Understanding Bank-Run Contagion

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Abstract: We study experimental coordination games to examine through which transmission channels, and under which information conditions, a panic-based depositor-run at one bank may trigger a panic-based depositor-run at another bank. We find that withdrawals at one bank trigger withdrawals at another bank by increasing players' beliefs that other depositors in their own bank will withdraw, making them more likely to withdraw as well. Observed withdrawals only affect depositors' beliefs, and are thus contagious, when they form an informative signal about bank fundamentals.

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1. Introduction

Financial contagion, i.e., the situation in which liquidity or insolvency risk is transmitted from one financial institution to another, is viewed by policy makers and academics as a key source of systemic risk in the financial sector (Allen *et al.,* 2011). Events in the 2007-2009 financial crisis and the recent European sovereign debt crisis highlight the potential contagion of deposit withdrawals across banks and the resulting implications for financial stability. The liquidity support by the Bank of England to the UK mortgage lender Northern Rock in September 2007 was primarily motivated by fears that restricted access to deposits for Northern Rock clients could trigger a deposit run throughout the UK financial system.[1] When liquidity support to Northern Rock did trigger a depositor run on this bank, the UK authorities announced that all deposits at Northern Rock would be guaranteed. This move came after first signs that the depositor run on Northern Rock might indeed spread to other, similar, UK financial institutions.[2]

Beyond such recent events, the contagion of deposit withdrawals across banks has been documented for the U.S. during the Great Depression (Saunders and Wilson, 1996; Calomiris and Mason, 1997) as well as more recently in emerging markets (Iyer and Peydro, 2011; De Graeve and Karas, 2014). However, the existing literature provides only scarce guidance on which economic and informational conditions may foster contagious bank runs. In this paper, we use a laboratory experiment to explore under which information conditions a panic-based run at one bank may trigger a panic-based run at another bank, and through which transmission channels this contagion occurs. In line with Goldstein (2013) we define a panic-based bank run as one which takes place although fundamentals could have supported a non-run outcome.

Our use of a laboratory experiment allows us to overcome two key obstacles in identifying contagion of panic-based bank runs and the driving forces behind them. First, it is difficult to disentangle the contagion of panic-based bank runs from other potential causes of

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[1] The Run on the Rock: Fifth report of session 2007-08. Vol. 1, page 55.
http://www.publications.parliament.uk/pa/cm200708/cmselect/cmtreasy/56/56i.pdf

[2] http://www.theguardian.com/business/2007/sep/18/politics.money1

correlated deposit withdrawals across banks: correlated liquidity shocks across households; or correlated performance shocks across banks, i.e., due to macroeconomic shocks; or common exposure to asset shocks which could trigger correlated deposit withdrawals based solely on fundamentals. Second, even if field data would identify cases of contagion of panic-based bank runs, the data would hardly enable us to explain how the runs became contagious. In order to understand the drivers of contagious runs, we would need to measure the beliefs of depositors about the liquidity / solvency of their bank, as well as their beliefs about the propensity of their fellow depositors to withdraw, and how these beliefs are affected by the observation of a run at another bank (Goldstein, 2013).

The underlying game in our experiment is a two-person coordination game with stochastic payoffs. This game captures the essence of models of panic-based bank-runs in which the fundamentals of banks are uncertain. In this set-up we examine under which conditions a run at one bank may trigger a run at another bank. In our experiment there are two types of depositors: *leaders* and *followers*. Subjects in the roles of followers observe the outcome of a leaders game before they make their own deposit withdrawal decisions.

Our two main treatments allow us to identify under which informational conditions the withdrawal behavior of leaders affects the withdrawal behavior of followers. In our No-Linkages treatment followers know that the realized payoff structure of the leaders bank and their own bank are uncorrelated. Thus observed withdrawals in the leaders game are uninformative with respect to bank fundamentals in the followers game. In our Linkages treatment followers know that the realized payoff structure of the leaders game is identical to their own. Moreover, they know that leaders know the fundamentals of their bank before they make their decision. In this treatment observed withdrawals in the leaders game provide a noisy signal of bank fundamentals in the followers game. The comparison between the Linkages and No-Linkages treatments allows us to test whether contagion is more likely to occur when observed withdrawals in the leaders game provide a (noisy) public signal about the fundamentals of the followers bank. Our results suggest that deposit withdrawals can be strongly contagious across banks, but only when they are informative about bank fundamentals. Followers in the Linkages treatment who observe leaders withdrawals are three times more likely to withdraw than followers who observe no withdrawals by leaders. By contrast, in the No-Linkages treatment leaders' withdrawals do not affect the withdrawal behavior of followers. We document that the main channel through which contagion occurs in the Linkages treatment is not through an updating of beliefs about bank fundamentals, but through an updating of beliefs about the other depositor in their game withdrawing. Followers in this treatment who observe withdrawals by leaders are much more likely to believe that the other follower in their bank will withdraw. Moreover, beliefs about the withdrawal behavior of the other depositor have a stronger impact on withdrawal behavior than in the No-Linkages treatment.

Our results speak to models of bank runs which study the role of imperfect information about bank fundamentals and noisy signals thereof in triggering panic-based bank runs. Chari and Jagannathan (1988) emphasize that the withdrawal behavior of informed depositors provides a noisy public signal of bank fundamentals to uninformed depositors of the same bank. Chen (1999) examines a setting in which the behavior of informed and uninformed depositors at one bank inform depositors of other banks. In a global games framework, Goldstein and Pauzner (2005) study how private noisy signals about bank fundamentals affects the coordination of depositors. Gu (2011) and He and Manela (2015) study models of dynamic deposit withdrawals in which depositors both receive private signals about bank fundamentals and learn from observed behavior of others.

We provide novel empirical evidence on the key mechanisms emphasized in these models. We confirm that the observed behavior of well-informed depositors influences the behavior of less-informed depositors by providing a noisy signal of bank fundamentals. Crucially though, our results show that observed withdrawals can become contagious even if they only have a modest impact on beliefs about bank fundamentals. The reason is that observed withdrawals have a strong coordinating effect on the beliefs of the observing depositors about their mutual withdrawal behavior. This mechanism is emphasized in global games models (Goldstein and Pauzner, 2005)[3]: a noisy signal about bank fundamentals can trigger a run even if the beliefs about bank fundamentals would support a non-run outcome.

Our study contributes to a growing literature using experimental methods to examine the economic and behavioral determinants of bank runs.[4] Madies (2006), Garratt and Keister (2009), and Arifovic *et al.* (2013) study static models of bank runs with sunspot equilibria. Schotter and Yorulmazer (2009) as well as Kiss *et al*. (2012, 2014) study dynamic deposit withdrawals within a given bank. Closest to our paper, Chakravarty *et al.* (2014) study the contagion of withdrawals across and within banks over time. Our design differs in an important aspect from their setup: We measure explicitly the beliefs of depositors in the followers game – a feature which is absent in Chakravarty *et al.* (2014). This allows us to document the transmission mechanism through which withdrawals in the leaders bank affect the behavior of observing depositors in other banks. We show how observed withdrawals affect followers' subjective probabilities (beliefs) about the fundamentals of their bank and their subjective probability that the paired depositor will withdraw.

2. Experimental Design

2.1. The Depositors' Coordination Problem

The underlying game in our experimental design is based on a two-person coordination game. In this game there are two depositors, Depositor A and Depositor B, in a bank. Both depositors decide simultaneously whether to keep their deposit in the bank until maturity, or to withdraw their funds. If both depositors keep their funds in the bank, the bank does not have to liquidate any investments and both depositors receive a payoff R. If either depositor withdraws her deposit the bank is liquidated. We assume that the liquidation value of the bank's investment is L. If only one depositor withdraws that depositor receives a payoff of L and the other depositor receives 0. If both depositors withdraw, each receives a payoff of $L/2$.

Figure 1 presents the payoff matrix of this two-person bank-run game for which there

[3] Morris and Shin (1998) present a global games model of currency crises.

[4] Dufwenberg (2015) provides an excellent survey on experimental banking literature.

are two symmetric pure-strategy equilibria: [Keep deposit; Keep deposit] and [Withdraw; Withdraw]. In the experiment, R takes either the value R_{strong}=60 or R_{weak}=50, indicating a bank with a strong or a weak portfolio of assets, respectively. The liquidation value is set at L=40.

Figure 1: The Depositors' Coordination Problem

Depositor A \ Depositor B	Keep deposit	Withdraw
Keep deposit	*R, R*	*0, L*
Withdraw	*L, 0*	*L/2, L/2*

2.2 Treatments

The aim of our study is to examine under which circumstances public information about withdrawals at one bank may trigger panic-based withdrawals at another bank. To this end we employ a sequential structure, in which two pairs of subjects play the bank-run game after each other. The first pair of subjects are called the *leaders*. The second pair of subjects are called the *followers*. In all treatments the leaders are informed about the structure of the game as displayed in Figure 1 and are informed about whether R takes either the value R_{strong}=60 or R_{weak}=50 for their bank. With this information these two subjects simultaneously make their decision to keep their deposits in their bank or withdraw them.

In all treatments, followers are informed that half of the followers' banks have strong assets (R_{strong}=60) and the other half have weak assets (R_{weak}=50). Thus, in contrast to the leaders, followers are uncertain about the asset quality of their bank. The information set of the followers is varied across treatments.

Our first treatment is called the *No-Linkages* treatment. In this treatment, the result of the leaders' game, i.e., the number of withdrawals that occurred —0, 1, or 2— is communicated to the followers and becomes common knowledge. Both followers are also informed that the leaders knew the asset quality of their bank before they made their decisions. Importantly though, in the No-Linkages treatment, followers are informed that the realization of the actual asset quality of their bank is independent of that of the leaders' bank.

In this treatment the withdrawal behavior of leaders provides no information about the fundamentals of the follower's bank.

Our second treatment is called the *Linkages* treatment. As in the No-Linkages treatment, the followers are informed about the number of withdrawals that occurred in the leaders' game, and that the leaders knew the asset quality of their bank before they made their decisions. In contrast to the No-Linkages treatment, followers are informed that the asset quality of their bank is identical to that of the leaders' bank they observe. In this treatment the observed behavior of the leaders does provide a noisy signal of bank fundamentals in the followers game - as long as followers believe that leaders are less likely to withdraw from a bank with strong fundamentals.

Our third treatment is called the *Baseline* treatment. In this treatment the followers are not informed about the behavior of the leaders. As in the other two treatments, followers are uncertain about the asset quality of their bank and know that R takes either the value R_{strong}=60 or R_{weak}=50 with equal probability. This treatment serves as a benchmark for the behavior of subjects in our bank-run game with uncertain payoffs.

It is important to stress that in the Linkages treatment (as in the No-Linkages treatment) the followers game constitutes a coordination game, independent of the information transmitted from the leaders game. While the observation of the leaders behavior may provide the followers in this treatment with a signal of the asset quality of their own bank (R_{strong}=60 or R_{weak}=50), the followers game features two pure-strategy equilibria independent of their beliefs about asset quality. Our design thus allows us to test a hypothesis akin to predictions from global games models (Goldstein and Pauzner, 2005), namely that (noisy) information about bank fundamentals (in the Linkages treatment) can trigger a panic based bank run, i.e., a run on a bank at which the fundamentals would support a non-run outcome.

2.3. External Validity of the Design

Several features of our experimental design warrant discussion with respect to their external validity. First, in our experiment leaders know the fundamentals of their bank, while followers can only infer the fundamentals of their bank from observing leaders behavior. This information structure paves the way for contagion of runs across banks as the leaders' behavior may provide a noisy signal of the fundamentals to depositors in the followers bank. Without knowledge of the fundamentals of their bank, the leaders' withdrawal behavior would be completely uninformative with respect to bank fundamentals in the followers game, thus very similar to the No-Linkages treatment in terms of contagion. Our assumptions of heterogeneity in information and timing of withdrawals are in line with depositor-level evidence documenting that well-informed and more sophisticated depositors do withdraw early from distressed banks (Davenport and McDill, 2006; Iyer *et al.*, 2015). Our assumption that followers can observe leaders withdrawals are in line with evidence documenting that deposit withdrawals by some households trigger withdrawals among geographically or socially proximate households (Kelly and O Grada, 2000; Iyer and Puri, 2012; Ramirez and Zandbergen, 2014). Our assumption on observability is also consistent with cases from the recent financial crisis where massive liquidity withdrawals at major commercial banks (e.g., Northern Rock, Washington Mutual, UBS) became public through the media.

Second, followers in our design are faced with uncertainty about the payoffs of the bank in the case of no-liquidation as opposed to uncertainty about the liquidity position of the bank.[5] This design choice is motivated by the idea to capture the potential role of asset-commonality of banks as modeled by Chen (1999) and Ahnert and Georg (2012). Our design choice implies that followers face a stochastic return to their deposits as opposed to a fixed income payment. This design feature is a shortcut to modelling uncertainty about expected returns on deposits due to insolvency risk.

Third, our experiment abstracts from institutions such as deposit insurance or the lender of last resort. We argue, however, that our findings are relevant well beyond understanding the behavior of uninsured retail depositors or wholesale depositors. Several recent studies emphasize that retail depositors have very limited knowledge about deposit insurance (Sträter *et al.*, 2008; Bartiloro, 2011), and that even informed and insured

[5] See Chakravarty *et al.* (2014) for a bank-run game in which the liquidation value of the bank is uncertain.

depositors are likely to withdraw deposits from distressed banks (Iyer and Puri, 2012; Pyle *et al.,* 2012; Karas *et al.*, 2013; Brown *et al.*, 2014).

Fourth, our experiment is implemented in the lab with a student population. This gives rise to broader concerns that the observed behavior may not reflect that of real-life depositors whose life-savings are at stake if a bank collapses. We acknowledge that there are limits to the generalization of the findings in a lab experiment on bank runs:[6] Household wealth, portfolio structure, structure of bank relationships, and financial sophistication are very likely to affect withdrawal behavior and thus the magnitude of contagion of bank runs (see e.g., Brown *et al*., 2014). That said, the aim of our experiment is not to provide estimates of the likelihood and severity of contagion. Instead, our aim is to better understand the channels through which such contagion may occur in a qualitative sense. A significant body of evidence suggests that the behavioral mechanisms observed in lab experiments are robust to using non-student pools and substantial variations in stakes (Huck and Müller, 2012; Noussair *et al*., 2014; Fréchette, 2015).[7] Indeed, Levy (1994) argues that experimental participants create their own frame of mind in which they make decisions for modest stakes in the same way as they would make decisions outside the lab for significant stakes.

2.4. Procedures

We conducted 14 experimental sessions, with either 16 or 20 subjects in each session. In total 264 undergraduate students of the University of Amsterdam participated in our experiment.[8] In each session the 16–20 subjects were randomly matched in groups of four players. At the beginning of the session, one group of four players was randomly assigned to the role of

[6] Obviously this statement also applies to empirical studies and field experiments based on data from specific financial institutions in specific institutional settings.

[7] In other contexts of financial intermediation, i.e., the impact of credit information sharing on loan repayment, experimental results are also qualitatively robust across student and expert subjects (Brown and Zehnder, 2007; Cornee *et al*., 2012).

[8] The experiment was programmed and run using z-Tree software (Fischbacher, 2007). Instructions and an overview of the different sessions are provided in the online appendix.

leaders. The other three or four groups were assigned the role of followers.[9] Each subject played two rounds of the bank run game: within each group of four, the players were assigned to pairs in round 1 and round 2 so that they played the two-person coordination game with a different participant within their group in each of the two rounds. In total, 60 subjects were assigned the role of leaders and 204 the role of followers. In each session all players assigned the role of followers played the same treatment.

From the group of leaders we obtain four observations of the bank-run game in each session (two games in round 1 and two games in round 2). Two of the leaders' games were implemented with strong assets (R_{strong}=60) and two were implemented with weak assets (R_{weak}=50). Which of the leaders' games was implemented with strong or weak assets was determined randomly prior to the beginning of each session. The outcome of the randomization was communicated to leaders.

In each session of the No-Linkages and Linkages treatments we showed the outcome of the four leaders' games to a different group of followers. For each follower group the quality of bank assets was constant in both rounds. In the No-Linkage treatment the quality of bank assets for followers was randomly determined prior to the beginning of the session: Two groups of followers were assigned strong bank assets, while the other two were assigned weak bank assets. In the Linkages treatment the quality of followers' bank assets was directly linked to that of the observed leaders, and thus also randomly determined prior to the beginning of the session. In the Baseline treatment the quality of bank assets for each follower pair was randomly determined prior to the beginning of the session.

All followers were informed about the process of determining the quality of bank assets for their group. This allowed us to (i) refer in the instructions to actual numbers of banks that were weak or strong, and (ii) make sure that in each session there was an equal number of weak and strong banks for leaders, and followers were aware of that fact.

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[9] There were two exceptions to this design. First, in all the sessions in which treatment Baseline was played, there were no leaders, since followers did not receive any information about the leaders' game. Second, we ran a separate session in which all the 20 subjects were assigned the role of leaders.

Prior to each decision by followers we elicited their beliefs about the behavior of the other depositor in their bank and about the asset quality of the bank. First, we asked subjects to express their beliefs about how likely it was that their bank has strong assets. Then all followers had to state the likelihood that the other depositor with whom they are matched with is withdrawing her deposit. Beliefs were measured on a 7-point Likert scale, and normalized to a scale from 0 (very unlikely) to 1(very likely).

Subjects received written general instructions at the beginning of the session that were also read aloud. Subjects received the specific instructions for the bank-run game directly on-screen. Leaders received different instructions on screen than followers. Importantly, leaders did not know that their choices would later be communicated to followers, to avoid any effects of such observability on their behavior. Followers were informed that leaders did not know that their choices were observed by others. The bank-run game was framed in the banking context. Before the experiment started, each subject had to pass a test with control questions for which they had to calculate the payoffs for both players to make sure that they understood the payoff structure and the decision process. These practice questions were not paid, but the payoffs in these test questions were identical in size and structure to the game studied in the real task. Only after all subjects correctly calculated the payoffs did the program continue to the main task.

Depending on the outcome of the bank-run game, subjects could earn between 0 and 60 experimental units in each round. At the end of the experiment one round was randomly selected for real payment to avoid wealth effects. Each experimental unit translated into €0.10 at the end of the experiment for real payment, on top of a show up fee of €7.

Loss aversion has been found to affect behavior in coordination games,[10] and we therefore control for it in the current experiment. After subjects had made their decisions in both rounds of the bank-run game we elicited loss attitudes using a lottery choice task (see the online appendix for details). Subjects earned experimental units according to their decisions, depending on the outcome of the risky lotteries. At the end of each session we also

[10] See Cachon and Camerer (1996), Rydval and Ortmann (2005), and Trautmann and Vlahu (2013).

elicited selected socio-economic characteristics (age, gender, nationality, number of bank accounts) through an on-screen questionnaire.

3. Predictions

The underlying game in our experiment is a coordination game with stochastic payoffs. Independent of the realized payoff structure, however, there are two, Pareto-ranked Nash-equilibria. Existing evidence on common-interest coordination games suggests that the payoff structure of the game (e.g., payoff dominance vs. risk dominance of the equilibria) gives rise to focal points for the behavior in all our treatments.[11] The theory of global games suggests that in situations in which the behavior of other agents is uncertain, information about the payoff structure may serve as a coordination device for behavior. Noisy information however, may lead to dispersed interpretations across agents.

We conjecture that the decision of a depositor in our experiment to choose [Keep deposit] or [Withdraw] depends on her subjective probability that the bank has strong fundamentals (*p*) and her subjective probability that the other depositor in her bank will withdraw her deposit from the bank (*q*). Given the parameters of our game and her subjective probabilities (*p, q*) the expected payoffs of a depositor are:

$$E[payoff \mid Keep] = (1-q)\cdot p \cdot R_{strong} + (1-q)\cdot(1-p)\cdot R_{weak} = (1-q)(50+10p)$$

$$E[payoff \mid Withdraw] = (1-q)L + q\cdot L/2 = (2-q)\cdot 20$$

The difference in expected payoffs between withdrawing the deposit and keeping it in the bank is thus strictly increasing in *q* and decreasing in *p*:

[1] $$E[payoff \mid Withdraw] - E[payoff \mid Keep] = 30q - (10-10q)p - 10$$

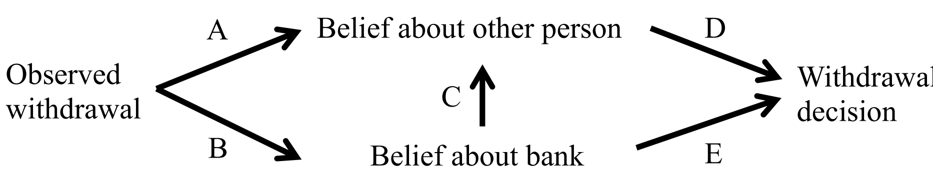
Based on condition [1] we conjecture that information which increases the beliefs of the depositor that the bank has strong fundamentals (Δp>0) will reduce the propensity of a depositor to withdraw. By contrast, information which increases the belief that the other

[11] Camerer (2003) discusses equilibrium selection criteria in coordination games.

depositor will withdraw her deposit from the bank (Δq>0) increases the propensity to withdraw.

Within this framework we suggest the following transmission channels for bank run contagion from leaders' banks to followers' banks in our Linkages and No-Linkages treatment (see Figure 2): An observed withdrawal at the leaders bank can affect directly the belief of a depositor in the followers bank about her paired depositor (Δq: path A), or the depositor's belief regarding the bank's strength (Δp: path B). Moreover, beliefs about the banks' strength may also induce beliefs about the other depositor's behavior (path C). As conjectured above, changes in the beliefs (*p, q*) subsequently influence the withdrawal decision (paths D and E).

Figure 2: Transmission Channels of Bank Run Contagion



We conjecture that the transmission from the observed withdrawal behavior in the leaders game to the beliefs (*p, q*) should differ across treatments. In the Linkages treatment, depositors may update their beliefs about the quality of the bank's assets upon observing the leaders' behavior (path B). Because the [Keep deposit; Keep deposit] equilibrium is more payoff dominant when bank assets are strong (R_{weak}=60) than when bank assets are weak (R_{strong}=50), incentives for leaders to coordinate are stronger for strong banks. Leaders' withdrawal behavior may thus provide a noisy public signal of the followers bank's fundamentals in the Linkages treatment. An update of the followers' expectations of their bank's strength may subsequently also lead to an effect on the beliefs regarding the other depositor (path C). In the spirit of global games models this would be the case if subjects presume that other depositors draw similar inferences from the observed withdrawals as they did themselves.

The above transmission channel (path B and path C) should not be relevant for behavior of depositors in the No-Linkages treatment as observed withdrawals from the leaders game are uninformative about the followers bank's assets. However, in the No-Linkages treatment (as well as in the Linkages treatment) there can be a direct effect of the observed withdrawals of the leaders on the belief regarding other depositors (path A). For example, evidence on saliency effects (Cooper *et al.,* 1990; Mehta *et al.,* 1994) suggests that the common observation of leaders withdrawal behavior by the followers may affect their beliefs about how the other depositor perceives the game (path A). Alternatively, observed withdrawals by leaders may trigger withdrawals by followers due to conformity rather than an updating of beliefs.[12]

We test for the presence of these different channels for contagion in the experiment. Because of the multiplicity of transmission mechanisms in the Linkages treatment, with both the bank fundamentals and the pure salience channel possible, we expect contagion to be at least as strong in Linkages as in No-Linkages, where only the salience channel could be relevant.

4. Results

4.1. Leaders Behavior

Table 1 presents the withdrawal behavior in leaders games, contingent on the asset-quality of the bank. We find more leaders' withdrawals when the asset-quality of the bank is weak compared to when the asset-quality of the bank is strong. While the outcome of the leaders game is not of primary interest for our study, the Table 1 results are reassuring for two reasons: First, we obtain variation in the leaders withdrawals which are communicated to the followers in the Linkages and No-Linkages treatments. Second, the withdrawal rates by leaders suggest that in the Linkages treatment leaders' withdrawals do provide followers with a noisy signal of the quality of their bank.[13] At the individual level, 37.5% of leaders choices lead to a withdrawal if the bank is weak, and 22.5% lead to a withdrawal if the bank is strong.

[12] See Banerjee *et al.* (2015) on the role of conformity and learning in the diffusion of financial behavior.

[13] There was no indication that leaders behaved differently when followed by a follower game compared to the situation where there was no follower game.

Overall, 19 leaders games with no withdrawals, and 21 leaders games with at least one withdrawal are communicated to the followers. As we find very few instances in which both leaders withdraw, for the remainder of the analysis we will contrast leaders games in which no withdrawal was made to those in which at least 1 withdrawal was made.

Table 1. Withdrawals – Leaders

Bank type:	Strong bank	Weak bank
Number of leaders games:	20	20
0 withdrawals	12	7
1 withdrawal	7	11
2 withdrawals	1	2
Percentage of games with any withdrawal observed	40%	65%
Percentage of withdrawal at the individual level	22.5%	37.5%

Notes: Numbers based on both Linkages and No-Linkages treatments, and both rounds of leaders game

4.2. Contagion of Deposit Withdrawals Across Banks

Our analysis of contagion across banks is based on the first-round behavior of followers in the Baseline, No-Linkages and Linkages treatments. We ignore the second-round behavior of followers in order to not confound contagion across banks, i.e., from leaders to followers, with potential spillover effects within banks, i.e., from followers in round 1 to followers in round 2.[14] Table 2 provides summary statistics of the behavior and beliefs of followers by treatment. In the No-Linkages and Linkages treatments we report the behavior for followers conditioned on whether they observed a withdrawal in the leaders game or not.

In the Linkages treatment we find that leaders' withdrawals have a strong effect on the behavior and beliefs of followers. The propensity of a follower to withdraw is four times lower if she observes no leader withdrawing (13%), compared to when she observes at least one leader withdrawing (52%). A comparison with the Baseline treatment (23% withdrawal rate) suggests that withdrawals in the leaders game are highly contagious: they more than

[14] An analysis of second-round behavior is provided in the online appendix.

double the propensity of followers to withdraw. The observation of no-withdrawal in the leaders game reduces the propensity of followers to withdraw compared to the Baseline treatment, albeit this effect is not statistically significant.

In the Linkages treatment we find that withdrawals in the leaders game affect followers' beliefs about the asset-quality of their bank as well as their beliefs about the propensity of the other depositor in their bank to withdraw. Leaders withdrawals have a very strong impact on followers' beliefs about the behavior of the other depositor in their bank. If a follower observes withdrawals in the leaders game her belief that that the other depositor in her bank will withdraw reaches .52 compared to .31 in the Baseline. Note that the expected probability of withdrawal by the other depositor is substantially higher than the average withdrawal frequency in leaders games, even when the bank's assets are weak (.375). This observation suggests that leaders withdrawals have a strong impact on the saliency of the [Withdraw, Withdraw] equilibrium in the Linkages treatment. In line with our finding that leaders' withdrawals provide only a very noisy signal of asset-quality we find that in the Linkages treatment followers update their beliefs about their bank's assets only by a limited magnitude. Compared to the Baseline treatment followers become more pessimistic about the asset-quality of their bank (the belief that the bank is strong reaches 0.50, lower than 0.55 in Baseline) when at least one withdrawal is observed.

In the No-Linkages treatment, the withdrawal behavior of followers is not related to leaders' withdrawals. Independent of whether followers observed withdrawals by leaders their propensity to withdraw is indistinguishable from that in the Baseline treatment. As expected, leaders' withdrawals do not affect the beliefs of followers about the asset-quality of the bank. Contrary to predictions based on saliency or conformity, we find that leaders' withdrawals do not affect the beliefs of followers about the withdrawal propensity of the other depositor in their bank.

Table 3 presents a multivariate analysis of followers' withdrawals and beliefs in the Baseline, Linkages, and No-Linkages treatments. In all specifications we control for selected socio-economic characteristics of subjects: Age, gender, number of bank accounts, as well as their loss-attitudes. The column 1 and 2 results confirm that beliefs about the asset-quality of the bank and the withdrawal propensity of the other follower are unrelated to the leaders' withdrawals in the No-Linkages treatment. In contrast, column 5 and 6 results confirm that beliefs about the asset-quality of the bank and the withdrawal propensity of the other follower are strongly affected by leaders' withdrawals in the Linkages treatment.

Columns 3-4 and 7-9 consider the effect of the two types of beliefs on the withdrawal decision. Simultaneously including beliefs about banks and beliefs about other depositors (columns 3, 7, and 9) we find that the expected behavior of the other depositor is a strong predictor of withdrawals, while the belief regarding the bank is not. The coefficient for the belief regarding the other person is almost identical in the No-Linkages and the Baseline conditions (columns 3, 9). The coefficient is almost 1.5 times larger in the Linkages treatment (column 7) compared to the estimate in the No-Linkages or the Baseline treatments. The point estimate reported for *Belief other withdraw* in column 7 suggests that an increase in this belief by 22 percentage points – which is the average effect of observing a withdrawal in the leaders game – would increase the propensity of a follower to withdraw by 23 percentage points (1.053 * .22 = .23). This compares to the observed difference in withdrawal rates of 39 percentage points for the case of observing a withdrawal as opposed to observing no withdrawal by leaders in the Linkages treatment. Columns 4 and 8 document that the estimates for *Belief other withdraw* in the No-Linkages treatment and Linkages treatments are robust to additionally including *Leaders withdrawals* as an explanatory variable. This mitigates concerns that strong association between beliefs about others and withdrawal may be driven by underlying saliency or conformity effects which affect both.

While these results show that beliefs about the bank have no direct impact on withdrawal, they may still exert an effect on withdrawal by amplifying the effect of beliefs about other depositors (path C in Figure 2). Indeed, in the Baseline and Linkages treatments, the two beliefs are significantly correlated; including beliefs that the bank is strong separately from the beliefs about depositors predicts a significant reduction in withdrawals (not shown in table, p=.064 in Linkages and p=.022 in Baseline). The strong effect of the beliefs about other depositors in Linkages may thus derive from the amplification caused by the reduced belief in a strong bank after observing a withdrawal. We have already seen that this pathway is absent in No-Linkages.

Together the above results suggest that in the Linkages treatment observed withdrawals by leaders coordinate behavior among followers. This finding is in line with predictions of global games models (Morris and Shin 1998, 2002; Goldstein and Pauzner 2005) which suggest that informative signals about fundamentals affect behavior through an updating of beliefs about other players behavior. Contagion of deposit withdrawals across banks requires information about bank fundamentals, but it is still panic-based. Therefore, our results are consistent with predictions of models with incomplete information, which combines features from both panic-based theories (Diamond and Dybvig, 1983; among others) and fundamentals-based theories (Chari and Jagannathan, 1988; among others). Our findings, however pose a challenge to global games models which emphasize the role of private as opposed to public signals of bank fundamentals in triggering runs. We find that even in absence of private signals, public noisy signals may trigger mis-coordination among observing depositors. One way to rationalize this is that even if signals about bank fundamentals are common, the fact that these signals are noisy may lead to heterogeneous interpretations of the same signal across agents.

It is noteworthy that overall the frequency of withdrawals is low. Using Eq. 1, we can predict whether a depositor should withdraw or keep her deposit, on the basis of her individual level beliefs about the bank and the other depositor. When comparing this prediction with a depositor's actual withdrawal behavior, we observe that actual behavior is strongly biased toward keeping the deposit in place: of 204 followers' choices, 143 are correctly predicted; in 52 cases the prediction is too pessimistic (wrongly predict withdrawal); and in 9 cases the prediction is too optimistic. A significant belief shock seems necessary to induce a depositor to withdraw their deposit.

Table 2: Followers' Withdrawals and Beliefs – Univariate Results

Treatment	No-Linkages		Linkages		Baseline						
Observed withdrawal by leaders	Yes	No	Yes	No		T-tests (p-values)					
	[1]	[2]	[3]	[4]	[5]	[1] vs.[2]	[1] vs.[5]	[2] vs.[5]	[3] vs.[4]	[3] vs.[5]	[4] vs.[5]
Withdraw	0.21	0.16	0.52	0.13	0.23	0.559	0.845	0.356	0.001	0.002	0.270
	(0.42)	(0.37)	(0.50)	(0.34)	(.43)						
Belief other withdraw	0.43	0.38	0.52	0.31	0.31	0.414	0.070	0.243	0.005	0.000	0.954
	(0.27)	(0.27)	(0.29)	(0.30)	(.30)						
Belief bank strong	0.56	0.56	0.50	0.60	0.55	0.953	0.746	0.753	0.026	0.099	0.124
	(0.21)	(0.17)	(0.20)	(0.18)	(.14)						
Observations	n=28	n=44	n=48	n=24	n=60	n=72	n=88	n=104	n=72	n=108	n=84

Note: *Withdraw* is a dummy variable which is 1 if the subject withdraws and 0 otherwise. *Belief other withdraw* captures the belief of the subject (as a probability) that the other depositor in her bank will withdraw. *Belief bank strong* captures the belief of the subject (as a probability) that the bank has strong assets (i.e., that *R=60*). Columns (1-5) of the table present the mean (standard deviation) of each variable conditional on the treatment and observed withdrawals in the leaders game.

Table 3: Followers' Beliefs and Withdrawals: Multivariate Results

Treatment	No-Linkages				Linkages				Baseline
Dependent variable	*Belief other withdraw*	*Belief bank strong*	*Withdraw*	*Withdraw*	*Belief other withdraw*	*Belief bank strong*	*Withdraw*	*Withdraw*	*Withdraw*
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
Leaders withdrawal	0.0593	0.026		0.0575	0.223***	-0.117**		0.164*	
	[0.0656]	[0.0494]		[0.0871]	[0.0750]	[0.0472]		[0.0915]	
Belief other withdraw			0.695***	0.684***			1.053***	0.980***	0.722***
			[0.166]	[0.171]			[0.132]	[0.139]	[0.185]
Belief bank strong			-0.188	-0.199			-0.0413	0.033	-0.217
			[0.219]	[0.226]			[0.203]	[0.208]	[0.230]
Observations	72	72	72	72	72	72	72	72	60
Socio-economic controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.10	0.11	0.27	0.27	0.14	0.12	0.51	0.53	0.30
Model	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS

Note: In this table we examine the beliefs and withdrawal behavior of followers in the first round only. The dependent variables are *Belief other withdraw, Belief bank strong*, and *Withdraw*. Columns (3, 4, 7, 8, 9) report estimates from linear probability models. In (unreported) robustness tests we yield similar marginal effects of probit estimates. *Leaders withdrawal* is 1 if there is at least one withdrawal in the leaders game and 0 otherwise. *Belief other withdraw* captures the belief of the subject (as a probability) that the other depositor in her bank will withdraw. *Belief bank strong* captures the belief of the subject (as a probability) that the bank has strong assets (i.e., that $R=60$). Robust standard errors reported in brackets. *, **, *** indicate significance at the 10%, 5% and 1% level, respectively.

5. Discussion and Concluding Remarks

We conduct a laboratory experiment to examine through which channels and under which information conditions a panic-based run by depositors at one bank may trigger a panic-based run at another bank. We provide novel empirical evidence on the mechanisms emphasized in models which feature imperfect and heterogeneous information about bank fundamentals. We confirm that the observed behavior of well-informed depositors influences the behavior of less-informed depositors by providing a noisy signal of bank fundamentals. In line with global games models though, our results show that observed withdrawals can become contagious even if they only have a modest impact on beliefs about bank fundamentals. The reason is that observed withdrawals have a strong coordinating effect on the beliefs of the observing depositors about their mutual withdrawal behavior.

Our findings however also pose a challenge to global games models which emphasize the role of private as opposed to public signals of bank fundamentals in triggering runs. We find that even in absence of private signals, public noisy signals may trigger mis-coordination among observing depositors. One way to rationalize this is that even if signals about bank fundamentals are common, the fact that these signals are noisy may lead to heterogeneous interpretations of the same signal across agents.

From a policy perspective our findings suggest that economic linkages between banks due to common asset exposure and/or similar portfolio characteristics may have a further negative impact on financial stability beyond their direct economic impact on banks financial statements and equity returns.[15] Economic linkages between banks give rise to contagion of deposit withdrawals across banks, especially when depositors are aware of these economic linkages. Such systemic problems can be more acute for banking systems characterized by clusters of domestic banks which share the same business model (e.g., *cajas* in Spain or Sparkassen / Volksbanken in Germany). Our results are consistent with theories of Acharya (2009), Wagner (2010), and Ibragimov *et al*. (2011) which point to the dark side of diversification by highlighting the negative externalities of lack of diversity on the asset side

[15] Aharony and Swary (1996) and Goldsmith-Pinkham and Yorulmazer (2010) show that banks with similar characteristics to those of the failed banks are very likely to experience negative abnormal equity returns.

of financial institutions. For regulators this accentuates the question of how to monitor economic linkages between banks stemming from similar exposures, in order to assess financial fragility.[16]

Our results are informative towards the design of financial safety networks – i.e. the lender of last resort and deposit insurance systems. They suggest that in financial sectors populated by many similar banks the financial safety network is only credible if it is designed to cope ex-post with aggregate liquidity shocks. For example, the lender of last resort should have contingency plans to deal with system-wide as opposed to just idiosyncratic liquidity shocks. Likewise, the deposit insurance scheme would need to be funded so as to be able to cope with system-wide as opposed to isolated bank-runs. By contrast, in financial sectors not characterized by clusters of similar banks, the lender of last resort and deposit insurance may arguably be designed in a less resilient manner. For example, deposit insurance schemes may be credible even if they are not fully funded or have government backing.

Finally, our findings inform the discussion about which policy measures may be more effective in preventing the spread of panic-based runs across banks in the first place. Our results confirm the conjecture that it is not beliefs about bank fundamentals, but rather beliefs about the behavior of other depositors' behavior which are crucial to triggering contagious bank runs. Thus, regulators may want to place particular emphasis on informing the public about the liquidity position and net deposit flows at a bank which is a potential victim of contagion. If depositors are reassured that fellow customers are not running, then emergency measures such as the issue of a blanket guarantee to all deposits (or an increase in deposit insurance coverage limit) – as in the case of Northern Rock – may not be necessary. Indeed, our findings suggest that ad-hoc changes to the safety net may be counterproductive in mitigating the spread of bank-runs. This would be the case if the public communication of such measures reinforces the beliefs of depositors that other depositors are indeed running.

[16] See Acharya and Yorulmazer (2007, 2008a, and 2008b) for theories on how banks, due to limited liability which allows them to not fully internalize the cost of failure, choose endogenously highly correlated portfolios to increase the likelihood of joint failure and regulatory bailout.

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