Do Social Networks Prevent or Promote Bank Runs?

Kiss, H. J., Rodriguez-Lara, I., Rosa-Garcia, A.

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. Theoretically, 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. Depositors who are observed by others at the beginning of the line are more likely to keep their money deposited, leading to less bank runs. When withdrawals are observed, bank runs are more likely even when the mere observation of actions should prevent them.

"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 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). Other 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 banks in Spain.

One of the leading explanations for the occurrence of bank runs concerns the existence of coordination failure among 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 so 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 model, descrip-

---

[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.

tions of real-world bank runs (Sprague, 1910; Wicker, 2001) and statistical data (e.g. 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, 2012; Kelly and O Grada, 2000). As it is shown in Kiss, Rodriguez-Lara and Rosa-Garcia (2012a), the information flow among depositors might have policy implications (e.g., for the optimal design of deposit insurance); therefore 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. In our model, we consider three depositors who differ in their liquidity needs. There are two patient depositors and one impatient depositor, so there is no aggregate uncertainty about the number of depositors of each type. Depositors decide in sequence whether to withdraw their deposit or to wait.[2] The impatient depositor withdraws for sure, whereas patient depositors get the highest possible payoff if they both wait. If at least one patient depositor withdraws immediately, we say that a bank run occurs.

To allow for observability of decisions, our model builds on the assumption that depositors are located at the nodes of a network and 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. Using the standard convention in game theory we refer to simultaneous decision when depositors decide without knowing the actions chosen by other, even though decisions are made at different points in time. By contrast, sequentiality implies that previous decisions are known. In our case, the connected depositors 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.

We study the impact of different network structures on the emergence of bank runs. We show theoretically that if the link between the first two

---

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

depositors to decide (henceforth, link 12) is in place, no bank run arises in equilibrium (i.e., both patient depositors should wait). 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. Hence, non-observability of initial decisions makes banks fragile (multiple equilibria).

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 setup described above.

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 total 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 concrete manner as observing early withdrawals triggers runs as well.

Our findings are consistent with the individual decisions at the depositors' level. We observe that link 12 (as well as the link 13) significantly reduces depositor 1's withdrawal rate, with respect to the case of no links. Regarding depositor 2, the experimental data show the importance of the link 12. Depositor 2's likelihood of withdrawal is significantly lower when she observes a waiting, but is higher upon observing a withdrawal. The latter finding goes against the theoretical prediction. Observing previous decisions is also important in the case of depositor 3, who is less likely to withdraw if she observes a waiting or the two previous actions.

Overall, the results gleaned from our experiment suggest that depositor 1's behavior is mainly driven by the fact that her action is observed. By waiting, depositor 1 can induce the other patient depositor to follow suit. Depositors 2's and 3's departures from equilibrium predictions point out the importance of observability of decisions. In particular, a link at the beginning of the sequence can prevent the emergence of bank runs, but only when depositors observe a waiting. If a withdrawal is observed, then bank runs may be even more frequent than in the case without observability (i.e., social networks can promote runs). Importantly, these runs cannot be explained by coordination in a simulatenous setup nor by fundamental

problems of the bank, the two main culprits identified by the literature. Panic-based bank runs are identified in our context, where depositors decide sequentially.

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. While there are other studies in which depositors may observe previous decisions (e.g. Schotter and Yorulmazer, 2009; Kiss, Rosa-Garcia and Rodriguez-Lara 2012a), those studies analyze only the extreme cases: nothing vs. all previous actions observed. We study systematically all information setups, including the possibility of partial observability. The aforementioned empirical studies (Kelly and O Grada, 2000; Starr and Yilmaz, 2007 and Iyer and Puri, 2012) suggest that during real bank runs observability is in fact partial, making our investigation relevant and complementary to the existing results. Although we focus on banks, run-like phenomena occur in other institutions and markets as well (such as money-market, hedge or pension funds) and our analysis applies analogously to them.

In the next section, we present our model and derive the theoretical prediction. In Section 3 we detail our experimental design. Section 4 reports our experimental results, which are discussed in light of the existing literature in Section 5. Section 6 concludes.

2. The Theoretical Setup

This section presents our theoretical model, which considers a coordination problem among three different depositors. In our framework, decisions are taken sequentially and there is neither fundamental uncertainty about the bank, nor uncertainty regarding the liquidity types of depositors.[3]

---

[3]We consider a small number of depositors so that agents in our model can be interpreted as big creditors in the wholesale market or large investors in a hedge fund. Models involving few depositors are often analyzed in the literature that focuses on bank runs (e.g., Green and Lin, 2000; Peck and Shell, 2003). The experimental literature on bank runs does also consider a few number of depositors (e.g., Trautmann and Vlahu, 2013). The interested reader on a more general approach to our problem can consult Rosa-Garcia and Kiss (2012).

1.1 2.1. The Underlying Model

Consider three depositors who deposit their endowment of $e > 0$ monetary units in the bank at $t = 0$. The bank invests the deposits $(3e)$ at $t = 0$ and the investment earns a positive net return only if not liquidated until $t = 2$. If investment is liquidated at $t = 1$, the net return is zero. We do not consider liquidation costs. The deposit contract specifies the depositors' payoffs depending on two factors: (a) depositors' choice at $t = 1$, and (b) the available funds of the bank.

Two of the depositors are patient and one is impatient. The latter suffers a liquidity shock at the beginning of $t = 1$ and only values payoffs at $t = 1$, so she withdraws always in that period. Patient depositors do not need their funds urgently, they value payoffs in both periods $(t = 1, 2)$. Types are private information. There is no aggregate uncertainty and the number of patient and impatient depositors is common knowledge (Diamond and Dybvig, 1983).

Depositors decide sequentially according to their position in the line that is known to them. Position is determined randomly and exogenously and any depositor has the same probability to be at any position. Positions are independent of types (e.g., the impatient depositor is not more probable to be at the beginning of the sequence).

1.1.1 2.1.1. Payoffs

Any depositor can withdraw at time t=1 and receive $c_1(.)$ or wait until period 2 and receive $c_2(.)$. The payoff that depositors receive depends on their decisions, but also on the position in the line since it is related to the available funds of the bank.[4] We denote period-1 payoffs as $c_1(xw)$, where x is the number of previous withdrawals (w). Period-2 payoffs are denoted as $c_2(yw)$, where y indicates the total number of withdrawals in period 1.

In the spirit of Diamond and Dybvig (1983), we assume that $c_1(0w) = c_1(1w) > e > c_1(2w)$. In words, the bank commits to pay $c_1(0w)$ to the first two withdrawing depositors. This amount is higher than the depositor's initial endowment (e) because it is assumed that the immediate withdrawal yields a payoff equal to the initial endowment plus an interest (in the Di-

---

[4]This is one of the main differences with respect to Diamond and Dybvig (1983), as depositors who withdraw in our model are served sequentially depending on their position in the line, instead of in a random order.

amond and Dybvig's model, the interest exists because of the risk-sharing feature of the first best allocation). If a depositor withdraws after two withdrawals, then she gets the remaining funds in the bank $c_1(2w)$, which amounts to less than her initial endowment e. This is the case, since if everybody withdraws, then all investments are liquidated at $t = 1$, and hence no net return is earned.

We also assume that $c_2(1w) > c_1(0w) > c_2(2w)$. That is, for a patient depositor it pays off to wait if the other patient depositor waits as well. Otherwise, she is better-off if she withdraws early (in position 1 or 2).[5] We assume that if only one depositor waits, she earns more than by withdrawing after two withdrawals, but still her payoff falls short of the initial endowment. That is, $e > c_2(2w) > c_1(2w)$.

Overall, the relation between the payoffs is the following:

$$c_2(1w) > c_1(0w) = c_1(1w) > e > c_2(2w) > c_1(2w) \tag{1}$$

We rely upon this relation of payoffs in our experimental design, described in Section 3.

1.1.2   2.1.2. Networks

We model the information flow among depositors through a network. A network 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. We assume that the network structure is not commonly known, information is local and thus no depositor knows whether the other two depositors are connected. Links are independent of types, so depositors of the same type are not more likely to be linked, nor is there any relationship between types and the number of links.

In the case of three depositors, there are 8 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 $(12, 23, 13)$

---

[5]Note that $c_2(1w)$ and $c_2(2w)$ are only defined for patient depositors who waited in the first period. In that regard, $c_2(0w)$ does not exist because the impatient depositor always withdraws at t=1.

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 all predecessors' actions.

1.1.3   2.1.3. Decisions and types

At the beginning of $t = 1$, depositors learn their types, their links and their position in the sequence of decisions ($i = 1, 2, 3$). Private types and equiprobable positions imply that only the conditional probability of the type sequence is known. For instance, if depositor 1 is patient, then both type sequences (patient, patient, impatient) and (patient, impatient, patient) have probability $1/2$. Since the impatient depositor always withdraws at $t = 1$, we focus on the patient ones. They derive utility $u(.)$ from payoffs at any period, where $u'(.)>0$ and $u''()<0$. When patient depositors 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.

1.2   2.2. Theoretical prediction

In order to derive a theoretical prediction, we first define a bank run in the following way.

Definition.   *A bank runoccurs if at least one patient depositor withdraws.*

This definition is the broadest, and accordingly, a withdrawal due to a patient depositor already constitutes a bank run.

Proposition. *If the link 12 exists, any Perfect Bayesian Equilibrium (PBE) satisfies the condition that bank runs do not occur. In any network in which the link 12 does not exist, there are multiple equilibria, so bank runs may occur in equilibrium.*

Proof: The rationale for this proposition relies on the fact that depositor 3 has a dominant strategy and always waits if patient. Waiting yields a higher payoff than withdrawal if the other two previous depositors have withdrawn ($u(c_2(2w)) > u(c_1(2w))$) or if only the impatient depositor withdrew $u(c_2(1w)) > u(c_1(1w))$.

Consider next the case when the link 12 exists and depositor 2 observes a waiting. Since $u(c_1(0w)) < u(c_2(1w))$, a patient depositor 2 waits after observing a waiting. Hence, in any equilibrium a patient depositor's optimal strategy is to wait when i) observing a waiting in position 2; ii) being in position 3.

Given the existence of the link 12 and the equilibrium strategies previously described, as a consequence of sequential rationality a patient depositor 1 knows that if she waits, the other patient depositor will wait as well. Therefore, in any equilibrium a patient depositor 1 should wait if the link 12 exists.

Consider a depositor 2 who observes a withdrawal. In a PBE, consistency of beliefs requires that she assigns probability 1 to depositor 1 being impatient, given that equilibrium strategies imply that a depositor 1 who is patient waits always. Therefore, when observing a withdrawal she must assign probability 1 to depositor 1 being impatient (i.e., depositor 2 assigns probability 1 to depositor 3 being patient). In that case, given the payoffs depositor 2 should wait as well in any equilibrium.

As a result, if the link 12 is in place any equilibrium strategy profile requires that patient depositors wait in any information set that may arise (being in position 1; being in position 2 and observing either a waiting or a withdrawal; being in position 3 and observing anything). Thus, the behavioral strategy profile in which all patient depositors wait is the unique PBE.[6]

The second part of the proposition assumes that link 12 does not exist. We show multiplicity of equilibria by constructing a no-bank-run and a bank-run PBE. A profile of strategies in which patient depositors wait always in any position is a no-bank-run equilibrium. Recall that a patient depositor in the third position waits in any equilibrium. If the strategy of depositor 1 (depositor 2) when patient is to wait, then the best response of depositor

---

[6]There exist other strategy profiles that are Bayes-Nash equilibria that lead to bank runs but they are not PBE. For instance, imagine that depositor 3 is impatient and the network is complete (just to make things simpler). The strategy profile in which depositor 2 always withdraws is a Bayes-Nash equilibrium. This occurs because a Bayes-Nash equilibrium is not imposing beliefs on the continuation game. Thus, if depositor 2 decides to withdraw regardless of what depositor 1 does, then depositor 1's best response is to withdraw as well. By using the concept of PBE we constrain off-equilibrium beliefs and eliminate the possibility of depositor 2 choosing withdrawal after observing a waiting.

2 (depositor 1) is also to wait. Therefore for the patient depositors "waiting at any position" defines a PBE.

In the bank-run equilibrium, consider the profile of strategies where depositors 1 and 2 withdraw if patient. Assuming expected-utility maximizing depositors, note that if depositor 1 (depositor 2) withdraws if patient, the best response of depositor 2 (depositor 1) is also to withdraw if $u(c_1(0w)) > \frac{1}{2}[u(c_2(1w)) + u(c_2(2w))]$ is satisfied. This is the case because Bayesian updating requires that depositor 2 (depositor 1) believes that depositor 1 (depositor 2) is patient or impatient with probability $\frac{1}{2}$. Thus if the link 12 is absent, for $c_1(0w)$ high enough (but maintaining that $c_2(1w) > c_1(0w)$), there exists a bank run equilibrium. As a result, there are multiple equilibria.

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 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 exist, there are multiple equilibria.

Although there is no clear-cut prediction in the absence of the link 12, we formulate some conjectures on what can be expected. On the one hand, the existing experimental evidence in setups with no aggregate uncertainty (e.g. Garratt and Keister (2009)) predicts the no–run–equilibrium. On the other hand, 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 on coordination). Hence, 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 the following depositors to wait if they observed a waiting from depositor 1 or depositor 2. In that vein, depositors 1 and 2 would be more likely to wait if linked with depositor 3.

2   3. The 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.[7] The average length of each session was 45 minutes. Subjects received on average 12 Euros for participating, including a show-up fee of 2 Euros.

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 knew that one of the depositors in the bank was simulated by the computer.

Depositors deposited *e*=40 pesetas in each round in the bank and were asked to choose between withdrawing or waiting.[8] The payoff consequences of each action were explained to subjects using Table 1.

<div align="center">Table 1. Payoffs of the experiment</div>

The rationale of these payoffs is that the bank commits to pay $c_1(0w) = c_1(1w) = 50$ to the two first withdrawing depositors. If a depositor withdraws after two withdrawals, then she gets the remaining funds in the bank $c_1(2w) = 3e - c_1(0w) - c_1(1w) = 20$. If a depositor decides to wait, her

---

[7]The instructions are in the Appendix A.

[8]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.

payoff depends on the action of the other patient depositor. If both of them wait, then the investment project earns a positive net return and the bank pays $c_2(1w)$=70 to each of them. If only one patient depositor decides to wait, then the available money after two withdrawals (20 pesetas) earns the returns of the investment (10 units) and then this amount given to the depositor who waited, that is $c_2(2w)$=30.[9]

Before making their decisions, subjects were informed about their position in the line, the decisions they were able to observe (as determined by the network) and the links to subsequent depositor(s). Subjects were aware that the information structure and the position in the line were equiprobable and exogenously determined. It was commonly known that position in the line, the network structure, or both changed in each round. Once subjects made their choices in a particular round, they received information about their own payoff and a new round started. At the end of the experiment, we paid subjects for the 15 rounds.

We mention a few noteworthy aspects of the experimental design. First, types (patient or impatient) were not publicly observed in our experiment, and there was no 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 theoretical models like Andolfatto, Nosal and Wallace, 2007; Ennis and Keister, 2009; 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.[10]

---

[9]Note that the amount that a patient depositor gets if she waits alone is smaller than her initial endowment. Kiss, Rodriguez-Lara and Rosa-Garcia (2012a) interpret the value of $c_2(2w)$ as the level of deposit insurance and investigate how $c_2(2w)$ affects the likelihood of bank runs depending on whether decisions are sequential or simultaneous.

[10]The optimal decision on *when* to go to the bank has not been studied in 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.

3   4. Experimental Evidence

This section reports our experimental evidence. In Section 4.1 we provide some summary statistics of our behavioral data and perform statistical tests to see how the presence of link 12 affects the likelihood of bank runs. We also discuss in that section how the depositors' behavior may be affected by what is being observed. A regression analysis to disentangle how the presence of the links and what is being observed affects the withdrawal decision of each depositor is presented in Section 4.2, where we also control for the effect of the experience in previous rounds. For simplicity, we refer in both sections to the impatient as the computer, whereas experimental subjects are called simply depositors.

3.1   4.1. Descriptive Statistics and Aggregate Analysis

We summarize the data gathered during the experimental sessions in Table 2. We report the network structure in the first column. The second column specifies the position of the computer, and the third column shows the number of observations.[11] In the next three columns, we present the frequency of withdrawal for 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. We compute deviations from the maximum possible payoff that can be received (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 computer's position, which is not observed by subjects in our experiment.

Table 1: Table 2. 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

---

[11]We had a problem in one of the banks and were not able to record the subjects' decision in one of the rounds; so we have 718 observations (instead of 720) coming from the 48 subjects choosing during 15 rounds.

can see that networks that produce the smallest likelihood of bank runs and then the minimum efficiency losses have the link 12. The network structures at the bottom of the ranking -that perform worse in terms of bank runs and efficiency- do not have this link. On average, the likelihood of bank run when there is (there is not) link 12 is 0.27 (0.51), respectively. The test of proportions rejects the null hypothesis that bank runs are equally likely in both cases ($z = 4.51$, *p-value*=0.000).[12]   We do pairwise comparisons and test the null hypothesis that the frequency of bank runs in any network structure with the link 12 is the same as the frequency of bank runs in a network without this link against the alternative that bank runs are less likely when there is link 12.[13]   We reject that null hypothesis except when we compare (12,13) or (12) against (13,23) or (13). In all the remaining cases, the rate of withdrawal is always significantly lower in the networks with the link 12. Though these results do not correspond literally to our theoretical prediction, which establishes that no bank run will be the unique equilibrium if the link 12 exists, we observe that there are considerably less bank runs in networks where the theory predicts none, than in those where multiple equilibria are predicted.

We also conjectured that depositors might interpret links as an important device to make observable that they wait, inducing the other depositor to do so 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 likelihood of bank runs. Statistically, the former produces significantly less bank runs than the latter (*p-value*= 0.016). We can also see in Table 2 that if the link 12 does not exist, 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. Again, the difference between bank runs in the network (13,23) and in the empty network is statistically significant (*p-value*= 0.044). Our first result summarizes these findings and 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*

---

[12]All the statistical tests in this section refer to the test of proportions.

[13]When performing pairwise comparisons, we always correct for multiple testing using the Bonferroni correction. This is the most stringent method to avoid type I errors. The interested reader can see Appendix B for the values of the statistics and further details on the statistical tests.

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 structure, we look now at the disaggregated data which account for the computer's position. The ranking in Table 2 indicates 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, 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 among the worst ones. Contrariwise, we see that the complete network has the lowest frequency of bank runs (0% and 14%), 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 computer 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 by inducing depositors 1 and 2 to wait. We see in Table 2 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. The evidence is not so clear for depositor 2 as her decision seems to be affected by the position of the computer. In particular, when the link 12 exists, depositor 2 is more likely to withdraw when depositor 1 is the computer. As a result, we observe that conditional on the existence of the link 12, the likelihood of bank run is always higher when depositor 1 is the computer (z=3.84, *p-value*=0.000). This suggests that observing a withdrawal with certainty plays a role in depositor 2's decision. We summarize our findings regarding the link 12 as follows.

Result 2 *The effect of link 12 depends on the computer's position. When the first depositor to decide is the computer, the link 12 significantly increases the likelihood of bank runs, otherwise the frequency of bank runs significantly decreases in the presence of link 12.*

15

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 but the action that is being observed is also important to explain behavior. In the presence of the link 12, when the computer is in position 1, a withdrawal will be certainly observed at the beginning of the sequence and it may trigger a run. The beneficial effects of the link 12 therefore materializes when the first depositor to decide is not the computer, so that she can induce the other depositor to follow suit.

Finally, remember that depositor 3 has a dominant strategy to wait. In our data, depositor 3 waits in more than 80% of the cases (i.e., 194 out of the 239 decisions correspond to waiting). All the 48 subjects that participated in our experiment were at position 3 at least three times. Among them, a total of 20 (19) never withdraw (withdraw once) in position 3. Only 6 of our 48 subjects withdraw more frequently than they wait. We then conclude that most of the subjects behave according to the theoretical prediction and decide to wait. In Table 2, however, we observe that the likelihood of withdrawal varies between 0% in the networks (13,23) and (23), and 42% in the network (12,13), in all these cases being the computer the first to decide. These findings seem to suggest that observing previous decisions can affect depositor 3's behavior. A detailed analysis of depositors' behavior in each position is presented in the next section.

3.2 4.2. Depositor's Behavior and Econometric Analysis

We have seen the importance of the link 12 in reducing bank runs. In this section we analyze the depositors' behavior more in detail. Our aim is to disentangle the effect of links and the observed actions on depositors' behavior, controlling for the effect of experience whose effect cannot be gleaned from Table 2. For example, one of the questions to be addressed is whether depositor 2 simply cares about the presence of the link 12 (as the theory predicts) or if she is also affected by what is observed. We also want to investigate whether deviations from the equilibrium prediction of depositor 3 occur in a particular manner.

For each depositor $i = 1, 2, 3$, we estimate a logit model in which the dependent variable is the probability of withdrawal of the depositor in posi-

tion i, $\Pr_i(w)$. Because the depositor 1's decision may depend on the links that she has we propose the following specification for depositor 1:

$$\Pr_1(w) = F\left(\alpha_0 + \alpha_1 L12 + \alpha_2 L13 + \alpha_3 L12L13 + \alpha_4 History\right) \qquad (2)$$

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. In line with Garratt and Keister (2009), our proposed specification controls for what depositors have observed in previous rounds. More specifically, "History" is defined as the fraction of previous rounds in which the subject witnessed a bank run.

The estimates of equation (2) are presented in Table 3. The reported standard errors of the parameters take into account the matching group clustering and are corrected using the bias reduced linearization (Bell and McCaffrey, 2002) that inflates residuals to correct for standard errors. If we did not perform this correction in our logit specifications, the standard errors would be biased and we would be more likely to reject the null hypothesis than our p-values would suggest (see Angrist and Pischke, 2008). The marginal effects are evaluated at the level of the sample means and the magnitude of the interaction effect $L12L13$ is estimated according to Ai and Norton (2003) where its is shown that the magnitude of the interaction term in logit models does not equal the marginal effect of the interaction term.[14]

Table 2: Table 3. Logit model for depositor 1

We find that the propensity to withdraw significantly decreases when the links 12 and 13 exist. 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.,

---

[14]We undertake the same approach for depositors 2 and 3 as well. We thank a referee for pointing out these issues.

$H_0 : \alpha_1 = \alpha_2$), we cannot reject that hypothesis at any common significance level (*p-value*=0.815). Similarly, we cannot reject the null hypotheses that $H_0 : \alpha_2 + \alpha_3 = 0$ and $H_0 : \alpha_1 + \alpha_3 = 0$ (*p-values* are 0.289 and 0.233, respectively). This means that neither the link 13 nor the link 12 reduces the probability of withdrawal once the other link is already in place. The results in Table 3 reveal that an increase in History tends to increase depositor 1's probability of withdrawal (i.e., withdrawal is more likely if more bank runs have been observed previously). As we shall see below, the same result holds for depositor 2 and 3. These findings are consistent with Garratt and Keister (2009) where it is found that subjects who experienced more bank runs are more likely to withdraw.[15] 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 one of these links, the other one does not have any additional effect on reducing the probability of withdrawal.*

In order to analyze depositor 2's behavior, we decompose the link 12 and account for the information it transmits. The dummy variable $Y1$ ($Y0$) takes the value 1 when depositor 2 observes withdrawal (waiting) and is zero otherwise. Therefore, if depositor 1 and 2 are not connected (i.e., if the link 12 does not exist), $Y1 = Y0 = 0$. We propose to model depositor 2's choice as follows:

$$\Pr_2(w) = F(\alpha_0 + \alpha_1 Y1 + \alpha_2 Y0 + \alpha_3 L23 + \alpha_4 Y1L23 + \alpha_5 History) \quad (3)$$

where F and *History* are defined as above. Now we define L23 as a dummy variable for the existence of the link 23. The variable $Y1L23$ com-

---

[15]A related issue concerns whether learning occurs in our experiment. Because subjects have different information in each round (i.e., they face a different problem with a different equilibrium prediction) we cannot disentangle whether changes in behavior are due to the experience in previous rounds (that is not captured by "History") or due to the new information structure. However, we tested whether subjects changed their behavior after some rounds. If this were the case, we should observe changes in the regression coefficients. We consider a Chow test 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 change in behavior for any of the depositors, as we reject that they behave differently in the last part of the experiment.

bines information about what depositor 2 observes and whether she is observed (i.e., this variable takes the value 1 only if depositor 2 observes a withdrawal and has a link with depositor 3).[16].

Table 3: Table 4. 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 4 show that observing a withdrawal, significantly increases the probability of withdrawal by nearly 30%, while observing waiting significantly decreases this probability by 24%. 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 that the link 23 does not exists. We reject that hypothesis at the 5% significance level ($\chi_1^2 = 4.90$, *p-value*=0.028). We also reject the hypothesis that $H_0 : \alpha_2 = \alpha_1 + \alpha_4$, therefore observing a withdrawal and a waiting is not the same if we account for the link 23 ($\chi_1^2 = 4.01$, *p-value*=0.046). Our data suggest that the link 12 does matter for depositor 2, and unlike what the theory predicts, the observed decision is also important. In turn, this finding indicates that bank runs may not only be due to problems with the fundamentals of the bank or coordination problem among depositors in a simultaneous setup. Bank runs can also be caused by panic-based behavior in a sequential framework.

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.*

Although most of the time depositor 3 follows the dominant strategy to wait, one interesting question to be addressed concerns whether the propensity to withdraw is affected by what is being observed. We define the dummy variables $Z1$, $Z11$, $Z0$ and $Z10$ by relying on each of the possible information

---

[16]The explanatory variable Y0 L23 is not considered in Table 4 because it predicts waiting perfectly. That is, when depositor 2 observes a waiting and is linked with depositor 3, she always waits (10 observations)

sets that depositor 3 may have. Depositor 3's decision may come after only observing a withdrawal ($Z1 = 1$), after observing two withdrawals ($Z11 = 1$), after only 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:

$$\Pr_3(w) = F(\alpha_0 + \alpha_1 Z1 + \alpha_2 Z11 + \alpha_3 Z0 + \alpha_4 Z10 + \alpha_5 History) \quad (4)$$

where F and *History* are defined as above. The estimates of equation (**??**) are reported in Table 5.

Table 4: Table 5. Logit model for depositor 3

Although depositor 3 has a dominant strategy to wait and the network structure should not affect her behavior (i.e., all coefficients should be statistically insignificant), the marginal effects reported in Table 5 reveal that compared to the case without links, the propensity to withdraw decreases when depositor 3 observes a waiting, or the two previous actions (i.e., two withdrawals, or a waiting and a withdrawal). 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 $\chi_1^2 = 1.09$, *p-value*= 0.298). Similarly, we cannot reject that the behavior of depositor 3 is the same when observing two actions, regardless of what she observes (i.e., for the null hypothesis $H_0 : \alpha_2 = \alpha_4$ we find that $\chi_1^2 = 0.55$, *p-value*=0.460). We find, however, that observing a withdrawal is not the same as observing a waiting ($\chi_1^2 = 3.97$, *p-value*=0.047) or observing two withdrawals ($\chi_1^2 = 3.32$, *p-value*= 0.069).

These findings suggest that *strategic uncertainty* (i.e., uncertainty concerning the action of the other depositor) may play a major role in explaining deviations from waiting. When depositor 3 observes nothing or a withdrawal, she does not know with certainty what the other patient depositor has done. The observed withdrawal may come from the computer or from the other depositor. However, when a waiting or the two previous actions

are observed, depositor 3 does know what the other depositor has done. Importantly, this is related to the computation of payoffs in our experiment. When there is no uncertainty about the other depositor's decision, 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 more demanding in these cases because she has to compare payoffs when she believes that the other depositor has withdrawn and when not. For instance, if depositor 3 observes either nothing or only a withdrawal, she 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.[17] We summarize these findings as follows.

Result 5 *Compared with the case with no links, the probability of withdrawal significantly decreases (is not affected) when depositor 3 can infer (cannot infer) what the other patient depositor has done.*

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 depositor 1 values the fact of being observed, whereas depositors 2 and 3 seem to be affected by the information transmitted through the links.

4   5. Discussion

In this paper we have studied the emergence of bank runs in a sequential environment. 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

---

[17]The work of Klos and Sträter (2013) is an attempt to investigate how bounded rationality affects bank runs. We do not elaborate on this explanation in the current study, but the interested reader can consult the working paper version of our manuscript for further details (see Kiss, Rodriguez-Lara and Rosa-Garcia, 2012b).

problem that involves simultaneous decisions. In the experimental literature, researchers have considered simultaneous decisions to investigate the problem of coordination among depositors (e.g., Arifovic, Jiang and Xu, 2013) or analyze if bank runs can be contagious (Brown, Trautmann and Vlahu, 2012). Observability of past actions has received scarce attention in the theoretical literature (see Gu, 2011), but has been investigated in laboratory experiments.[18] Schotter and Yorulmazer (2009) motivate their paper claiming that sequentiality should be taken into account when studying bank runs. In their experiment they use simultaneous and sequential treatments, so they are the first to compare outcomes when the degree of observability differs. They investigate how different factors (e.g. asymmetric information, deposit insurance) affect how quickly depositors withdraw.[19] Theoretically, subjects' behavior should be invariant to the form of the game, but Schotter and Yorulmazer (2009) find that the available information (e.g. about past decisions) affects the subjects' choices. More precisely, 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. In our experiment, we find that the observation of previous withdrawals increases the rate of withdrawals even in a setup where that observation should prevent bank runs. Moreover, we underline the positive effect of observing other depositors' waiting, and that the possibility of being observed also decreases the tendency to withdraw. Importantly, our results emerge in an environment without uncertainty about the fundamentals of the bank, which is an important element in Schotter and Yorulmazer (2009).[20]

Two novel elements in Garratt and Keister (2009) are that in some treatments subjects were given up to three opportunities of withdrawal and some-

---

[18] In Brown, Trautmann and Vlahu (2012) depositors of the same bank decide simultaneously, but depositors may observe the decisions of depositors of other banks.

[19] Kiss, Rodriguez-Lara and Rosa-Garcia (2012a) and Madies (2006) also investigate the efficiency of deposit insurance to curb bank runs by means of laboratory experiments. In Kiss, Rodriguez-Lara and Rosa-Garcia (2012a), we study how deposit insurance affects depositor behavior depending on whether decisions are simultaneous (empty network) or fully sequential (complete network), but do not consider the case of partial information.

[20] 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.

times faced forced withdrawals. When subjects had 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 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. 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, so that there is no aggregate uncertainty in our model. 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, in previous studies observability is implemented by giving subjects multiple opportunities to withdraw and before each decision they obtained information about the number of previous withdrawals. In our framework, subjects are given only one opportunity to withdraw in each round and observability of previous decisions is constrained by the network structure. 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. Identifying 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, 2013; Schotter and Yorulmazer, 2009; Garratt and Keister, 2009), which do not characterize 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. The closest paper to our in this respect 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 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.

5   6. Conclusion

An important question regarding the emergence of bank runs is what kind of information depositors have about other depositors' decisions. Most of the 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 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 order in which patient and impatient depositors are called to decide 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. Likewise, she is influenced by the link 13, being the possibility to communicate her own decision which drives the behavior at the beginning of the line. 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. Overall these findings contribute to the literature showing that panic-based runs may emerge in a context when fundamental problems or uncertainty about the distribution of types are absent (see Schotter and Yorulmazer, 2009; Garratt and Keister, 2009).

Panic-based bank runs are usually discussed in the context of simultaneous decisions (Diamond and Dybvig, 1983), whereas in our context runs occur in a sequential framework. 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. On the other hand, if patient depositors are the first to decide, then making their decisions observable helps to prevent bank runs. The fact that we do not see many bank runs (even in crisis times) suggests that observability is not complete or other factors not considered in this paper play also an important role. For instance, the presence of insiders with valuable information about the fundamentals of the bank may matter as well. In a setup with insiders Schotter and Yorulmazer (2009) show that "wider dissemination of information about an evolving crisis" may slow down the crisis. Garratt and Keister (2009) show that when withdrawal demand is uncertain, then more information may be counterproductive, hence the role of information is intricate.

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.

References

Ai, A., Norton, E. C., 2003. Interaction terms in logit and probit models. Economics Letters 80, 123-129. Allen, F., Gale, D., 1998. Optimal financial crises, Journal of Finance 53, 1245-1284 Andolfatto, D., Nosal, E., Wallace, N., 2007. The role of independence in the Green-Lin Diamond-Dybvig Model. Journal of Economic Theory 137, 709-715. Angrist, J. D., Pischke, J.-S., 2008. Nonstandard standard error issues, in: Mostly Harmless Econometrics: An Empiricists Companion. Princeton University Press. Arifovic, J. Jiang, J. H., Xu, Y., 2013. Experimental evidence of bank runs as pure coordination failures. Journal of Economic Dynamics and Control 37, 2446-2465. Baba, N., McCauley, R N., Ramaswamy, S., 2009. US dollar money market funds and non-US banks, BIS Quarterly Review, March, 64-81. Bell, R., McCaffrey, D., 2002. Bias reduction in standard errors for linear regression with multistage samples. Survey Methodology 28, 169-181. Bernanke, B. S., 1983. Nonmonetary effects of the financial crisis in the propagation of the Great Depression. American Economic Review 73, 257-276. Brandts, J., Cooper, D.J., 2006. Observability and overcoming coordination failure in organizations: An experimental study. Experimental Economics 9, 407-423. Brown, M., Trautmann, S., Vlahu, R., 2012. Contagious Bank Runs: Experimental Evidence. University of St.Gallen, Working Paper on Finance 2012/7. Calomiris, C., Mason, J., 2003. Fundamentals, panics and bank distress during the depression. American Economic Review 93, 1615-47. Calomiris, C., Gorton, G., 1991. The Origins of Banking Panics: Models, Facts, and Bank Regulation. in Financial Markets and Financial Crises, R. Glenn Hubbard, editor Choi, S., Gale, D., Kariv, S., 2008. Sequential equilibrium in monotone games: A theory-based analysis of experimental data. Journal of Economic Theory 143, 302-330. Choi, S., Gale, D., Kariv, S., Palfrey, P., 2011. Network architecture, salience and coordination. Games and Economic Behavior 73, 76-90. Crawford, V. P., Costa-Gomes, M. A., Iriberri, N., 2013. Structural models of nonequilibrium strategic thinking: theory, evidence and ap-

plications. Journal of Economic Literature 51, 5-62. Diamond, D.W., Dybvig, P.H., 1983. Bank runs, deposit insurance and liquidity. Journal of Political Economy 91, 401-419. Duffie, D., 2010. The failure mechanics of dealer banks. Journal of Economic Perspectives 24, 51-72. Ennis, H.M., 2003. Economic fundamentals and bank runs. Federal Reserve Bank of Richmond Economic Quarterly 89, 55-71. Ennis, H.M., 2012. Strategic behavior in the tri-party repo market, mimeo. Ennis, H. M., T. Keister, 2009. Run equilibria in the Green–Lin model of financial intermediation. Journal of Economic Theory 144, 1996-2020. Fischbacher, U., 2007. z-Tree: Zurich toolbox for readymade economic experiments. Experimental Economics 10, 171-178 Garratt, R., Keister, T., 2009. Bank runs as coordination failures: An experimental study. Journal of Economic Behavior and Organization 71, 300-317. Goldstein, I., Pauzner, A., 2005. Demand deposit contracts and the probability of bank runs. The Journal of Finance 60, 1293-1328. Gorton, G., 1988. Banking panics and business cycles. Oxford Economic Papers 40, 751-781 Gorton, G. and Metrick, A., 2011. Securitized banking and the run on repo, Journal of Financial Economics, forthcoming. http://dx.doi.org/10.1016/j.jfineco.2011.03.016 Gorton, G., Winton, A., 2003. Financial intermediation, in: G.M. Constantinides, G.M., Harris, M., Stulz, R.M. (Eds), Handbook of the Economics of Finance, Vol. 1A, North Holland, Amsterdam, pp. 431-552. Green, E.J., Lin, P., 2000. Diamond and Dybvig's classic theory of financial intermediation: What's missing?. Federal Reserve Bank of Minneapolis Quarterly Review 24, 3-13. Green, E.J., Lin, P., 2003. Implementing efficient allocations in a model of financial intermediation. Journal of Economic Theory 109, 1-23. Gu, C., 2011. Herding and Bank Runs, Journal of Economic Theory 146, 163-188. Ivashina, V. and Scharfstein, D., 2010. Bank lending during the financial crisis of 2008. Journal of Financial Economics 97, 319-338. Iyer, R., Puri, M., 2012. Understanding bank runs: The Importance of depositor-bank relationships and networks. American Economic Review 102, 1414-1445. Kelly, M., O Grada, C., 2000. Market contagion: Evidence from the panics of 1854 and 1857. American Economic Review 90, 1110-1124. Kennedy, P., 2008. A Guide to Econometrics. Blackwell Publishing Ltd. Kiss, H. J., Rodriguez-Lara, I., Rosa-Garcia, A., 2012a. On the effects of observability and

deposit insurance on bank runs: An experimental study. Journal of Money, Credit and Banking 44, 1651-1665. Kiss, H. J., Rodriguez-Lara, I., Rosa-Garcia, A., 2012b. Do Social Networks Prevent Bank Runs? ERICES Working Paper DPEB 08/12. Klos, A., Sträter, N., 2013. How strongly do players react to increased risk sharing in an experimental bank run game? QBER Discussion Paper No. 6/2013. Madies, P., 2006. An experimental exploration of self-fulfilling banking panics: Their occurrence, persistence, and prevention. Journal of Business 79, 1831-1866. Peck, J., Shell, K., 2003. Equilibrium bank runs. Journal of Political Economy 111, 103-123. Rosa-Garcia, A., Kiss, H.J., 2012. Coordination Structures. IVIE Working Paper WP-AD 2012-12. Schotter, A., Yorulmazer, T., 2009. On the dynamics and severity of bank runs: An experimental study. Journal of Financial Intermediation 18, 217-241. Sprague, O.M.W., 1910. History Of Crises Under The National Banking System. Washington, DC: U.S. Government Printing Office. Starr, M.A., Yilmaz, R., 2007. Bank runs in emerging-market economies: Evidence from Turkey's special finance houses. Southern Economic Journal 73, 1112-1132. Trautmann, S.T., Vlahu, R.E. (2013). Strategic loan defaults and coordination: An experimental analysis. Journal of Banking and Finance 37, 747-760. Wicker, E., 2001. The Banking Panics of the Great Depression. Cambridge University Press.

Appendix A: Instructions

Welcome to the experiment!

This is an experiment to study decision making, so we are not interested in your particular choices but in individuals' average behavior. Therefore, during the experiment you'll be treated anonymously. Neither the experimenters nor the people in this room will ever know your particular choices.

Next, you will find the instructions in the computer screen explaining how the experiment unfolds. The instructions are the same for all subjects in the laboratory and will be read aloud by experimenters. It is important for you to understand the experiment before starting, as the money that you will earn will depend on your choices. You also have a copy of the instructions on your table.

Number of rounds

This experiment has 18 rounds in total. The first 3 rounds are for you to become familiar with the software. The remaining 15 rounds will be used to determine your final payoff, so please be sure that you understand the experiment before starting the 4th round. This will help you to earn more money.

What is this experiment about?

At the beginning of each round, you will be provided a certain amount of money (40 pesetas) to be deposited in a bank. The same will be done with two other depositors. The bank in which you will invest your money will be formed by 3 depositors: one of them is you, the other one is someone else in this room and the third depositor is simulated by the computer. Therefore, the bank in which you deposit your money will have 120 pesetas per round in total.

Choice and earnings

In principle, your decision is to choose whether to withdraw your money from the common bank in the first period or to wait until the second period,

---

taking into account that your earnings will depend not only on your choice but also on other depositors' choices. Indeed, it is important to know that the computer will always withdraw her money and, thus that your earnings in each round will only depend on your choice and the choice of the other depositor in this room.

Specifically, if you both wait until the second period to withdraw your money, you will get 70 pesetas, corresponding to your initial investment plus interests generated during the first period of time (in which you have decided to wait).

If only one of you withdraws the money, then the one who withdraws takes 50 pesetas (exactly the same amount that the computer will take in this case). The depositor who waits will receive 30 pesetas. In this case, this depositor receives the amount that remains in the bank after the first period -20 pesetas- plus an additional quantity of interest.

Finally, it might be the case that you both withdraw your money in the first period. As a result, your earnings will depend on the available amount in the bank and your position in the line. Therefore, if you are at Position 1 or Position 2 in the line and decide to withdraw, you will take 50 pesetas, but if you are the last one in the line (Position 3), only 20 pesetas will remain in the bank and this is exactly the amount of money that you will receive.

Therefore, your payoffs can be summarized in the following table:

Table 1. Payoffs of the experiment

Please remember that the depositor simulated by the computer will always withdraw the money in the first period.

Before starting, it may be important for you to consider that:

1. The person with whom you are linked will change every round. As a result, do not think that you are going to play with the same person.

2. You will always know your position in the line, but this position might change in each round. In particular, you may be located at Position 1, Position 2 or Position 3 with the same probability. The same is true for the computer.

3. In each round, you will have different information about what other depositors at your bank have done. Therefore, in some cases, you will know what has happened before you arrived at the bank (number of deferrals and withdrawals) and in some other cases, you will not. At the time of

30

making your choice, you will also know whether someone else will observe your decision. It may be of your interest to consider this information when making your decision. The information will appear at the left-hand side of the computer screen:

E.g., You are at Position 1. Depositors at Position 2 and Position 3 will observe your choice.

E.g., You are at Position 2. Depositor at Position 1 has waited. Depositor at Position 3 will not observe your choices

We are now going to start with the first three rounds. At the end of the three rounds, you can ask any questions to make sure that you have understood the procedure. If you have any doubt afterwards, please raise your hand and remain silent. You will be attended by the experimenters as soon as possible. Talking is forbidden during this experiment.

Appendix B: Statistical tests

We provide in this appendix some statistical tests to complement our analysis in the paper. We focus on Table 2 and compare the likelihood of bank runs depending on whether the link 12 exists or not. The test of proportion using pairwise comparisons always rejects the null hypothesis that the frequency of bank runs in any network structure with the link 12 is the same as the frequency of bank runs in a network without this link in favor of the alternative that bank runs are less likely when there is link 12, except in three cases; namely, the comparison between (12,13) and (13,23), as well as the comparison between the network (12) and the networks (13,23) or (13). In all these cases, the rate of withdrawal is always lower in the networks with the link 12, but the difference is not statistically significant. The value of the statistics is reported in Table B1 below, where we indicate significance after correcting for multiple testing using the Bonferroni correction.

Table B1 here

Table 1. Payoff table for the experiment

Number of previous withdrawals	If you withdraw	If you wait then…	
		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

Table 2. Likelihood of bank runs and level of efficiency in each possible network

Network	Computer Position	Number Decisions	Frequency of withdrawal			Likelihood Bank run	Efficiency Losses	Ranking	Pooled Data		Ranking
			$Pr(y_1=1)$	$Pr(y_2=1)$	$Pr(y_3=1)$				Likelihood Bank Run	Efficiency Losses	
(12,13,23)	1	44	-	0.39	0.25	0.54	-32.10	15			
	2	44	0.09	-	0.05	0.14	-8.18	2	0.21	-12.52	1
	3	52	0.00	0.00	-	0.00	0.00	1			
(12,23)	1	24	-	0.23	0.15	0.25	-16.67	9			
	2	26	0.15	-	0.15	0.23	-14.61	6	0.22	-14.32	2
	3	24	0.17	0.17	-	0.17	-11.67	4			
(12,13)	1	24	-	0.50	0.42	0.67	-42.50	22			
	2	26	0.15	-	0.08	0.15	-10.00	3	0.35	-22.70	3
	3	24	0.25	0.17	-	0.25	-16.67	9			
(12)	1	24	-	0.58	0.08	0.58	-35.83	18			
	2	24	0.25	-	0.25	0.42	-25.83	12	0.39	-24.16	4
	3	24	0.08	0.17	-	0.17	-10.83	4			
(13,23)	1	26	-	0.23	0.00	0.23	-14.40	6			
	2	24	0.33	-	0.08	0.42	-25.00	12	0.41	-24.93	5
	3	24	0.25	0.42	-	0.58	-35.83	18			
(13)	1	26	-	0.15	0.23	0.38	-23.07	11			
	2	22	0.18	-	0.27	0.45	-27.27	14	0.49	-29.43	6
	3	22	0.18	0.55	-	0.64	-39.10	21			
(23)	1	26	-	0.25	0.00	0.23	-14.40	6			
	2	22	0.73	-	0.18	0.73	-45.45	23	0.55	-34.20	7
	3	22	0.45	0.45	-	0.73	-45.45	23			
(∅)	1	48	-	0.38	0.33	0.58	-36.25	18			
	2	48	0.29	-	0.33	0.54	-33.33	15	0.56	-34.44	8
	3	48	0.29	0.38	-	0.54	-33.75	15			

Notes: In total we have 718 decisions. 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. 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 3. Logit model for depositor 1

	Intercept	L12	L13	L12L13	History
Coefficient (α)	-3.265*** (0.97)	-0.919** (0.41)	-1.031*** (0.14)	0.358 (0.54)	5.322*** (1.19)
Marginal effect		-0.109* (0.06)	-0.122*** (0.04)	0.072 (0.06)	0.623*** (0.09)

Notes. The dummy variable Lij, stands for the existence of the link ij. The estimated standard errors in parentheses take into account matching group clustering and are corrected using the Bias Reduced Linearization (Bell and McCaffrey 2002). Significance at *10%, **5%, ***1%. Number of observations: 238. Wald χ^2-test (p-value) = 0.000

Table 4. Logit model for depositor 2

	Intercept	Y1	Y0	L23	Y1L23	History
Coefficient (α)	-2.881*** (0.68)	1.397** (0.69)	-2.145** (0.96)	-0.005 (0.51)	-1.259 (1.11)	4.047*** (0.88)
Marginal effect		0.298** (0.15)	-0.240** (0.07)	-0.001 (0.15)	-0.220 (0.15)	0.724*** (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 parentheses take into account matching group clustering and are corrected using the Bias Reduced Linearization (Bell and McCaffrey 2002). Significance at *10%, **5%, ***1%. Number of observations: 241 (231 after eliminating the observations that predict waiting perfectly). Wald χ^2-test (p-value) = 0.0000

Table 5. Logit model for depositor 3

	Intercept	Z1	Z11	Z0	Z10	History
Coefficient (α)	-3.391*** (0.58)	-0.056 (0.68)	-1.558 (1.12)	-1.001 (0.93)	-0.777*** (0.12)	4.215*** (1.01)
Marginal effect		-0.006 (0.07)	-0.106*** (0.02)	-0.087* (0.04)	-0.073*** (0.02)	0.465*** (0.10)

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 parentheses take into account matching group clustering and are corrected using the Bias Reduced Linearization (Bell and McCaffrey 2002). Significance at *10%, **5%, ***1%. Number of observations: 239. Wald χ^2-test (p-value) = 0.0000