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On the dynamics and severity of bank runs: An experimental study ☆

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ABSTRACT

This paper presents an experimental investigation of the factors that affect the dynamics and severity of bank runs. Our experiments demonstrate that the more information laboratory economic agents can expect to learn about the crisis as it develops, the more willing they are to restrain themselves from withdrawing their funds once a crisis occurs. Furthermore, our results indicate that the presence of insiders, who know the quality of the bank, significantly affects the dynamics of bank runs and helps mitigate their severity. We also show that deposit insurance, even of a limited type, can help diminish the severity of bank runs.

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1. Introduction

The recent financial turmoil that started in the summer of 2007 and the bank run on Northern Rock in the UK, the first bank run in the UK since the collapse of the City of Glasgow Bank in 1878, once again showed that crises and bank runs are an important feature of our financial landscape.[2]

☆ The views expressed in this paper are those of the authors and do not necessarily reflect the views of the Federal Reserve Bank of New York or the Federal Reserve System.

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[2] Lindgren et al. (1996) show that during the period 1980–1996, of the 181 IMF member countries, 133 have experienced significant banking problems. Such problems have affected developed, as well as developing and transitional countries. Also, see Dell'Ariccia et al. (2008) for an analysis of the real effects of banking crises.

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When one looks at the economic literature on bank runs (Diamond and Dybvig, 1983; Allen and Gale, 1998; Calomiris and Kahn, 1991; Chari and Jagannathan, 1988; and others) one sees a wide variety of models most of which have the same two features. With some notable exceptions (see Chen, 1999; von Thadden, 2002; Green and Lin, 2003; and Yorulmazer, 2003), most of the models on bank runs are static two-period equilibrium based models with a continuum of agents played in simultaneous move form. In many of these models, the bank-run problem is viewed as an equilibrium selection problem embedded in a coordination game in which all agents would be better off if they did not create a run on the bank (withdraw early) while it is an equilibrium to both "withdraw early" and to "withdraw late." In addition, they mainly focus on whether deposit contracts are optimal arrangements in the presence of the possibility of a bank run.

However, Brunnermeier (2001) makes an important observation about the bank-run models in the literature: "Although withdrawals by deposit holders occur sequentially in reality, the literature typically models bank runs as a simultaneous-move game." Since most of these models are static, they do not attempt to explain the dynamics and severity of bank runs.

In this paper, we present an experiment that concentrates on the dynamics and severity of laboratory bank runs measured by how fast money is withdrawn from the banking system during a crisis and ask questions such as[3]:

- Are bank runs more severe (i.e. does money get withdrawn more quickly) when depositors observe the action of other depositors and can see when they withdrew and how much they received?
- Are bank runs more severe when some depositors have insider information?
- Can partial deposit insurance be effective in mitigating the severity of bank runs?
- Is the severity of bank runs influenced by cyclical factors in the economy, that is, should we expect runs to be more severe when the economy is in a down-cycle?

While these are important issues, some of these questions cannot be answered with two-period static models. Except for a few exceptions (see Kelly and Ó Gráda, 2000 and Iyer and Puri, 2007), micro data on these issues do not exist. Therefore we chose to examine these issues in the context of experiments using a dynamic model. To our knowledge, the only experimental papers on bank runs are Garratt and Keister (2005) and Madies (2006), who do not deal with their dynamics and severity, but rather focus on their existence.

In this paper, we look at two types of policy interventions—informational and deposit insurance. With respect to the first we are interested in whether there is certain information, which, if released during the progress of a bank run, could slow it down. Such information, for example can be information about whether those who withdrew were paid or not. We also investigate the role of asymmetric information in our bank-run experiments. Here, some subjects are "insiders" who are informed about the soundness of their bank while others are not. We analyze the effect of insiders on the dynamics of bank runs and ask whether the presence of such insiders exacerbates or dampens their severity.

With respect to deposit insurance, we are interested in the minimal insurance that is needed to slow down bank runs. Full insurance may not be desirable as it distorts depositors' incentives to differentiate between sound and unsound banks, creating moral hazard on banks' side.[4] Garcia (2000) recommends providing low coverage as a good practice but suggests that which deposits should be

[3] Our emphasis on how quickly bank runs occur is motivated by the fact that in the majority of crises, at the earlier stages, the extent and the exact source of problems (idiosyncratic vs. system-wide, or liquidity vs. solvency) is usually not known to market participants and authorities due to the opaque nature of banks. Hence, the time horizon over which the crisis takes place is of prime importance since the market's and the authority's capability to sort out problems crucially depend on time on hand.

[4] Some argue that guarantees actually make bank failures more likely. Demirguc-Kunt and Detragiache (2002) analyze panel data for 61 countries during 1980–1997 and conclude that "explicit deposit insurance tends to be detrimental to bank stability, the more so when institutional environment is weak, when the coverage is extensive and when the insurance is run by the government." Hoggarth et al. (2005) show that the provision of safety nets reduces the overall ex-post impact of banking crises, but makes it more likely ex ante that the banking system will face a crisis. In particular, they show that countries with an explicit unlimited deposit protection scheme are the most likely ones to experience banking crises. They also show that the group least likely to experience a crisis is that with an explicit but *limited* deposit protection scheme.

covered and at what level are important issues.[5] Hence, the optimal level of insurance remains to be an open question to date and our study is an attempt to search for the optimal level of deposit insurance coverage.

We embed our experiment in a four period bank-run model whose equilibria we calculate. Our experiments turn up a number of interesting findings that inform both theory and policy. First, we find that laboratory bank-run behavior is influenced by the information subjects have on hand when a crisis occurs. For example, in one treatment we run the experiment using a simultaneous form where all subjects choose when to withdraw their money at once and in ignorance of what the other subjects are doing. In another treatment subjects play the game in the sequential form where they decide, period by period, if they want to withdraw conditional on what has happened before them, i.e., how many people withdrew and what their payoffs were. We find that behavior is consistent with the predictions of the theory mostly when the game is played in the sequential form with high level of information given between periods (information describing how many people withdrew and what payoff they received). This is despite the fact that behavior should be invariant to the form of the game.

Second, we show, both theoretically and empirically, that the presence of insiders increases welfare by leading to later withdrawals. Hence, ceteris paribus, money stays longer in the banking system when there is insider information. Third, we find that deposit insurance, even of a limited type, can help slow down bank runs. More precisely, in some of our experiments we provide insurance, which covers either 20% or 50% of deposits, and even with this minimal coverage, we observe later withdrawals. Finally, we show that the dynamics and the severity of bank runs depend on the state of the economy when a crisis occurs. When the economy is performing poorly, i.e. when the average return in the banking industry is relatively low, we show that deposits are withdrawn more quickly than in relatively good times.

Section 2 has the related literature. Section 3 presents our bank-run model and describes the theoretical results that underlie our experiments. Section 4 describes the experimental design and procedures. Section 5 presents the empirical findings and Section 6 concludes.

2. Related literature

Our paper is related to the literature on bank runs as well as games of timing. While our model does not nest any other well known bank-run model fully as a special case, in this section, we briefly discuss the relation of our paper to these two strands of literature.

2.1. Bank-run literature

There are different views on the origins of bank runs in the literature. According to one view, bank runs are random events that are generated by mass hysteria as Kindleberger (2000) argues. This view has been modeled by Diamond and Dybvig (1983) as one of multiple equilibria, in which, if depositors believe that other depositors will run, then it is optimal for them to do so, as otherwise, no funds will be left for them at the bank. According to this view, bank runs are self-fulfilling random events.

However, historical evidence suggests that in many instances, bank runs are closely tied to the current economic conditions. Gorton (1988) conducts an empirical analysis using US data from the late 19th and early 20th century and finds a close relation between the occurrence of banking panics and the overall state of the economy. In parallel with this evidence, another view of origins of bank runs claims that bank runs are natural consequences of the business cycle and they are information driven. This view of bank runs has been modeled by Allen and Gale (1998). Our model is in the spirit of the business cycle view of bank runs. Therefore we refrain from analyzing issues such as preference shocks of depositors. In our model there is asymmetric information where depositors have

[5] Jayanti and Whyte (1996) point out the lack of international consensus on the provision of deposit insurance: "In reality, however, deposit insurance schemes vary across countries in terms of, inter alia, the extent of coverage (maximum amount per deposit or per customer), scope of coverage (whether foreign banks and foreign offices of domestic banks are covered), types of deposits covered (whether residents and non-residents deposits and foreign currency deposits are covered)."

information on the overall state of the banking system but cannot assess the soundness of individual banks, which is consistent with the literature (Saunders and Wilson, 1996 and Chen, 1999).

The most important feature of our paper is that it provides a dynamic analysis of bank runs. While there are few exceptions that model bank runs in a dynamic setting, to the best of our knowledge, our paper is the first experiment on bank runs that uses a dynamic setting. One theoretical exception in the literature is von Thadden (2002) (a generalization of von Thadden, 1998), which generalizes the Diamond–Dybvig model to the case of continuous time to analyze liquidity provision in a dynamic setting. Using a model that allows for repeated investment in a setup with ongoing uncertainty, this paper shows that a depositor has an incentive to withdraw her deposit, even without liquidity needs, thus realizing the liquidity premium the deposit contract provides, and to reinvest it directly. This arbitrage behavior has a potentially destabilizing effect on the efficient provision of liquidity by the bank.

2.2. Models of timing

Our bank-run game has similarities with timing games, which can broadly be classified into "preemption" games, where the first player to move claims the highest payoff, and "wars of attrition," where the last player claims the highest payoff. In the famous "grab-the-dollar" game, a player can either grab the money on the table (bank deposit in our game) or wait for one period; meanwhile the pot increases by one unit (deposits accumulate interest). In this game, players want to be the first to take the money, but may prefer to wait for a larger pot. Our bank-run game lies somewhere between the two extremes of preemption games and wars of attribution. Since a bank, even the worst one, always has enough money to pay the promised amount to some of the depositors who show up before others, the player who moves after a few players, but before all players have moved, claims the highest payoff.[6] In that sense, our bank-run game is closest to Park and Smith (2008), where rewards are increasing up to the kth player and decreasing afterwards.

Our model has similarities with models where payoffs depend on the timing of moves of other key players. Brunnermeier and Morgan (2005) introduce the notion of clock games and experimentally test them. In their setup, each player's clock starts on receiving a signal about a payoff-relevant state variable. Since the timing of the signals is random, clocks are de-synchronized. A player must decide how long to delay his move after receiving the signal. They show that equilibrium is always characterized by strategic delay regardless of whether moves are observable or not, and delay decreases as clocks become more synchronized. Similar to our results with insiders, they show that when moves are observable, players "herd" immediately after any player makes a move.

One literature that has been extensively studied where payoffs depend on the timing of moves of others is the literature on speculative currency attacks (see Obstfeld, 1996). Chamley (2003) provides a dynamic model of currency attacks, where he shows that multiple periods are necessary for the existence of speculative attacks. Cheung and Friedman (2005) analyze speculative attack models using experiments in a dynamic setting. Morris and Shin (1998) use Carlsson and van Damme's (1993) global games technique to derive a unique equilibrium that can be determined by macroeconomic fundamentals. Costain (2003) provides a dynamic model where agents move sequentially and most agents can observe a few previous actions before choosing, instead of moving simultaneously, and shows that multiplicity of outcomes is restored. Similarly, Costain et al. (2005), using experiments where subjects move sequentially, find that when most previous actions are observed, there is an intermediate region of fundamentals where "all players attacking" and "no player attacking" both occur with more than 1% probability.

3. Bank-run model

We have a model with $N = 6$ agents (depositors) all of whom deposit their money in the same bank. Depositors do not know the quality of their bank's investments. We model this uncertainty by

[6] In our bank-run game, for low bank returns, 4 out of 6 players, and for high returns, 5 out of 6 players are guaranteed to receive their promised return from their bank.

assuming that there are five types of banks in the economy denoted by B_1, B_2, B_3, B_4 and B_5. We call Bank B_3 the "mean bank" since it has a rate of return on its investment that is the mean return, denoted by r^*, among the five types of banks. The other banks, B_1, B_2, B_4 and B_5, are banks whose rate of returns are $(\frac{1}{3}r^*)$, $(\frac{2}{3}r^*)$, $(\frac{4}{3}r^*)$, $(\frac{5}{3}r^*)$, respectively. The bank that the depositors' money is in is drawn randomly with a uniform density $f_b = 1/5$ for each type of bank $b = 1, 2, 3, 4, 5$.

Time is divided into 4 periods $t = 1$, 2, 3 and 4, and all deposits must be withdrawn at the fourth period if it is kept in the bank that long. The bank promises to pay a net interest of r' on deposits and does so as long as it has the funds when depositors withdraw. If the bank does not have the required funds, then it pays each depositor who wants to withdraw at that time an equal share of what it has available on hand, and the depositors who show up in later periods receive nothing. Hence, a bank is solvent only when its realized rate of return is greater than the one it promises to depositors.

Formally, each person starts off with a deposit of $\$K$ (normalized to \$1 as our results are independent of K) and if she keeps her money in the bank for l periods she receives $\$(1+r')^l$ if the bank has the necessary funds available to pay all depositors who want to withdraw at that time. Formally, for each bank $b = 1, \dots, 5$ and for any vector of withdrawals $n = (n_1, n_2, n_3, n_4)$, where n_t represents the number of players who withdraw at time t for $t = 1, 2, 3, 4$, we can calculate how much money is in each type of bank at the beginning of each period before that period's withdrawals have been materialized. We denote that amount by $V_t(b, n)$. Using V_t, we can calculate the payoff of players who withdraw at period t, for each type of bank b, denoted by $\pi_t(b, n)$.

Note that, if there is not enough money left in the bank to pay their promised return to all depositors who withdraw at that period, that is, when $V_t < n_t(1+r')^t$, then the bank distributes all it has equally among the depositors who withdraw at period t and no money is left in the bank for depositors who show up later. Hence, we have

$$V_t = \begin{cases} [V_{t-1} - n_{t-1}(1+r')^{t-1}](1+r_b) & \text{if } \pi_{t-1} = (1+r')^{t-1}, \\ 0 & \text{otherwise.} \end{cases} \tag{1}$$

Using this we get

$$\pi_t = \begin{cases} \min\{(1+r')^t, \frac{V_t}{n_t}\} & \text{if } \pi_{t-1} = (1+r')^{t-1}, \\ 0 & \text{otherwise.} \end{cases} \tag{2}$$

This scenario defines a game. In this game nature makes the first move and randomly selects the bank. The bank chosen is not revealed to the agents; they only know the distribution. When played in the simultaneous version, this game has a strategy set consisting of the four integers $\{1, 2, 3, 4\}$ representing the four time periods at which money can be withdrawn, and the expected payoff function for player i is given as

$$E(\pi_{it}) = E_b\big(\pi(t, n_1, \dots, n_t, b, r', r^*)\big), \tag{3}$$

where the expectation is over five possible types of banks.[7]

When played in the sequential form, each subject has to decide period by period if she wants to withdraw. The sequential form of the game can have several different informational varieties. For example, after each period no information can be given to the players as to how many people withdrew and what they received. This form is equivalent to the simultaneous form and we call it the Low-Information Sequential form. Alternatively, we can specify a high-information version of the game in which after each period both the number of people who withdrew and the amount they received is revealed. This High-Information Sequential form allows for an expanded strategy space since players can condition their withdrawal strategy both on how many people withdrew and what they received.

[7] The predictions of our model are made under the assumption of risk neutrality. We have chosen not to induce risk neutral preferences on our subjects by using the techniques from Roth and Malouf (1979) and Berg et al. (1986) for several reasons. First, our experiment is already complicated and we felt that the added level of complexity created by enlarging our already long instructions would stretch the ability of our students to comprehend the true tradeoffs in the experiment. Second, there has not been incontrovertible evidence that such procedures work although experiments such as that of Prasnikar (1993, 2003) do offer some support. Finally, for the stakes paid in the experiment it is reasonable to assume that utilities are linear and, as with most experiments, we rely on this fact to avoid preference induction.

3.1. Experimental parameterization

Our model is parameterized by the vector (r^*, r', T, N, K, f_b) as defined above. In our experiment, we set $T = 4$, $N = 6$, $r' = 0.12$ and $K = 10$ for all treatments, while r^* is allowed to vary from 0.14, to 0.07 and to 0.08, and f_b is uniform.[8] We call this set of parameters our experimental parameterization.

In the symmetric information version of our game, subjects are ignorant of the quality of the bank their money is in except for the distribution f_b. As discussed, in the simultaneous version each player's strategy is a function from the set of parameters describing the game to the set of withdrawal times $\{1, 2, 3, 4\}$, while the expected payoff is defined by Eq. (3). The same is true for the Low-Information Sequential form of the game. In the High-Information Sequential form, the strategy set is expanded since subjects are able to see how many people withdrew before them and can condition their action on those withdrawals. Here a strategy specifies a complete plan of action defining when to withdraw with the possibility of conditioning that action on any withdrawal sequence. It is important to note, however, that in the symmetric-information game withdrawals have no informational value, i.e., they do not reveal that any player has learned anything about the bank, and, as a result, do not affect players' beliefs about the quality of the bank.

In the asymmetric-information experiments we introduce two insiders who know the quality of the bank while the remaining four depositors are uninformed, that is, they only know the distribution f_b. This information asymmetry changes the strategy space of the subjects since it provides more information upon which they can condition their actions on. For example, informed subjects can condition their actions on the quality of the bank while uninformed subjects can condition their actions on withdrawals before them. We call a strategy for informed subjects a "conditional strategy" if their withdrawal time is a non-constant function of their insider information about the quality of the bank in addition to the parameters of the model. We call a strategy for the uninformed subjects a "conditional strategy" if, in addition to the parameters of the model, they condition their withdrawal times on withdrawals before them (i.e. uninformed subjects do not withdraw until they observe a withdrawal and withdraw right after they see someone withdraw). Finally, we call an equilibrium to our bank-run model a "conditional equilibrium" if each subject's strategy is conditional.[9]

The far right hand column of Table 1 presents the equilibrium predictions of our games.[10]

First note that no new equilibria are introduced by having the game played in its High or Low-Information Sequential form. We will prove this result below. Furthermore, from Table 1, we observe that our bank-run model, with symmetric information and its present parameterization, yields equilibria that have distinct features. First, they involve all agents withdrawing at the same time. Second, if there are multiple equilibria, then they are adjacent i.e., "all withdraw in period 1" and "all withdraw in period 2." Third, as the mean rate in the industry, r^*, increases, agents withdraw later.[11] Fourth, in our experimental parameterization, the equilibria for the Simultaneous form game remain to be the only pure strategy equilibria for both the Low and High-Information Sequential form games. Finally, although not indicated in Table 1, in our experiments with asymmetric information money stays

[8] We also run treatments where there is deposit insurance so that subjects are guaranteed either 20% or 50% of their promised amount.

[9] Note that this implies that in a conditional equilibrium, uninformed subjects never withdraw before informed subjects. See Section 5.1.2 and footnote 25 for a detailed discussion and some examples of how a conditional equilibrium would look like.

[10] In our paper, we only consider the symmetric pure strategy predictions of our model. Testing for the existence of mixed strategy equilibria is difficult for a number of reasons. First, we concentrate primarily on the first period behavior of subjects and it is impossible to infer if mixed strategies are being used there either on the individual or the population level (where one could look at the frequency of choices made in the population and see if they conform to the predictions of a mixed strategy being used on the individual level). Second, mixed strategies imply that subjects are using *i.i.d.* strategies across periods and we see no evidence of that. Subjects' choices are either obviously correlated over time or time invariant but unchanging, neither of which indicate a mixed strategy is being used. Finally, such strategies are not easy to compute here both for the analyst (authors) and even more so for the subjects. Hence, from a cognitive point of view we expect that such strategies lie outside of the cognitive competency of our subjects.

[11] If one were to take r^* as a cyclical indicator (average rate of return in the economy), one would expect money to be withdrawn faster in a bank run when it occurs during bad times as opposed to good times.

Table 1
Experimental design

Experiment	Form	Information	Rounds	Subjects	Equilibria
$r^* = 7\%$	Simultaneous	NA	21	48 (8 groups)	(6, 0, 0, 0) (0, 6, 0, 0)
$r^* = 14\%$	Simultaneous	NA	21	30 (5 groups)	(0, 0, 6, 0) (0, 0, 0, 6)
$r^* = 7\%$	Sequential	Low, Symmetric	21	42 (7 groups)	(6, 0, 0, 0) (0, 6, 0, 0)
$r^* = 7\%$	Sequential	High, Symmetric	21	24 (4 groups)	(6, 0, 0, 0) (0, 6, 0, 0)
$r^* = 7\%$ (20% insurance)	Sequential	High, Symmetric	21	24 (4 groups)	(6, 0, 0, 0) (0, 6, 0, 0)
$r^* = 7\%$ (50% insurance)	Sequential	High, Symmetric	21	24 (4 groups)	(0, 6, 0, 0)
$r^* = 14\%$	Sequential	Low, Symmetric	21	24 (4 groups)	(0, 0, 6, 0) (0, 0, 0, 6)
$r^* = 14\%$	Sequential	High, Symmetric	21	24 (4 groups)	(0, 0, 6, 0) (0, 0, 0, 6)
$r^* = 8\%$	Sequential	High, Symmetric	21	24 (4 groups)	(0, 6, 0, 0)
$r^* = 8\%$	Sequential	High, Asymmetric	21	24 (4 groups)	NA[+]

[+] Equilibria here are defined as functions and described in the paper.

longer in the bank in a conditional equilibrium compared to the symmetric-information experiments, that is, bank runs are less severe when there is insider information.

3.2. Theoretical results

The results in Table 1 are summarized in the following propositions that will serve as the basis for the hypotheses we test in Section 5. We state and prove three propositions on the existence and the characteristics of the equilibria in our model. The first two apply to our symmetric information game while the last one applies to our asymmetric information game. All proofs are presented in Appendix A.

Proposition 1 *(Existence). For any r' and t, there exists a range of r^* values such that all subjects withdrawing at time t is a pure strategy equilibrium to our bank-run game.*

Corollary 1 *(Experimental Equilibrium Characterization). In our experimental parameterization with* $r' = 0.12$, *the withdrawal vectors $n = (n_1, n_2, n_3, n_4)$ that can be sustained as an equilibrium are as follows*:

$$n = \begin{cases} (6,0,0,0) & \text{for } r^* \in [0, 0.074], \\ (0,6,0,0) & \text{for } r^* \in [0.057, 0.135], \\ (0,0,6,0) & \text{for } r^* \in [0.082, 0.240], \\ (0,0,0,6) & \text{for } r^* > 0.098. \end{cases}$$

Note that for a given r' and r^* there may exist multiple equilibria. For example, when r^* is between 0.057 and 0.074, withdrawing at both time periods 1 and 2 are equilibria. Furthermore, in equilibrium, for the $r' = 0.12$, $r^* = 0.07$ experiments, subjects withdraw early (period 1 and 2), while for the $r' = 0.12$, $r^* = 0.14$ experiments, they withdraw later (periods 3 and 4). Clearly, as the mean return in the banking industry, r^*, increases, for any given r' and any vector of withdrawals, it is less risky to keep your money in the bank longer since the bank has more funds on average.

Proposition 2 *(Informational Invariance). For any configuration of r^* and r', a withdrawal vector $n = (n_1, n_2, n_3, n_4)$ is an equilibrium to the High-Information or Low-Information Sequential form game if and only if it is an equilibrium to the Simultaneous form game.*

Hence, no new equilibria are introduced when we move from the Simultaneous form to the High-Information and Low-Information Sequential forms.

Proposition 3 *(Insider Information and Bank Run Severity). Let EL_{SI} and EL_{AI} be the excepted length of time money stays in the bank in any equilibrium of our experimental bank-run game for $r^* = 0.08$ with symmetric information (SI) and any conditional equilibrium for the asymmetric-information game (AI), respectively. Then, $EL_{AI} > EL_{SI}$.*

Thus, the presence of insiders mitigates the severity of bank runs since in any conditional equilibrium of our bank-run game with asymmetric information, money is withdrawn later than it is withdrawn in the equilibrium to the same game with symmetric information.

4. Experimental procedures and design

For our experiments, groups of six subjects were recruited from undergraduate Economics classes at New York University (NYU) and asked to arrive at the experimental laboratory of the Center for Experimental Social Science at NYU. Subjects were paid $5 for showing up on time and earned on average about $22 more in the 1.5 hour experiment.

Instructions were administered on subjects' computer screens. Subjects were handed tables presenting their payoff function.[12] These tables told them what their payoff would be conditional on any scenario of withdrawals and on each of the five banks, as well as the expected payoff given the probability distribution over banks. To test subjects' knowledge of the payoff table, instructions present them a series of quizzes. In addition, subjects could use an on-screen "calculator."[13] This calculator allowed them to enter any scenario of withdrawals and would tell them what expected payoff each hypothetical subject would get.[14]

The promised rate of return, r', is kept constant at 0.12 while the average rate of return r^* varied from 0.07, to 0.08 and to 0.14. In addition, we ran the experiment under several informational conditions. Each combination of r' and $r^* \in \{0.07, 0.14\}$ was run in the Simultaneous form and under the High and Low-Information Sequential forms. We ran the asymmetric-information experiments where two of the six subjects were informed about the quality of the bank using $r^* = 0.08$.[15] Finally, we ran a set of experiments with partial deposit insurance to compare the behavior of subjects with and without such insurance.

In this paper, we wanted parameter values that would determine an "early" and a "late" equilibrium. In the "early-equilibrium" experiment ($r^* = 0.07$), subjects are faced with a greater risk of loosing their deposits if they withdraw too late since there was no bank that could pay all subjects their promised amount. In addition, no matter what the pattern of withdrawals is, (even in equilibrium) there will always be some subjects who will not be able to get their promised amount. The equilibria in this treatment were for all subjects to "withdraw in period 1" or for all to "withdraw in period 2." In contrast, in the late-equilibrium experiment ($r^* = 0.14$), where all subjects either "withdraw in period 3" or all "withdraw in period 4," such risks were lessened since three out of five banks could pay the promised amount to all subjects.

To analyze the effect of the two policy interventions, informational and deposit insurance, we use parameter values where we have the early equilibria since bank runs are more severe in those cases. Hence, for the experiments with deposit insurance, we set $r^* = 0.07$. Finally we set $r^* = 0.08$ for the asymmetric-information experiments since with $r^* = 0.08$ the equilibrium to our symmetric-information experiment is unique and we can make a clean comparison of the impact of insiders on withdrawal behavior by comparing the two treatments.

[12] Instructions and payoff tables are available from the authors.

[13] The calculator was presented in a window on their screen if they clicked on a button labeled "calculator."

[14] Subjects used this calculator both before and during the experiment. They also referred to their payoff tables repeatedly during the experiments.

[15] To be able to identify the effect of asymmetric information, for comparison, we ran a set of experiments with symmetric information for $r^* = 0.08$ in the High-Information Sequential form.

In our experimental design, while we run the bank-run experiment for 21 rounds, we pay higher stakes in the first round. More precisely, the payoffs in the first round is worth 20 times as much as any of the remaining rounds. We do this because bank runs, while important, are rather rare occurrences. In many countries, ordinary citizens rarely experience a bank run in their entire lifetime. For this reason, we pay high stakes for the first round expecting this behavior to be relevant for common citizens. However, since some professionals such as institutional investors may have more experience with market runs, and possibly with bank runs, we allow our experiments to continue for 20 more rounds to analyze learning behavior. We feel that this is an important feature of our design where we allow subjects to play for high stakes over a horizon that matches the horizon in the real world, yet, lets them learn for low stakes later on in the experiment. Learning results are discussed in Section 5.3.

5. Experimental results

In this section, we present our experimental results, where we use our propositions to generate our working hypotheses.

5.1. Information and comparative statics

First, we present our results from the symmetric-information experiments and then show the results from the experiments with insiders.

5.1.1. Symmetric information

Proposition 2 states that the equilibria of the bank-run game for any configuration of parameters should be invariant to the form of the game, which gives us our first hypothesis.

Hypothesis 1 *(Information).* For any given set of parameters r' and r^*, there is no difference in the play of our bank-run game as informational treatments vary.

Fig. 1 presents the withdrawal frequencies across treatments. We can see that in the $r^* = 0.07$ experiment there is no significant difference in the withdrawal behavior of our subjects across different informational treatments.[16] For example, while 50% of subjects withdrew in period 1 or 2 in the Simultaneous-form experiment, 42% and 33% withdrew in period 1 or 2 in the Sequential High-Information and Sequential Low-Information forms, respectively. These differences were not significant at the 5% level using a test of proportions.[17]

However, the same cannot be said for the $r^* = 0.14$ experiments, where there is a clear tendency for subjects to withdraw later in the High-Information Sequential experiments. For example, only 8% of the subjects withdrew in period 1 or period 2 in the High-Information Sequential experiments compared to 27% and 25% for the Simultaneous and the Low-Information Sequential experiments, respectively. Using a test of proportions, we can show, at the 5% significance level, that subjects tend the withdraw later in the High-Information treatment compared to the Simultaneous treatment ($z = 1.7847$, $p = 0.0372$).[18]

[16] While the length of time it takes subjects to make their decisions, hence the time for the game to proceed in the sequential form, can provide subjects a hint for how seriously other subjects were thinking about withdrawing, we have to keep in mind that there is a limit to how informative that can be. In particular, the time it takes for the game to proceed is equal to the longest of the time taken by each subject to make her decision. Hence, it is possible that while most subjects make their decisions in a short period, only one subject can delay the entire game. Thus, the time for the game to proceed can only provide some limited information about how seriously subjects were thinking about withdrawing their money.

[17] Test results are as follows: (i) Simultaneous versus Sequential High: $z = 0.6409$, $p = 0.5216$; (ii) Simultaneous versus Sequential Low: $z = 1.6298$, $p = 0.1031$; (iii) Sequential High versus Sequential Low: $z = 0.7316$, $p = 0.4644$.

[18] Though close to the threshold, a test of proportions was not able to show (at the 5% significance level) that subjects tend to withdraw later in the High-Information treatment compared to the Low-Information treatment ($z = 1.5866$, $p = 0.0563$). Also, from the test of proportions, the difference between the Simultaneous and the Sequential-Low treatments is not significant at the 5% level ($z = 0.1663$, $p = 0.8679$).

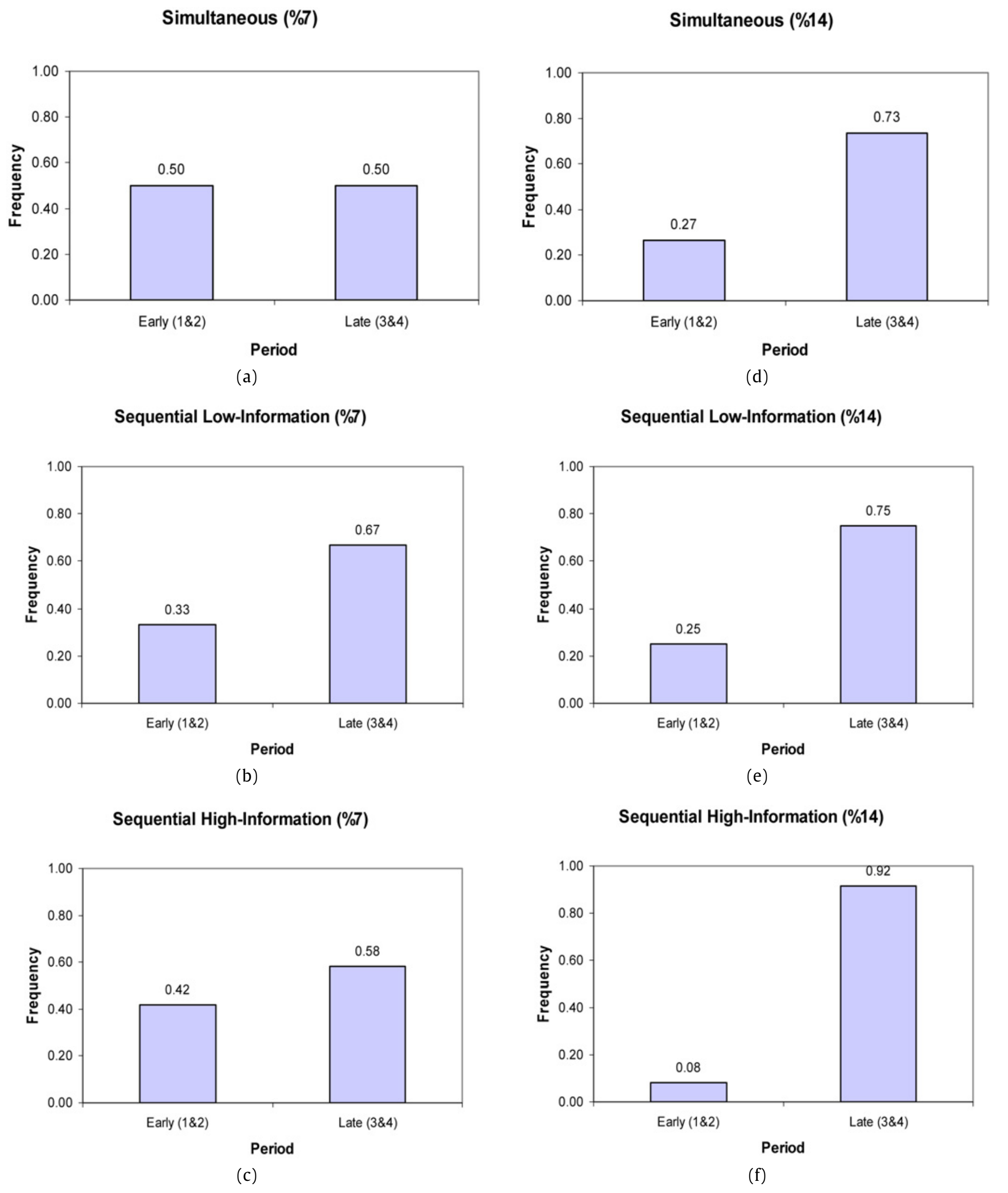

Fig. 1. Withdrawals in the first round.

Bank runs appear to be less severe when subjects have more information about what other subjects have done, but this is true only when the economy is in a relatively good state ($r^* = 0.14$). This may be the case because later withdrawals are less risky when banks perform well and subjects are more willing to wait and see what others are doing. A logical consequence of this result is that wider dissemination of information about an evolving crisis may be helpful in slowing it down if people know in advance that they will have access to such information. Also, we know from other studies (see Schotter et al., 1994 and Cooper and Van Huyck, 2003) that play of the same game in the simultaneous and sequential form may not be equivalent since, perhaps, these two forms highlight different features of the decision problem.

Our second hypothesis is about the relation between bank runs and the business cycle, in particular, whether money stays longer in the banking system in the $r^* = 0.14$ as opposed to the $r^* = 0.07$ experiment. Data presented in Fig. 1 can be used to test this hypothesis.

Hypothesis 2 *(Comparative Statics).* Under any information condition, subjects withdraw later in the $r^* = 0.14$, $r' = 0.12$ experiment than they do in the $r^* = 0.07$, $r' = 0.12$ experiment.

Our results mostly support this hypothesis. Using a set of bilateral Wilcoxon tests to compare the mean withdrawal times in the first period of our $r^* = 0.07$ and $r^* = 0.14$ experiments, we find that there is a statistically significant difference in the withdrawal times of subjects between the $r^* = 0.07$ and the $r^* = 0.14$ experiments when the game is played in the High-Information Sequential or Simultaneous versions.[19] For some reason there was no significant difference when comparing the Sequential Low-Information experiments. Also, note that while in the High-Information Sequential $r^* = 0.14$ treatment only 8% of the subjects withdraw in periods 1 or 2 (early withdrawals) and 92% withdraw in rounds 3 and 4 (late withdrawals), in the $r^* = 0.07$ High-Information Sequential treatment these percentages are 42% and 58% respectively (see Fig. 1(c) and (f)).

5.1.2. Asymmetric information

In these experiments, run with $r^* = 0.08$ and $r' = 0.12$, we informed two subjects before each round about the type of the chosen bank, while the other four received no information.[20] The actual identity of the informed agents is kept private. In each round the bank was drawn randomly in an *i.i.d.* fashion.

In our model, all conditional equilibria share one important feature: They are welfare improving compared to the (unique) equilibrium of our $r^* = 0.08$, $r' = 0.12$ game played with symmetric information, since in any conditional equilibrium of the asymmetric-information game, on average, money stays longer in the bank.

Below we investigate evidence of conditional strategies in our asymmetric-information treatments.[21] We are interested in several aspects of the asymmetric-information game: Do subjects follow conditional strategies, that is, do the informed condition their withdrawal times on the quality of the bank and do the uninformed wait until they see a withdrawal? Do we observe later withdrawals in the asymmetric compared to the symmetric-information experiments?

5.1.2.1. Withdrawal times Fig. 2 presents the histograms of the first-round withdrawal times for our asymmetric and symmetric-information $r^* = 0.08$, $r' = 0.12$ experiments.

Note that the most significant difference between the two experiments is the difference in the frequency of withdrawals in period 4, with 21% more withdrawals in the asymmetric-information experiment. On average, money stayed longer in the bank in the asymmetric-information experiment than in the associated no-insider experiment. For example, in the first round, money stayed in the bank, on average, for 2.83 periods in the no-insider experiments while it stayed for 3.25 periods in the asymmetric-information experiments. A Wilcoxon test run to test the hypothesis that these withdrawal times came from the same population against the one-sided alternative that money is withdrawn later in the asymmetric-information experiment rejects the null at the 5% significance level ($z = 1.871$, $p = 0.030$).

[19] Test results for withdrawal times for $r^* = 0.07$ versus $r^* = 0.14$ are as follows: (i) Simultaneous: $z = -2.5601$, $p = 0.0052$; (ii) Sequential Low: $z = -1.2422$, $p = 0.1071$; and (iii) Sequential High: $z = -3.3194$, $p = 0.0005$.

[20] The same two people always functioned as the informed subjects.

[21] Note that the use of conditional strategies is not sufficient to demonstrate that a full-fledged conditional equilibrium is being used, since there must be consistency between the conditional strategies used by the subjects. Still, the use of conditional strategies is necessary for a conditional equilibrium and evidence for conditional strategies suggests that subjects were grouping to reach a conditional equilibrium.

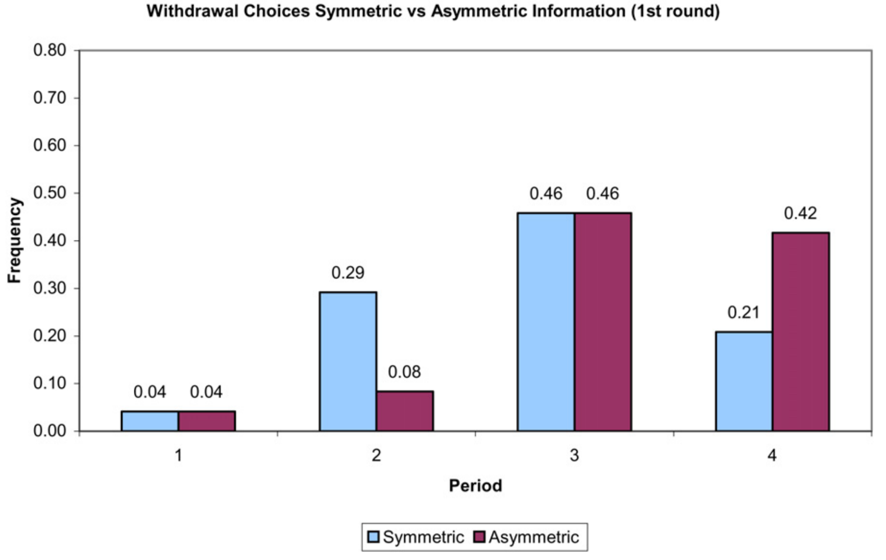

Fig. 2. Withdrawal choices, symmetric vs. asymmetric information (1st round).

Since insiders had some information, we have to keep in mind that the quality of the bank in the first round of the asymmetric-information treatment might have affected behavior. In order to address this issue, we also looked at the data from all 21 rounds and, similar to the results we got from the analysis of the first round withdrawal times, the average time money stayed in the bank was significantly longer in the asymmetric-information experiments than the average time for the no-insider experiments (3.12 periods vs. 2.91 periods, respectively).[22]

Fig. 3 presents the histogram of the removal times for all 21 rounds of the Asymmetric Information and Symmetric Information experiments and provides results similar to the ones presented in Fig. 2. In particular, as in Fig. 2, the most significant difference between the two experiments is the frequency of period 4 withdrawals, with 15% more withdrawals in the asymmetric-information experiment. Furthermore, a Wilcoxon test run to test the hypothesis that withdrawal times came from the same population against the one sided alternative that money is withdrawn later in the asymmetric-information experiment rejects the null at the 1% significance level ($z = 4.6386$, $p = 0.00$).

An important feature of the experiments with insiders is that for better banks, on average, money stayed longer in the banking system, that is, runs were correct runs on average. We can see this from the average time money stayed in each type of bank in the asymmetric-information experiments for the data pooled over the 21 rounds given as: Bank 1 = 2.73, Bank 2 = 2.85, Bank 3 = 3.02, Bank 4 = 3.11 and Bank 5 = 3.23.

5.1.2.2. Withdrawal strategies We are interested in knowing if subjects used conditional strategies in this experiment. As discussed in Section 3.1, such strategies have a number of characteristics. Most importantly, informed subjects should condition their withdrawal choices on the bank while unin-

[22] To check that the difference between the results of our asymmetric and symmetric-information treatments were not an artifact of the difference in the distribution of the quality of banks, we compared the distribution of bank quality across our asymmetric and symmetric treatments over 21 rounds. The frequency of different banks in the 21 rounds of the symmetric (asymmetric) information games is as follows: Bank 1: 19 (19); Bank 2: 18 (17); Bank 3: 16 (17); Bank 4: 18 (14); Bank 5: 13 (17). We performed a series of bilateral χ^2 tests, which compare the distribution of banks in our treatments with each other, and with what a uniform distribution would look like. According to our test results, we cannot reject the null hypothesis that the distribution of banks in the symmetric information, asymmetric information and from the uniform distribution are equal: (i) Symmetric versus Asymmetric: $\chi^2 = 2.201$, $p = 0.70$; (ii) Symmetric versus Random: $\chi^2 = 1.357$, $p > 0.80$; (iii) Asymmetric versus Random: $\chi^2 = 0.761$, $p > 0.90$.

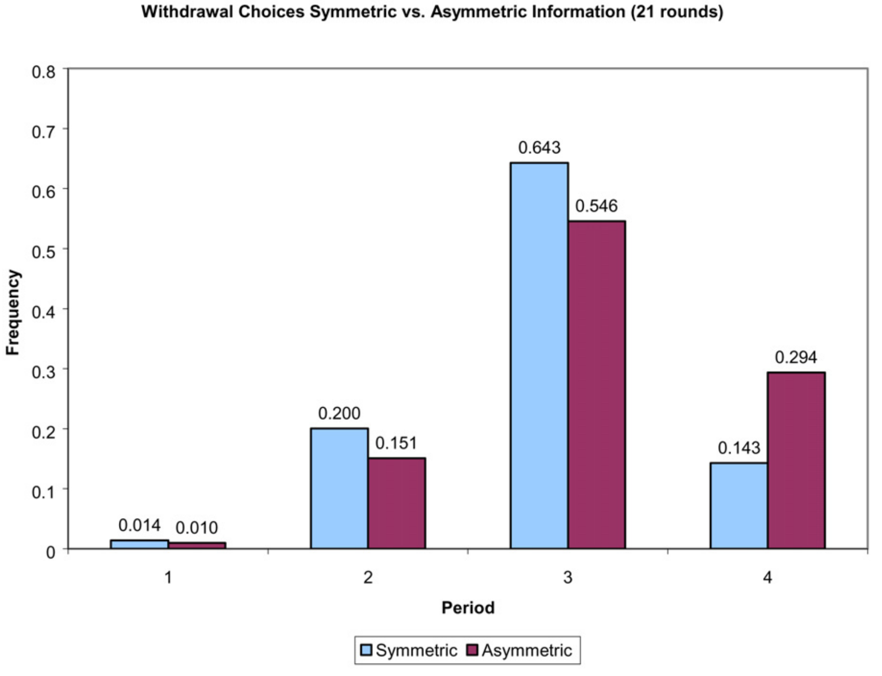

Fig. 3. Withdrawal Choices, Symmetric vs. Asymmetric Information (21 rounds).

formed subjects should condition their withdrawal choices on withdrawals before them. We look at the data for evidence to substantiate this behavior.

Fig. 4 shows withdrawal times of informed subjects for each realized bank, where observations are pooled over all informed subjects and over the entire length of the experiment. The figure clearly supports the idea that the informed subjects followed a conditional strategy.

If the use of conditional strategies was evident in the data and informed subjects actually conditioned their withdrawal times on the observed bank, then for informed subjects, we should expect to see the distributions of withdrawal times shift (to the right) as the realized bank gets better and the mean withdrawal times should increase. We can see in Fig. 4 that this is in fact the case. For example, the modal withdrawal time is period 2 when the bank is Bank 1, period 3 when it is Bank 2 or 3, and period 4 when it is Bank 4 or 5.

Using a Wilcoxon test we can reject the hypothesis that withdrawal times were identical for any pair of adjacent banks. More precisely, a set of Wilcoxon tests reject the hypothesis that withdrawal times are equal for comparisons of Bank 1 vs. Bank 2, Bank 3 vs. Bank 4 and Bank 4 vs. Bank 5 at the 1% significance level in favor of the one tailed alternative that subjects withdrew later the better the bank.[23,24] Also, note that when Bank 5 is announced informed subjects withdraw in period 4 in 97% of the time and do so 68% of the time for Bank 4. No informed subject withdrew in period 4 when Bank 1 is announced.

Perhaps a more direct way to establish that informed subjects followed a conditional strategy is to estimate their withdrawal strategy. To do that we ran an ordered probit regression. In this regression

[23] One-tailed Wilcoxon test results are as follows: (i) Bank 1 versus Bank 2: $z = -4.7603$, $p = 0.00$; (ii) Bank 2 versus Bank 3: $z = -1.4649$, $p = 0.07$; (iii) Bank 3 versus Bank 4: $z = -4.3406$, $p = 0.00$; and (iv) Bank 4 versus Bank 5: $z = -3.0749$, $p = 0.00$.

[24] Furthermore, calling banks 3, 4 and 5 healthy banks and banks 1 and 2 weak banks, we can easily reject the hypothesis of equality of mean withdrawal times across these categories in favor of the one-tailed alternative that informed subjects withdrew later when healthy banks were realized ($z = 8.5786$, $p \approx 0$).

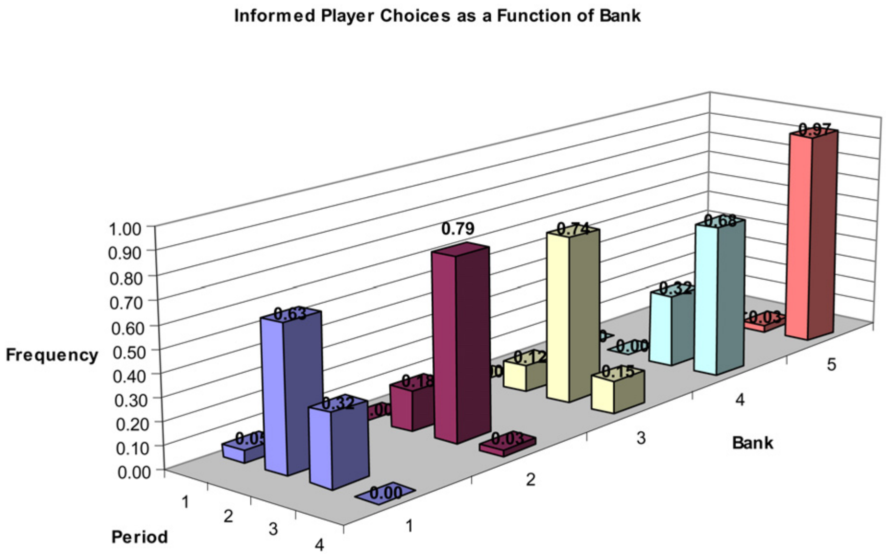

Fig. 4. Informed players' choice as function of bank

the dependent variable was a discrete variable taking on values of 1, 2, 3 or 4 depending on the period of withdrawal. The independent variable was the realized bank rate. When our ordered probit regression is run on the pooled data from all informed subjects we find a highly significant and positive coefficient for the bank rate variable indicating a positive relationship between the bank rate and the probability of withdrawing later, as can be seen in Table 2. Furthermore, the predicted probabilities from this regression, given in Table 3, confirms this strong relationship.

With respect to uninformed subjects, in order to support the claim that these subjects used a conditional strategy we need to show that uninformed subjects conditioned their withdrawals on withdrawals before them in a way that they never withdraw until they observe a withdrawal. To see this, we checked whether uninformed subjects followed a conditional strategy of the form given as follows (starting from $t = 1$, going forward)[25]:

(i) Do not withdraw at $t = 1$.
(ii) If you see a withdrawal at $t = 1$, withdraw at $t = 2$. Otherwise, do not withdraw at $t = 2$.
(iii) If you see a withdrawal at $t = 2$, withdraw at $t = 3$. Otherwise, withdraw at $t = 4$.

For our analysis, we created a dummy variable (*cond*) that takes the value 1 if an observation satisfies the above description and 0 otherwise. This approach is similar to counting the number of observations that conform to the conditional strategy described above. In the asymmetric information experiment, out of 336 observations for the uninformed subjects, 169 (50.3%) conform to the conditional strategy. This number is 184 (36.5%), out of 504 observations, in the symmetric-information experiments.[26]

We ran a probit regression where the dependent variable is the variable *cond* and the independent variable is a dummy variable (*asym*) that takes the value of 1 for asymmetric-information experiments and the value of 0 otherwise. Our results are given in Table 4.

[25] It can be shown that this conditional strategy for the uninformed subjects and the following conditional strategy of the informed subjects constitute a conditional equilibrium: (i) If Bank 1 or Bank 2, withdraw in period 1; (ii) If Bank 3, withdraw in period 3; (iii) If Bank 4 or Bank 5, withdraw in period 4.

[26] A test of proportions shows that uninformed subjects in the asymmetric information experiments are more likely to follow a conditional strategy compared to subjects in the symmetric-information experiments at the 1% significance level ($z = 3.9697$, $p = 0.0001$).

Table 2
Ordered probit results for withdrawal behavior of informed subjects

Explanatory var.	Coefficient	Std. Err.	z	p
Bank rate	0.4321	0.0442	9.79	0.000

$n = 168$, Pseudo $R^2 = 0.4470$, Log Likelihood $= -102.60$.

Table 3
Predicted probabilities of withdrawal for informed subjects for different banks

	Period 1	Period 2	Period 3	Period 4
Bank 1	0.051	0.643	0.305	0.001
Bank 2	0.003	0.266	0.705	0.026
Bank 3	0.000	0.037	0.742	0.221
Bank 4	0.000	0.002	0.343	0.655
Bank 5	0.000	0.000	0.064	0.936

Table 4
Probit results for conditional strategies of uninformed subjects

Explanatory var.	Coefficient	Std. Err.	z	p
Asym	0.1533	0.0350	4.35	0.000

$n = 830$, Pseudo $R^2 = 0.017$, Log Likelihood $= -556.512$.

Table 5
Ordered probit results for withdrawal behavior of uninformed subjects

Explanatory var.	Coefficient	Std. Err.	z	p
Before	0.2839	0.0494	5.74	0.000
Asym	0.5462	0.0985	5.54	0.000
Asym ∗ Before	−0.2405	0.0840	−2.86	0.004

$n = 840$, Pseudo $R^2 = 0.034$, Log Likelihood $= -788.04$.

Note that the coefficient for *asym* dummy is positive and significant, that is, uninformed subjects in the asymmetric-information experiments are more likely to follow a conditional strategy compared to the subjects in the symmetric-information experiments.

Perhaps a more direct way of comparing the behavior of uninformed subjects in the asymmetric-information experiments with the behavior in the symmetric-information experiments is to look at the differences in the impact of observed withdrawals in these two experiments. To do that, we pooled the data from the symmetric-information experiments with the observations for the uninformed subjects in the asymmetric-information experiments and ran an ordered probit regression, where the dependent variable is the withdrawal period taking on values of 1, 2, 3 and 4. The independent variables are the number of observed withdrawals before an uninformed player withdraws (*before*),[27] the dummy variable *asym*, and an interaction variable which is simply the multiplication of the variables *asym* and *before*.

The results in Table 5 show that the coefficients of *asym* and *asym* ∗ *before* are significant, which confirms that the behavior of uninformed subjects in the asymmetric-information experiments is different from the behavior in the symmetric-information experiments. In particular, the positive coefficient of the dummy *asym* shows that uninformed subjects in the asymmetric-information experiment tend to withdraw later compared to the symmetric-information experiments.[28] Furthermore, the

[27] These are withdrawals in previous periods that have been observed. For example, if a depositor decides to withdraw at $t = 4$, that decision is taken at $t = 3$ (as $t = 4$ is the last date) and only withdrawals at $t = 1$ and $t = 2$ are observed, whereas withdrawals at $t = 3$ are not. Hence, for a depositor who withdraws at $t = 4$, the variable *before* is the sum of withdrawals at $t = 1$ and $t = 2$.

[28] While 87% of the uninformed subjects withdraw in periods 3 and 4 in the asymmetric-information experiment, only 67% of the symmetrically-informed subjects do so. A Wilcoxon test rejects the hypothesis of equality between the two samples in

negative coefficient of the interaction variable $asym * before$ shows that in the asymmetric-information experiments, withdrawals in earlier periods lead to immediate subsequent withdrawals, more so compared to the symmetric-information experiments. This is consistent with the predictions of our model since withdrawals in the asymmetric-information experiments, in addition to the coordination effect as funds in the bank gets depleted due to withdrawals, can reveal information about the quality of the bank and hence is more likely to lead to immediate subsequent withdrawals.[29]

In summation, it seems like the behavior of our subjects in the asymmetric-information experiments was consistent with the behavior of subjects following conditional strategies. Informed subjects clearly conditioned their withdrawals on the bank drawn while uninformed subjects appeared to wait longer before withdrawing and condition their withdrawal choice on withdrawals before them. These stylized facts were supported by comments made by our subjects in post-experiment questionnaires presented in Box 1.

5.2. Deposit insurance

The second policy tool we analyze is deposit insurance. In the deposit insurance experiments we imposed a 50% and a 20% insurance rate in two experiments, that is, no subject can loose more than 50% or 80% of their deposits, respectively. We used the parameter values $r^* = 0.07$, $r' = 0.12$ since subjects were supposed to withdraw early, resulting in more severe bank runs. We also used the High-Information Sequential version of the experiment.[30]

The results from our experiments are presented in Table 6 and Fig. 5. Note that while 42% of subjects withdraw early (period 1 or 2) with no insurance, only 25% and 17% of the subjects withdrew in these periods in the 20% and 50% insurance experiments, respectively.

A Wilcoxon test run to test the hypothesis that withdrawal times without insurance and with 50% insurance came from the same population against the one-sided alternative that money stayed longer in the bank in the 50% insurance experiment rejects the null at the 5% significance level ($z = 2.0276$, $p = 0.023$). Hence, 50% insurance seems to be effective in slowing down bank runs. Also, note that 50% insurance totally eliminates period 1 withdrawals. However, the same test to compare the withdrawal times with no insurance and 20% insurance fails to reject the null hypothesis at the 5% significance level ($z = 1.4014$, $p = 0.0805$), which shows that 20% insurance seems to be too little to affect behavior.

We ran an ordered probit regression of the withdrawal period on the insurance rate (0%, 20% or 50%) for the first-round data pooled across all the three experiments and found that insurance has a positive and significant impact on the withdrawal time as shown in Table 7.

This relation can be seen from the predicted probabilities in Table 8.

5.3. Equilibria and learning

While we designed our experiments to capture the one-shot aspect of bank-run phenomenon since few people have much experience with repeated bank runs, we do repeat our experiments for an

favor of the one-tailed alternative that the mean withdrawal time of the uninformed subjects in the asymmetric-information experiment is greater than the mean withdrawal time in the symmetric-information experiments at the 1% significance level ($z = 3.514$, $p \approx 0.0004$).

[29] In a rather indirect way, we ran separate ordered probit regressions for the uninformed subjects in the asymmetric-information experiments and the subjects in the symmetric-information experiments, where the dependent variable was the withdrawal period, and the independent variable was the bank rate. The results from the symmetric-information experiments show that the bank rate is not significant at the 5% level, which is expected as there is no possibility for subjects to learn about the bank rate in these experiments. However, the results for the uninformed subjects in the asymmetric-information experiments show that the bank rate is significant at the 5% level with a positive coefficient, indicating the positive relationship between the bank rate and the probability of withdrawing later for the uninformed subjects. Note that the only way uninformed subjects can learn about the bank rate is through the actions of the informed players. This suggests that uninformed subjects were in a way waiting for informed subjects to move first (if they move at all), which provides support for our conditional-strategy hypothesis.

[30] We share the views of Brunnermeier (2001) that bank runs occur sequentially in reality. Therefore, we use the High-Information Sequential form of our experiment for the policy analysis.

Box 1: Student Reports

Here, we present student reports from one session of our asymmetric-information experiments. The following two statements are from the two informed subjects:

Player 1 (Informed)
If it was Bank 1, I withdrew in period 2.
Bank 2: Period 2 or 3 (depending on how many withdrew before me).
Bank 3: Always period 3.
Bank 4 & Bank 5: Always period 4.

Player 4 (Informed): *After observing that no one withdrew ever during the first time period, I withdrew in the 2nd time period for Bank 1. For Bank 3 or 4, I withdrew in the 3rd time period (only when it was Bank 1, did anyone withdraw before the third period—I assume it was me and the other informed player). For Bank 5, I left the money in until the end.*

While these strategies were not coordinated, they indicate that these two informed subjects conditioned their withdrawal times on the realized bank.

The uninformed subjects clearly attempted to condition their withdrawal choices on withdrawals before them as the following reports show:

Player 2 (Uninformed): *I tried to wait and see what the two informed players were doing. If they got out quickly, so did I. There was also a fair amount of intuition involved. Sometimes I went with the feeling to get out/stick with it when I was unsure of the moves of the informed. I tried to wait until period 4 if the informed had not moved in the first two periods. But sometimes I panicked and got out early*.

Player 5 (Uninformed): *Because I was uninformed and knew that 2 were informed, I withdrew as soon as I saw 2 people had withdrawn their money*.

The other two uninformed subjects reported:

Player 3 (Uninformed): *Wait until the last period, only withdraw earlier if people withdrew in the second period. I came up with this strategy only after a couple of rounds.*

Player 6 (Uninformed): *Waited until not too many people got out. If zero people came out in the first 2 time periods, I hold out till the 3rd period. If people withdrew in the beginning then I cashed out right after them.*

Table 6
Withdrawal Times with and without Insurance

Experiment	Period			
	1	2	3	4
No Insurance	0.17	0.25	0.54	0.04
20% Insurance	0.04	0.21	0.67	0.08
50% Insurance	0.00	0.17	0.75	0.08

Table 7
Ordered Probit Results for Deposit Insurance

Explanatory var.	Coefficient	Std. Err.	z	p
Insurance rate	0.0142	0.00679	2.09	0.036

$n = 72$, Pseudo $R^2 = 0.0318$, Log Likelihood $= -68.014$.

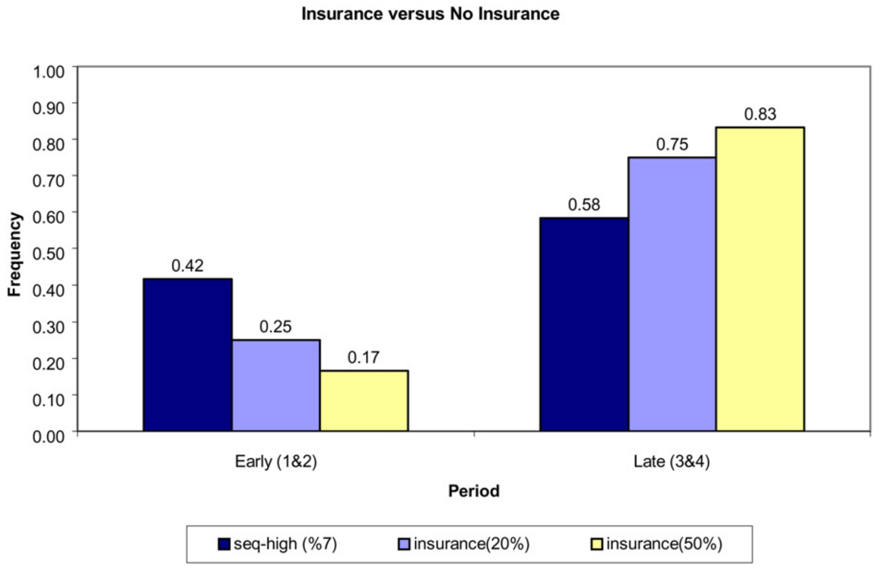

Fig. 5. Effect of different levels of insurance on withdrawal times.

Table 8
Predicted probabilities of withdrawal for different levels of insurance

	Period 1	Period 2	Period 3	Period 4
No insurance	0.111	0.280	0.578	0.031
20%	0.066	0.222	0.655	0.057
50%	0.027	0.135	0.714	0.124

additional 20 rounds which allows us to look at learning behavior. In this section, we start out by analyzing the first-round behavior of our subjects and use that data to test our theory. We then investigate learning. Proposition 2 yields the following hypothesis.

Hypothesis 3 *(Equilibria).* The behavior observed by our subjects in the first round of the Simultaneous, Low and High-Information treatments of our bank-run experiment is consistent with the behavior predicted by the equilibria of the model.

Support for this hypothesis is mixed. In Fig. 1 we have the histograms of the actions chosen by subjects in the first round of our bank-run experiment in the Simultaneous, Low-Information Sequential and High-Information Sequential forms of the game for the $r' = 0.12$, $r^* = 0.07$ (Fig. 1 (a)–(c)) and $r' = 0.12$, $r^* = 0.14$ (Fig. 1 (d)–(f)) treatments.

In the $r^* = 0.07$ experiments all early withdrawals, in the $r^* = 0.14$ experiments all late withdrawals are equilibrium actions since they are consistent with some Nash equilibrium. We present these figures since, with multiple equilibria, it may be too much to ask that subjects solve the coordination implied by the theory in the first round of the experiment. However, we can check at least that they acted in accordance with some equilibrium. Hence, we call all early (late) withdrawals in the $r^* = 0.07$ ($r^* = 0.14$) experiment "equilibrium" actions.

If the predictions of the theory were substantiated, we would see all withdrawals either on periods 1 and 2 ($r^* = 0.07$) or 3 and 4 ($r^* = 0.14$). This is true for the $r' = 0.12$, $r^* = 0.14$ case, where we see that 73%, 75% and 92% withdraw in periods 3 and 4 in the Simultaneous, Low and High-Information Sequential treatments, respectively. This behavior is close to that predicted by the theory especially when our subjects have not had a chance to learn the equilibrium. The same is not true, however, for

Table 9
Frequencies of withdrawal choices in the first and last 5 rounds

	Rounds	Period 1	Period 2	Period 3	Period 4
Simultaneous (7%)	First 5	0.08	0.42	0.43	0.07
	Last 5	0.18	0.32	0.44	0.07
Sequential-Low (7%)	First 5	0.10	0.35	0.41	0.14
($z = 1.8,\ p = 0.04$)	Last 5	0.06	0.51	0.36	0.07
Sequential-High (7%)	First 5	0.11	0.36	0.43	0.10
	Last 5	0.04	0.37	0.50	0.09
Insurance 20%	First 5	0.04	0.27	0.50	0.19
($z = 2.6,\ p = 0.005$)	Last 5	0.03	0.43	0.45	0.09
Insurance 50%	First 5	0.06	0.29	0.48	0.17
	Last 5	0.03	0.45	0.43	0.10
Simultaneous (14%)	First 5	0.02	0.17	0.39	0.42
($z = -3.73,\ p = 0.0001$)	Last 5	0.00	0.00	0.43	0.58
Sequential-Low (14%)	First 5	0.04	0.23	0.38	0.35
($z = -2.52,\ p = 0.006$)	Last 5	0.02	0.05	0.52	0.41
Sequential-High (14%)	First 5	0.04	0.11	0.48	0.38
($z = -3.61,\ p = 0.0002$)	Last 5	0.01	0.03	0.39	0.58
Sequential-High (8%)	First 5	0.04	0.24	0.57	0.15
	Last 5	0.01	0.22	0.72	0.06
Asymmetric	First 5	0.03	0.08	0.55	0.33
	Last 5	0.01	0.07	0.41	0.41

the $r' = 0.12$, $r^* = 0.07$ experiment. While the theory predicts no late withdrawals, we see that 50%, 67% and 58% of the subjects withdraw in late periods in the Simultaneous, Low and High-Information Sequential treatments, respectively. Hence there seems to be a difference in behavior in these two cases.[31]

One possible explanation for the failure of subjects in the $r^* = 0.07$ experiment to withdraw early was their perception that, given the parameters of the game, waiting until a later period was not that risky. More precisely, define c^* as the critical number of subjects such that the first c^* subjects to withdraw are guaranteed to receive their promised amount. For each experiment with $r^* = 0.07$, we have $c^* = 4$. This number may have been sufficiently high to make subjects feel secure in waiting although equilibrium behavior suggests otherwise.[32]

As stated before, we do not consider learning a very relevant subject for bank-run experiments since few of us will ever have repeated experience with bank runs in our lifetimes. However, we did run our experiments 21 times in an effort to see if the equilibrium predictions of our model had drawing power. Table 9 compares the withdrawal times of our subjects over the first and last five rounds of each experiment.

The results of this comparison are mixed. Subjects in the $r^* = 0.14$ experiment do change their behavior over the 21 rounds when we compare their actions in the first and last 5 rounds, with a clear tendency to move toward the equilibrium predictions. These differences are significant at the 1% level using a Wilcoxon test to test the null hypothesis of no change against the alternative of change in the direction of the equilibrium predictions. In the $r^* = 0.07$ experiments we can only reject the null hypothesis of no change in the Sequential Low-Information treatment at the 5% significance level. These same tests indicate that withdrawal times are closer to the equilibrium withdrawal times for the

[31] These differences can also be seen in the disaggregated first-round data in Table 10 in Appendix A. One can see that the behavior is more consistent with the equilibrium predictions of the theory for the $r^* = 0.14$ treatment. Here, there are a number of groups where all subjects chose according to some equilibrium strategy in the first round (three out of the four groups in the Sequential-High treatment and one out of four in the Sequential-Low treatment, and also, five or more subjects chose late in seven out of the thirteen $r^* = 0.14$ groups). The equilibrium predictions tended to do less well on a group-by-group basis for $r^* = 0.07$ where it is rare that four or more subjects remove their money early in any group (only three out of nineteen).

[32] Also, the feedback subjects received during the experiment did not teach them otherwise since they failed to withdraw earlier over the last five rounds of the experiment (see Table 9).

20% and 50% insurance experiments as well but there is no change in the $r^* = 0.08$ and Asymmetric Information experiments.[33]

Hence, there are two puzzling features of our data that need explanation. First, why are our subjects overly sensitive to the imposition of partial insurance in the first round of the experiment and not sensitive to changes in r^* from 7% to 14% in the low-information treatment? Second, why, over time, their experience leads them in the opposite direction, i.e., the impact of insurance diminishes while differences in r^* get accentuated?

Since at least the first round results are counter to theory, we look for a behavioral explanation. First, note that in the first round of the insurance treatments, if subjects make mistakes it is by withdrawing too late in comparison to the equilibrium predictions. This, we feel, is a reflex response on their parts to the idea that they are "insured" (although we never used that word in the instructions). Knowing that at least some of their losses would be covered lead subjects in the first round to mis-estimate the impact of this insurance on their payoffs. Put differently, this experiment (like the real world it is trying to capture) is complex and challenges the cognitive abilities of our subjects. Offering them insurance gives them a simple device to guide their behavior or a simple rule of thumb to follow: "I am insured so I will withdraw later, since even if I have a loss, I am covered." As time progresses, however, the true value of this insurance becomes apparent and subjects withdraw earlier realizing that avoiding losses altogether is better than experiencing them in a partial manner.

Changes in r^* in the low-information treatment, however, do not provide subjects with such an easy-to-calculate rule of thumb. When information is high, subjects tend to wait and see how others behave but, in the low-information treatment, such a strategy is not available. As a result, it is harder to decide on what to do in the first round. As time progresses, however, subjects learn that the $r^* = 7\%$ and $r^* = 14\%$ treatments are fundamentally different and change their behavior accordingly. Both of these movements in behavior, for the partially insured and the low information subjects, are in the direction of the equilibrium and hence the puzzle is actually a result of puzzling behavior in the first round.

6. Conclusion

In this paper, we investigated the factors that affect the dynamics of bank runs and determine their severity in order to flesh out possible policies that can help dampen them. We have demonstrated that in general the more information economic agents can expect to have about an ongoing crisis, i.e. the more they can expect to learn about the crisis as it develops, the more willing they are to restrain themselves in withdrawing their funds from banks once a crisis occurs. In addition, we have seen that the presence of insiders who know the quality of the bank is welfare improving in the sense that when such insiders exist, subjects tend to withdraw later than they would without such insiders. Finally, we have seen that deposit insurance, even of a limited type, has a mitigating effect on the severity of bank runs.

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[33] It is possible that some of our results might have been affected by the fact that we present our results in an aggregated fashion over all groups. To check whether we observe convergence for individual groups, we looked at data at the individual group level (available from the authors). We observed that in the $r^* = 14\%$ experiments, there is strong convergence towards equilibrium withdrawal times (periods 3 and 4). However, for the $r^* = 7\%$ experiments, there is convergence towards equilibrium withdrawal times (periods 1 and 2) only in three groups out of a total of twelve.

Table 10
Disaggregated data

First round withdrawal data for $r^* = 0.07$				First round withdrawal data for $r^* = 0.14$			
	Simultaneous	Seq. Low	Seq. High		Simultaneous	Seq. Low	Seq. High
Group 1	0, 3, 3, 0	1, 3, 2, 0	1, 2, 3, 0	Group 1	0, 2, 2, 2	1, 2, 1, 2	0, 0, 3, 3
Group 2	0, 3, 1, 2	1, 2, 2, 1	0, 2, 4, 0	Group 2	1, 1, 4, 0	0, 1, 4, 1	1, 1, 3, 1
Group 3	0, 4, 2, 0	0, 1, 3, 2	1, 2, 2, 1	Group 3	0, 2, 1, 3	0, 0, 4, 2	0, 0, 3, 3
Group 4	2, 0, 4, 0	1, 2, 3, 0	2, 0, 4, 0	Group 4	0, 1, 2, 3	1, 1, 3, 1	0, 0, 4, 2
Group 5	1, 1, 4, 0	0, 1, 4, 1		Group 5	1, 0, 4, 1		
Group 6	1, 2, 2, 1	0, 2, 4, 0					
Group 7	1, 3, 2, 0	0, 0, 6, 0					
Group 8	2, 1, 2, 1						

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Appendix A

A.1. Proof of Proposition 1

Establishing a (6, 0, 0, 0) equilibrium. Suppose that for a given r' all other players are withdrawing in period 1. In this case (6, 0, 0, 0) will be an equilibrium for r^* values for which no player wants to deviate to another period. Note that the only relevant deviation we need to check is withdrawing at $t = 4$.[34] No player wants to deviate to period 4 when

$$\sum_{i=1}^{5} \min\left\{(1+r'), \left(1+\frac{ir^*}{3}\right)\right\} \geqslant \sum_{i=1}^{5} \min\left\{(1+r')^4, V_4^i\right\}, \tag{4}$$

where V_4^i is the money leftover in Bank i, after 5 players withdrew at $t = 1$:[35]

$$V_4^i = \left(\max\left\{0, \left[6\left(1+\frac{ir^*}{3}\right) - 5(1+r')\right]\right\}\right)\left(1+\frac{ir^*}{3}\right)^3. \tag{5}$$

Hence, (6, 0, 0, 0) can be sustained as an equilibrium when inequality (4) is satisfied.

The left-hand side of the inequality is the expected payoff from withdrawing at $t = 1$, when all others withdraw at $t = 1$. Note that you either get your promised return of $(1 + r')$ or you share the money in Bank i with other players. On the right-hand side we have the expected payoff from withdrawing in period 4, when all others withdraw at $t = 1$, which is the minimum of the promised return of $(1 + r')^4$ or the amount left in Bank i that has accumulated until $t = 4$.

For $r^* = 0$, for any $r' > 0$, (6, 0, 0, 0) can be sustained as a unique equilibrium since by withdrawing at $t = 1$ players get an expected return of 1 while any player who deviates to $t = 4$ gets something less than 1. Also, both the right-hand and the left-hand sides of inequality (4) are continuous in r^*. Hence, there exists a (positive) neighborhood of 0 where for $r' > 0$ and for r^* values in this neighborhood, (6, 0, 0, 0) can be sustained as an equilibrium.

Establishing a (0, 0, 0, 6) equilibrium. For a given r', (0, 0, 0, 6) will be an equilibrium for r^* values for which no player wants to deviate to another period. Note that the only relevant deviation is withdrawing at $t = 3$.[36]

[34] Note that withdrawing in period 4 is a better deviation than withdrawing in period 3 (period 2) since the funds that remain after five players remove in period 1 will compound one (two) more period(s).

[35] To be more precise, the notation $V_4^i(5, 0, 0, 1)$ can be used to indicate the exact withdrawal vectors. To simplify notation, we use V_4^i instead in the entire proof.

[36] Withdrawing in period 3 is a better deviation than withdrawing in period 2 (period 1) since the funds at the bank will compound one (two) more period(s).

No player wants to deviate to period 3 when

$$\sum_{i=1}^{5}\min\left\{(1+r')^4,\left(1+\frac{ir^*}{3}\right)^4\right\}\geqslant\sum_{i=1}^{5}\min\left\{(1+r')^3,6\left(1+\frac{ir^*}{3}\right)^3\right\}. \tag{6}$$

Hence, (0, 0, 0, 6) can be sustained as an equilibrium when inequality (6) is satisfied.

The left-hand side of the inequality is the expected payoff from withdrawing at $t=4$, when all others withdraw at $t=4$. On the right-hand side, we have the expected payoff from withdrawing in period 3, when all others withdraw at $t=4$. Note that for $r^*\geqslant 3r'$, even the worst bank can pay the promised return. Hence, it is a dominant strategy to withdraw at $t=4$ and (0, 0, 0, 6) is the unique equilibrium.

Note that both the right-hand side and the left-hand side of inequality (6) are continuous in r^*. Hence, there exists a neighborhood (to the left) of $3r'$ where for r^* values in this neighborhood, (0, 0, 0, 6) can be sustained as an equilibrium.

Establishing a (0, 6, 0, 0) equilibrium. For a given r', (0, 6, 0, 0) will be an equilibrium for r^* values for which withdrawing in period 2 is a best response to the situation faced by our subject. There are two deviations from (0, 6, 0, 0) that are relevant, that is, withdrawing in period 1 and withdrawing in period 4. We can establish (0, 6, 0, 0) as an equilibrium if, for a given r', we can find at least one r^* such that these deviations are not profitable. No player wants to deviate to period 1 when

$$\sum_{i=1}^{5}\min\left\{(1+r')^2,\left(1+\frac{ir^*}{3}\right)^2\right\}\geqslant\sum_{i=1}^{5}\min\left\{(1+r'),6\left(1+\frac{ir^*}{3}\right)\right\}. \tag{7}$$

No player wants to deviate to period 4 when

$$\sum_{i=1}^{5}\min\left\{(1+r')^2,\left(1+\frac{ir^*}{3}\right)^2\right\}\geqslant\sum_{i=1}^{5}\min\left\{(1+r')^4,V_4^i\right\}, \tag{8}$$

where V_4^i is the money leftover in Bank i, after 5 players withdrew at $t=2$:

$$V_4^i=\left(\max\left\{0,\left[6\left(1+\frac{ir^*}{3}\right)^2-5(1+r')^2\right]\right\}\right)\left(1+\frac{ir^*}{3}\right)^2. \tag{9}$$

The withdrawal vector (0, 6, 0, 0) can be sustained as an equilibrium when inequalities (7) and (8) are satisfied simultaneously. Note that, inequalities (7) and (8) have similar interpretations to inequalities (6) and (4), respectively. If, for a given r', we can find r^* values for which inequalities (7) and (8) are satisfied simultaneously, we can establish a (0, 6, 0, 0) equilibrium. Proving that these inequalities have a positive solution is tedious but an analytic solution can be proven to exist using Mathematica.[37]

Establishing a (0, 0, 6, 0) equilibrium. In a similar fashion the inequalities needed to be satisfied to make (0, 0, 6, 0) an equilibrium are as follows. No player wants to deviate to period 2 when

$$\sum_{i=1}^{5}\min\left\{(1+r')^3,\left(1+\frac{ir^*}{3}\right)^3\right\}\geqslant\sum_{i=1}^{5}\min\left\{(1+r')^2,6\left(1+\frac{ir^*}{3}\right)^2\right\}. \tag{10}$$

No player wants to deviate to period 4 when

$$\sum_{i=1}^{5}\min\left\{(1+r')^3,\left(1+\frac{ir^*}{3}\right)^3\right\}\geqslant\sum_{i=1}^{5}\min\left\{(1+r')^4,V_4^i\right\}, \tag{11}$$

[37] We thank Marina Agranov for here assistance here. For a full description of the procedure generating the solution, see http://homepages.nyu.edu/~as7/Appendix.pdf.

where V_4^i is the money leftover in the ith bank, after 5 players withdrew at $t = 3$:

$$V_4^i = \left(\max\left\{0, \left[6\left(1 + \frac{ir^*}{3}\right)^3 - 5(1 + r')^3\right]\right\}\right)\left(1 + \frac{ir^*}{3}\right). \tag{12}$$

Note that $(0, 0, 6, 0)$ can be sustained as an equilibrium when inequalities (10) and (11) are satisfied simultaneously. These inequalities have similar interpretations to inequalities (7) and (8), respectively. Again, proving that these inequalities have a positive solution is tedious but an analytic solution can be proven to exist using Mathematica. □

A.2. Proof of Corollary 1

Using Mathematica, a numerical solution to these inequalities can be found given any r'. Hence, for $r' = 0.12$ we obtain the solution presented in the corollary. [38] □

A.3. Proof of Proposition 2

The proof follows from the fact that withdrawal vectors in the sequential form (low or high information) offer no information about the fundamentals of the game (i.e. the type of the bank). Take any vector of withdrawals. To test whether this is an equilibrium in the simultaneous and the sequential form, we need to know whether any subject wants to deviate. But the information available to players is identical in both forms of the game, i.e. the best response correspondences are the same. Hence, any deviation that is profitable in one form would be profitable in the other and the equilibria must be identical. □

A.4. Proof of Proposition 3

The proof uses certain domination relationships concerning the payoffs to informed subjects to calculate the minimum expected number of periods money remains in the bank in any conditional equilibrium. Since, from Corollary 1, for $r' = 0.12$, we have "everyone withdraws at $t = 2$" as the unique equilibrium for $r^* \in (0.074, 0.082)$ in the symmetric-information experiment, if the minimum we calculate is greater than 2 periods, we have proven our result.

First, we show that if Bank 3 is chosen, in any conditional equilibrium, no informed subject will withdraw in period 1. To show this assume that a conditional equilibrium did in fact exist where, conditional on Bank 3, all informed subjects move in period 1. In addition, assume that such an equilibrium directs the four uninformed subjects to move in period 2, resulting in a withdrawal vector of $(2, 4, 0, 0)$. In this equilibrium the two informed subjects receive their promised return of $(1 + r')$. However, if either of them decides to deviate and withdraw in period 2, she receives $[\frac{1}{5}[6(1 + r^*) - (1 + r')](1 + r^*)]$ from Bank 3. Hence, this is a profitable deviation as long as $\frac{1}{5}[6(1 + r^*) - (1 + r')](1 + r^*) > (1 + r')$. We can show that this is the case for all $r^* \in (0.074, 0.082)$ when $r' = 0.12$.[39]

Note that informed players will earn even more if the uninformed decide to withdraw later. Therefore, assuming that the uninformed move in period 2, if the informed find it beneficial to deviate, then they will do so under other assumptions. So no conditional equilibrium can have informed subjects withdrawing in period 1 when the bank is Bank 3. Furthermore, if the bank chosen is Bank 5, it is a dominant strategy for the informed subjects to wait until period 4 for all $r^* \in (0.74, 0.82)$. Hence, in any conditional equilibrium, when the bank is Bank 3, the withdrawal period cannot be earlier than period 2 while if it is Bank 5 it is a dominant strategy to wait until period 4.

Given these facts consider the following proposed strategy pair which has the property that, if it were to actually be an equilibrium, it would be the one with the shortest withdrawal time that respects the two properties we have mentioned above.

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[38] A different proof for this Corollary is also provided by the authors in an online appendix to the paper at: http://homepages.nyu.edu/~as7/Appendix.pdf.

[39] In particular, the informed player who deviates to $t = 2$ receives 11.40, which is higher than the promised return of 11.20 of period 1, even for $r^* = 0.074$.

Informed: If Bank 1 or Bank 2, withdraw in period 1. If Bank 3 or Bank 4, withdraw in period 2. If Bank 5, withdraw in period 4.

Uninformed: Do not withdraw in period 1 (since withdrawing in period 1 cannot be part of a conditional strategy). If somebody withdraws in period 1, withdraw in period 2. If somebody withdraws in period 2, withdraw in period 3. Otherwise, withdraw in period 4.

Even in this worst case scenario, money stays in the bank for 2.53 periods, which is longer than the 2 periods in the symmetric-information experiment.[40] □

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[40] The expected time money stays in the bank for each type of bank is given as follows: Bank 1: $(\frac{2(1)+4(2)}{6}) = \frac{5}{3}$; Bank 2: $(\frac{2(1)+4(2)}{6}) = \frac{5}{3}$; Bank 3: $(\frac{2(2)+4(3)}{6}) = \frac{8}{3}$; Bank 4: $(\frac{2(2)+4(3)}{6}) = \frac{8}{3}$; and Bank 5: 4, which gives us an average of 2.53.

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