people still use pesetas to express monetary values in their everyday life. In this respect, by using a "real" currency we avoid the problem of framing the incentive structure of the experiment using a scale (e.g., "experimental currency") with no cognitive content.

[17] In order to derive an optimal contract, we would need to know participants' utility functions, which is not feasible. In that vein, we follow previous papers in this literature and specify an arbitrary contract as in Garratt and Keister (2009) and Schotter and Yorulmazer (2009). A common feature with these experimental papers is that depositors cannot choose whether to invest their endowment in the bank or not. Although this implies that we cannot disentangle incentives to withdraw due to violation of individual rationality and due to observability of actions, we note that our objective is to compare depositors' behavior across network structures. To that aim, we only need to assume that withdrawals that are due to violation of individual rationality are not affected by the network structure.

split up equally among the depositors who have waited, yielding the following payoffs at $t = 2$ for $i = 1, 2, 3$,

$$c_0^i = \begin{cases} c_{00} = 70 \text{ if } y^{-i} = \{1, 0\} \\ c_{01} = 30 \text{ if } y^{-i} = \{1, 1\} \end{cases},$$

where the first symbol (0) in the subscript shows that depositor i waits, while the second symbol denotes the other patient depositor's decision. In words, if both patient depositors wait at $t = 1$, then the total amount $E_1 = 70$ is doubled and divided equally among them. If only one patient depositor decides to wait, then the available money after the two withdrawals ($E_2 = 20$) is incremented by 10 units and then given to the patient depositor who waited, that is, $c_{01} = 30$.[18]

Figure 1 summarizes the timing of our model:

Figure 1. Timeline for the sequence of events

A key element of the model is that when depositors decide, they know their position, but they may not be sure of the payoff they will receive. For instance, if a patient depositor 1 waits, then her payoff depends on what the other patient depositor does (i.e., $c_0^1 \in \{70, 30\}$). Similarly, if depositor 3 has no links and decides to withdraw, she does not know whether she will receive $c_1 = 50$ or $c_{11} = 20$.

We define a bank run in the following way.

Definition 1 *A* bank run *occurs if at least one patient depositor withdraws, that is, there exists a bank run whenever* $\sum_{i=1}^{3} y^i > 1$.

This definition is the broadest, and accordingly, a withdrawal due to a patient depositor already constitutes a bank run. Our theoretical result states that, for any payoff structure satisfying condition (1), the link 12 prevents bank runs.

Proposition 1 *If the link 12 exists, any perfect Bayesian equilibrium satisfies the condition that bank runs do not occur. In any network in which the link 12 does not exist, bank runs may occur in equilibrium.*

The formal proof is relegated to the Appendix B**.** Proposition 1 establishes that in the set of networks comprised of $\{(12, 23, 13), (12, 23), (12, 13), (12)\}$ bank runs should never occur. The intuition for this result is the following. Depositor 3 has a dominant strategy and always waits if she is patient, regardless of the network structure. This waiting occurs because for any possible history, waiting yields a higher payoff than

[18] In the experiment, we justified these payoffs by stating that the bank carries out a project at $t = 1$, and obtains the benefits at $t = 2$. The profits of the projects depend on the amount (E_1 or E_2) at $t = 1$. Kiss, Rodriguez-Lara and Rosa-Garcia (2012) vary the value of c_{01} so as to analyze the effect of deposit insurance on the likelihood of bank runs.

withdrawing. Next, suppose that the link 12 is in place. If a patient depositor 2 observes a waiting, her optimal decision is to wait. As a consequence, a patient depositor 1 waits because she receives the highest payoff either because she will induce depositor 2 to wait as well or because depositor 3 is waiting (i.e., when depositor 2 is impatient, she will not wait, but depositor 3 will). Then, depositor 2, upon observing a withdrawal, must infer that it is due to the impatient depositor with certainty and that the best she can do is to wait. When the link 12 does not exist, in equilibrium depositor 1 (depositor 2) believes that depositor 2 (depositor 1) is patient with probability $\frac{1}{2}$, given that each possible type of sequence describing positions in the line is equiprobable.[19] In this case, depositor 1 and depositor 2 may withdraw in equilibrium, even if patient, as their optimal strategy depends on their beliefs about what the other patient depositor does. However, they may also choose to wait, hence there are multiple equilibria in pure strategies.

The existence of the link 12 helps us to disentangle network structures in which the equilibrium is unique and network structures in which there is multiplicity of equilibria. If the link 12 exists, the unique perfect Bayesian equilibrium predicts that patient depositors will wait regardless of their position in the line. Therefore, a bank run that occurs in the presence of the link 12 cannot be explained by fundamentals or coordination on the bank run outcome. When the link 12 does not exists, there are multiple equilibria. Payoff-dominance predicts that there will not be any bank run in equilibrium, while risk dominance would predict the no-run equilibrium or the run equilibrium, depending on the risk aversion of depositors.[20]

Although there is no clear-cut prediction in the absence of the link 12, Schotter and Yorulmazer (2009) highlight the benefits of information and find that more information leads to a better outcome because depositors withdraw later (see also Brandts and Cooper (2006), Choi, Gale and Kariv (2008), Choi et al., (2011), for experimental evidence on the effects of information in coordination). Our conjecture is that network structures that contain a higher number of links would perform better than networks with less links. Since links enable observability of actions in our model, a patient depositor at the beginning of the line can interpret that it would be easier for depositor 3 to wait if she observed a waiting from depositor 1 or depositor

[19] It is possible to calculate these conditional probabilities because positions are exogenously and randomly determined in our experiment. In the case of endogenous positions, computing the same conditional probabilities would be complicated as one would need to know depositors' beliefs about the position of the other patient depositor.

[20] For the case in which the link 12 does not exist, payoff dominance selects the equilibrium of no bank run since it yields the highest payoff of 70. In order to obtain the risk dominance prediction, we simplify the game assuming that the depositor 3 always follows her dominant strategy, therefore we ignore the links with this depositor in the analysis. Consider a patient depositor in the first position. If she withdraws, she gets 50. If she and the other patient depositor wait, she gets 70. If she waits and the other patient withdraws, she gets 30 with 0.5 probability (if the other patient is a position 2) or 70 with 0.5 probability (if the other patient depositor is at position 3). If depositors have a CRRA utility function $u(c) = \frac{c^{1-\rho}}{1-\rho}$, risk dominance predicts in this game the no-run equilibrium for $\rho < 2.5726$ and the run equilibrium for $\rho > 2.5726$.

2 (i.e., this waiting represents the depositors' strategic commitment to wait). In that vein, depositors 1 and 2 would be more likely to wait if linked with depositor 3, although this observed waiting does not have any additional value besides making strategic uncertainty to disappear.

3 Experimental Evidence

Descriptive Statistics and Aggregate Analysis

In this section, we summarize the data gathered during the experimental sessions. The main results and insights are presented in Table 1. We report the network structure in the first column. The second column specifies the position of the impatient depositor (i.e., the computer), and the third column shows the number of observations. In the next three columns, we present the frequency of withdrawal for patient depositors 1, 2 and 3. The bank run column indicates the frequency of bank runs in each scenario. Recall that there is no bank run if neither of the two patient depositors withdraws; therefore, this column contains the likelihood of the complementarity of that event. For the sake of completeness, we report in parenthesis the proportion of bank runs that are due to both patient depositors withdrawing, which measures the severity of the run. We compute the depositors' payoffs' deviations from the maximum possible payoff that they can receive (190 pesetas) and report them as "Efficiency losses". We rank the information structures according to the level of efficiency in the next column. Finally we pool the data in the last three columns ignoring the impatient depositor's position.

Table 1. Likelihood of bank runs

To appreciate the effect of the network structure, it is worth looking first at the pooled data in the last three columns. At the top of the ranking, we can see the networks that produce the smallest likelihood of bank runs and then the minimum efficiency losses. All these networks have the link 12, whereas the network structures at the bottom of the ranking -that perform worse in terms of bank runs and efficiency- do not have this link.[21] This is in line with our theoretical prediction, which establishes that no bank run will be the unique equilibrium if the link 12 exists. We also conjectured that patient depositors might interpret links as an important device to make observable the commitment to wait, inducing the other depositor to do it as well, and hence making bank runs less likely. Conditional on the existence of the link 12, the complete network (12,13,23) is the best one in terms of efficiency, whereas the network (12) produces the highest

[21] The interested reader can see Appendix C for further details on the statistical tests.

likelihood of bank runs. We can also see in Table 1 that if the link 12 does not exists, then bank runs are less likely to occur in the network (13,23) than in (13) and (23), which do perform better than the empty network. Our first result therefore confirms our theoretical prediction that banks are fragile in the absence of the link 12.

Result 1. *The network structure matters and plays a key role in determining the likelihood of bank runs and the level of efficiency. In particular, the link 12 significantly reduces the likelihood of bank runs and produces the highest levels of efficiency. Bank runs are less likely when the network structure has more links, both when there is link 12 and when there is not.*

To further appreciate the effect of the network structures, we look now at the disaggregated data which account for the impatient depositor's position. At this level, our theoretical prediction is partially confirmed and some interesting results emerge.

When we consider the impatient depositor's position, the results in Table 1 indicate that the top-five network structures have the link 12. On the contrary, four out of five network structures at the bottom of the ranking do not contain this link. As an example, note that in the empty network depositors know their position, but it is of no help to prevent bank runs. As a result, the frequencies of bank runs are in the worst third of the cases. Contrariwise, we see that the complete network has the lowest frequency of bank runs (0% and 13%), which suggests that if information abounds due to the existence of many links, then bank runs are less likely to occur. However, in the complete network, it is also worth noting that when the impatient depositor is the first one to decide, the frequency of a bank run surges and reaches a level that is comparable to the case of the empty network. This is an indication that both the amount of information and what is being observed matter.

Theoretically, we have seen that the existence of the link 12 prevents bank runs. We see in Table 1 that depositor 1's withdrawal rate is between 0% and 25% when the link 12 is present, whereas it is between 18% and 73% when the link 12 does not exist. However, the evidence is not so clear for depositor 2, as her decision seems to be affected by the position of the impatient depositor. In particular, when the link 12 exists, depositor 2 is more likely to withdraw when the depositor 1 is the computer. This result suggests that observing a withdrawal with certainty plays a role in depositor 2's decision.[22]

In Table 1, we can also see that in any network in which the link 12 does not exist, the smallest frequency of bank runs occurs when depositor 1 is impatient. In addition, if we look at the likelihood that a bank run

[22] Note that the observation of a withdrawal seems to affect depositor 3 as well. See, for example, the network (12,13) when the computer is depositor 1. We relegate the discussion of the depositor 3's behavior to the regression analysis.

occurred because both patient depositors withdrew (in parentheses) we see that runs are more severe when the link 12 is present and the computer is depositor 3. Overall, these findings (and statistical tests reported in Appendix C) confirm that the impatient depositor's position is relevant both to affect the likelihood and the severity of bank runs.

Result 2. *The effect of link 12 depends on the impatient depositor's position. When the first depositor to decide is impatient, the link 12 significantly increases the likelihood of bank runs, otherwise the frequency of bank runs significantly decreases in the presence of link 12. We also find that when the third depositor to decide is impatient, the link 12 exacerbates the severity of the bank run.*

Our theoretical prediction establishes that non-observability of decisions makes banks fragile (multiple equilibria) and the existence of the link 12 represents a sufficient condition to prevent bank runs. Our result 2 highlights that observability affects the emergence of bank runs in a history-dependent way. In the presence of the link 12, the position of the impatient depositor can make observable a withdrawal at the beginning of the sequence what might trigger a run. The beneficial effects of the link 12 therefore materializes when the first depositor to decide is patient, so that she can induce the other patient depositor to follow suit. If the first depositor to decide is patient and withdraws, then the link 12 exacerbates the severity of the run that is already underway.

Depositors' Behavior

Next, we analyze depositors' behavior in detail. We estimate a logit model in which the dependent variable is the probability of withdrawal.[23] Recall that $y^i \in \{0,1\}$ for depositor $i = 1, 2, 3$ denotes her decision, where 0 stands for keeping the money, whereas 1 indicates withdrawal. We propose the following specification for depositor 1.

$$\Pr(y^1 = 1) = F(\alpha_0 + \alpha_1 L12 + \alpha_2 L13 + \alpha_3 L12L13) \tag{2}$$

where $F(z) = e^z/(1+e^z)$ and the explanatory variable Lij is defined as a dummy variable that takes the value 1 (0) when link ij is (not) present for $i = 1$ and $j \in \{2, 3\}$. L12L13 is then obtained as the product of the two dummy variables L12 and L13, and it stands for the cases in which both links are present (networks $(12, 13)$ and $(12, 13, 23)$). L12L13 enables us to see whether there is some additional effect of having both links apart from the effect that the links generate separately.

Equation (2) accounts for all the possible information that depositor 1 might have and states that the probability of withdrawal for depositor 1 may depend on the existence of the links 12 and 13. We run the

[23] The probit specification yields qualitatively the same results.

logit model in (2) over 238 observations. The results are presented in Table 2. The estimated standard errors of the parameters take into account the matching group clustering.[24] The marginal effects are evaluated at the level of the sample means.

Table 2. Logit model for depositor 1

All the coefficients are significantly different from 0 except α_3, so the links 12 and 13 jointly have no additional effect apart from the separate effects that they have. The marginal effects in Table 2 reveal that the probability of withdrawal depends negatively on the existence of the links 12 and 13. The link 12 decreases the probability of withdrawal for depositor 1 around 20% whereas the link 13 decreases this probability by 10%. Both probabilities are significantly different from zero at the 1% significance level. If we test the hypothesis that the link 12 has the same impact as link 13 in reducing the probability of depositor 1's withdrawal (i.e., $H_0 : \alpha_1 = \alpha_2$), we cannot reject that hypothesis at any common significance level ($\chi_1^2 = 0.98$, $p - value = 0.3213$). We do also investigate the marginal effect of each of these links, when a link already exists. If the link 12 is in place, we cannot reject the hypothesis $H_0 : \alpha_2 + \alpha_3 = 0$ at any common significance level ($\chi_1^2 = 0.85$, $p - value = 0.3568$). This means that the link 13 does not reduce the probability of withdrawal if the link 12 is already in place. On the contrary, the link 12 helps to reduce the withdrawal rate even if the link 13 already exists, given that the null hypothesis $H_0 : \alpha_1 + \alpha_3 = 0$ is rejected at 5% significance level ($\chi_1^2 = 5.62$, $p - value = 0.0178$). These results suggest that the link 12 fosters most the elimination of the bank-run outcome, as predicted by the theory.

We summarize these findings in the following way:

Result 3. *Compared with the case with no links, both the link 12 and the link 13 significantly reduce the probability of withdrawal of depositor 1. When depositor 1 has the link 13, the link 12 has an additional effect on reducing the probability of withdrawal. The opposite is not true.*

In order to analyze depositor 2's behavior, we define the dummy variable $Y1$ ($Y0$), which takes the value 1 when depositor 2 observes withdrawal (waiting) and is zero otherwise. Therefore, if depositor 1 and 2 are

[24] An important feature in our depositor's analysis is to investigate whether learning affects our results. Because subjects have different information in each round (i.e., they probably face a different problem with a different equilibrium prediction) we cannot disentangle whether changes in behavior are due to the experience in previous rounds or due to the new information structure. However, we tested whether subjects changed their behavior after some rounds. If subjects in the lab changed their behavior, we should observe changes in the regression coefficients. For this purpose, we consider a Chow test in equation (2) where we define a dummy variable that takes the value 1 if decision is taken in the last 7 rounds (see, for example, Kennedy, 2008). The results indicate that there is no learning, as we reject that depositor 1 behaves differently in the last part of the experiment ($\chi_3^2 = 10.94$, $p - value = 0.0121$). The same result is obtained for depositor 2 ($\chi_3^2 = 2 \cdot 10^5$, $p - value = 0.0000$) and depositor 3 ($\chi_3^2 = 6047.74$, $p - value = 0.0000$).

not connected, $Y1 = Y0 = 0$. We propose to model depositor 2's choice as follows:

$$\Pr(y^2 = 1) = F(\alpha_0 + \alpha_1 Y1 + \alpha_2 Y0 + \alpha_3 L23 + \alpha_4 Y1L23) \tag{3}$$

where $F(\cdot)$ is defined as above. We consider the explanatory variable L23 for the existence of the link 23. The variable $Y1L23$ combines information about what player 2 observes and whether she is observed. This variable takes the value 1 only if depositor 2 observes a withdrawal and has a link with depositor 3. We run the regression (3) over 207 observations, taking into account matching group clustering.[25] The marginal effects are evaluated at the level of the sample means.

Table 3. Logit model for depositor 2

The fact that the coefficients α_1 and α_2 are significantly different from 0 suggests that the link 12 considerably affects the behavior of depositor 2 with respect to the case in which she has no links. The marginal effects in Table 3 show that observing a withdrawal, increases the probability of withdrawal by nearly 20%, while observing waiting decreases this probability by 33%. Both probabilities are significant at the 1% significance level. The theoretical prediction states that no matter what depositor 2 observes, she must always wait. We test $H_0 : \alpha_1 = \alpha_2$ to confirm that observing a withdrawal or a waiting is equally important for depositor 2 given any network structure. We reject that hypothesis at any common significance level ($\chi^2_1 = 8.42$, p-value=0.0032). Therefore, our data suggest that the link 12 does matter for depositor 2, and unlike what the theory predicts, the observed decision is also important. Table 3 also indicates that α_3 is significantly different from 0 at the 10% significance level. This result highlights the importance of links.

Result 4. *Compared with the case with no links, the link 12 affects depositor 2's behavior. Observing a waiting (withdrawal) significantly decreases (increases) the depositor 2's probability of withdrawal. The link 23 seems to reduce the probability of withdrawal.*

Finally, we consider depositor 3. We define the dummy variables $Z1$, $Z11$, $Z0$ and $Z10$ by relying on each of the possible information sets that depositor 3 may have. Depositor 3's decision may come after observing a withdrawal ($Z1 = 1$), after observing two withdrawals ($Z11 = 1$), after observing a waiting ($Z0 = 1$), after observing a withdrawal and a waiting ($Z10 = 1$) or simply after observing nothing ($Z1 = Z11 = Z0 = Z10 = 0$). As a result, we propose the following specification to model depositor 3's behavior:

$$\Pr(y^3 = 1) = F(\alpha_0 + \alpha_1 Z1 + \alpha_2 Z11 + \alpha_3 Z0 + \alpha_4 Z10) \tag{4}$$

[25] The explanatory variable $Y0L23 \equiv Y0 \cdot L23$ predicts waiting perfectly (36 observations). As a result, when depositor 2 observes a waiting and is linked with depositor 3, she always waits. We do not consider these observations in Table 3.

where $F(\cdot)$ is defined as above. In Table 4, we present the results, that are obtained after running the regression (4) over 237 observations, taking into account matching group clustering. The marginal effects are evaluated at the level of the sample means.

Table 4. Logit model for depositor 3

Remember that patient depositor 3 has a dominant strategy to wait, implying that the network structure should not affect her behavior and all coefficients should be zero. However, our data show that observing waiting or withdrawal has a different effect on depositor 3's choice. The marginal effects reveal that compared to the case without links, depositor 3 does not change her behavior upon observing only withdrawals, whereas observing a waiting (or a waiting and a withdrawal) significantly decreases her probability of withdrawal by roughly 15%. In fact, once depositor 3 observes waiting, it does not matter whether a withdrawal is also observed (i.e., we cannot reject the null hypothesis $H_0 : \alpha_3 = \alpha_4$ given that $\chi^2_1 = 0.10$, $p - value = 0.7554$). Moreover, we cannot reject that the behavior of depositor 3 is the same when observing two actions, independently of what she observes (i.e., for the null hypothesis $H_0 : \alpha_2 = \alpha_4$ we find that $\chi^2_1 = 0.06$, $p - value = 0.812$). We summarize these findings as follows.

Result 5. *Compared with the case with no links, if depositor 3 observes one action, her probability of withdrawal significantly decreases (is not affected) when observing a waiting (a withdrawal). When depositor 3 observes two actions, it does not matter what is being observed so that depositor 3 does not behave differently when observing two withdrawals or a waiting and a withdrawal.*

Given these findings on the individuals' behavior we may draw some conclusions about whether information structures (i.e., social networks) matter for the emergence of bank runs. The answer is positive as, when it is compared with the case without any links, we see that the frequency of bank runs is different in networks that enable the observation of other depositors' decision. In particular, bank runs are less likely in those network structures that contain the link 12, which leads to the highest levels of efficiency. Although the likelihood of bank runs depends on what is being observed, the theory predicts some behavior fairly well. When a patient depositor 1 is linked to other depositors, she tends to wait, inducing the other patient depositor to follow suit. We also observe in the experimental data that link 12 has a crucial role in eliminating the bank-run outcome, as it decreases the probability of withdrawal, even in the presence of link 13. Observing a waiting also leads to choices predicted by theory. Nevertheless, depositor 2 observing a withdrawal tends to withdraw, although the withdrawal is generally due to the impatient depositor (i.e., when withdrawals are observed observability worsens the situation). We also observe that depositor 3 is less likely to withdraw upon observing waiting, even though the observation of actions should not affect her decision. These striking findings are not in line with the theoretical prediction. In the next section we consider a level-k model, that provides an explanation for the observed anomalies.[26]

4 Discussion: Level-k Analysis

While our analysis is based upon the existence of rational depositors, our experimental findings suggest that depositors' behavior depart from this assumption in some situations. There are two puzzling features that require explanation. Counter to theory, depositor 2 is more likely to withdraw upon observing a withdrawal (Result 2). Depositor 3's decision is also affected by what is being observed (Result 3). This goes against her dominant strategy of waiting. We further illustrate this point in Figure 2, which displays the likelihood of withdrawal for depositors 3 by considering each possible history of decisions. Error bars reflect one standard error.

Figure 2. Depositor 3's likelihood of withdrawal for each possible history of decisions

Figure 2 shows that depositor 3 is less likely to withdraw upon observing a waiting or the two previous decisions. Note that in all these cases, there exists no uncertainty about the other patient depositor's decision, so it is easy for depositor 3 to compute her payoffs. If she observes a waiting (or a waiting and a withdrawal), she knows that by waiting she will get 70, whereas withdrawal yields 50. If depositor 3 observes two withdrawals, depositor 3 gets 30 by waiting and 20 by withdrawing, computation of payoffs being also straightforward. Although waiting is a dominant strategy when depositor 3 observes either nothing or only a withdrawal, the computation of payoffs is complicated in these cases because there exists strategic uncertainty. In particular, depositor 3 does not know whether waiting (withdrawing) will yield 70 or 30 (50 or 20). Under these circumstances, an individual with bounded rationality might not recognize that waiting is a dominant strategy.

We propose a level-k model that reconciles with our data and explains why observing early withdrawals might trigger runs. Assume that level-0 depositors (i) choose their optimal decision when the computation of payoffs is straightforward and (ii) randomize if they are not sure about the payoff that they will get. Under these assumptions, level-0 depositors should wait (being either depositor 2 or depositor 3) if they observed a waiting or the two previous decisions (depositor 3). In any other possible information set, the

[26] We are enormously thankful to two anonymous referees who suggested us the possibility of exploring the idea of bounded rationality.

level-0 depositors would randomize, choosing waiting or withdrawal with probability 0.5.[27]

Following the literature on strategic sophistication (see Crawford, Costa-Gomes and Irriberi, 2012 for a review), we assume that all depositors with a level $k > 0$ believe all other depositors to be k-1 with probability 1, and respond optimally to them. Consider then a level-1 depositor who is at position 1 and has only the link 12. If she withdraws then she will get 50. If she waits, she will induce a level-0 depositor to follow suit only if depositor 2 is patient, which occurs with probability 0.5. If the link 12 exists, but depositor 2 is impatient, the level-0 depositor 3 will randomize, either because she does not observe anything or because she does only observe the withdrawal of the impatient depositor 2. As a result, it is optimal for depositor 1 to wait, if she is level-1 and not too risk averse.[28] If we follow this reasoning it can be shown that level-1 depositors withdraw (only) in the following situations:

1. Depositor 1: when her action is not being observed by any other depositor.

2. Depositor 2: when she does not observe anything and is not observed by depositor 3.

3. Depositor 2: when she observes a withdrawal and is not observed by depositor 3.

In the first two cases, level-1 depositors withdraw because they will not be able to show their waitings to the other (level-0) patient depositor, who will then randomize. In that vein, the depositor of level 1 will not withdraw if the link 13 or 23 were in place. This kind of behavior is in line with our findings for the logit regression, showing that links different from the link 12 do affect depositors' behavior and decrease the likelihood of withdrawal. The third case is probably the most interesting one as it predicts a bank run in the presence of the link 12. Depositor 2 has observed a withdrawal and her decision will not be observed by depositor 3. Note that the withdrawal can be due to the impatient depositor or to a level-0 patient depositor who is randomizing (i.e., there exists strategic uncertainty with respect to the action of the other patient depositor). The depositor 2, in turn, assigns a positive probability to the fact of observing the action of the other "patient" depositor (of level-0). Moreover, in the case of observing the impatient one, she will not be

[27] This assumption implies that a level-0 depositor 1 will always randomize because she does not know what the other patient depositor will do (at position 2 or 3). It could also be assumed that level-0 depositors randomize in all information sets, regardless of their position. But this would imply that level-0 depositors randomize when decisions are trivial (for instance, after observing a waiting). Although our modelling choice is quite reasonable, we note that different assumptions on level-0 depositors yield different predictions (these results are available upon request).

[28] We are assuming that individuals are risk averse but not too much. In particular, our results hold for depositors with a CRRA utility function that satisfies $\rho \in (0, 1.6445)$ (see Appendix D). We note that Diamond and Dybvig (1983) and most of the subsequent literature assume that $\rho > 1$.

able to show her waiting to the hypothetical patient depositor 3. This leads to the conclusion that depositor 2 optimally withdraws in this information set.

As it is shown in Table 5, this bounded rationality model predicts the depositors' behavior fairly well. In the first line of Table 5 we pool the observations of all the information sets that correspond to the predictions in which level-0 depositors randomize, level-1 depositors withdraw and level-2 (or higher) depositors wait. The second line presents the observations in which level-0 depositors randomize and level-1 (or higher) depositors wait, whereas the last one considers the cases in which depositors are predicted to wait.[29].

Table5. Likelihood of withdrawal: level-k predictions and observed behavior at the depositor's level.

We find that those information sets that produce the highest likelihood of withdrawal in the experiment are precisely the ones in which the theory predicts that level-0 (level-1) depositors will randomize (withdraw with probability 1). In the same vein, the lowest frequencies of withdrawals in the experiment usually occur in those information sets in which level-0 and level-1 depositors are assumed to wait. Pairwise comparisons using one-sided tests of proportion show that the difference in the likelihood of withdrawal is significant in all cases ($p - values < 0.0000$), what confirms the predictive power of the level-k model.

Interestingly, the possibility of level-k depositors implies that some bank runs are not due to coordination problems or problems with the fundamentals of the bank. In particular, the theory predicts that there will not be bank runs in equilibrium in the presence of the link 12 because of any of these two reasons. The level-k approach, however, suggests that depositors might rush to withdraw when there exists strategic uncertainty (i.e., after observing a withdrawal, patient depositors who are not fully rational can assign a positive probability to the possibility that the other patient depositor withdraws. The depositor's reaction in this case might trigger the run).

5 Conclusion

An important question regarding the emergence of bank runs is what kind of information depositors have about other depositors' decisions. Existing theoretical models leave aside this issue and use a simultaneous-move game to approach the problem. We generalize the information structure and suppose that an underlying social network channels the information among depositors. This modeling choice allows for incorporating both simultaneous and sequential decisions in the same framework and conform to the empirical descriptions.

We derive a theoretical prediction about depositors' behavior in a tractable environment that resembles a classic bank-run setup. We show that the information structure determines whether the equilibrium is

[29] We provide the complete analysis of this level-k model in Appendix D.

unique or multiple, contributing to the debate on this issue. No bank run is the unique equilibrium if the first two depositors are connected. This result does not depend on the type sequence and pinpoints the importance of links enabling information flow among the depositors at the beginning of the sequence.

We design a controlled laboratory experiment to test the theoretical predictions. We find evidence that the link 12 reduces the likelihood of bank runs and produces the highest levels of efficiency. We also observe that depositor 1's behavior is influenced by the link 12, as predicted by theory. The link 12 also affects the choice made by depositor 2, who tends to act as her observed predecessor. The information transmitted through the links matters also for depositor 3, who withdraws less often upon observing waiting.

Although our setup is simple, our results imply that policymakers should be careful about the information channels. Early withdrawals are seen as signs of a bank run, inducing patient depositors to withdraw. As a result, if there are many withdrawals at the beginning of the sequence of decision, observability may ignite a bank run, which does not occur because of fundamentals or coordination problems. These runs seem to be due to the combination of bounded rationality and strategic uncertainty. On the other hand, if patient depositors are the first to decide, then making their decisions observable helps to prevent bank runs.

Schotter and Yorulmazer (2009) formulate a strong policy recommendation advising "wider dissemination of information about an evolving crisis", because in their view it may slow down the crisis. Garratt and Keister (2009) show that when withdrawal demand is uncertain, then this policy recommendation may result counterproductive. Our empirical results indicate that the effect of more information is history-dependent in the sense, that more information may prevent bank runs if waitings are observable, but in presence of withdrawals wider information about past action increases the likelihood of further withdrawals.

We speculate that possibly there is a relationship between types (patient and impatient) and depositors decision of when to go to bank. It seems a promising venue for future research to explore the relationship between types and position in the line, both theoretically and experimentally. Another topic worth of further investigation is the role of aggregate uncertainty or the possibility of having an endogenous network in which depositors form their links prior to decide between waiting or withdrawing.

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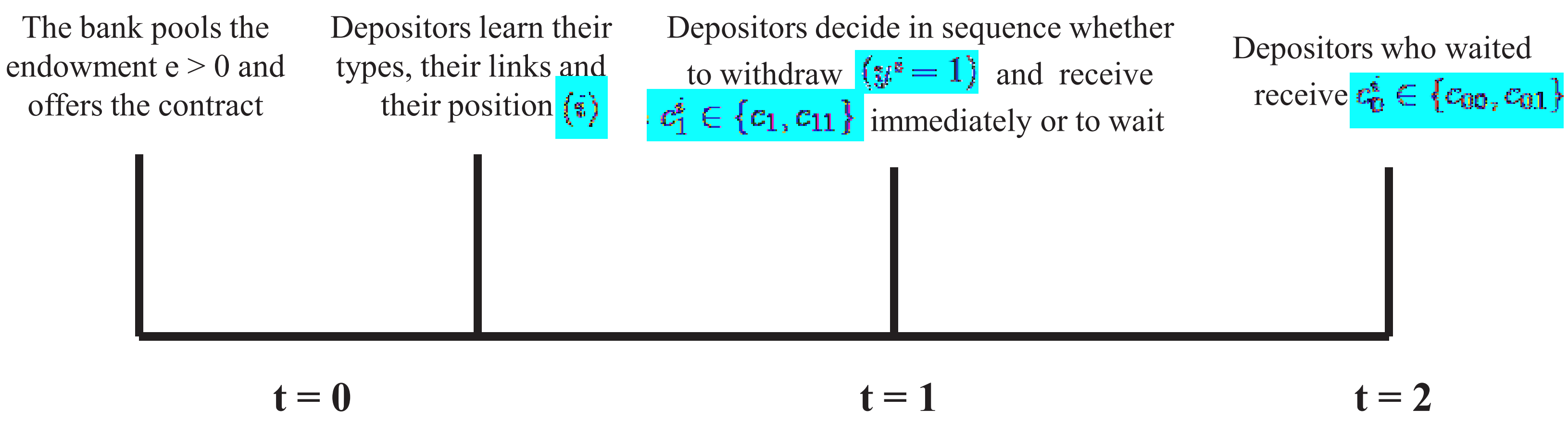


Figure 1. Timeline for the sequence of events.

Figure2

Figure 2. Depositor 3's likelihood of withdrawal for each possible history of decisions

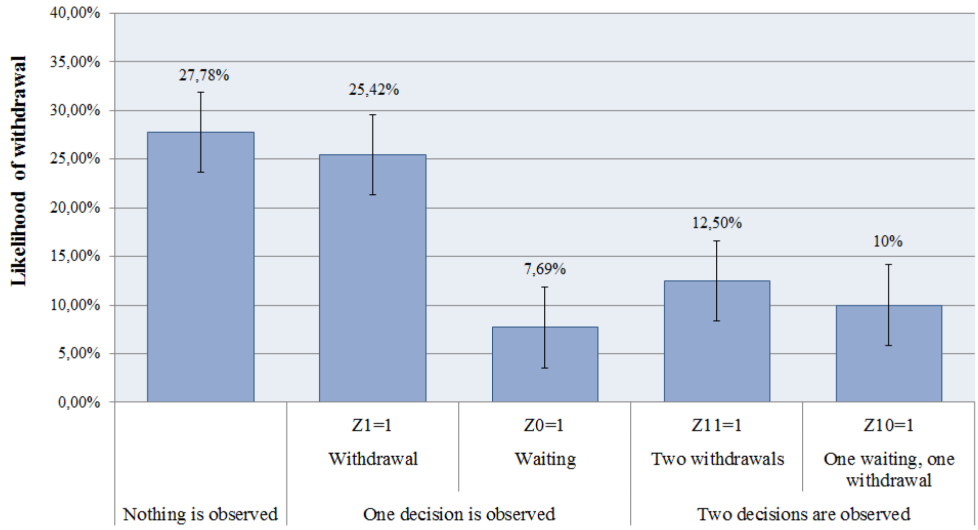
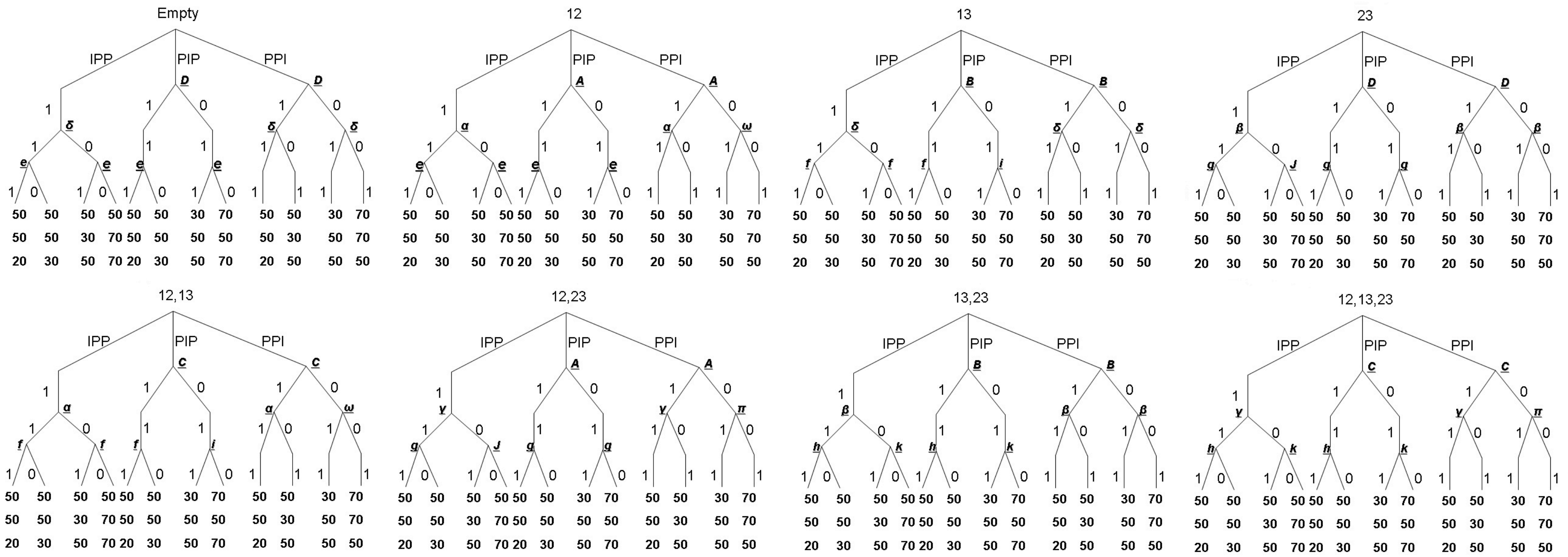


Figure Z. Representation of our bank-run game (not for publication)



Sequence of events:

- Nature selects one of the (eight) network structure and the sequence of types (i.e., the order of decisions) where P (I) denotes Patient (Impatient).
- Each patient depositor decides between waiting (0) or withdrawing (1). The impatient depositor always withdraws (1).

Table1

Table 1. Likelihood of bank runs and level of efficiency in each possible network

Network	Impatient Position	Number Decisions	Frequency of withdrawal: $Pr(y^1=1)$	$Pr(y^2=1)$	$Pr(y^3=1)$	Likelihood Bank run	Efficiency Losses	Ranking	Pooled Data: Likelihood Bank Run	Efficiency Losses	Ranking
	1	44	-	0,39	0,25	0,53 (26%)	-32,10	15			
(12,13,23)	2	44	0,09	-	0,05	0,14 (0%)	-8,18	2	0,21 (21%)	-12,52	1
	3	52	0,00	0,00	-	0,00 (-)	0,00	1			
	1	24	-	0,23	0,15	0,25 (66%)	-16,67	9			
(12,23)	2	26	0,15	-	0,15	0,23 (33%)	-14,61	6	0,22 (62%)	-14,32	2
	3	24	0,17	0,17	-	0,17 (100%)	-11,67	4			
	1	24	-	0,50	0,42	0,67 (37%)	-42,5	22			
(12,13)	2	26	0,15	-	0,08	0,15 (50%)	-10,00	3	0,35 (46%)	-22,70	3
	3	24	0,25	0,17	-	0,25(67%)	-16,67	9			
	1	24	-	0,58	0,08	0,58 (14%)	-35,83	18			
(12)	2	24	0,25	-	0,25	0,42 (20%)	-25,83	12	0,39 (21%)	-24,16	4
	3	24	0,08	0,17	-	0,17 (50%)	-10,83	4			
	1	26	-	0,23	0,00	0,24 (0%)	-14,4	7			
(13,23)	2	24	0,33	-	0,08	0,42(0%)	-25,00	12	0,41 (7%)	-24,93	5
	3	24	0,25	0,42	-	0,58 (14%)	-35,83	18			
	1	26	-	0,15	0,23	0,38 (0%)	-23,07	11			
(13)	2	22	0,18	-	0,27	0,45 (0%)	-27,27	14	0,49 (6%)	-29,43	6
	3	22	0,18	0,55	-	0,64 (14%)	-39,10	21			
	1	26	-	0,25	0,00	0,24 (0%)	-14,40	7			
(23)	2	22	0,73	-	0,18	0,73(25%)	-45,45	23	0,55 (21%)	-34,20	7
	3	22	0,45	0,45	-	0,73 (25%)	-45,45	23			
	1	48	-	0,38	0,33	0,58 (21%)	-36,25	18			
(∅)	2	48	0,29	-	0,33	0,54(15%)	-33,33	16	0,56 (20%)	-34,44	8
	3	48	0,29	0,38	-	0,54 (21%)	-33,75	16			

Notes: The dummy variable y^i takes the value 1 when depositor *i* withdraws. We report the frequency of withdrawal for each experimental subject depending on the computer's position (impatient position). We also report the frequency of bank runs, i.e Prob($\sum_{i=1}^{3} y^i > 1$) and the level of efficiency in each network. This level of efficiency measures deviations from the maximum possible payoff (190 pesetas). The column ranking orders the network structures by considering the levels of efficiency (the lowest ranking belonging to the most efficient network). If two different network structures have the same level of efficiency, they are assigned the same ranking.

Table 2. Logit model for depositor 1

	Constant	L12	L13	L12L13
Coefficient (α)	-0.4654*	-1.1688***	-0.6921***	0.0825
	(0.27)	(0.36)	(0.14)	(0.56)
Marginal Effect		-0.1890***	-0.1109***	0.0133
		(0.06)	(0.02)	(0.09)

Notes.- The dummy variable Lij, stands for the existence of the link ij. The estimated standard errors in parenthesis take into account matching group clustering. Significance at *10%, **5%, ***1%. Number of observations: 238. Pseudo-R2=0.0741

Table 3. Logit model for depositor 2

	Constant	Y1	Y0	L23	Y11L23
Coefficient (α)	-0.5705***	0.8582**	-2.3739***	-0.4619*	-0.4136
	(0.07)	(0.39)	(0.73)	(0.25)	(0.55)
Marginal Effect		0.1944**	-0.2940***	-0.0957*	-0.0793
		(0.09)	(0.04)	(0.05)	(0.09)

Notes.- The dummy variable Y1 (Y0) takes the value 1 when depositor 2 observes a withdrawal (waiting) and it is zero otherwise. The dummy L23 stands for the existence of the link 23. The estimated standard errors in parenthesis take into account matching group clustering. Significance at *10%, **5%, ***1%. Number of observations: 233. Pseudo-R2=0.0640

Table 4. Logit model for depositor 3

	Constant	Z1	Z11	Z0	Z10
Coefficient (α)	-0.5894***	-0.0718	-0.5609	-0.8366***	-0.7033***
	(0.11)	(0.26)	(0.56)	(0.43)	(0.12)
Marginal Effect		-0.0182	-0.1125	-0.1616***	-0.1482***
		(0.06)	(0.07)	(0.05)	(0.02)

Notes.- The dummy variable Z1 (Z0) takes the value 1 when depositor 3 observes a withdrawal (waiting). The dummy Z11 stands for the case in which depositor 3 observes 2 withdrawals and Z10 for the case in which she observes a withdrawal and a waiting. The estimated standard errors in parenthesis take into account matching group clustering. Significance at *10%, **5%, ***1%. Number of observations: 237. Pseudo-R2=0.0542

TableA1

Table A.1. Payoff table for the experiment

		If you wait, then…	
Number of previous withdrawals	If you withdraw	If the other depositor in the room waits and only the computer withdraws	If the other depositor in the room and the computer withdraw
0	50	70	30
1	50	70	30
2	20	Not applicable	30

Table5

Table. 5 Likelihood of withdrawal: level k-predictions and observed behavior at the depositor's level.

Level-k prediction			Experimental Data	
k =0	**k =1**	**k ≥ 2**	**Prob (y=1)**	**N. Obs.**
0.5	1	0	0.3944	229
0.5	0	0	0.2031	566
0	0	0	0.0683	161

The reported level-k predictions assume that depositors have a CRRA utility function with a risk aversion parameter $\rho \in (0,1.6445)$. The experimental data pool the observations by information sets.

TableC1

Table C.1. Test of proportions for pairwise comparisons on the level of efficiency.

	(13,23)	**(13)**	**(23)**	**(**
(12,13,23)	0.0009***	0.0000***	0.0000***	0.0000***
(12,23)	0.0054***	0.0003***	0.0000***	0.0000***
(12,13)	0.2281	0.0511*	0.0083***	0.0021***
(12)	0.3931	0.1224	0.0271**	0.0209**

Note. The reported p-values consider the one-sided test of proportion. Significance at ***1%, **5%, *10%..

Table D.1. Level k-predictions and observed behavior in each information.

	Level-k prediction			Experimental Data	
	k= 0	k = 1	k ≥ 2	Prob (y=1)	N. Obs.
Depositor 1					
No links	0.5	1	0	0.380	129
L12	0.5	0	0	0.176	85
L13	0.5	0	0	0.313	80
L12 L13	0.5	0	0	0.075	133
Depositor 2					
Nothing	0.5	1	0	0.361	72
L23	0.5	0	0	0.333	48
Y0	0	0	0	0.050	20
Y1	0.5	1	0	0.571	28
Y0, L23	0	0	0	0.000	36
Y1, L23	0.5	0	0	0.157	89
Depositor 3					
Nothing	0.5	0	0	0.278	72
Z0	0	0	0	0.077	39
Z1	0.5	0	0	0.254	59
Z10	0	0	0	0.100	50
Z11	0	0	0	0.125	16

The reported level-k predictions assume that depositors have a CRRA utility function with a risk aversion parameter $\rho \in (0,1.6445)$.