DNB Working Paper
No. 665 / January 2020

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DeNederlandscheBank
EUROSYSTEEM

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* Views expressed are those of the authors and do not necessarily reflect official positions of De Nederlandsche Bank.

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January 2020

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Bank instability:
Interbank linkages and the role of disclosure

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January 2020

Abstract: We study the impact of disclosure about bank fundamentals on depositors' behavior in the presence (and absence) of economic linkages between financial institutions. Using a controlled laboratory environment, we identify under which conditions disclosure is conducive to bank stability. We find that bank deposits are sensitive to perceived bank performance. While banks with strong fundamentals benefit from more precise disclosure, an opposing effect is present for solvent banks with weaker fundamentals. Depositors take information about economic linkages into account and correctly identify when disclosure about one institution conveys meaningful information for others. Our findings highlight both the costs and benefits of bank transparency and suggest that disclosure is not always stability enhancing.

JEL classification: D81, G21, G28.

Keywords: Disclosure, Banks, Interbank linkages, Coordination, Beliefs.

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We are grateful for comments from colleagues in Heidelberg and at De Nederlandsche Bank, as well as from the audiences at the Experimental Finance 2017 and Bank of Finland. The views expressed are those of the authors only and do not reflect the position of DNB or the Eurosystem.

1. Introduction

In the aftermath of the financial crisis, greater regulation and efforts to increase the transparency of the banking industry have been at the forefront of the policy debate. Rigorous stress testing has been introduced as a key method for assessing the financial sector's ability to withstand large-scale correlated shocks to multiple (macro-)economic factors. With the rise of these regular tests of risk-bearing ability and capital adequacy of financial institutions on both sides of the Atlantic, the questions of whether or not to release results publicly and at what level of detail, have been discussed controversially by politicians, researchers and the media alike.

The reason for the observed controversy can be understood by looking at the trade-off between market discipline and financial stability. On the one hand, it is clearly in depositors' and investors' interest to know the state of their financial institutions in order to be able to make well-informed financial decisions. Increased public awareness of bank risks may thus enhance market discipline, which penalizes financial institutions for excessive risk taking. At the same time, it is also clear that insolvent financial institutions need to be identified and resolved quickly in order to prevent subsequent negative ripple effects on other institutions, potentially endangering the whole banking system. As evidence from the great financial crisis suggests, the lack of disclosure might impede financial activity. Increased uncertainty about which banks have incurred losses led to situations in which banks were unable to raise additional funds to withstand liquidity demand because of a market freeze (i.e., potential lenders were unable to assess the solvency of individual banks due to balance sheet opacity, and as a result, fearing information asymmetries, they were reluctant to lend). On the other hand, disclosing stress test results to the public may also have self-fulfilling effects in the sense that knowledge of an institution's subpar, yet not in itself a dangerous result, may still lead to strong depositors' reactions and a dramatic tightening of liquidity. Such a liquidity squeeze might then lead to a bank failure, regardless of whether the bank is solvent in the long run or not.

Furthermore, stress tests usually cover only a subsample of all financial institutions, leaving depositors of untested banks in the dark even if results are published for others. This aspect highlights the potential importance of knowledge about economic linkages between financial institutions. How similar are different banks in their capital adequacy? Are various banks exposed to the same levels and types of risk? Knowledge of such linkages can be crucial in understanding if and how disclosed information about certain institutions may lead to panic behavior among depositors with the potential to subsequently spread to other institutions in a contagious fashion.

In our study we focus on a direct information-based mechanism. Depositors obtain factual information of varying precision by means of public communication, rather than observation of behavior of others. Real world justification for this approach can be found in the stylized sequence of events in bank runs. Large reductions of bank deposits through wire transfers often preceded the more easily observable depositor run at bank counters. Statistical information about deposit levels is usually published with a lag of multiple months, precluding timely observation of withdrawals through channels other than actual cash withdrawals. One example of a depositor run following this sequence is Greece, where deposits levels had fallen tremendously after the elections of 2014 (the information event), yet the more easily observable depositor run by retail customers only started about half a year later (European Central Bank, 2015).

The theoretical literature provides useful insights on the underlying mechanisms of bank runs, information disclosure and contagion effects. However, there is little empirical work on the effects that information precision about bank's fundamentals, as well as the simultaneous consideration of both disclosure about fundamentals of individual banks and information about economic linkages across banks, might have on depositors' behavior and the stability of solvent banks. We study these fundamental mechanisms in a laboratory experiment. This approach allows us to implement tighter control over the decision situation and cleaner treatment manipulation than would be possible by basing the analysis on empirical data and natural experiments. At the same time, it offers us the opportunity to study the effects of information disclosure on depositors' behavior in the presence (and absence) of economic linkages between financial institutions in a unified setting. Our experiment is based on the Diamond and Dybvig (1983) framework, which treats bank runs as *coordination games* with inherent strategic uncertainty. In this setup, we first examine how different degrees of information precision about a bank's fundamentals create conditions for bank runs. We find that more precise information about banks with strong fundamentals reduces the propensity of deposit withdrawals. This effect is reversed for banks with weaker fundamentals, which are confronted with an increased incidence of withdrawals. Second, we study if noisy information about interbank linkages in combination with transparency over the fundamentals of one bank can trigger a run at another bank for which there is no disclosure. While we find that disclosure about one institution affects withdrawal rates at another one in the presence of noisy information about their interbank linkages, this is not the case in the absence of linkages.

Our paper fits into several strands of literature. First, it is related to the literature examining the effects of information disclosure and, more specifically, to the debate on the publication of bank stress test results. Second, it is linked to the bank run literature in general, and to the experimental bank run literature in particular. We discuss the existing evidence, both theoretical and empirical, regarding the effects of disclosure policies on bank stability and contagion in Section 2. The discussion motivates our experimental approach and hypotheses presented in the following sections. Section 3 presents the stylized banking setting for our experiment and introduces the depositors' coordination problem, as well as the experimental design and procedures. Section 4 formulates our hypotheses. Results on depositor behavior are in Section 5, and results on beliefs are in Section 6. Section 7 considers variations in beliefs and confidence. The final section summarizes the conclusions from the current research.

2 Disclosure and bank stability: Theoretical and empirical insights

2.1 Financial disclosure

Morris and Shin (2002) highlight the potential for adverse effects of publicly releasing information. They argue that public disclosure does not only comprise information about fundamentals, but also has the potential to serve as a coordination device by creating incentives for market participants to disregard their private information (cf. Angeletos and Pavan 2007). The coordination aspect of public information might render disclosure "too effective" (Morris and Shin 2002, p. 1522) in influencing behavior of market participants, as they tend to overreact to the information provided. Publicly released information is hardly a perfect, but rather a noisy signal.[1] Given the overreaction of agents to public information, noise in their private signal will be amplified, may affect their behavior, and ultimately deteriorate market outcomes. Deriving the welfare effects of variations in the precision of agents' signals in their model, the authors show that agents do not have to act irrationally for the aforementioned effects to arise.

Nier (2005) starts from the idea that disclosure can be a bad thing as it might aggravate the situation at hand. He uses a sharp drop in a bank's stock price as a bank-level indicator for severe banking problems and analyzes a large set of financial institutions across the globe over a six year time span. His empirical results show that the net effect of transparency is a reduction in severe banking problems and an enhancement of financial stability. Using an extended dataset, Nier and Baumann (2006) add to these results by showing that in the absence of governmental safety nets, information disclosure can strengthen market discipline and lead to larger bank capital buffers. They find government support to be detrimental to the effectiveness

[1] Morris and Shin (2002) mention "unwarranted public news or mistaken disclosure" (p. 1532) as examples for noise in public information.

of disclosure in enhancing financial stability. Similarly, Jordan et al. (1999) also report that more disclosure increases the effectiveness of market discipline.

Bouvard et al. (2015) find that disclosing bank-specific information enhances the stability of the financial system during crises, but has a contrary effect in normal times. In their model, regulators should increase transparency during crises. However, when the information about the aggregate shocks is private to the regulator, it generates a commitment problem: Given the signaling role of the disclosure policy, the regulator has incentives not to disclose any information in the first place, because no-information is seen as good news about the state of the economy. That is, the effect of information disclosure is context dependent. Given the anticipatory effects and the context dependency of disclosure effects, the optimal disclosure policy remains elusive. Goldstein and Leitner (2018) attempt to formulate such an optimal disclosure policy. In their model, they assume that the regulator has information about banks' ability to overcome future liquidity shocks. In this setting, they show that partial disclosure is optimal during times of distress, while not disclosing any information is beneficial in non-crisis times. Our experimental design models differences between normal times and times of distress implicitly through the existence of banks with stronger and weaker fundamentals. This allows us to empirically test these theoretical predictions. Goldstein and Yang (2019) review the channels through which financial disclosure works in financial markets.

Apart from this more general literature on the disclosure of financial information, there is also research directly concerned with the publication of stress test results. Several papers provide a theoretical costs and benefit perspective on stress tests (Faria-e Castro et al. 2017; Goldstein and Sapra 2014; Leitner 2014; Orlov et al. 2017; Prescott 2008; Quigley and Walther 2015; Shapiro and Skeie 2015; Spargoli 2012). Some conclude that disclosure of stress test results promotes financial stability, while others highlight potential harmful effects, such as banks with weaker fundamentals potentially suffering from increased disclosure due to market participants' overreaction. We test this prediction in the current study.

2.2 Bank run experiments

Arifovic et al. (2013) study bank runs as phenomena of pure coordination failure. Building on work by Temzelides (1997), they focus on the coordination parameter, i.e. the share of depositors that need to refrain from running the bank in order for not-running to yield higher payoffs than running. They show that for certain values of the coordination parameter the coordination outcomes are difficult to predict, despite the fact that depositors' behavior exhibits path dependence. Building on this result, Arifovic and Jiang (2014) demonstrate the effectiveness of *uninformative* public announcements as sunspot coordination devices. Depositors react most strongly to announcements in times of high uncertainty.

Schotter and Yorulmazer (2009) focus on the dynamics and severity of bank runs, rather than their occurrence. They find that informed insiders are less likely to withdraw than uninformed depositors. Their results support the theoretical findings on the importance of information availability for depositors' behavior in bank run contexts, a core aspect in our design. Further evidence on the contextual sensitivity of financial disclosure is provided by Davis and Reilly (2016), who study the effects of different re-contracting postures taken by the banking authorities. Re-contracting conditions may either favor depositors keeping their funds in the bank or those who withdraw. In addition, they assess the effects of disclosure in the form of revealing withdrawal behavior of depositors to the other depositors in the bank run coordination game. Their results show that the effects of disclosure may point in opposite directions, depending on the re-contracting posture adopted by the banking authority.

Shakina and Angerer (2018) study depositors' behavior in a much less restricted setting than previous studies. Their depositors can continuously withdraw and re-deposit funds without any order being enforced. The experimental environment allows for bank defaults to occur on the basis of deteriorating economic conditions, strategic uncertainty, or both. They run treatments with and without communication between depositors and analyze the frequency and mood of chat messages. The authors find evidence for both fundamentals-based and pure coordination-failure runs. Communication makes coordination on no-run behavior easier, with positively connoted chat messages having a stronger effect on withdrawal behavior than negative ones.

While factual information clearly is an important determinant of behavior, most experimental setups in the bank run context also feature an element of strategic uncertainty (i.e., uncertainty about the behavior of others) which co-determines own outcomes. A number of studies focus on this aspect. Garratt and Keister (2009) show how beliefs about the behavior of other depositors affect individual withdrawal behavior. Hegglin (2015) uses a global-game setting (cf. Carlsson and van Damme 1993) and studies the effects of past experience, risk aversion, level-k thinking, and quality of disclosure on investors' sensitivity to bad signals about bank fundamentals. He finds that noisier information positively correlates with the prevalence of banking crises and highlights that individual characteristics such as risk preferences and past experience are important determinants of withdrawal behavior. Similar results with respect to past experiences and loss aversion are reported in Trautmann and Vlahu

(2013). They also find that weaker banks (in the sense of risk dominance of the withdrawal equilibrium) experience more runs in a strategic defaulting context. In the current paper we test whether noisy revelation of bank weakness in a deposit context similarly increases the incidence of runs. Depositors' behavior is also affected by the ability for sophisticated reasoning (Klos and Sträter, 2013) and emotions (Dijk, 2017).

Besides bank run experiments with simultaneously moving depositors, there are some papers that treat bank runs as a phenomenon of sequentially deciding agents. Kiss et al. (2012) find that the effectiveness of deposit insurance in reducing the occurrences of bank runs depends on the degree of observability of depositors' actions. The authors also find evidence that depositors who are being observed are less likely to run and that depositors observing others condition their withdrawal decision on the action they observe (2014a, 2014b). Kiss et al. (2016) report that higher cognitive abilities reduce the frequency of withdrawals in the presence of strategic uncertainty. Finally, Kiss et al. (2018) document pure panic runs in the sequential-move bank run game and link their occurrence to an overestimation of the withdrawal probability of the observed depositors and loss aversion.

2.3 Financial contagion

Our study is closely linked to the issue of financial contagion, which Iyer and Peydro (2011) and De Graeve and Karas (2014) study in emerging markets. Their work points to the joint relevance of information about banks' fundamentals and about economic linkages between banks for depositors' decisions. Weaker banks face larger contagion effects while strong interbank linkages lead to larger deposit withdrawals.

Few papers succeed in studying financial contagion using real world data.[2] Individual depositors' behavior is especially hard to identify. Circumventing many empirical issues, Chakravarty et al. (2014) take the research on financial contagion to the experimental laboratory. They study bank run contagion in the Diamond and Dybvig framework and find evidence for contagion between two banks, independent of their fundamentals being economically linked or not. Brown et al. (2017) also study experimental coordination games to gain an understanding of the information conditions that lead a panic-based depositor run at one bank to trigger a panic-based depositor run at another bank. They identify pessimistic beliefs triggered by observing a depositor run elsewhere as a cause of own withdrawals. In contrast to Chakravarty et al. (2014), they only find evidence of contagion in the presence of economic

[2] Notable exceptions are Artavanis et al. (2019), Drechsler et al. (2018), Egan et al. (2017), Iyer and Puri (2012), and Iyer et al. (2016).

linkages between financial institutions. The results of Brown et al. (2017) are supported by Cipriani et al. (2018) who consider the informational channel of financial contagion. They find evidence of contagion between two markets, but only as long as asset fundamentals are correlated. Participants only apply information across markets if it is rational to do so.

Trevino (2019) identifies two classes of channels of financial contagion. She argues that contagion can be driven by factual information about fundamentals or by a social channel. The social channel comprises depositor behavior based on the observation of other market participants. Designing a model of financial contagion in a global games setting and testing its predictions experimentally, she finds that available information is not extracted optimally and, as a result, participants underweight their prior. This weakens the fundamental channel compared to the theoretical predictions. At the same time, participants suffer from an overreaction bias. They put too much emphasis on the behavior of others (the social channel) and fail to disregard the social signal even if it is completely uninformative.

In notable contrast to most experiments on the occurrence of bank runs, the aforementioned studies on financial contagion all involve sequentially moving depositors who can observe previous behavior of others. Our experimental design, in which all moves are simultaneous, allows us to study financial contagion in the same framework that is predominantly used to study bank runs. Kaufman (1994) and Glasserman and Young (2016) review large parts of the relevant literature on financial contagion. Alluding to purely psychological contagion, i.e. contagion affecting behavior exclusively through the belief channel, the latter state that information contagion can be triggered by "changes in market perceptions about the creditworthiness of particular institutions and the value of their assets […]" (p. 827). Our experiment enables us to directly test for the existence of this kind of contagion.

3 Banking setting and experimental design

3.1 Banking setting

We start with a general description of the experimental banking setting we use to study the effect of information disclosure and the role of economic linkages. We consider an economy with three dates (0, 1, 2) and no discounting. A bank operating in this economy takes deposits at date 0 and invests in assets that produce profits at date 2. Bank's deposits are uninsured and costly.[3] The creditors are repaid (with interest) at date 2 if their bank is solvent. Solvency depends on the bank's assets portfolio and depositors' actions. With respect to the former, we make assumptions about banks' fundamentals (e.g., liquidity position, quality of assets). With respect to the latter, depositors are facing uncertainty about the quality of banks' assets and may choose to withdraw their money before maturity, at date 1. In order to meet its payment obligations at date 1 the bank may be forced to liquidate (some of) its assets. Conditional on the liquidity and quality of a bank's assets at date 1, liquidation may be possible at a substantial discount. When the discount is too large, the bank may not be able to pay the remaining depositors at date 2, effectively rendering the bank insolvent. In this case, the bank is liquidated at date 1 and the liquidation value of its assets is distributed among those depositors who choose to withdraw. Upon bank bankruptcy, patient depositors (i.e., those without withdrawal claims at date 1) lose their deposits.

Information about the banking system is conveyed to market participants through disclosure. There are two types of disclosure, which may affect bank stability in this framework. First, there is the transparency about the quality and liquidity of bank's assets, which is arguably of highest importance to market participants. Such enhanced information about the bank's exposure to potential liquidity shocks may prevent (or, conditional on the type of information conveyed to the market, precipitate) individual bank runs as well as contagion effects across banks. Naturally, this type of disclosure may vary in its informativeness to depositors. Specifically, as we discuss in detail in Section 3.2, we consider various scenarios in which disclosed information about the banks' ability to withstand liquidity shocks is either non-informative, partially informative or fully informative. We assume that disclosed information is common knowledge among all depositors of a bank. More explicitly, all depositors receive the same information at the same time and no depositor has an advantage over the other depositors in reacting to it.

Second, the quality of information about the interbank linkages may contribute to the fragility of the banking sector. Common assets exposure is one important form of interbank linkages (Chen 1999; Ahnert and Georg 2018). Our experimental design captures this specific form. There are other forms of interbank linkages (e.g., interbank lending), but we abstract from

[3] The evidence on the link between deposit insurance and depositors' behavior is tenuous. Flannery (1998) finds that insured depositors are concerned about the solvency of their bank, as well as about that of deposits insurer. Deposit insurance schemes may not be credible (Martinez Peria and Schmukler 2001, Prean and Stix 2011), the coverage of the deposit insurance funds is limited (Demirguc-Kunt at al. 2005, 2015) and even insured depositors may withdraw deposits from distressed banks (Iyer and Puri 2012, Karas et al. 2013). Calomiris and Jaremski (2016) review the theoretical arguments behind the creation of deposit insurance and the empirical evidence on its performance.

them in this paper. Depositors typically face uncertainty about the existence of such linkages across different financial institutions. At one extreme, depositors might face maximum uncertainty when they are not aware of any explicit interbank linkages between their bank and other banks in the system. Rationally then, information disclosed about the capacity of another bank to withstand liquidity shocks is not informative about the liquidity position of their own bank. At the other extreme, depositors may be aware that their bank has an identical asset portfolio as other banks. In this case, information about one bank is informative about the fundamentals of another bank. In reality, the precision of information about the interbank linkages generates various potential scenarios between these two extreme cases. We deliberately abstract away from different aspects of similarity and instead model similarity as the probability of being identical. As we discuss in the next section, we consider various scenarios in which disclosed information about the interbank linkages is either non-informative or partially informative.

3.2 Experimental design

3.2.1 Banks and depositors

We model banks as one-shot, three-player coordination games with Pareto-ranked run and no-run equilibria in pure strategies. Each bank has three depositors who can individually choose between withdrawing and not withdrawing their money. All depositors act simultaneously and without knowing other depositors' decisions. To model banks with different risk exposures and to allow financial disclosure to provide meaningful information to depositors about bank fundamentals, we consider three types of banks: Good, Medium, and Weak. The banks differ with respect to their payoffs to depositors in case of early liquidation as well as in the case of no liquidation. While these payoffs are fixed payments in the experiment, we interpret these payoffs as the certainty equivalent of a stochastic return on deposits, in order to capture the role of uncertainty about expected returns on deposits on withdrawal decision. That implies that stronger banks offer higher returns. Note that under this condition, all the banks in our experiment are solvent in expectation. There is no exogenous shock to their asset portfolios and all the banks, regardless their type, are able to repay depositors in full if none of them withdraws before maturity.

Good banks have the strongest fundamentals. They are the least fragile to liquidity shocks and fail only if two or more of their depositors withdraw. These banks offer the highest payoffs to depositors regardless the number of withdrawals. If all depositors keep their money in the bank, the bank does not have to liquidate any investments and all depositors receive a payoff

R_G. If one depositor withdraws, the bank is able to repay him R_{Gw}, with $R_{Gw}<R_G$, thus the early depositor forgoes some of the potential future return. When at least two depositors withdraw, the bank is liquidated and the liquidation value L_G is shared among early depositors. In case of bank liquidation, the depositor (if any) who decides to keep money in the bank receives zero.

Medium banks are more fragile than good banks and fail if at least one depositor withdraws. In terms of payoffs, they are identical to good banks in case of no liquidation, i.e. when nobody withdraws each depositor receives R_G. However, they have a lower liquidation value L_M, with $L_M < L_G$. As with *Good* banks, in case of liquidation the depositors withdrawing from a failed bank share the available funds among themselves leaving nothing to the other depositors.

Finally, the *Weak* banks are identical with *Medium* banks in terms of fragility (i.e., they fail if at least one depositor withdraws) and payoffs upon liquidation (i.e., liquidation value is L_M). However, they are less profitable than *Medium* banks and therefore pay less to their depositors in case of no liquidation: R_W, with $R_W<R_G$.

Table 1: Depositors' payoff structure

Bank type and own decision	Number of other depositors withdrawing		
	0	1	2
Good			
not withdraw	$R_G = 210$	$R_G = 210$	0
withdraw	$R_{Gw} = 85$	$L_G/2 = 45$	$L_G/3 = 30$
Medium			
not withdraw	$R_G = 210$	0	0
withdraw	$L_M = 60$	$L_M/2 = 30$	$L_M/3 = 20$
Weak			
not withdraw	$R_W = 150$	0	0
withdraw	$L_M = 60$	$L_M/2 = 30$	$L_M/3 = 20$

Notes: Payoffs are given in experimental currency units. Exchange rate: 1 ECU = 0.01 EUR.

Table 1 presents the payoff matrix for this three-person coordination game (as used in the experiment; payments are in experimental currency units, 1 ECU = 0.01 EUR). The payoff structure can be rationalized as follows: Some banks may get exposure at date 0 to the same asset class (e.g., real estate). The individual bank's specific investments are not observable though. Ex-ante, the banks have identical expected returns and face identical cost of funding. This is due to the fact that the market does not have detailed information about individual banks' portfolios, but only aggregate information about the sectors to which the banks are investing in. However, after the investment is made and before the returns are realized, banks' depositors may receive some information about the quality of banks' assets. Upon receiving such information (via mandatory or voluntarily bank disclosure), depositors may find out that some banks have more valuable/liquid assets than other banks. For example, one bank may turn out to have a larger exposure to the prime real estate sector than another bank, which is heavily exposed to the subprime sector. This revelation may affect not only banks' valuation but also their perceived capacity to withstand depositors' withdrawals. Exposure to the subprime market may be associated with illiquidity: Banks investing in this real estate segment, when forced to liquidate their investments, are able to do so only at large discounts. This increases their vulnerability in face of depositors' demand for liquidity. Our payoff structure is motivated by the idea of capturing the role of disclosure in offering additional information to banks' depositors about the quality (and liquidity) of banks' assets at a certain point in time after the initial investment.

3.2.2 Treatments

The aim of our study is to examine whether different degrees of information, and the simultaneous consideration of both disclosure about fundamentals of individual banks and information about interbank linkages, may affect depositor's behavior and thus financial stability. The degree of disclosure about individual banks and interbank linkages varies between groups of participants. This variation allows us to observe the outcomes of their coordination games and to identify the conditions that make coordination failure (i.e., a bank run) most likely.

The first dimension of interest is disclosure about an individual bank (Bank A, hereafter). Participants take on the role of depositors of Bank A and receive information on Bank A's fundamentals. Depositors are aware of the payoff as shown in Table 1, and this is common knowledge among depositors. All depositors of a Bank A receive a signal of the form:

Bank A has [type] fundamentals.
This statement is correct with probability [p].

Type describes the quality of Bank A's fundamentals (i.e., Good, Medium, or Weak). Each group of three depositors that form a Bank A is shown only one of these potential values. Systematically varying the value of *p* across disclosure treatment conditions allows us to effectively implement three levels of disclosure for Bank A: (1) No-disclosure, in which the signal is non-informative (p = 33%), meaning that it is equally likely for Bank A to be Good, Medium, or Weak; (2) Partial-disclosure, in which the signal is partially-informative (p = 66%)

and reveals the most likely type;[4] and (3) Full-disclosure, in which the signal is fully-informative (p = 100%) and does not leave any room for uncertainty about Bank A's fundamentals. It is common knowledge that all members of a depositor group receive the same signal about their respective Bank A and decide simultaneously on whether to withdraw or not.

The second dimension we are interested in concerns the linkages (in form of assets commonality) between Bank A and a second bank (Bank B, hereafter), for which there is no explicit disclosure. Each participant in the experiment is a depositor at both banks and plays once the three-person coordination game with each bank (i.e., first with Bank A, and then with Bank B). Moreover, depositors know that they play the Bank B coordination game with a *new* group of 3 players. Depositors receive the following information regarding their respective Bank B:

With probability [q], Bank B has the same fundamentals as Bank A.
This statement is always correct.

We vary the value of *q* to implement two distinct levels of information about interbank linkages between the two banks: (1) No-linkages (q = 33%), in which the type of Bank B is completely independent of the type of Bank A since disclosure about Bank A fundamentals provides no information about fundamentals of Bank B; and (2) Partial-linkages (q = 66%), in which the two banks share the same type of fundamentals in two thirds of the cases.[5] Participants know that all depositors in their respective Bank B have received the same linkage information. Importantly, it is also common knowledge that their fellow Bank B depositors have received the same signal about Bank A, both with respect to the type of fundamentals and level of disclosure.[6] At the time depositors take the withdrawal decision for Bank B, the uncertainty about the fate of Bank A (i.e., how many depositors have withdrawn and whether the bank has failed or not) has not yet been resolved. However, Bank B depositors are reminded about the specific type of signal they received for Bank A on the decision screen.

Our treatments allow us to simultaneously study the behavioral effects of different types of information on depositor behavior, as well as potentially resulting contagion effects from Bank A to Bank B in a unified setting. To this end, we systematically vary the degree of disclosure about Bank A's fundamentals and about the linkages between Bank A and Bank B

[4] If the actual bank type does not match the type signaled, both of the remaining types are equally likely. This is made explicit on the decision screens. Implementation of the disclosure treatments is explained in Appendix A.

[5] As for the type signals for Bank A, if the types of the two banks do not match, the other types are equally likely. Implementation of the linkage treatments is explained in Appendix A.

[6] Appendix A describes in detail the matching procedure used to implement this feature in the experiment.

(i.e., the degree to which information about the financial health of Bank A is relevant for assessing the health of Bank B) in different treatment groups.

Our design is consistent with evidence on consumers' preference for maintaining multiple banking relationships and can be rationalized by assuming that depositors in Bank B already have some prior information about Bank A's fundamentals before receiving additional information about the potential linkages between these two banks. Abstracting from the laboratory setting, a more general interpretation is as follows: Imagine that depositors from a bank have no information about their bank's fundamentals because of balance sheet opacity. Yet, they all have identical information about another bank's fundamentals (information that has been obtained via publication of stress tests results or other public source). In addition to that, they receive identical information about the existing linkages between the banks. Both types of information may then influence their decisions regarding their own bank.

3.2.3 Procedures and supplementary data

The experiment was programmed and conducted using z-Tree (Fischbacher 2007). A total of 432 participants were recruited using both hroot (Bock et al. 2014) and ORSEE (Greiner 2015).[7] One half of the experimental sessions were conducted at AWI Lab in Heidelberg, the other half at mLab in Mannheim. We conducted 24 sessions with 18 participants taking part in each session.[8] Each session was structured as follows: First, participants were given general information about the session and the payoff modalities. They learned that they would be paid for two parts of the experiment and receive further instructions at the beginning of each task. Participants proceeded to part one, the bank run game. They were first given the instructions on screen and received a paper handout summarizing bank payoffs. Participants were asked to answer comprehension questions on the instructions and could only continue with the experiment after correctly answering all of them. They received feedback on the correctness of their answers, were given the opportunity to refer back to the instructions, and could correct their answers. They could also ask for assistance from the experimenters, although hardly anyone did. After the comprehension questions, participants subsequently took the withdrawal decisions for Banks A and B on two separate screens.

[7] Two participants requested their data to be deleted after the experiment, leaving us with data from 430 participants. In two sessions data from the final demographic questionnaire was not correctly saved to disk. A total of 18 questionnaires could be restored from z-Tree Gamesafe files. No behavioral data was lost.

[8] The dataset as well as the complete script of the experiment will be made available in a data repository.

For the purpose of the bank run game, each participant was randomized into two separate groups of three players each. One group represented the depositors of Bank A; the other one represented those of Bank B. Our protocol made sure that the group composition always differed between Bank A and Bank B in at least one participant.[9] Participants were matched in a way that also ensured that all depositors of the same Bank, i.e. members of a group, received identical information about their two banks. Both coordination games, i.e. the one for Bank A as well as the one for Bank B, were payoff relevant.

To get insights into the channels through which bank disclosure affects behavior in the bank run game in the absence (or presence) of interbank linkages, we also elicited participants' beliefs. For both banks, participants were asked to indicate their beliefs about how many of the other depositors (i.e., none, one, two) they thought would choose to withdraw and how confident (0 – 100%) they were in this judgement. We ask for confidence to get an individual level estimate for the perceived strategic uncertainty in the decision situation. For Bank B, we additionally asked participants to indicate their beliefs about how likely (0 – 100%) it was for Bank B to be of the type indicated by the signal about Bank A. To be least obtrusive, yet as close to participants' thought processes as possible, the unincentivized belief elicitation questions appeared on the same screens and at the same time as the payoff-relevant withdrawal decisions.

In part two, we also assess participants' attitudes towards losses. Loss aversion has been reported to affect behavior in coordination games (see Trautmann and Vlahu, 2013). We implement Gächter et al.'s (2010) incentivized lottery choice task to elicit individual loss attitudes. The loss attitude elicitation followed immediately after the withdrawal decisions for the two banks. Participants received their payment for the loss aversion task in addition to the payoffs from the bank-run game in part one.

Finally, at the end of each session, we collected demographics (age, gender, field of studies) and information on banking habits (number of bank accounts, customer of multiple banks, owning a savings account). Our participants are on average 22.6 years old, 52.4% are female, and 27.9% study economics. In terms of banking relationships, participants on average have 2.2 bank accounts with 70.9% owning a savings account. 61.7% of our participants hold accounts at more than one bank.

[9] Appendix A shows group assignments for both bank types.

Participants' payment consisted of a show-up fee, payoffs for the bank-run game, and the payoff for the loss aversion task. On average, participants earned EUR 8.02 and the sessions lasted approximately 40 minutes.

4 Hypotheses

This section derives our empirical hypotheses.

Hypothesis 1 (*Individual bank disclosure*). Conditional on the underlying bank type (i.e., Good, Medium, Weak), increased precision of disclosure about Bank A's fundamentals reduces the propensity of deposit withdrawal for banks with strong fundamentals (i.e., Good and Medium banks). Conversely, increased precision of disclosure about Bank A's fundamentals increases the propensity of bank withdrawal for banks with poor fundamentals (i.e., Weak banks).

This prediction derives from the literature reporting differential effects of financial information disclosure depending on the economic context (Bouvard et al. 2015, Leitner 2014, Nier 2005). Thus, we conjecture that reducing the uncertainty about a bank's type from full uncertainty (as is the case of No-disclosure treatment, when p = 33%) to none (as is the case of Full-disclosure treatment, when p = 100%), leads to more coordination and is beneficial for Good and Medium banks, but aggravates the coordination problem for Weak banks.

The following channel may be at work here: When disclosure reduces the uncertainty about a bank's type, it also affects the beliefs about the other bank's depositors' behavior. For those banks with strong fundamentals, more precise information about a bank's strength may increase the belief that the other depositors will keep the money in the bank. This in turn will reduce the propensity of withdrawing. The reverse holds for the banks with poor fundamentals.

Hypothesis 2 (*Absence of interbank linkages*). When the disclosure about interbank linkages is non-informative, the withdrawal decisions of Bank B's depositors are independent of their information about Bank A's type and the precision of that information.

This prediction derives from the fact that the type of Bank B is completely independent of the type of Bank A. In this framework, the disclosure about Bank A's fundamentals does not provide any information about the fundamentals of Bank B. Thus, we conjecture that Bank B's withdrawal rates will not exhibit significant variation conditional on the signal about Bank A's type and the precision of that signal: There is no purely psychological contagion.

Hypothesis 3 (*Partial interbank linkages*). When the disclosure about interbank linkages is informative, the withdrawal decisions of Bank B's depositors are positively correlated with the withdrawal decisions of Bank A's depositors across banks' types. The correlation is stronger for higher precision of disclosure about Bank A's type.

This prediction derives from the fact that in the presence of (partial) interbank linkages, disclosure about the types of Bank A provides a (noisy) signal about the type of Bank B. As a result, depositors in Bank B can learn about their bank's type from the disclosure about Bank A. Thus, we conjecture that on the one hand, when the signal about Bank A's type is non-informative, the withdrawals rates from Bank B will not exhibit significant variation across different signals about Bank A's type. On the other hand, as the precision about Bank's A type increases, the strength of bank fundamentals leads to more coordination towards repayment for Good and Medium banks than for Weak banks.

We conjecture the following channel: When disclosure about Bank A's type is non-informative, it has no effect on the beliefs about Bank B's type or on the beliefs about the behavior of other Bank B depositors. Thus, the pattern for withdrawals across banks' type is similar with that for Bank A in absence of disclosure. However, as the disclosure about Bank A's type becomes more precise, it affects the beliefs of Bank B's depositors about their bank's type, as well as the beliefs about other depositors' behavior. When more precise information about Bank A's type reveal that Bank A has strong fundamentals, information about partial linkages between Bank A and Bank B increases the belief that Bank B also has strong fundamentals while reducing the belief that the other Bank B depositors withdraw their money. These changes in beliefs in turn reduce the propensity of withdrawing.

5 Results: Behavioral outcomes

5.1 Individual bank disclosure

Table 2 presents the withdrawal behavior from Bank A, contingent on bank type and on the precision of disclosure about the bank's type. Despite all banks being solvent, we find statistically significant differences in withdrawal rates across the three disclosure levels and for all bank type signals. As shown in the first column of Table 2, for depositors who receive the type signal Good, the percentage of withdrawals drops significantly from 12.5% to 0% when the signal is partially informative rather than non-informative. Under Full-disclosure, the withdrawal rate is 2.1%, which is not statistically significantly different from the withdrawal rate in the Partial-disclosure condition ($p = 0.32$), but remains statistically significantly different from the No-disclosure treatment. These withdrawals rates suggest that Good banks benefit from increased disclosure.

From the second column we observe that when depositors receive the signal Medium, the withdrawal rate does not differ significantly between No-disclosure and Partial-disclosure treatments (p = 0.83). However, the difference in withdrawal rates between Partial-disclosure and Full-disclosure is statistically significant, while the difference between No-disclosure and Full-disclosure is marginally statistically significant. These findings suggest that Medium banks only benefit from full-disclosure.

Finally, for banks with a Weak type signal we observe a statistically significant increase in withdrawals between No-disclosure and Partial-disclosure treatments. The difference in withdrawal rates between Partial- and Full-disclosure, as well as that between No-disclosure and Full-disclosure, remain statistically insignificant (p = 0.42 and p = 0.13). In contrast to the other bank types, more precise disclosure is detrimental for Weak banks, which are more likely to suffer from liquidity problems triggered by reduced uncertainty about their assets' quality.

Table 2: Withdrawals from Bank A

Bank A Type signal	Good			Medium			Weak	
No-disclosure	12.5%	**	**	31.3%		*	25.0%	**
Partial-disclosure	0.0%			33.3%	**		47.9%	
Full-disclosure	2.1%			15.2%			39.6%	

Notes: The table shows the percentage of participants in each condition that chose to withdraw. The brackets signify two-sided tests of proportions. */**/*** denote statistical significance at 10%/5%/1%; N = 46-48 in each group.

We speculate that the biggest difference in terms of information for depositors might actually be the switch from having no information at all to having at least some information, irrespective of it being partially or fully informative. Thus, we pool the data from both disclosure treatments and compare it to the No-disclosure condition. The results are reported in Table 3. We observe that disclosure of any kind significantly reduces withdrawals from banks with a Good type signal and significantly increases withdrawals from banks with Weak type signal compared to the No-disclosure conditions. For depositors who receive a Medium type signal, the differences in withdrawal rates are not significantly different between the No-disclosure and Disclosure conditions (p = 0.39). The results for aggregated disclosure conditions are generally in line with those based on the fully differentiated treatment conditions and sharpen the picture: Disclosure works to reduce withdrawals from banks which are believed to have strong fundamentals, but aggravates the situation for those believed to have weak fundamentals. The results for Bank A are generally consistent with hypothesis 1.

Table 3: Withdrawals from Bank A with pooled disclosure conditions

Bank A Type signal	Good		Medium	Weak	
No-disclosure	12.5%	***	31.3%	25.0%	**
Disclosure	0.0%		24.5%	43.8%	

Notes: The table shows the percentage of participants in each condition that chose to withdraw. The brackets signify two-sided tests of proportions. */**/*** denote statistical significance at 10%/5%/1%. N = 48 for No-disclosure, N = 94-96 for Disclosure.

5.2 Interbank linkages disclosure

Next, we analyze the behavior of depositors in Bank B. This allows us to identify the impact of disclosure about Bank A's type on their withdrawal decisions, both in absence and presence of interbank linkages between the two banks. First, we focus on the No-linkages condition, for which all depositors know that the probability of both banks having the same type is 33%.

Table 4: Withdrawals from Bank B (No-linkages)

Bank A Type signal	Good	Medium	Weak
No-disclosure	33.3%	20.8%	29.2%
Disclosure	31.3%	27.1%	18.8%

Notes: The table shows the percentage of participants in each condition that chose to withdraw. N = 24 per group in No-disclosure, N = 48 per group in Disclosure.

The columns in Table 4 show depositors' withdrawal rates from Bank B contingent on different signals about Bank A's type. Having realized in the previous section that the distinction between partial and full disclosure is of minor importance to depositors, we pool both treatments for the analysis of withdrawals from Bank B. Neither in the No-disclosure nor in the Disclosure setting there are any statistically significant differences in pairwise proportions testing of the withdrawal rates from Bank B across Bank A's type (comparing along the rows, within the two disclosure conditions). At the same time, we also do not find any statistically significant differences in the withdrawal rates from Bank B across disclosure conditions, holding the signal about Bank A constant (i.e. comparing along the columns). In the absence of interbank linkages between the two banks, depositors do not seem to (inadequately) transfer information disclosed about Bank A to Bank B, i.e. we do not find any evidence for purely psychological financial contagion in the absence of interbank linkages. This result is in line with our Hypothesis 2, and consistent with findings in Brown et al. (2017) that contagion is not just occurring arbitrarily in the absence of economics linkages between banks.

Next, we report the results of the Partial-linkages condition, for which withdrawal rates from Bank B are depicted in Table 5. We first compare withdrawal rates along the rows. If depositors know that there is a two-thirds probability for Bank B having the same type as Bank A, but they do not have any information about the type of the latter (No-disclosure), withdrawal rates from Banks B do not differ statistically significantly across the three type of signals. In contrast, if depositors do receive valuable information about Bank A, they also take the presence of interbank linkages between the two banks into account when making their withdrawal decision for Bank B. In the presence of interbank linkages and meaningful disclosure about Bank A, the withdrawal rates from Bank B are statistically significantly lower if the signal for Bank A is Good rather than Weak. The difference in withdrawals from Bank B when the signal about Bank A's type reveal Good rather than Medium fundamentals remains marginally statistically significant. However, there is no statistically significant difference in withdrawals from Bank B between Medium and Weak type signals (p = 0.45). These observations are consistent with our third hypothesis, i.e. information disclosed about Bank A is used for Bank B only when it is meaningful.

Table 5: Withdrawals from Bank B (Partial-linkages)

Bank A Type Signal	Good	Medium	Weak
No-disclosure	16.7%	29.2%	29.2%
Disclosure	12.5%	26.1%	33.3%
	Good vs. Medium: *		Good vs. Weak: **

Notes: The table shows the percentage of participants in each condition that chose to withdraw. The brackets signify two-sided tests of proportions. */** denote statistical significance at 10%/5%. N = 24 per group in No Disclosure, N = 46-48 per group in Disclosure.

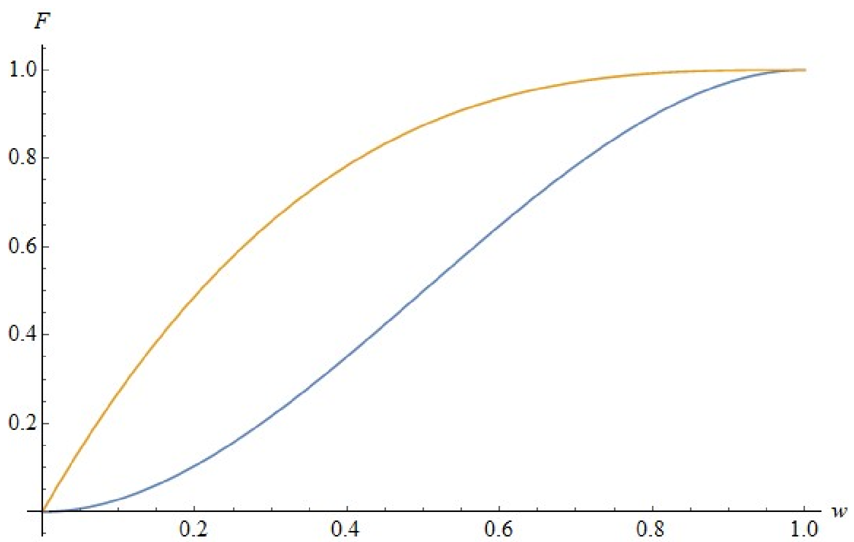
Again, it is also possible to compare withdrawal rates from Bank B in the Partial-Linkages condition along the columns. That is, we can hold the type signal for Bank A constant and compare withdrawal rates from Bank B between No-disclosure and Disclosure conditions.

Although disclosure seems on the one hand to reduce withdrawals from banks which are believed to have strong fundamentals (i.e., Good and Medium banks), and on the other hand to increase the rates for those believed to have poor fundamentals (i.e., Weak banks), none of the pairwise t-tests reveals statistically significant differences in withdrawal rates across treatments (all p-values > 0.6).

5.3. Bank failures

Apart from looking at individuals' withdrawal behavior, we also examine expected outcomes of the bank run coordination games.[10] The probability of a bank failure to occur depends directly on the probability that a randomly selected depositor withdraws. In turn, the probability of withdrawal is affected by the information a depositor has about their banks. In our setup, banks of Good type fail if two or more depositors withdraw. Banks of Medium or Weak type fail if at least one depositor withdraws. Thus, depositors' withdrawal propensities translate into expected bank failures differently.[11] Figure 1 shows the relationship between the withdrawal probabilities and the probability of bank failure for the three types.

Figure 1: Bank failure probabilities



Notes: F denotes the probability of bank failure, w denotes the probability of withdrawal. Graph for Medium and Weak bank types in orange (upper); graph for Good bank type in blue (lower).

Bank failure probabilities help us to understand the effects different withdrawal rates have for the various bank types. For example, if one third of the depositors of Good banks withdraw,

[10] We consider expected coordination outcomes rather than the actual outcomes in our experiments, because our total number of banks is relatively low and coordination outcomes depend on the depositor composition of each bank. As an example, consider 9 depositors in 3 banks of Weak type. If 3 of the 9 depositors withdraw, we could observe anywhere from one to three bank failures, depending on how depositors are randomized into groups.

[11] For Good types the probability of bank failure F_G depending on withdrawal rate w is given by $F_G(w) = 3w^2 - 2w^3$. For Medium and Weak types it is $F_{M,W}(w) = 1 - (1 - w)^3$.

this only leads to a probability of bank failure of 25.9%. In contrast, for Medium and Weak types in our setup, the same withdrawal probability translates into a 70.3% probability of bank failure (approx. 2.7 times as high). While individual depositors' withdrawal behavior might not be of biggest interest to policy makers and regulators, bank failures clearly are. This is because of the large number of depositors affected as well as the ripple effects bank failures can produce in the financial system. The exercise of calculating bank failure probabilities from observed withdrawal decisions highlights how small changes in depositor behavior interact with the potentially unobservable fragility of financial institutions to produce large differences in economic outcomes.

In Table 6 we show the expected bank failure rates based on observed withdrawal rates in our experiment. Overall, the bank failure rates are impressively high for all but the banks with type of signal Good. This is despite the fact that all of the banks in our setting are solvent and can meet their obligations as long as depositors do not withdraw.

Table 6: Probability of bank failure

Type Signal	Good	Medium	Weak
Bank A			
No-disclosure	4.3%	67.6%	57.8%
Partial-disclosure	0.0%	70.3%	85.9%
Full-disclosure	0.1%	39.0%	78.0%
Bank B (No-linkages)			
No-disclosure	25.9%	50.3%	64.5%
Disclosure	23.3%	61.3%	46.5%
Bank B (Partial-linkages)			
No-disclosure	7.4%	64.5%	64.5%
Disclosure	4.3%	59.6%	70.3%

Notes: Columns Good/Medium/Weak show expected bank failure probabilities for each bank type signal. These are calculated by treating observed withdrawal rates as withdrawal probabilities.

For banks with Good type signals, failure rates are lowest across the board. We speculate that labeling a bank as Good, even if the assignment of this label is known to be random, may act as a coordination device for depositors. This is particularly visible for Bank A in the No-disclosure condition and Bank B in the Partial-linkages regime. In these settings, the type signal does not convey meaningful information about the actual stability of the bank. Yet, failure rates are lower for banks that carried the Good label rather than the Medium or Weak ones. This observation is supported by actual withdrawal rates as shown in Tables 3, 4, and 5.

Banks which are believed to have poorer fundamentals face much higher failure rates in expectation. These range from 39.0% to 85.9% with most being upwards of 50%. Two treatments especially stand out. In the Partial-disclosure condition, expected failure rates for Medium and Weak banks reach 70.3% and 85.9%. In both cases the rates are higher under Partial-disclosure than under both No-disclosure and Full-disclosure regimes. It appears that *suspecting* that a bank might have poorer fundamentals may be more destabilizing than the limiting scenarios when perfect or no information about the fundamentals of the bank is available.

6 Results: The role of beliefs

6.1. Beliefs and actions

Having studied actual withdrawal behavior and observed large differences in the probabilities for observing subsequent bank failure, we now look at the mechanisms underlying the behavioral effects. As hypothesized, differences in withdrawal behavior in response to our treatment conditions could be the result of changes in the beliefs of depositors about the type of their banks as well as the behavior of their fellow depositors. Different precision levels of the disclosure for Bank A directly inform participants about the likelihood of encountering each type of bank. This should affect their belief about how many of the other depositors, who have received the same information, withdraw their money.

First, we need to establish whether individuals' beliefs about the number of other depositors withdrawing their money from the bank correlate with actual withdrawal decisions. We asked participants to indicate how many other depositors they think would withdraw their money from Bank A. We find a strong, positive, and statistically highly significant correlation between individuals' belief about how many of the others would withdraw and their actual withdrawal decision (Spearman's rho = 0.71, $p < 0.01$). There is also a strong correlation between the believed number of other withdrawals and participants' own withdrawal decision for Bank B (Spearman's rho = 0.55, $p < 0.01$). While the correlation is slightly less pronounced than for Bank A, it still points to widespread consistency between beliefs and actions. This holds for the No-linkages as well as the Partial-linkages conditions (rho = 0.56, $p < 0.01$ and rho = 0.54, $p < 0.01$). That is, higher numbers of believed withdrawals are associated with a higher propensity to withdraw. Participants rationally react to the expected behavior of their fellow depositors. The next step is to assess how our disclosure treatment variations affect the beliefs that participants form about the two banks.

6.2 Beliefs in Bank A

We observe a positive and statistically highly significant correlation between the type signal about Bank A (coded as 1 = Good, 2 = Medium, 3 = Weak) and the believed number of withdrawals by other depositors (withdrawals are 0, 1, 2, Spearman's rho = 0.29, $p < 0.01$). That is, signals of lower bank quality are associated with a higher number of expected withdrawals. Depositors also take disclosure (type signal precision) into account when forming their beliefs about the behavior of others: In the No-disclosure treatment, in which the type signal is uninformative, the correlation between signal type and believed number of withdrawals is low and only marginally statistically significant (rho = 0.1621, p = 0.052).[12] The correlation is much stronger and highly statistically significant in both treatments in which the signal is at least partially informative (Partial-disclosure: rho = 0.32, $p < 0.01$; Full-disclosure: rho = 0.40, $p < 0.01$). As expected, more precise type signals affect beliefs more strongly. The better the information available to depositors, the more they differentiate between the types.

Table 7: Multivariate analysis of withdrawal beliefs for Bank A

	(1)	(2)
Partial-disclosure	-0.220	-0.104
	(0.265)	(0.273)
Full-disclosure	-1.010***	-0.869**
	(0.338)	(0.353)
Medium signal	0.337	0.432*
	(0.248)	(0.263)
Weak signal	0.494**	0.565**
	(0.247)	(0.257)
Partial-disclosure x Medium signal	0.354	0.157
	(0.355)	(0.374)
Partial-disclosure x Weak signal	0.549	0.442
	(0.353)	(0.368)
Full-disclosure x Medium signal	0.373	0.033
	(0.430)	(0.465)
Full-disclosure x Weak signal	1.178***	1.065**
	(0.413)	(0.433)
Controls	No	Yes
Observations	430	398

Notes: Ordered probit model. Standard errors in parentheses. Dependent variable: Belief about how many other depositors in the group will withdraw. Base categories: No-disclosure and Good type signal. */**/*** denote statistical significance at 10%/5%/1%.

[12] Participants still seem to react to the different words used in the instructions (Good / Medium / Weak) even absent information content. There seem to be anchoring or framing effects at play here. This relates to the discussions on bank failure rates and on the variations in beliefs from sections 5.3 and 7, respectively.

The previous analysis hints at interaction effects between disclosure and signal types. We next turn to a multivariate regression framework, which also allows us to include additional control variables. In model (1) we regress the believed number of others' withdrawals on the level of disclosure, the bank type signal, and their interaction by means of an ordered probit regression.[13] In model (2), we also add controls for age, gender, loss aversion, being an economist, owning a savings account, having multiple bank accounts, banking with multiple banks, and having participated in Mannheim rather than in Heidelberg.[14] The estimation results are shown in Table 7.

The regression results reveal that the main factors behind the beliefs about the number of withdrawals are Full-disclosure (reduces withdrawal beliefs), receiving a Weak signal (increases withdrawal beliefs), and the combination of both situations (increases withdrawal beliefs strongly). These results are robust to the addition of control variables. Our results for Bank A suggest that precision of disclosure interacts with the signal about a bank's type and together they affect depositors' beliefs about how many fellow depositors will withdraw their money from the bank. Furthermore, beliefs translate into actual withdrawal decisions. It appears thus that one channel through which disclosure of information about bank fundamentals affects withdrawal behavior is through a change in beliefs about other depositors' likely actions. This finding is in line with our first hypothesis.

6.3 Beliefs in Bank B

The picture changes if we turn towards Bank B. Beliefs about the number of withdrawals do not correlate statistically significantly with either the signal about Bank A or the level of disclosure. While this is expected in the absence of interbank linkages, it is surprising in the presence of linkages.

We probe these observations in a multivariate framework that tries to uncover potential interaction effects of type signal and the level of disclosure. The model specifications follow those of Bank A. We estimate the models with and without our set of controls as well as separately for the case of No-linkages and Partial-linkages. Table 8 shows the ordered probit regression results.[15] The belief about the number of other depositors withdrawing from the bank is not significantly affected by either the level of disclosure, nor by the signal about Bank A or

[13] OLS regressions yield qualitatively similar results. The ordered probit model better fits the discrete dependent variable.

[14] There are no systematically statistically significant effects for any of the controls.

[15] We estimate the models separately for the two conditions to avoid the inclusion of a triple interaction term, which is notoriously hard to interpret. OLS regressions yield qualitatively similar results.

their interaction in either linkage condition. In stark contrast to the results for Bank A, we do not find a statistically significant influence of our treatments on the beliefs participants form about the number of other depositors withdrawing from Bank B. As established before, beliefs still translate into choices, but it is less clear how beliefs are formed for Bank B in the first place. Given that the link between banks A and B is partial at best, the signal that participants receive about the type of Bank B seems to be too noisy to induce a strong belief response.

Table 8: Multivariate analysis of withdrawal beliefs for Bank B

	(1) No-linkages	(2) No-linkages	(3) Partial-linkages	(4) Partial-linkages
Partial-disclosure	0.192	0.344	0.372	0.492
	(0.323)	(0.333)	(0.336)	(0.356)
Full-disclosure	-0.069	-0.007	-0.070	0.004
	(0.327)	(0.338)	(0.346)	(0.379)
Medium Signal	-0.150	-0.051	0.226	0.289
	(0.330)	(0.340)	(0.339)	(0.372)
Weak Signal	-0.357	-0.233	0.138	0.216
	(0.334)	(0.344)	(0.343)	(0.358)
Partial-disclosure x Medium	0.0855	0.032	-0.105	-0.419
	(0.461)	(0.482)	(0.471)	(0.512)
Partial-disclosure x Weak	-0.275	-0.316	0.0570	0.023
	(0.473)	(0.487)	(0.472)	(0.498)
Full-disclosure x Medium	0.342	0.228	-0.596	-0.695
	(0.465)	(0.487)	(0.507)	(0.565)
Full-disclosure x Weak	0.419	0.303	0.148	-0.137
	(0.468)	(0.481)	(0.484)	(0.544)
Controls	No	Yes	No	Yes
Observations	216	207	214	191

Notes: Ordered probit model. Standard errors in parentheses. Dependent variable: Belief about how many other depositors in the group will withdraw. Base categories: No-disclosure and Good type signal. */**/*** denote statistical significance at 10%/5%/1%.

7 Belief heterogeneity and confidence

Literature originating from Morris and Shin (1998) studies speculative attacks on currency pegs and builds on the global games approach of Carlsson and Van Damme (1993). In the currency attack game, agents independently choose whether to attack a currency or not. If fundamentals are common knowledge, these games have multiple equilibria. Morris and Shin (1998) show that introducing noise to agents' individual private signals can collapse the set of equilibria to a unique one. Various studies on the effects of information disclosure and the effects of transparency are based on these models (cf. Baeriswyl and Cornand 2014; Cornand and Heinemann, 2008; Heinemann and Illing 2002; Morris and Shin 2002, 2007). An important difference between this line of research and our approach to studying financial disclosure is that we do not introduce noise in agents' private signals nor limit information disclosure to a subset of all agents, but directly vary the precision of the publicly disclosed information. In our setting, all depositors possess the same (imprecise) information and know that all other depositors also have the same information. Yet, the question remains whether they react homogeneously to the information provided. If not, public disclosure would appear to induce a private noise component, after all.

Recall that in the No-disclosure conditions, each bank type is equally likely. The signal does not provide any additional information, as it just states that Bank A has Good, Medium, or Weak fundamentals with 33% probability. Yet, for Bank A, variations in beliefs are much higher with signals mentioning the possibility of Weak or Medium fundamentals than with those mentioning the Good type.[16] Clearly, participants process the signals differently, despite their identical information content. We see this as evidence for a heterogeneous private interpretation of identical public disclosure. As seen in section 5.3 on bank failures, the differences in processing the signals may lead to fundamentally different coordination outcomes.

How strongly interpretations of the public signal differ also depends on their content: In the Partial- and Full-disclosure treatments, variances of beliefs about Bank A are inversely related to the quality of bank fundamentals. The better the fundamentals, the lower the variation of beliefs. However, in these treatments the signals are informative and provide depositors with information about their most likely type of bank. Larger variances with lower quality fundamentals may indicate that strategic uncertainty increases in the coordination problem. The uncertainty also carries over across banks: For Bank B, the variance in withdrawal beliefs is significantly affected in the presence of partial linkages with full disclosure. Yet, only the Weak type signal carries enough power to increase variances compared to other type signals.

[16] To keep the discussion brief, we only report the main findings in the text. The detailed analysis including all test statistics can be found in Appendix B.

In a next step, we hold bank type signals constant and compare variances of beliefs across disclosure conditions. For Bank A, the effects of different levels of disclosure on the variation of depositors' beliefs are not uniform, but depend on the type signal. For Good signals, more precisely disclosed information serves to reduce variances in beliefs. For Weak signals, there is no statistically significant effect, while for Medium signals the evidence is mixed. The differences do not systematically transfer to Bank B in either linkage condition.

We also elicited confidence in withdrawal beliefs for all decisions in our experiment. Participants were asked to indicate how confident they were in their assessment of how many other depositors would withdraw on a 0 to 100 scale. While variances of beliefs tell us how similar beliefs are between depositors, this provides us with an individual-level, self-reported measure of confidence. Two observations stand out: i) Confidence is generally lower for Bank B than for Bank A; ii) For both banks we find that depositors are most confident in their belief when they indicate that either no other depositor or all other depositors will withdraw. Confidence in the belief that only one other depositor withdraws is significantly lower. In fact, this finding strongly resembles the predictions of the canonical, multi-equilibria model of Diamond and Dybvig (1983): Either everyone withdraws, or nobody. Similar to our earlier analyses of withdrawals, we find that the confidence in beliefs about Bank B is only affected by the level of disclosure in the presence of economic linkages. In their absence, it is not.

Overall, our results show that in a setting with common, yet noisy, public signals substantial belief heterogeneity emerges, which ultimately affects behavior. It appears that the unified setting, which incorporates public disclosure and models interbank linkages, reveals heterogeneity in the private interpretation of public signals and thereby connects the predictions of classic *bank runs as coordination games* models with findings on the effects of heterogeneous private signals originating from the global games literature.

8 Conclusion

We study the fundamental mechanism of information disclosure about the fragility of financial institutions. In line with our hypotheses and the literature, we find that the effects of increased precision in the information disclosed depend on the financial institutions' fundamentals. If banks are believed to have strong fundamentals and thus a large capacity to withstand liquidity shocks, disclosure that is more precise serves to reduce the likelihood of bank runs by reducing the probability of customers withdrawing their deposits before maturity. In contrast, *solvent* banks believed to have weaker fundamentals are confronted with significantly larger rates of early withdrawals when the signal about their fundamentals becomes more precise. Our belief data shows that disclosed information affects the beliefs about the number of depositors that is expected to withdraw. Participants then react accordingly.

In addition, our results suggest that disclosing meaningful information at all compared to not releasing any information has significant effects on depositors' withdrawal decisions. Disclosing *any* information also seems to play a more important role in shaping depositors' actions than increasing the precision in the disclosed information.

Moreover, our results shed some light on how and when the information disclosed about individual banks may affect the behavior of depositors from other banks. Notably, we are able to study both the information disclosure about an individual bank and the transmission of information between banks in a unified setting that considers both the precision of disclosure about bank fundamentals as well as that about interbank linkages. In the absence of interbank linkages, if information disclosed about one bank were to systematically affect depositors' likelihood of withdrawing their money from another bank, information would be inadequately applied to an unrelated entity. We do not find any evidence for this problematic form of purely psychological financial contagion in our experiment. This is consistent with findings in Brown et al. (2017), but not with those in Chakravarty et al. (2014).

However, in the presence of interbank linkages, we observe that information disclosed about one bank also affects withdrawal behavior of depositors at the linked institution. In this case, the disclosed information about one bank provides a meaningful, but noisy, signal about the fundamentals of the second bank. Our results suggest that depositors are able to identify when information is valuable for both institutions and act accordingly.

These findings are relevant to the policy debate on the costs and benefits of publicly releasing bank stress test results. Regulators need to consider not only the opposing effects that disclosure might have for banks with solid vs. fragile fundamentals, but also the potential contagion effects within the banking sector. Stress test results published for a subsample of banks can affect other banks which were not covered in the stress tests. Such dynamic effects are particularly relevant when some untested banks are considered similar to those that are stress tested in terms of business models, portfolio exposures, or other forms of interbank linkages.

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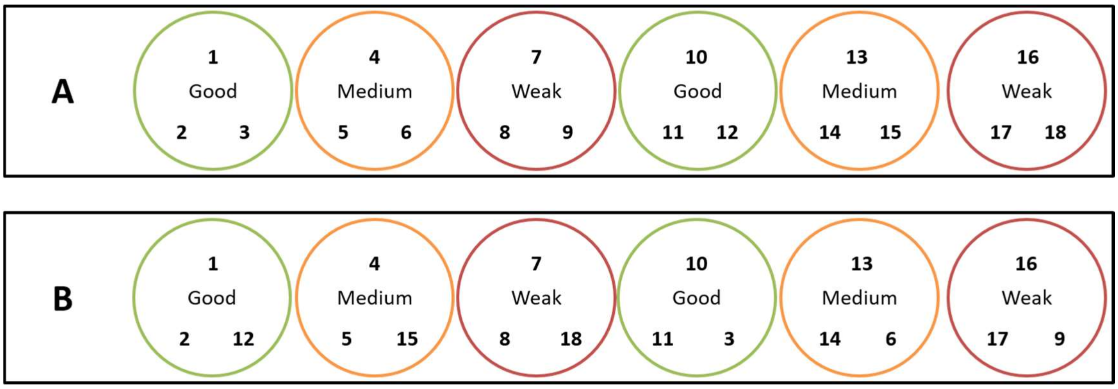
Appendix A

In each session, there were 18 participants. Participants were randomly assigned cubicles in the laboratory. The cubicles were always matched in the same way to ensure an equal number of banks of each type in all sessions and treatment conditions. There always were two Banks A of each type (Good, Medium, Weak) and two Banks B of each type in each session. Figure A.1 shows how cubicles, numbered from 1 to 18, were matched to bank types.

Figure A.1: Cubicle to actual bank type matching



Notes: The first row only shows Banks A, the second shows Banks B. Each circle represents a bank, i.e. a depositor group in the coordination game. Green (Orange, Red) circles represent Good (Medium, Weak) type banks. Depositors are represented by cubicle numbers.

Example: The first Bank A of type Good consists of participants sitting at cubicles 1 to 3. For depositors at cubicles 1 and 2, their Bank B is also of Good type. In Bank B, their third depositor is the participant in cubicle 12. Their fellow Bank A depositor in cubicle 3, however, is part of the fourth Bank B, which is of also of Good type. For each participant, banks A and banks B never consist of the same set of depositors.

Note that the figure shows the actual bank types, which participants typically do not know for sure. The only case in which they can be certain of a bank's type occurs in the Full Disclosure treatment, in which they know their Bank A's type for sure. The way we implement group matching allows us to make truthful statements about the probabilities of banks A and B having the same types in our linkages treatment, while at the same time ensuring that we can implement all information disclosure precision levels for banks of type A.

Table A.1 shows the Bank A type signal each individual receives. It depends on a random draw, which is automatically conducted by the computer at the beginning of each session. This random draw determines which of the different sub-cases of each treatment condition is implemented. Each case (within a treatment condition) is equally likely. The random draws ensure that the probabilities of each signal being correct are truthful. Take the No-disclosure treatment as an example. Each one of the three cases is implemented with 1/3 probability. Depending on the case, the members of exactly one bank type (Good, Medium, or Weak) receive a signal that perfectly corresponds (in its type) to the actual bank's type. As participants are randomized to player numbers (cubicles in the lab), there is a chance of exactly 1/3 that their bank actually has the type given by the signal. A similar argument holds for the Partial-disclosure treatment. In 2 out of 3 cases, participants receive a signal that matches their actual type of bank.

Table A.2 shows Bank B types for each participant. Again, a computerized random draw at the beginning of the session determines which of the cases is implemented. Note that the cases in this treatment directly determine the actual type of Bank B for each participant, rather than a signal about its type. This is the result of participants receiving a statement about the probability that their Bank B is of the same type as Bank A. In the No-linkages treatment and in each of its cases, the members of exactly one type of Bank A (Good, Medium or Weak) face a Bank B which is of the same type as A. In the Partial-linkages treatment and in each of its cases, the depositors of two Bank A types face a Bank B which is of the same type as A.

Table A.1: Bank A – Types and Signals

Player	**Bank A**	**Bank B**	**Type A**	**Signal A**									
				No-Disclosure			Partial-Disclosure						Full-Disclosure
				c1	*c2*	*c3*	*c1*	*c2*	*c3*	*c4*	*c5*	*c6*	
1 2 3	1	1 4	G	G	W	M	G	G	G	G	W	M	G
4 5 6	2	2 5	M	W	M	G	M	M	M	M	G	W	M
7 8 9	3	3 6	W	M	G	W	W	W	W	W	M	G	W
10 11 12	4	4 1	G	G	W	M	G	G	G	G	W	M	G
13 14 15	5	5 2	M	W	M	G	M	M	M	M	G	W	M
16 17 18	6	6 3	W	M	G	W	W	W	W	W	M	G	W

Notes: G/M/W denote Good/Medium/Weak bank type. c1 to c6 denote cases 1 to 6.

Table A.2: Bank B – Types

Player	Bank A	Bank B	Type A	Type B: No-Linkage *c1*	*c2*	*c3*	Partial-Linkage *c1*	*c2*	*c3*	*c4*	*c5*	*c6*
1 2 3	1	1 4	G	G	W	M	G	G	G	G	W	M
4 5 6	2	2 5	M	W	M	G	M	M	M	M	G	W
7 8 9	3	3 6	W	M	G	W	W	W	W	W	M	G
10 11 12	4	4 1	G	G	W	M	G	G	G	G	W	M
13 14 15	5	5 2	M	W	M	G	M	M	M	M	G	W
16 17 18	6	6 3	W	M	G	W	W	W	W	W	M	G

Notes: G/M/W denote Good/Medium/Weak bank type. c1 to c6 denote cases 1 to 6.

Appendix B

Belief heterogeneity

Table B.1 shows the distribution of the believed number of withdrawals by other depositors separated by precision of the disclosed information and the type signal about Bank A. It also includes means and standard deviations of the distributions of beliefs. We observe that in all disclosure conditions, standard deviations of beliefs are significantly lower with Good signals than with Medium or Weak signals (pairwise Levene's tests, No-disclosure: G/W: $p < 0.01$, G/M: $p < 0.05$; Partial-disclosure: G/W: $p <0.001$, G/M: $p < 0.001$; Full-disclosure: G/W: $p < 0.001$, G/M: $p < 0.001$). Differences given Medium and Weak signals are only significant in the Full-disclosure condition (No-disclosure M/W: $p = 0.327$; Partial-Disclosure M/W: $p = 0.053$; Full-disclosure M/W: $p = 0.001$).

Table B.1: Withdrawal beliefs for Bank A

	Withdrawals				
	0	1	2	Mean	SD
No-disclosure					
Good	68.8%	27.1%	4.2%	0.35	0.56
Medium	56.3%	33.3%	10.4%	0.54	0.68
Weak	59.0%	30.6%	10.4%	0.65	0.76
Partial-disclosure					
Good	70.0%	25.0%	0.0%	0.25	0.44
Medium	59.0%	37.5%	12.5%	0.63	0.70
Weak	43.8%	25.0%	31.3%	0.88	0.87
Full-disclosure					
Good	93.8%	6.3%	0.0%	0.06	0.24
Medium	80.4%	15.2%	4.4%	0.24	0.52
Weak	54.2%	14.6%	31.3%	0.77	0.91

Notes: Columns 0/1/2 show the share of participants with the respective combination of type signal and belief about the number of withdrawals by other depositors in the treatment. There are 24 observations per type signal.

The previous analysis establishes differences in the processing of the type signals, holding the level of disclosure constant. To study the effects of disclosure on the heterogeneity in beliefs, we can also hold type signals constant and compare across disclosure conditions. Doing so reveals that variances are statistically significantly lower under Full-disclosure than under No-Disclosure (pairwise Levene's tests: Good: $p < 0.001$; Medium: $p < 0.01$; Weak: $p < 0.05$). For intermediate comparisons of No- and Partial-disclosure as well as Partial-disclosure and Full-disclosure, the pattern is less evident. With a Good type signal, variances are comparatively lower with greater disclosure (No vs. Partial: $p < 0.05$; Partial vs. Full: $p < 0.001$), but for a

Weak signal, they are indistinguishable (No vs. Partial: p = 0.213; Partial vs. Full: p = 0.346). For a Medium signal, the evidence is mixed. (No vs. Partial: p = 0.801; Partial vs. Full: p < 0.001).

We repeat the same analyses for the believed number of withdrawals by other depositors from Bank B and report the distributions in Tables B.2 and B.3. For our No-linkages condition, in which the signal for the type of Bank A does not provide information about the fundamentals of Bank B, we do not find any statistical differences in the standard deviations of the belief distributions between the different type signals for any level of disclosure (pairwise Levene's tests, all p > 0.3). The picture is different in the Partial-linkages condition. Statistically significant differences appear in the Full-disclosure case, in which participants know the type of Bank A for sure and know that Bank B is of equal type with a probability of 2/3. Even then, only the Weak signal seems to be strong enough to affect the variance in beliefs significantly (Full-disclosure, G/W: p = 0.032, G/M: p = 0.374, M/W: p = 0.035). We do not find any significant differences for the Partial- and No-disclosure cases (all p > 0.17).

Holding type signals constant and again comparing across disclosure conditions, we do not find any statistically significant differences for the No-linkages condition (pairwise Levene's tests. All p > 0.42). For the Partial-linkages condition, we only observe a significantly lower standard deviation when comparing Partial- and Full-disclosure for the Medium type signal (Levene's test: 0.79 vs. 0.55, p = 0.015). The other differences are not statistically significant.

Table B.2: Withdrawal beliefs for Bank B (No-linkages)

	Withdrawals				
	0	1	2	Mean	SD
No-disclosure					
Good	41.7%	45.8%	12.5%	0.71	0.69
Medium	54.2%	29.2%	16.7%	0.63	0.77
Weak	58.3%	33.3%	8.3%	0.50	0.66
Partial-disclosure					
Good	33.3%	50.0%	16.7%	0.83	0.70
Medium	37.5%	45.8%	16.7%	0.79	0.72
Weak	62.5%	29.2%	8.3%	0.46	0.66
Full-disclosure					
Good	45.8%	41.7%	12.5%	0.67	0.79
Medium	41.7%	37.5%	20.8%	0.79	0.78
Weak	45.8%	37.5%	16.7%	0.71	0.75

Notes: Columns 0/1/2 show the share of participants with the respective combination of type signal and belief about the number of withdrawals by other depositors in the treatment. There are 24 observations per type signal.

Table B.3: Withdrawal beliefs for Bank B (Partial-linkages)

	Withdrawals				
	0	1	2	Mean	SD
No-disclosure					
Good	58.3%	37.5%	4.2%	0.46	0.59
Medium	50.0%	41.7%	8.3%	0.58	0.65
Weak	58.3%	29.2%	12.5%	0.54	0.72
Partial-disclosure					
Good	41.7%	50.0%	8.3%	0.67	0.64
Medium	45.8%	33.3%	20.8%	0.75	0.79
Weak	37.5%	45.8%	16.7%	0.79	0.72
Full-disclosure					
Good	58.3%	41.7%	0.0%	0.42	0.50
Medium	77.3%	18.2%	4.6%	0.27	0.55
Weak	54.2%	33.3%	12.5%	0.58	0.72

Notes: Columns 0/1/2 show the share of participants with the respective combination of type signal and belief about the number of withdrawals by other depositors in the treatment. There are 24 observations per type signal, except for Full-disclosure, Medium where there are 22.

Confidence

We report confidence values for Bank A in Table B.4. We find confidence to be increasing in disclosure (rho = 0.36, $p < 0.001$) and decreasing in type signal (recall: higher signal is worse; rho = -0.16, $p < 0.01$). The confidence in the belief that one other depositor would withdraw is significantly lower than the confidence in both other beliefs (pair-wise t-tests; 0 vs. 1: means 73.97 vs. 54.19, $p < 0.001$; 1 vs. 2: means 54.19 vs. 77.42, $p < 0.001$). There is no significant difference in confidence between zero and two withdrawals (t-test, means: 73.97 vs. 77.42, $p = 0.281$). Clearly, depositors are more confident in their belief when they indicate that either no other depositor or all other depositors will withdraw.

Table B.4: Confidence in beliefs for Bank A

	Withdrawals		
	0	1	2
No-disclosure			
Good	66.46%	44.31%	61.00%
Medium	66.78%	43.25%	82.20%
Weak	62.04%	55.86%	74.2%
Partial-disclosure			
Good	80.25%	63.58%	-
Medium	66.13%	55.89%	75.17%
Weak	57.91%	62.67%	75.4%
Full-disclosure			
Good	88.53%	62.67%	-
Medium	85.97%	61.86%	85.50%
Weak	71.73%	47.71%	82.47%

Notes: Columns 0/1/2 show the mean confidence in the respective combination of disclosure level, signal for Bank A and belief about the number of other depositors withdrawing.

Tables B.5 and B.6 show confidence values for Bank B. Confidence in the beliefs is generally lower for Bank B than for Bank A (two-sided paired t-test, means: 69.66 vs. 55.67, $p < 0.001$). While in the No Linkages condition confidence is uncorrelated with the level of disclosure, we find a significant positive association in the presence of linkages (rho = 0.25, $p < 0.001$). As seen in the analysis of withdrawal decisions and beliefs, depositors are able to cleanly separate between the two banks if they are not connected by economic linkages. However, the type signal received for Bank A does not affect confidence in beliefs about the number of withdrawals from Bank B in either of the two linkages conditions. (No Linkages: rho -0.06, $p = 0.362$; Partial Linkages: rho = -0.02, $p = 0.794$). Similar to the pattern of confidence observed for Bank A, we also find confidence in the belief that one other depositor will withdraw from Bank B to be significantly lower than the belief in zero or two others withdrawing (Pair-wise t-tests: No Linkages: 0 vs. 1: means 59.47 vs. 47.87, $p < 0.01$; 1 vs. 2: means 47.87 vs. 65.81, $p < 0.01$. Partial Linkages: 0 vs.1: means 59.23 vs. 49.05, $p < 0.01$; 1 vs. 2: means: 49.05 vs. 58.95, $p = 0.032$).

Table B.5: Confidence in beliefs for Bank B (No-linkages)

	Withdrawals		
	0	1	2
No-disclosure			
Good	61.30%	30.55%	74.33%
Medium	63.85%	46.86%	46.25%
Weak	63.00%	49.88%	73.00%
Partial-disclosure			
Good	71.13%	61.25%	67.00%
Medium	46.33%	44.64%	54.50%
Weak	52.67%	50.00%	82.5%
Full-disclosure			
Good	61.55%	59.20%	72.00%
Medium	64.00%	46.78%	66.00%
Weak	53.45%	41.00%	72.25%

Notes: Columns 0/1/2 show the mean confidence in the respective combination of disclosure level, signal for Bank A and belief about the number of other depositors withdrawing.

Table B.6: Confidence in beliefs for Bank B (Partial-linkages)

	Withdrawals		
	0	1	2
No-disclosure			
Good	53.14%	45.11%	50.00%
Medium	44.50%	49.5%	57.5%
Weak	48.43%	51.57%	82.33%
Partial-disclosure			
Good	57.50%	53.33%	60.00%
Medium	61.73%	42.125%	60.20%
Weak	48.22%	45.72%	49.50%
Full-disclosure			
Good	63.86%	49.3%	-
Medium	76.35%	64.50%	50.0%
Weak	71.00%	47.75%	52.33%

Notes: Columns 0/1/2 show the mean confidence in the respective combination of disclosure level, signal for Bank A and belief about the number of other depositors withdrawing.

Previous DNB Working Papers in 2020

No. 662 **Carin van der Cruijsen-Knoben, Jakob de Haan and Ria Roerink**, Financial knowledge and trust in financial institutions
No. 663 **Jon Frost,** Economic Forces Driving FinTech Adoption
No. 664 **Anna Samarina and Nikos Apokoritis,** Evolution of monetary policy frameworks in the post-crisis environment

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