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UNDERSTANDING BANK-RUN CONTAGION

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MACROPRUDENTIAL RESEARCH NETWORK

In 2014 all ECB publications feature a motif taken from the €20 banknote.

Macroprudential Research Network

This paper presents research conducted within the Macroprudential Research Network (MaRs). The network is composed of economists from the European System of Central Banks (ESCB), i.e. the national central banks of the 27 European Union (EU) Member States and the European Central Bank. The objective of MaRs is to develop core conceptual frameworks, models and/or tools supporting macro-prudential supervision in the EU.

The research is carried out in three work streams: 1) Macro-financial models linking financial stability and the performance of the economy; 2) Early warning systems and systemic risk indicators; 3) Assessing contagion risks.

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The paper is released in order to make the research of MaRs generally available, in preliminary form, to encourage comments and suggestions prior to final publication. The views expressed in the paper are the ones of the author(s) and do not necessarily reflect those of the ECB or of the ESCB.

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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. Importantly though, observed withdrawals affect depositors' beliefs, and are thus contagious, only when depositors know that there are economic linkages between their bank and the observed bank.

JEL classification: D81; G21; G28

Keywords: Contagion; Bank runs; Systemic risk

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.[1] 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.[2] 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.[3] More recently, in 2012, massive withdrawals from Spanish banks sparked fears that depositors of the UK subsidiary of Banco Santander may "run" on their bank.[4,5]

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[1] Allen *et al*. (2011, chapter 3) identify five sources for systemic risk: common exposure to asset price bubbles; mispricing of assets; fiscal deficits and sovereign default; currency mismatches in the banking system; maturity mismatches and liquidity provision. A growing literature examines a wide range of channels through which contagion in the banking sector may occur, such as common asset exposure (Acharya, 2009; Ibragimov *et al*., 2011; Wagner, 2010), domino effects through the payments system or interbank markets due to counterparty risk (Allen and Gale, 2000; Dasgupta, 2004; Freixas and Parigi, 1998; Freixas *et al*., 2000; Rochet and Tirole, 1996), or price declines and resulting margin requirements (Brunnermeier and Pedersen, 2009).

[2] 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

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

[4] In July 2012 alone, outflows amounted to €74 billion which accounts for 7% of Spain's GDP.

[5] http://www.thesun.co.uk/sol/homepage/news/money/4325476/Santander-insists-Brits-should-not-fear-Spanish-banks-panic.html.
http://www.telegraph.co.uk/finance/personalfinance/consumertips/banking/9276164/Withdrawals-at-Santander-UK-amid-Spain-fears.html

Beyond these recent events, the contagion of deposit withdrawals across banks has been documented for the U.S. during the Great Depression (Calomiris and Mason, 1997; Saunders and Wilson, 1996) as well as more recently in emerging markets (De Graeve and Karas, 2010; Iyer and Puri, 2012). However, the existing literature provides only scarce guidance on which underlying economic and informational conditions may foster contagious bank runs. Recent bank-level evidence by Iyer and Peydro (2011) documents that deposit withdrawals from a distressed bank can trigger withdrawals at similar banks in the same region, especially if these banks have interbank exposures to the distressed bank. 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.

Our use of a laboratory experiment allows us to overcome two key obstacles in identifying contagious bank runs and the driving forces behind them: First, it is almost impossible to disentangle the contagion of bank runs from other potential causes of correlated deposit withdrawals across banks: correlated liquidity shocks across households; correlated performance shocks across banks, i.e., due to macroeconomic shocks; or common exposure to asset shocks. Second, even if field data would identify cases of pure contagion of bank runs, the data would hardly enable us to explain why 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.

Our experiment is based on a two-person coordination game which captures the essence of models of panic-based bank-runs (Diamond and Dybvig, 1983).[6] In this set-up we examine under which conditions a depositor run at one bank may trigger a run at another bank. In each bank there are two depositors who decide simultaneously whether to keep their deposit in the

[6] For other models of coordination failure among depositors see Bryant (1980), Postlewaite and Vives (1987) or Goldstein and Pauzner (2005). Freixas and Rochet (2008), Degryse *et al*. (2009), and Gorton and Winton (2003, section IV) survey the theoretical and empirical literature on bank runs, respectively.

bank or withdraw their deposit. If either depositor withdraws her funds, the bank must be liquidated. In this game both a "no-run" equilibrium (neither depositor withdraws) and a "bank-run" equilibrium (both depositors withdraw) exist. 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 three 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 there are no economic linkages between the leaders' and the followers' banks (i.e., the asset qualities of the two banks are unrelated). In our Linkages treatment followers know that there are economic linkages, i.e., common asset exposure, between the leaders' and the followers' banks. The comparison between the Linkages and No-Linkages treatment 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. We also compare the outcome of the No-Linkages and Linkages treatments to a Baseline treatment in which followers do not observe the outcome of a leaders game.

Our results show that deposit withdrawals can be strongly contagious across banks, but only when depositors know that the banks are economically related. In all treatments we find that - consistent with the basic intuition of the Diamond-Dybvig framework - depositors' likelihood to withdraw is positively related to their beliefs (or subjective probabilities) about the other depositor withdrawing. However, only in the Linkages treatment do we find that withdrawals in the leaders game affect the beliefs in the followers game: Followers 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 Baseline and No-Linkages treatment. As a result followers in the Linkages treatment which observe leaders withdrawals are three times more likely to withdraw than followers that observe no withdrawals by leaders, and more than twice as likely to withdraw compared to followers in the Baseline treatment. By contrast, in the No-Linkages treatment leaders' withdrawals do not affect the beliefs of followers about the withdrawal behavior of their paired depositor so that the withdrawal behavior of followers does not differ from that in the Baseline treatment.

In an extension, we find that the contagion of deposit withdrawals across banks in the Linkages treatment is mitigated by positive experience within the followers bank: After observing the outcome of the leaders game, followers play the bank-run game twice with changing partners. We find that among those followers which observe withdrawals by leaders the withdrawal propensity in the second round is three times lower for those followers which experience no withdrawal by their paired depositor in round 1.

Our study contributes to a growing literature using experimental methods to examine the economic and behavioral determinants of bank runs.[7] Madies (2006) shows that sunspot bank runs can occur and that a suspension of convertibility or a full (as opposed to partial) deposit insurance may be required to prevent bank runs. Garratt and Keister (2009) show that when liquidity demand is not subject to stochastic shocks, panic-driven bank runs are unlikely to occur. With stochastic liquidity shocks, however, self-fulfilling bank runs are frequent. Schotter and Yorulmazer (2009) examine the dynamics of runs on individual banks in a bank-run game with sequential withdrawal opportunities. Their results suggest that when depositors expect to acquire information about the solvency of the bank they may be more willing to temporarily restrain from withdrawing their deposits. Kiss *et al*. (2012a, 2012b) study how observability of depositors' withdrawals within a given bank and deposit insurance affect the likelihood of bank runs.

Closest to our paper, Chakravarty *et al.* (2012) study the contagion of withdrawals across and within banks over time. These authors confirm our results of contagion in the case of linkages, but also find contagion when there are no economic linkages between banks. Our analysis differs in one main aspect from that of Chakravarty *et al.* (2012): As we measure the

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[7] Besides studying bank runs, laboratory experiments have been recently employed in the empirical literature on financial intermediation to examine the strategic behavior of borrowers (Trautmann and Vlahu, 2013) and the impact of information sharing and long-term banking relationships on borrower and lender behavior (Brown and Zehnder 2007, 2010; Fehr and Zehnder, 2009). Dufwenberg (2013) provides an excellent survey on experimental banking literature.

beliefs of depositors in the followers game we can document the transmission mechanism through which withdrawals in the leaders game 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.

Our paper thus contributes to the empirical literature on bank runs by providing the first evidence on the transmission mechanisms behind the contagion of deposit runs from one bank to another. In particular, we document the channel of subjective belief updates by which withdrawals from one bank lead to withdrawals by depositors at another bank, and how this channel may break down when no economic linkages exist between the banks. Importantly, we show that even when withdrawals at one bank provide only a very noisy signal about the fundamentals of other banks they can have a strong impact on the beliefs of observing depositors. These findings speak to theories which emphasize the role of noisy public information in triggering bank panics (Chari and Jagannathan, 1998; Goldstein and Pauzner, 2005; Morris and Shin, 2002).

2. Experimental Design

2.1. The Depositors' Coordination Problem

Our experimental design is based on a two-person coordination game which captures the essence of the sunspot model of bank runs (Diamond and Dybvig, 1983).[8] 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. As a consequence, if only one depositor withdraws that depositor receives a payoff of L and the

[8] Our experiment does not capture the behavior of "impatient" or "early" consumers in the Diamond & Dybvig (1983) model. We focus our design on the coordination problem between "patient" or "late" consumers.

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 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.

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

FIGURE 1: THE DEPOSITORS' COORDINATION PROBLEM

2.2 Treatments

The aim of our study is to examine under which circumstances a coordination failure among depositors at one bank may trigger a coordination failure among depositors 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.[9] 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.

[9] There are many ways to interpret the information structure available to the leaders. It can represent either detailed information contained in a recent annual report, or forecasts of banking industry analysts, both sources providing relevant information and future guidance for the market participants.

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. It is thus common knowledge among the followers that there are no economic linkages between their bank and that of the leaders.

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 they observe. In this treatment it is thus common knowledge among the followers that there are economic linkages between their bank and that of the leaders.

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. Table 1 summarizes our experimental treatments.

TABLE 1. TREATMENTS

Treatment / Conditions for followers	No-Linkages	Linkages	Baseline
Uncertainty about asset quality of their bank	Yes	Yes	Yes
Observe leaders behavior	Yes	Yes	No
Asset quality of leader-bank and follower-bank are identical	No	Yes	-

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. The Linkages treatment thus differs in structure from models of information-driven bank runs in which deposit withdrawal is the unique equilibrium in some states of the world and the behavior of other depositors provides a noisy signal about which state of the world has been realized (Chari and Jagannathan, 1988; Jacklin and Battacharya, 1988). Our Linkages treatment also differs from models of market discipline in which bad investment behavior by banks may induce deposit withdrawals to be a unique best response of depositors (Calomiris and Kahn, 1991)

Two specific features of our experimental design warrant discussion with respect to their external validity. First, our underlying bank-run game features a sequential service constraint but no deposit insurance. This does not imply that the findings of our experiment are only relevant to understanding the behavior of uninsured retail depositors or wholesale depositors.[10] Several recent studies emphasize that retail depositors have very limited knowledge about deposit insurance (Bartirolo, 2011; Sträter *et al.*, 2008) and that even informed and insured depositors are likely to withdraw deposits from distressed banks (Iyer and Puri, 2012; Karas *et al.*, 2013; Pyle *et al.*, 2012). Moreover, the design provides an experimental counterfactual for discussions of a reduction of current levels of deposit insurance in the context of bank incentives.

Second, followers in our design are faced with uncertainty about the payoffs of the bank in the case of no-liquidation. This approach stands in contrast to Chakravarty *et al.* (2012) who implement a bank-run game in which the liquidation value of the bank is uncertain. Our design choice is motivated by the idea to capture the potential role of asset-commonality of banks in the Linkages treatment. At the same time our design choice implies

[10] While uninsured, public or private bond holders are typically not subject to a (symmetric) sequential service constraint.

that followers face an "uncertain" return to their deposits. We interpret this uncertainty as the potential effect of insolvency risk (due to credit risk, interest rate risk, market risk) on the expected returns to (uninsured) deposits.

2.3. 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.[11] 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 leaders. The other three or four groups were assigned the role of followers.[12] 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 184 the role of followers. In each session all players assigned the role of followers played the same treatment. Table 2 provides an overview of our sessions.

TABLE 2. SESSIONS AND PARTICIPANTS

Sessions	Treatment	Number of Leaders	Number of Followers
1, 2, 3	Baseline	–	60
4, 5, 6, 10, 13	No Linkages	20	72
7, 8, 9, 11, 12	Linkages	20	72

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

[11] The experiment was programmed and run using z-Tree software (Fischbacher, 2007). Instructions are available online at: https://dl.dropbox.com/u/11242744/20121030_BTV_onlineappendix.pdf.

[12] 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, in order to secure comparability, we run a separate session in which all the 20 subjects were assigned the role of leaders.

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.

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, and we therefore control for it in the current experiment.[13] After subjects had made their decisions in both rounds of the bank-run game we elicited loss attitudes by offering subjects six risky lotteries that give an equal chance of either a gain or a loss in terms of experimental units. (see Appendix for details). Subjects earned experimental units according to their decisions in all six choices, depending on the outcome of the risky prospects. At the end of each session we also elicited selected socio-economic characteristics (age, gender, nationality, number of bank accounts) through an on-screen questionnaire.

3. Transmission Channels: Predictions

The bank-run game in our experiment is a coordination game with 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.[14]

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

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[13] See Cachon and Camerer (1996) and Rydval and Ortmann (2005).

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

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 ($\Delta p>0$) will reduce the propensity of a depositor to withdraw. By contrast, information which increases the belief that the other depositor will withdraw her deposit from the bank ($\Delta q>0$) increases the propensity to withdraw. Moreover, the condition shows that given the parameters of our underlying coordination game, a change in q will have a stronger impact on the behavior of the depositor (in absolute magnitude) than an identical change in p.

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).

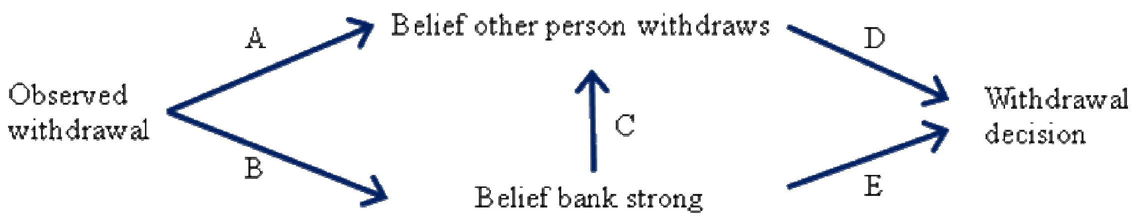

FIGURE 2: TRANSMISSION CHANNELS OF BANK RUN CONTAGION

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). This happens if people 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 perception of the coordination problem, and their beliefs about how the other depositor perceives the game.

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 3 presents the withdrawal behavior of leaders, contingent on the asset-quality of their bank. We find more leaders' withdrawals when the asset-quality of the bank is weak (38%) compared to when the asset-quality of the bank is strong (23%). While the outcome of the leaders game is not of primary interest for our study, the Table 3 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.

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 3. WITHDRAWALS – LEADERS

Bank type:	Strong bank	Weak bank
Number of leaders' games:	(n=20)	(n=20)
Number of leaders:	40	40
0 withdrawals	12	7
1 withdrawal	7	11
2 withdrawals	1	2
Withdrawal frequency	23%	38%

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. Table 4 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 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 – confirming pathways A and B in Figure 2. 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 (.38). 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.[15] Compared to the Baseline treatment followers become more pessimistic about the asset-quality of their bank (the belief that the

[15] The updating of beliefs about the bank's asset quality by followers in the Linkages treatment is largely consistent with the observed behavior by leaders. Bayesian updating would suggest that followers which observe a withdrawal in the leaders game would revise their beliefs that the bank's assets are strong to 0.375. Followers which observe no withdrawal would revise their beliefs that the bank's assets are strong to 0.554.

bank is strong reaches 0.50, lower than 0.55 in Baseline) when at least one withdrawal is observed.

In contrast to our predictions we find that 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 our predictions though, we find that leaders' withdrawals do not affect the beliefs of followers about the withdrawal propensity of the other depositor in their bank. Our results thus suggest that leaders' withdrawals do not affect the saliency of the bank-run equilibrium in the No-Linkages treatment.

TABLE 4: FOLLOWERS' WITHDRAWALS AND BELIEFS – UNIVARIATE RESULTS

Treatment	No-Linkages		Linkages		Baseline	t-tests (p-values reported)					
Observed withdrawal by leaders	Yes	No	Yes	No							
	[1]	[2]	[3]	[4]	[5]	[1]vs.[2]	[1] vs.[5]	[2] vs.[5]	[3] vs.[4]	[3] vs.[5]	[4] vs.[5]
Withdrawal frequency	21%	16%	52%	13%	23%	0.559	0.845	0.356	0.001	0.002	0.270
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
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
Observations	n=28	n=44	n=48	n=24	n=60	n=72	n=88	n=104	n=72	n=108	n=84

Notes: The table reports the percentage of followers who withdraw in round 1, mean beliefs about the other depositor in their bank, and mean beliefs about the asset-quality of bank. *Withdrawal* 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 $R=60$).

TABLE 5: FOLLOWERS' BELIEFS AND WITHDRAWALS: MULTIVARIATE RESULTS

Treatment	No-Linkages			Linkages			Baseline
Dependent variable	*Belief other withdraw*	*Belief bank strong*	*Withdraw*	*Belief other withdraw*	*Belief bank strong*	*Withdraw*	*Withdraw*
	[1]	[2]	[3]	[4]	[5]	[6]	[7]
Leaders withdrawal	0.0593	0.026		0.223***	-0.117**		
	[0.0656]	[0.0494]		[0.0750]	[0.0472]		
Belief other withdraw			0.695***			1.053***	0.722***
			[0.166]			[0.132]	[0.185]
Belief bank strong			-0.188			-0.0413	-0.217
			[0.219]			[0.203]	[0.230]
Observations	72	72	72	72	72	72	60
Socio-economic controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.10	0.11	0.27	0.14	0.12	0.51	0.30
Model	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, 6, 7) report estimates from linear probability models. In (unreported) robustness tests we yield similar marginal effects of probit estimates. Observed 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.

Table 5 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 4 and 5 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. Thus, both pathways A and B of the contagion channel are only active in the presence of linkages.

Columns 3, 6, and 7 consider the effect of the two types of beliefs on the withdrawal decision. Simultaneously including beliefs about banks and beliefs about other depositors, in all three treatments we observe 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. The coefficient is almost 1.5 times larger in the Linkages treatment compared to the estimate in the No-Linkages or the Baseline treatments. The point estimate reported for *Belief other withdraw* in column 6 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.

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 to 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.[16]

Together the above results suggest that in the Linkages treatment leaders' withdrawals strongly affect the saliency of the bank-run equilibrium. In this treatment, leaders' withdrawals have a significant impact on the beliefs of followers that the other depositor in their bank will withdraw. In line with the concept of secondary salience (Mehta *et al.*, 1994) followers also condition their withdrawals more strongly on their beliefs about the behavior of other depositors in their bank. By contrast, our results suggest that leaders withdrawals have no impact on the saliency of the bank-run equilibrium in the No-Linkages treatment. In this treatment, leaders' withdrawals do not affect the beliefs of followers about the withdrawal propensity of their fellow depositors. Moreover, the beliefs of followers have a similar impact on their withdrawal behavior as in the Baseline treatment.

4.3. Does Personal Experience Mitigate Contagion?

In all three treatments followers played the bank-run game in two consecutive rounds. The results presented above are based only on first-round behavior, as this allows us to isolate the impact of leaders withdrawals on followers behavior. In this section, we use the second round behavior of followers in order to study whether the contagion of bank runs from leaders to followers may be mitigated by personal experience of the followers in the first round. Our procedures were chosen so that the leaders game observed by followers did not change from round 1 to round 2 (and this is common knowledge among followers). Moreover, it is common knowledge that followers are paired with a different subject in round 1 and round 2. The second round behavior thus enables us to study how past personal experience in a one-shot coordination game mitigates the impact of observed withdrawals from the leaders game on the propensity of followers to withdraw.

[16] A 2SLS instrumental variable regression using observed withdrawals as an instrument for either belief variable replicates OLS results in terms of significance levels, but suggests that OLS coefficients are somewhat downward biased. That might explain the divergence between the predicted 23 percentage points versus the observed 39 percentage point increase in withdrawal after observing some withdrawal in the leaders game.

Table 6 presents summary statistics for followers behavior in the 2nd round by treatment. The importance of personal experience of followers in our game is confirmed by the results presented for the Baseline treatment. In that treatment we find that followers who witnessed a withdrawal by their paired depositor in round 1 are more than twice as likely to withdraw in round 2 than followers who witnessed no withdrawal by their paired depositor in round 1 (57% vs. 24%).[17] This result is in line with previous experimental evidence on the role of experience in repeated coordination games (Dubois *et al.*, 2012; Trautmann and Vlahu, 2011; Van Huyck et *al.*, 1990)

For the Linkages and No-Linkages treatments we report the withdrawal frequency for followers conditional on the withdrawals observed in the leaders game and conditional on whether the subject they were paired with in round 1 withdrew in that round. We are particularly interested in whether contagious bank-runs in the Linkages treatment may be contained by positive personal experience of followers in the first round. The Table 6 results suggest that this is the case. Followers who observed a leaders withdrawal but did not witness a withdrawal by their paired depositor in round 1 are three times less likely to withdraw in round 2 than followers which observed a leaders withdrawal and witnessed a withdrawal by their paired depositor in round 1 (22% vs. 68%).[18]

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[17] A two-sided t-test suggests that this difference is statistically significant (n= 60, p=0.02)

[18] A two-sided t-test suggests that this difference is statistically significant (n= 48, p<0.01).

TABLE 6: FOLLOWERS' WITHDRAWALS IN ROUND 2

Treatment	No-Linkages				Linkages				Baseline	
Leaders withdrawal	Yes		No		Yes		No			
Withdrawal round 1	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Withdrawal frequency	33%	18%	14%	16%	68%	22%	0%	5%	57%	24%
Observations	n=6	n=22	n=7	n=37	n=25	n=23	n=3	n=21	n=14	n=46

Note: This table summarizes the withdrawal behavior of followers in the second round only, conditional on whether the follower observed a withdrawal in the leaders game and whether the follower experienced a withdrawal by the other depositor in her bank in round 1. *Leaders withdrawal* is 1 if there is at least one withdrawal in the leaders game and 0 otherwise. Withdrawal round 1 is 1 if in period 1 the other depositor in the followers bank withdrew, and 0 otherwise.

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. Our results suggest that panic-based deposit withdrawals can be strongly contagious across economically related banks as a bank-run at one bank makes the bank-run equilibrium more salient for depositors at other banks, leading to an update of subjective beliefs. We find no evidence for the contagion of deposit withdrawals between banks without economic linkages. The novelty of these results is that we document that (i) the contagion of bank runs are initiated by expectations regarding other depositors, that (ii) this expectation channel is not active when banks' assets are unrelated, and that (iii) the effect on the withdrawal decision is eventually transmitted through beliefs about other depositors.

Our findings support the conjecture that *"because moving away from a good equilibrium requires a large change in beliefs, the initiation of a run when none was expected requires something that all (or nearly all) depositors see (and believe that others see)"* (Diamond 2007, p.197). However, our results also suggest that a further necessary condition for the initiation of a run may be that the commonly observed event is perceived to be economically related to the bank at hand. Thus, panic contagion is not simply an irrational psychological effect, but is driven by relevant economic events and their effects on subjective beliefs. One such event could be the observation of a bank run at a bank which is perceived to be similar, increasing the saliency of the bank-run equilibrium. Our results are thus consistent with theories of financial contagion due to information about bank defaults in presence of assets commonality (Ahnert and Georg, 2012; Chen, 1999).

Our findings put an interesting perspective on the distinction between panic-based and information-based bank runs. They suggest that while bank runs may be caused by panic, this does not necessarily imply that their occurrence is random. Our results suggest that economically related information increases the probability of a panic-based bank-run – even if that information does not change the monetary incentives to withdraw deposits. The fact that information increases the salience of the bank-run equilibrium may be sufficient to trigger a run.

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.[19] 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. Our results are consistent with theories of Acharya (2009), Ibragimov *et al*. (2011) and Wagner (2010) which point to the dark side of diversification by highlighting the negative externalities of lack of diversity on the asset side of financial institutions. For regulators this accentuates the question of how to monitor and regulate economic linkages between banks stemming from similar exposures, in order to mitigate financial fragility and to encourage greater diversity in the financial system.[20]

Our findings also inform the discussion about information disclosure and stability in the financial sector. In our experiment followers did not have perfect information about the asset-quality of their bank. But they did have perfect information about whether their bank had economic linkages with the leaders' bank. Our results suggest that transparency about economic linkages between banks may foster contagion of deposit withdrawals across banks. Whether less transparency about the existence (or non-existence) of linkages between banks would lead to less (or more) contagion is a question we leave open for future research.

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[19] Aharony and Swary (1983, 1996), Goldsmith-Pinkham and Yorulmazer (2010), and Swary (1986) show that banks with similar characteristics to those of the failed banks are very likely to experience negative abnormal equity returns.

[20] 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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Appendix. Elicitation of Loss-Attitudes

Each subject completed an individual decision task, which was aimed at eliciting subjects' attitude towards losses (Gächter *et al*., 2007). We elicit loss attitudes by offering subjects a series of risky lotteries that give an equal chance of either a gain or a loss in terms of experimental units. For each lottery, subjects could choose to play or not to play (see Table A1).

TABLE A1. CHOICE LIST MEASURE OF LOSS AVERSION

Lottery (50%–50%)	Accept to play?
Lose 9 units or Win 27 units	Yes O No O
Lose 15 units or Win 27 units	Yes O No O
Lose 18 units or Win 27 units	Yes O No O
Lose 21 units or Win 27 units	Yes O No O
Lose 27 units or Win 27 units	Yes O No O
Lose 33 units or Win 27 units	Yes O No O

Subjects were free to accept or reject any prospect, that is, we did not require single switching from acceptance to rejection as the loss increases along the list. For losses smaller than 27, rejecting to play the prospect implies a significant reduction in the expected value that may be explained more easily by a gain-loss framing and a kinked utility function of wealth changes, than by a concave utility of wealth. We call subjects who reject more lotteries in this task more *loss averse.*