Bank Runs as Coordination Failures: An Experimental Study[*]

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Abstract

We use experimental methods to investigate what factors contribute to breakdowns in coordination among a bank's depositors. Subjects in our experiment decide whether to leave their money deposited in a bank or withdraw it early; a bank run occurs when there are too many early withdrawals. We explore the effects of adding uncertainty about fundamental withdrawal demand and of changing the number of opportunities subjects have to withdraw. Our results show that (i) bank runs are rare when fundamental withdrawal demand is known but occur frequently when it is stochastic, and (ii) subjects are more likely to withdraw when given multiple opportunities to do so than when presented with a single decision. For the multiple-opportunity case, we evaluate individual withdrawal decisions according to a set of simple cutoff rules. We find that the cutoff rule corresponding to the payoff-dominant equilibrium of the game, which involves Bayesian updating of probabilities, explains subject behavior better than other rules.

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1 Introduction

Bank runs are an important economic phenomenon. They were frequent events in the United States before the mid-1930s and have occurred more recently in a wide range of countries. A widespread run in Argentina, for example, resulted in the temporary closure of the banking system in 2001. The banking system in Russia experienced a partial run in the summer of 2004. The September 2007 run on Northern Rock in the U.K. lead to its rescue by the Bank of England and eventual nationalization. Observers have also described some events in modern financial markets are being fundamentally similar to a run on a bank; the collapse of the U.S. investment bank Bear Stearns in March 2008 is one of several recent examples.

A sizable theoretical literature has attempted to shed light on the underlying cause of these runs. One of the leading explanations that has been offered is that a run results from a coordination failure. The seminal paper of Diamond and Dybvig (1983) showed how the game played by a bank's depositors naturally has multiple equilibria. In one, the level of withdrawal demand is "normal" and depositors only withdraw their funds if they need to. In the other equilibrium, however, all depositors rush to withdraw because they fear the bank will run out of funds. These actions cause the bank to fail, fulfilling the original beliefs. A bank run can then be interpreted as a switch from the good equilibrium to the bad one.[1]

We use experimental methods to test the extent to which breakdowns in coordination can lead to bank runs. Our goal is to determine the plausibility of this explanation in a laboratory setting, as well as to investigate what factors make failures in coordination more or less likely to occur in this context. The subjects in our experiment play the role of depositors in a bank; each chooses between withdrawing her money early and waiting to withdraw. We begin with a pure coordination game in the spirit of Diamond and Dybvig (1983). If everyone waits to withdraw, they will each receive their initial deposit plus a profit. However, if too many subjects withdraw early, the bank will run out of funds and all remaining depositors will receive nothing. The experiment is designed so that the bank can absorb a certain number of early withdrawals before it becomes unable to meet its obligations to the remaining depositors. We then explore variations of the model that involve randomly forcing some subjects to withdraw and changing the number of opportunities subjects

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[1] There is a sizable literature based on the Diamond-Dybvig model. See, for example, Wallace (1988,1990), Cooper and Ross (1998), Green and Lin (2003), Peck and Shell (2003), and Ennis and Keister (2006, 2007). Another explanation of bank runs is based on the release of negative information about the value of the portfolio of an individual bank or of the entire banking system (see, for example, Gorton, 1988, and Saunders and Wilson, 1996). It is unclear which of these explanations is better supported by historical data (see Ennis 2003). Hence, investigating the plausibility of the coordination failure explanation in the laboratory is an important exercise.

have to withdraw.

The possibility that some subjects will be forced to withdraw is intended as a proxy for macroeconomic conditions; in bad times, more depositors need to withdraw funds from their banks, which places a “squeeze” on the amount of liquidity available to meet further withdrawals. Models with a random number of forced withdrawals have been studied extensively in the theoretical literature (see Wallace, 1988, Green and Lin, 2003, and Peck and Shell, 2003). However, the theory does not offer any guidance as to whether or not depositors would behave differently in this situation, since the set of equilibria is qualitatively similar (both a “run” and a “no-run” equilibrium exist) with and without random forced withdrawals. Our interest is in whether the existence of these shocks, which involve aggregate uncertainty, makes coordination failure more likely.

The answer turns out to be tightly linked to our second treatment variable: the number of opportunities subjects have to withdraw. In half of our experimental sessions, subjects played a simultaneous-move coordination game. Each subject decided whether to withdraw early or to wait, and then the game ended and payoffs were assigned. In the other half of the sessions, however, we gave subjects three opportunities to withdraw before the game ended, informing them of the total number of withdrawals after each opportunity. This treatment gave subjects the option of waiting and observing some information about the actions of others and the aggregate shock before making a final decision. The information they received this way was partial, since they were not told if an observed withdrawal was forced or voluntary. It was also not costless, since the bank could run out of funds while they waited if too many other subjects withdrew early. This treatment adds a realistic feature of banking: depositors have a period of time during which they can choose to withdraw their funds, and they are able to observe some information about the actions of other depositors, for example, by noticing if a line is forming outside the bank. They cannot, however, observe the reason why another depositor is withdrawing (whether she “needs” to withdraw or is panicking); motives for withdrawing are private information.

The theory is silent on how both of our treatment variables should affect play, as the set of equilibria is qualitatively similar under any combination of the number of withdrawal opportunities (multiple or single) and the presence or absence of forced withdrawals. However, our empirical findings are unambiguous. In the absence of forced withdrawals, voluntary withdrawals are rare and subjects effectively coordinate on the no-run outcome. Adding forced withdrawals has a positive, but small, initial effect on voluntary withdrawal rates regardless of the number of withdrawal opportunities. Over time, the interaction of forced withdrawals and multiple withdrawal opportunities leads to high withdrawal rates and almost total bank failures, something that does not happen with forced withdrawals alone.

The difference in the occurrence of bank failures across treatments is traced to differences in subjects' reactions to their exposure to bank runs across treatments. With forced withdrawals, some banks runs occur even when voluntary withdrawal rates are low. Occasionally, an unfortunate combination of a high realization of the number of forced withdrawals and, possibly, a few voluntary withdrawals depletes the bank's assets. In the treatment with a single withdrawal opportunity, exposure to such a bank run has a limited effect on future withdrawal behavior. As a result, the total number of bank runs observed over time is low and relatively constant. In the treatment with multiple withdrawal opportunities, on the other hand, exposure to a bank run has a "snowballing" effect that leads to future bank failures. These results show that bank runs are more likely to occur in environments where (i) there is significant uncertainty about fundamental withdrawal demand and (ii) depositors receive information about the behavior of other depositors while there is still time to withdraw.[2]

In order to better understand the forces generating the observed group outcomes in the treatment with multiple withdrawal opportunities, we evaluate individual withdrawal decisions according to various simple cutoff rules. Interestingly, we find that the cutoff rule corresponding to the payoff-dominant equilibrium of the game, which involves Bayesian updating of the probability of a forced withdrawal, outperforms more naive decision rules in explaining observed subject behavior.[3] However, as subjects' beliefs that the payoff dominant equilibrium will be played deteriorate, we naturally see a deterioration of this Bayesian play as well.

The observed deterioration of the payoff dominant equilibrium may be interpreted as a breakdown in trust among the subjects. Previous experimental work suggests that subjects who are put in situations that are similar to our withdrawal game exhibit trust and reciprocity. For instance, Berg, Dickhaut, and Mccabe (1995) find that subjects will invest part of their endowment on their partner's behalf in hopes that he or she will reciprocate and that recipients of these investments

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[2] This finding is loosely connected to the theoretical work of Gale (1995), which studies a dynamic game in which players decide when to make an investment. In Gale's setting, the coordination problem vanishes as the period length shrinks to zero. This resembles our finding that groups experience a lower run frequency in the treatment with a single withdrawal opportunity.

[3] This aspect of the design was meant to capture whether people update their perception of the general well-being of the population in response to positive (or negative) personal shocks. The experiment was designed so that subjects did not need to update perfectly in order to make the correct choice.

often do reciprocate. In our setting, subjects simultaneously play the role of trustor and trustee as they decide whether to invest in the future by not withdrawing today. In not withdrawing, each subject is trusting that the others will do the same. At the same time, the decision not to withdraw can be interpreted as reciprocating for the expected non-withdrawal decisions of their fellow players. As expected from this literature, subjects initially coordinate on the payoff-dominant equilibrium. However, once enough withdrawals are observed, subjects no longer trust that other subjects will not withdrawal and panic sets in. This breakdown in trust is observed only in the treatment with multiple withdrawal opportunities.

While there has been much experimental work on coordination games,[4] we know of only two other studies that have conducted an experimental investigation of bank runs: Schotter and Yorulmazer (2007) and Madies (2006). Although our experimental design differs substantially from both of these studies, our results have elements in common with each of them. Schotter and Yorulmazer (2007) study the factors that affect the severity of a run. In their setup, the bank is assumed to be insolvent and, hence, a run is certain to occur. Their interest is in how quickly resources are taken out of the banking system once a crisis is underway and in how various factors (deposit insurance, asymmetric information, etc.) affect this speed. Our primary focus, in contrast, is on whether or not a run occurs at all and what factors affect the prevalence of runs. Despite this difference in focus, the results share an important theme: both papers demonstrate that subjects play significantly differently when there are multiple opportunities to withdraw funds than when withdrawing is a one-shot decision. These results indicate that the standard approach of modeling bank runs as a one-shot, simultaneous-move game (as in Diamond and Dybvig, 1983, and many others) may not be the most appropriate.

Madies (2006) studies the prevalence of bank runs in a setting where a no-run equilibrium always exists. Among other findings, he shows that bank runs occur less frequently when the bank is more "liquid" in the sense that a larger number of early withdrawals is needed to make the bank insolvent. This relationship is also supported by our results. Beyond this point, however, the papers diverge. Madies (2006) focuses on the effects of partial deposit insurance schemes, while we study the effects of uncertain fundamental withdrawal demand and multiple withdrawal opportunities.

Although we present our analysis in terms of the classic notion of a run on the banking system,

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[4] See, for example, Cooper *et al.* (1990), Van Huyck *et al.* (1990), and the surveys by Ochs (1995) and Cooper (1999).

we believe our results also generate insight into other types of financial crises that have occurred around the world in recent years. Investors in Mexican tesobonos in 1994, for example, were very much like the depositors in a bank. Each chose whether to withdraw her investment (by not rolling it over on the due date of the bond) based on her beliefs about the quality of the investment *and* about what others would choose to do. Investors in the market for auction-rate securities in the U.S. in early 2008 were in a similar position, each deciding whether or not to remain active in the market based on, in large part, on her belief about how many other investors would remain active. Such coordination motives are also thought to have played an important role in the East Asian crisis of 1997-8. We believe, therefore, that the insights gained from the experimental analysis of our simple model can also be helpful for understanding the potential for breakdowns in coordination in modern financial markets.[5]

The rest of the paper is organized as follows. The next section describes the experimental design, including the basic game played by subjects and the different treatments applied. Section 3 explains the theoretical predictions and presents the results for the case where there is a small chance of a bank failure due to forced withdrawals alone. These results include an econometric analysis of treatment effects, as well as a description of how often bank runs occurred in each of the treatments and how the escalation in the frequency of bank runs differed across the treatments. Section 4 provides a classification of individual decisions according to various cutoff rules. Section 5 explains the theoretical predictions and presents the results for the case where there is no chance of a bank failure due to forced withdrawals. Finally, Section 6 contains some concluding remarks.

2 Experimental Design

We devised a computer-controlled experiment in which subjects play multiple rounds of a withdrawal game with varying strategy sets and payoffs. We ran four experimental sessions, each involving 20 subjects who participated in 19 rounds (3 unpaid and 16 paid). In each round, subjects were randomly and anonymously divided into groups of 5 and were required to make withdrawal decisions. Groups were reshuffled after every round. In two of the four sessions, subjects had a single opportunity to withdraw in each round. In the other two sessions, subjects had three withdrawal

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[5] See, for example, Cole and Kehoe (1996) on the Mexican crisis and Krugman (“A Crisis of Faith,” *New York Times*, February 15, 2008) on the auction-rate securities market. See Boyd *et al.* (2006) for a detailed analysis of the available data on modern banking and financial crises.

opportunities per round. Payoffs in each round were specific to the play in that round. At the end of each round, feedback was given to all subjects regarding the withdrawal behavior of other players in their group, as well as their resulting payoffs. Any form of communication between subjects was strictly forbidden.

We begin by describing the treatment involving a single withdrawal opportunity in each round. The instructions for these sessions are provided in Appendix A.

2.1 Single Withdrawal Opportunity

Subjects began each round with one dollar deposited in their group's bank. At the beginning of a round, subjects were shown a chart that described their payoffs from withdrawing or not withdrawing as a function of the total number of withdrawals. This payoff chart is reproduced in the instructions provided in Appendix A. Subjects had 30 seconds to withdraw their dollar. If they did not, it remained deposited. The experiment had two stages corresponding to different payoff specifications. Payoffs in the first stage of the experiment were defined so that the bank was able to absorb 2 withdrawals (*i.e.,* give two people their dollar back) without defaulting on its promise to pay remaining depositors \$1.50. If one or two subjects placed withdrawal requests, they each got their dollar back and the remaining depositors each were paid \$1.50, as promised. If three subjects placed withdrawal requests, they each got their dollar back, but this required liquidating all of the bank's assets, and hence remaining depositors received nothing. If more than three subjects put in withdrawal requests, the bank's assets were completely liquidated (at a rate of \$0.60 on the dollar) and all requesters were given equal share. Again, any depositors who had not placed a withdrawal request received nothing.

Stage 1 began with four rounds (2 unpaid and 2 paid) without forced withdrawals. These rounds were conducted to (i) familiarize subjects with the simpler game before complicating it with forced withdrawals, and (ii) establish that subjects would play the payoff-dominant equilibrium of this game in the absence of forced withdrawals.[6] We then conducted eight rounds with random forced withdrawals. In these rounds, the computer first randomly selected the number of forced withdrawals, and then randomly chose that number of subjects and submitted a withdrawal request on their behalf.[7] The probability distribution over forced withdrawals in stage 1 was chosen so that

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[6] We believed that two unpaid trials followed by two paid trials would be enough to achieve these goals and, as we describe below, this was indeed the case.

[7] As mentioned in the introduction, these random forced withdrawals correspond to the liquidity-preference shocks

there was a small probability that forced withdrawals would cause the bank to fail. In particular, there was a 1/8 probability of zero forced withdrawals, a 3/8 probability of one forced withdrawal, a 3/8 probability of two forced withdrawals, and a 1/8 probability of three forced withdrawals. Subjects were made aware of the forced withdrawal probabilities. At the end of each round, subjects were told the number of withdrawals in their group, but not whether withdrawals by others were forced or voluntary.

After stage 1 was completed, we conducted a second stage using payoffs that allowed the bank to absorb 3 withdrawals without defaulting on its obligations to the remaining depositors. This was done by setting the liquidation rate at $0.80, so that each withdrawal caused a smaller reduction in the bank's assets. We conducted 3 rounds (1 unpaid and 2 paid) with the new payoffs without forced withdrawals. Then we conducted 4 paid rounds with forced withdrawals, using the same withdrawal probabilities as in the first stage. Subjects were aware that the forced withdrawal probabilities were the same as in stage 1. Hence, subjects knew that in stage 2 there was *no* chance that forced withdrawals alone would cause the bank to fail.

2.2 Three Withdrawal Opportunities

The other two sessions followed the same treatment plan described above, but subjects had three opportunities to withdraw their $1 within each round. (Instructions are provided in Appendix B.). Withdrawal requests in each opportunity were treated equally: subjects got their dollar back, or if there was not enough money to do this at the specified liquidation rate, they equally shared the liquidated value of the bank's assets. Any funds not liquidated during a withdrawal opportunity were used to meet withdrawal requests in subsequent opportunities and to pay remaining depositors at the end of the round. Payoffs thus followed a quasi-sequential service rule: within each opportunity requesters were treated identically, but across opportunities depositors who requested to withdraw first were served first.

After each withdrawal opportunity, subjects were shown a screen that told them the total number of withdrawals in their group. In rounds with forced withdrawals, they were not told whether the withdrawals that occurred were forced or not. Subjects were also told how much each withdrawing subject received and the projected payment to remaining depositors. At the end of the

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commonly used in the theoretical literature on bank runs. In particular, our sessions with forced withdrawals correspond to the case of *aggregate* uncertainty about liquidity demand, as studied in Section IV of Diamond and Dybvig (1983) and in Wallace (1988, 1990), Peck and Shell (2003), and others.

final opportunity, subjects received information on their group's outcome for that round, i.e., how many people withdrew, the payoff to withdrawers, the payoff to remaining depositors, and a report of their cumulative individual earnings.

Once a player withdrew, she had no more decisions to make in that round. Such players were still updated on the outcome of their own group at the end of each opportunity. If members of a group made sufficient withdrawals to bankrupt the bank, all members of that group were informed that the bank was out of money and told to wait until the beginning of the next round.

Forced withdrawals occurred over the three withdrawal opportunities. In particular, there was a 1/2 probability that one subject would be forced to withdraw and a 1/2 probability that no one would be forced to withdraw in *each opportunity*.[8] This setup was explained to the subjects before the rounds with forced withdrawals began. The probabilities were chosen so that the cumulative distribution of forced withdrawals over the course of a round is the same in the sessions with a single withdrawal opportunity, which facilitates a meaningful comparison across treatments.

2.3 Participation and Earnings Summary

Eighty undergraduate students from the University of California, Los Angeles participated in the four sessions of the experiment. In addition to their earnings in the experiment, players received a \$5.00 show-up fee. Total earnings were \$517.00 and \$495.00 for sessions 1 and 2, respectively, of the treatment with a single withdrawal opportunity and \$478.75 and \$445.00 for sessions 1 and 2 of the treatment with three withdrawal opportunities. The gap between the highest and lowest payoff was between \$3.25 and \$5.00 in each session.

All sessions were conducted in the California Social Science Experimental Laboratory (CASSEL) at UCLA. Players were individually seated in the CASSEL, which consists of 60 networked computer workstations in separate cubicles. Each cubicle contains a computer monitor, keyboard, mouse, and a set of written instructions. The supervisor read the instructions and answered questions to ensure that everyone understood the operation of the computers, game design, and payoff function. Very few questions were asked.

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[8] Note that because the number of forced withdrawals is independent across opportunities, the observed number of withdrawals in one opportunity contains no information about the number of future forced withdrawals. See Chari and Jagannathan (1988) and Jacklin and Bhattacharya (1988) for models where observed withdrawals do potentially contain information about the state of the nature, which in their models is the (random) return on the bank's assets.

3 Low Risk of Bank Failure from Forced Withdrawals

In this section we examine the first stage of each session, where the parameter values are set so that the bank can absorb two withdrawals without defaulting on its obligations to the remaining depositors. When forced withdrawals are added to this stage, there is a small chance that the forced withdrawals alone will cause the bank to fail. We first provide a brief analysis of equilibrium in this game under each treatment scenario: with single or multiple withdrawal opportunities and in the presence or absence of forced withdrawals. We then present the experimental results.

3.1 Equilibrium Analysis

A. No Forced Withdrawals. We begin by looking at the scenario with no forced withdrawals and a single withdrawal opportunity. In this game, each player simply decides whether or not to withdraw her funds. We can write the strategy set of a player as $\{W, N\}$, where W denotes the action "withdraw" and N the action "not withdraw." This game corresponds closely to the standard bank-runs model studied by Diamond and Dybvig (1983) and many others. As in the existing literature, there are exactly two pure-strategy Nash equilibria of this game. All players choose N in the payoff-dominant equilibrium, and all players choose W in the "banking panic" equilibrium.

When there are three withdrawal opportunities, the strategy set of a player is more complex because, in each opportunity, her action can depend on the history of withdrawals to that point. Let a_j denote the (cumulative) number of withdrawal requests submitted through opportunity j, where $j = I$ or II. Let $A = \{0, 1, 2\}$ denote the set of possible values for a_j. (Recall that, for the payoffs used here, the game ends once there are 3 or more withdrawal requests.) A strategy for a player is then a 3-tuple (s_I, s_{II}, s_{III}), where

$$s_I \in \{W, N\} \text{ and } s_{II}, s_{III} : A \to \{W, N\}. \tag{1}$$

We consider only pure-strategy, subgame-perfect equilibria.

With no forced withdrawals, the set of equilibria is qualitatively the same as in the single-opportunity case. There is a payoff-dominant equilibrium in which no player withdraws; the strategy profile associated with this equilibrium is $s_I = N$, $s_{II}(a_I) = N$ if and only if $a_I \leq 2$, and $s_{III}(a_{II}) = N$ if and only if $a_{II} \leq 2$. To verify this, consider first the decision faced by a player in withdrawal opportunity III. This opportunity is only reached if the number of previous withdrawals is less than 3. In any such subgame (i.e., for any $a_{II} \leq 2$), if a player believes that all other players will follow the strategy above and not withdraw, her payoff will be \$1.00 if she withdraws and \$1.50 if she waits. Hence her optimal strategy will be to also follow the strategy above and not withdraw. Working backward, the same reasoning applies to each of the first two withdrawal opportunities; thus, the strategy profile is indeed an equilibrium.[9]

There is also a panic equilibrium in which all players withdraw in the first opportunity. Notice that this is the only panic equilibrium. There cannot, for example, be an equilibrium where players do not withdraw in the first opportunity, but then do withdraw in the second or third opportunity. Suppose a player expects everyone else to withdraw in one of the later opportunities. If she waits and withdraws at the same time as the others, she will receive her share of the liquidated assets (\$0.60). If she instead withdraws in the first opportunity, her request will be the only one received at that point and she will receive \$1.00. In general, if a player expects the bank to run out of funds, she would like to withdraw before the other players do. The only panic equilibrium, therefore, must have all players withdrawing in the first opportunity.

B. Forced Withdrawals. When there is a single withdrawal opportunity, the addition of forced withdrawals does not change the set of equilibria under our baseline parameter values. It is once again the case that there are exactly two pure-strategy equilibria: a payoff-dominant equilibrium in which no player voluntarily withdraws and a panic equilibrium in which all players withdraw.

In the scenario with three withdrawal opportunities, on the other hand, the presence of forced withdrawals complicates the game in interesting ways. Withdrawals may now occur in equilibrium even if no players are voluntarily withdrawing and, as a result, more decision nodes will lie on the equilibrium path of play. In addition, a player must take into account the fact that she may be forced to withdraw in some later opportunity, which affects the expected payoff from not withdrawing in the current opportunity. These effects make the analysis of equilibrium more complex.

There is again a payoff-dominant equilibrium in which no player voluntarily withdraws. The strategy profile in this equilibrium is different from that in the case with no forced withdrawals; it

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[9] There are other, payoff-equivalent equilibrium strategies that differ from the one described here only at nodes that lie off the equilibrium path. One example is $s_I = N$, $s_{II}(a_I) = N$ iff $a_I \leq 1$, and $s_{III}(a_{II}) = N$ iff $a_{II} \leq 1$. In this strategy profile, players "panic" and all withdraw if they observe a withdrawal in the previous opportunity. Since no withdrawals occur equilibrium, this profile leads to the same equilibrium payoffs as the profile listed above. However, at the individual level, behavior is clearly different under the two strategies. When studying payoff-dominant equilibria, we focus on the "minimal panic" strategy profile where players do not withdraw unless doing so is a dominant strategy.

is now $s_I = N$, $s_{II}(a_I) = N$ if and only if $a_I \leq 1$, and $s_{III}(a_{II}) = N$ if and only if $a_{II} \leq 2$. Notice that players now have a lower panic threshold for observed withdrawals going into the second opportunity because they know that additional, forced withdrawals may occur. However, since at most one forced withdrawal occurs in each opportunity, voluntary withdrawals will never be observed in equilibrium when players follow this strategy.

To verify that this strategy profile is an equilibrium, consider first the decision facing a player in withdrawal opportunity III. Recall that this opportunity is only reached if the number of previous withdrawals is less than 3. A player who has not been forced to withdraw must calculate the probability that one of the other players has been forced to withdraw in this opportunity. Suppose there are k remaining depositors after opportunity II. Then the probability that player i should assign to a forced withdrawal having occurred in opportunity III, conditional on her not being forced to withdraw, is

$$\text{Prob[forced withdrawal = yes} \mid \text{player } i \text{ forced = no]} = \frac{k-1}{2k-1}. \tag{2}$$

This probability decreases from 4/9 to 1/3 as k ranges from 5 to 2. Importantly, the probability a player should assign to a forced withdrawal having occurred, conditional on not having been forced to withdraw, is always strictly lower than the unconditional probability of one-half. Given the appropriate conditional probability, the expected payoff from waiting in opportunity III – under the belief that no one else will voluntarily withdraw – is greater than the expected payoff to withdrawing in each of the possibilities. This is confirmed in Appendix C, which shows payoffs and optimal actions under each withdrawal scenario.[10] Hence in the opportunity-III subgame, there is always an equilibrium where no player voluntarily withdraws.

Next, consider opportunity II and suppose $a_I = 2$ holds. In this case, the likelihood that one of the other players has been forced to withdraw in the current opportunity (again calculated using (2)) combined with the prospect of a future forced withdrawal in the final opportunity makes withdrawing the optimal action. If, on the other hand, $a_I = 1$ (or 0), then despite considerations of forced withdrawals, it is optimal to not withdraw if one believes there will be no voluntary withdrawals. Turning to the first withdrawal opportunity, similar calculations show that a player who expects all others to follow the strategy given above will choose to not withdraw. As a result, the

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[10] The subjects were not shown anything like the table in Appendix C. During each withdrawal opportunity subjects saw only the relevant, updated payoff tables (see the instructions in Appendices A and B).

strategy profile listed above is a subgame perfect equilibrium of the game with forced withdrawals. The calculations for each decision node are presented in Appendix C.

There is also a panic equilibrium in which all players withdraw in opportunity I. As in the previous scenarios, this follows from the fact that withdrawal requests from all but one player will cause the bank to run out of funds, leaving nothing for a player who did not withdraw. The game with multiple withdrawal opportunities and forced withdrawals may also have other, "conditional panic" equilibria. For example, under our baseline parameter values the following strategy is also a subgame perfect equilibrium: $s_I = N$, $s_{II}(a_I) = N$ if and only if $a_I = 0$, and $s_{III}(a_{II}) = N$ if and only if $a_{II} \leq 1$. Under this strategy, players "panic" and withdraw in the second opportunity if they observe any withdrawals in the first opportunity. Notice that while this strategy is of the same general form as the one associated with the payoff-dominant equilibrium, it is not payoff-equivalent because voluntary withdrawals will occur along the equilibrium path of play (whenever a forced withdrawal is realized in the first opportunity).

In our analysis of subject behavior below, we focus primarily on the two most "natural" outcomes of the game: the payoff-dominant equilibrium and the banking panic equilibrium. In the remainder of this section, we discuss the extent to which observed group behavior is consistent with these equilibria, and we analyze the determinants of individual withdrawal decisions. In Section 4, we broaden the scope of the analysis by comparing individual subject behavior with three simple cutoff rules. These rules are chosen to correspond to the strategies in the payoff-dominant equilibrium, the panic equilibrium, and the conditional panic equilibrium described above.

3.2 Observed Behavior

A. No Forced Withdrawals. In the rounds with no forced withdrawals, we observed the payoff-dominant Nash equilibrium in 16 out of 16 games in the sessions with a single withdrawal opportunity. In the sessions with 3 withdrawal opportunities the payoff-dominant subgame-perfect equilibrium occurred in only 8 out of 16 games, however 72 out of 80 subjects (90 percent) played strategies consistent with the payoff dominant equilibrium.[11] Hence, while having multiple withdrawal opportunities appears to increase withdrawal rates in the absence of forced withdrawals, none of the banks in which withdrawals occurred defaulted on the promise to pay $1.50 to remaining depositors. In other words, there were no observed bank runs in either treatment.

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[11] All 8 withdrawals occured in different groups.

B. Forced Withdrawals. In the first round with forced withdrawals, there was no significant numerical difference between the withdrawal rates in the treatment with a single withdrawal opportunity and that in the first opportunity of the treatment with three withdrawal opportunities. The frequencies of voluntary withdrawals were 2 out of 29 in the former and 1 out of 36 in the latter. There was, however, a meaningful difference in these withdrawal rates over the subsequent rounds. In particular, the voluntary withdrawal rate (the number of voluntary withdrawals divided by the number of subjects who were not forced to withdraw) rose significantly more quickly over time in the treatment with multiple withdrawal opportunities.

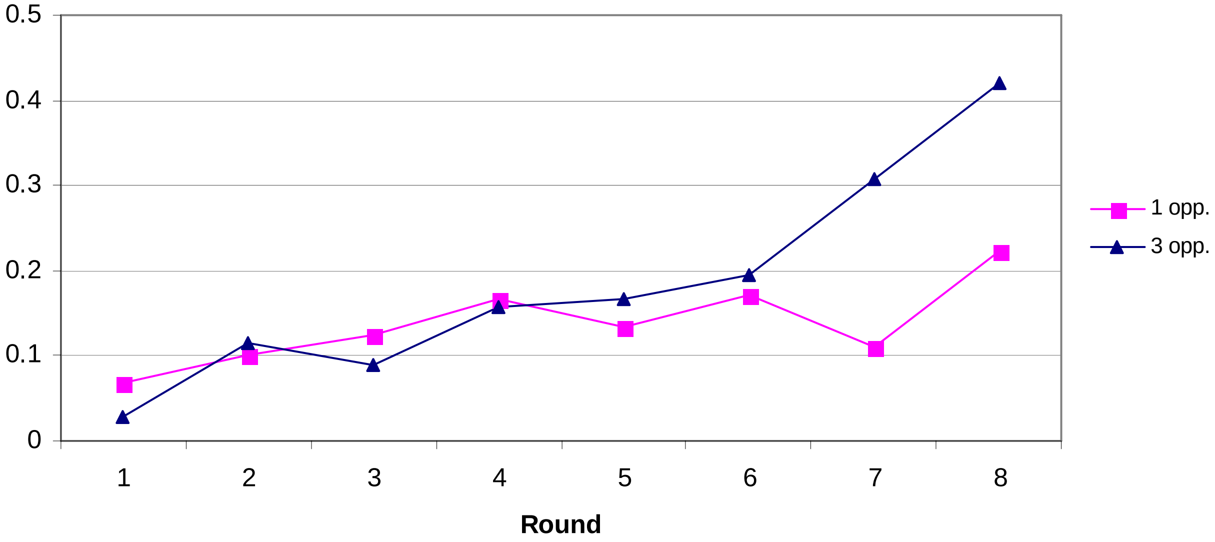

Figure 1: Panic equilibrium strategies; Low risk case; 8 rounds with forced withdrawals.

Figure 1 shows the percentage of observed actions that were consistent with the panic equilibrium strategy in each round for each of the treatments. The differences in the slope of the trend lines for these two series is significant at the 95% level. However, we do not draw any conclusions from this observation alone. The tendency for some subjects to become more panicky over the course of the experiment might be influenced by their own personal history: how often they see others withdrawing and how many bank runs they observe. This personal history shapes their posterior view of how many players in the population are likely to withdraw, and the distribution of personal histories is unique to each experimental session. Even though the parameters are the same across sessions, variability in the outcomes of random forced withdrawals and random matching will produce different individual histories even for identical voluntary withdrawal rates. Hence, it is necessary to control for differences in personal histories before reaching conclusions on how the learning effect on voluntary withdrawal rates compares across treatments.

Ideally, we would compare groups of individuals with identical histories across treatments, but this requires more data than we are able to obtain. Our approach is instead to construct a summary statistic that reflects an individual's history with respect to exposure to bank runs. The variable, called "History," is defined as the fraction of previous rounds in which the subject witnessed a bank run. We want to allow for the possibility that subjects' interpretation of the History variable differs over time; in later trials, the value of History contains more information about the withdrawal tendencies of the population. Hence, in the regression analysis that follows we interact the history variable with a variable measuring the round in which the decision was made.[12]

Table 1 shows the marginal effects from a Probit regression designed to test the null hypothesis that, controlling for differences in personal histories, there is no difference in withdrawal behavior across the two treatments. The dependent variable, "Withdraw," is equal to 1 if the subject voluntarily withdrew at the first opportunity and 0 otherwise. "Round" is a discrete variable that counts up from 1 to 7.[13] "Treat" is a dummy variable that equals 0 for the treatment with a single withdrawal opportunity and 1 for the treatment with three withdrawal opportunities. Our null hypothesis can be formulated as the restriction that the underlying coefficients on all variables involving the treatment dummy are jointly zero. The likelihood ratio test rejects this hypothesis at a 1% level.[14] Hence, we conclude that withdrawal behavior, conditional on personal histories, is significantly different in the two treatments.

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[12] There are, of course, other ways that one could construct the history variable. We would like to emphasize that we did not experiment with alternative specifications of this variable and, hence, the reported significance levels are valid.

[13] The values 1 through 7 for the Round variable correspond to rounds 2 through 8 with forced withdrawals in the experiment. The first round with forced withdrawals is not included since the history variable is not defined.

[14] The test statistic, which has a chi-square distribution with 4 degress of freedom, is 20.92. The probability of a draw at least this large under the null hypothesis is 0.0003.

Variable	Coeffecient	Std. Err.	$\partial F/\partial x$	$\overline{x}$
Round	-0.1481	0.0929	-0.0278	4.03
History	-1.7219	1.0783	-0.3235	0.37
Treat[†]	-3.1158**	1.0299	-0.6983	0.57
Treat * Round	0.5062*	0.2101	0.0951	2.30
Treat * History	5.4367**	1.5855	1.0214	0.25
History * Round	0.6628*	0.2642	0.1245	1.68
Treat * History * Round	-0.8987*	0.3550	-0.1688	1.15
obs. P	.183		Number of obs:	453
pred. P	.110 (at x-bar)		Pseudo R^2:	.192

* and ** represent significance at the 5% and 1% level, respectively

[†] $\partial F/\partial x$ is for discrete change of dummy variable from 0 to 1

Table I: Results of Probit analysis.

To better understand how behavior differs across treatments, we can look in more detail at how the Round and History variables impact the predicted probability of withdrawal. Due to the interaction terms in the regression, measuring each of these effects involves combining several different terms from the Table I. These overall effects are summarized in Table II, which presents the estimated total marginal effect of an increase in each variable on the probability of withdrawal for each of the treatments, in all cases evaluated at the mean of the independent variables. The table also presents, for each variable, the likelihood ratio test of the null hypothesis that the effect is the same for the two treatments. The table shows that an increase in either variable tends to increase subjects' propensity to withdraw. In both cases, the effect is stronger in the treatment with three withdrawal opportunities and these differences are statistically significant.

Variable	Treatment		χ^2	prob $> \chi^2$
	0	1		
Round	0.019	0.051	7.54	0.0230
History	0.178	0.519	18.21	0.0001

Table II: Total Effects of History and Round Variables.

3.3 Bank Run Analysis

We now turn to an analysis of group-level outcomes, focusing on the frequency of bank runs. A bank run is defined to have occurred if the bank liquidates all of its assets before the end of a round. No runs occurred without forced withdrawals. Bank runs occurred regularly with forced withdrawals, even though there was only 1/8 probability that forced withdrawals alone would cause the bank to fail. Figure 2 shows bank run frequencies (out of 8 groups) that occurred in each round of each treatment with forced withdrawals. It is apparent from the figure that frequencies of bank runs rose much more quickly in the treatment with 3 withdrawal opportunities than the treatment with 1 withdrawal opportunity, despite similar occurrences of bank runs in the early rounds.

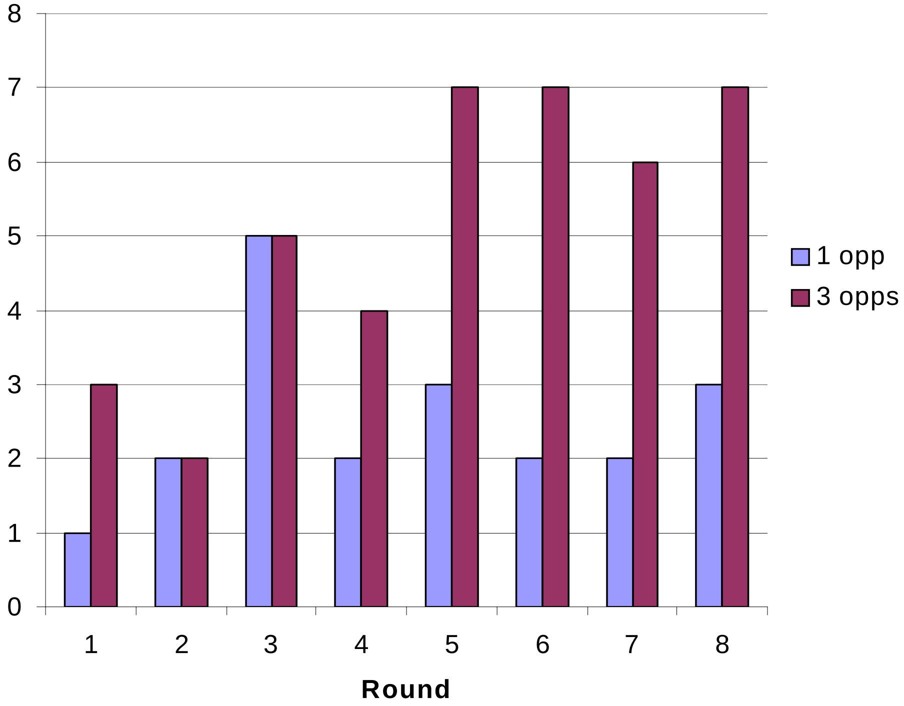

Figure 2: Bank run frequencies for each treatment, 8 rounds with forced withdrawals.

The explanation for this pattern was revealed by the Probit analysis above. While early-round exposure to bank runs was similar across the two treatments, subjects reacted more strongly to exposure to bank runs in the treatment with multiple withdrawal opportunities (see Table II). As a result, bank runs had a more significant "snowballing" effect on withdrawal rates in the treatment with multiple opportunities. Subjects experiencing a run in this treatment were more likely to withdraw in the next round. This behavior made it more likely that they (and others) would experience a run in the next round, which, in turn, made them even more likely to withdraw in the following round. The pattern in Figure 2 shows a significant snowballing effect for the treatment with multiple withdrawal opportunities, but not for the treatment with a single withdrawal opportunity.

4 Evidence of Cutoff Rules with 3 Withdrawal Opportunities

When designing the experiment, we conjectured that subjects in the treatment with three withdrawal opportunities would follow simple cutoff rules for determining their withdrawal decisions. The simplest such rule would be to withdraw if and only if a certain number of withdrawals have occurred in the previous opportunities. A slightly more elaborate (or "variable") cutoff rule would factor in the timing of the withdrawal decision. Since the possible number of future forced withdrawals is greater in the earlier opportunities, one might expect cutoff rules of the form: do not withdraw in opportunity I, withdraw in opportunity II if and only if Y or more withdrawals occur in opportunity I, and withdraw in opportunity III if and only if $Y+1$ or more withdrawals occur in opportunities I and II. The strategy corresponding to the payoff-dominant equilibrium under stage 1 payoffs is of this type with $Y = 2$. We now examine the extent to which observed subject behavior in stage 1 was consistent with two variable cutoff rules, $Y = 1$ and $Y = 2$, as well as with the panic strategy of withdrawing in opportunity I.[15]

Interestingly, if a subject were to fail to update her belief regarding the probability of a forced withdrawal when she was not forced to withdraw (i.e., she continued to assign probability 0.5 to this event instead of using (2)), then she would perceive the panic rule to be a (weakly) dominant strategy and hence we might expect this subject to withdraw in the first opportunity. Why does failure to do Bayesian updating of this probability have such a big effect on the perceived optimal strategy of the subjects? The reason is that it changes the decision the subject makes in opportunity III if she observes two past withdrawals and believes there will be no voluntary withdrawals. In this situation, the subject realizes that one more forced withdrawal will bankrupt the bank. Hence, if she does not withdraw she will receive zero if there is a forced withdrawal and \$1.50 if there is no forced withdrawal. She also realizes that if she withdraws, she will receive \$1.00 if there is no forced withdrawal and \$0.50 if there is a forced withdrawal. Given a chance to make a decision, a Bayesian player observes that she, herself, has not been forced to withdraw and, using equation (2), calculates the probability that one of the other players has been forced to withdraw to be 0.4. Under the belief that others will not withdraw, the expected payoff to not withdrawing is therefore $0.6 * (\$1.50) + 0.4 * (\$0) = \$0.90$, which is greater than the expected payoff to withdrawing of $0.6 * (\$1.00) + 0.4 * (\$0.50) = \$0.80$. Hence she chooses to not withdraw.

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[15] Note that an individual's observed choices can be consistent with more than one rule, depending on the actual decisions she faced, hence reported frequencies within sessions will exceed the total number of subjects.

A non-Bayesian player, however, regards the probability of a forced withdrawal having occurred to be 0.5 and hence calculates the expected payoff to not withdrawing as being lower than a Bayesian would. In fact, her (perceived) expected payoff to not withdrawing is the same as her (perceived) expected payoff to withdrawing; both are $\$0.75$. It is thus a (weakly) dominant strategy for her to withdraw. Moreover, we might expect her to do so because the payoff from withdrawing has a lower variance. This decision feeds back to opportunity II and changes her decision under $n_I = 1$ to withdraw, which in turn implies that in opportunity I she prefers to withdraw. Hence, in the absence of Bayesian updating, a player might be expected to follow the panic rule.

This logic illustrates that subjects will be more inclined to withdraw if they do not recognize that their own forced-withdrawal outcome provides information on the outcome of others. In fact, as we demonstrate below, subjects did not tend to withdraw in the situations described above. Behavior, especially in the later withdrawal opportunities, was more consistent with the Bayesian story. Notice that a player did not need to correctly calculate the posterior probability in order to realize that withdrawing immediately is not a dominant strategy. The payoffs were designed so that she only needed to realize that the posterior probability was strictly less than the prior probability of one-half.

We begin by analyzing the data from the first rounds with forced withdrawals. Table III shows frequencies of observed play for the cutoff rules $Y = 2$ (payoff-dominant equilibrium) and $Y = 1$ (conditional panic equilibrium), as well as for the panic strategy. The number of observed strategies in each session is less than 20 (the number of subjects) because of forced withdrawals in the first opportunity. A subject's actions are classified as being consistent with a particular rule if the subject obeys that rule in each decision she faces. Subjects who are forced to withdraw after the first opportunity are classified according to their observed actions prior to that point. The table shows that the cutoff rule from the payoff-dominant equilibrium $(Y = 2)$ is superior to the others in terms of frequencies.

	$Y = 2$	$Y = 1$	Panic	Obs.
Session 1	14 (77.8%)	9 (50.0%)	0 (0.0%)	18
Session 2	14 (77.8%)	9 (50.0%)	1 (5.6%)	18
Combined	28 (77.8%)	18 (50.0%)	1 (2.8%)	36

Table III: Cutoff rule frequencies, first round with forced withdrawals

This result is also evident in the data from the later rounds. Figure 3 shows the cutoff-rule frequencies for the combined sessions for the eight rounds with forced withdrawals.[16] The figure reveals two things. First, it shows that the superiority of the $Y = 2$ cutoff rule is not limited to the first round. Second, it shows that "learning" matters in the experiment, in the sense that the fraction of "panicky" subjects (i.e., subjects who withdrew immediately) increased substantially over time. In fact, this increase almost fully explains the deterioration of the other two rules; most of the drop in subjects following $Y = 1$ and $Y = 2$ can be attributed to subjects changing their withdrawal decision in opportunity I.

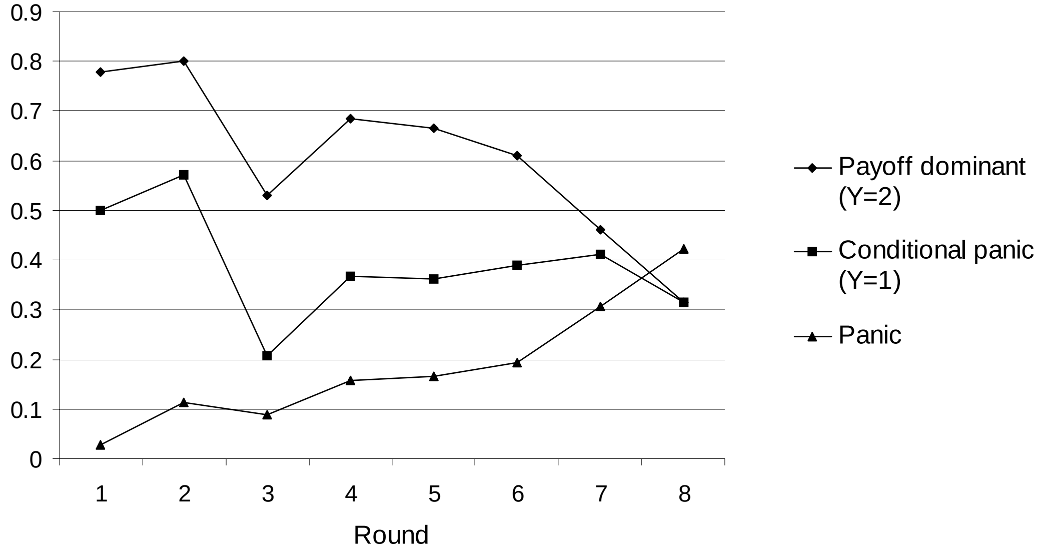

Figure 3: Cutoff rule frequencies, Rounds 1-8 with forced withdrawals.

In order to understand why the $Y = 2$ rule is superior to the $Y = 1$ rule for explaining subject behavior, we must examine the differences in observed behavior at the two instances where these rules differ: in opportunity II with $n_I = 1$ (83 occurrences) and opportunity III with $n_{II} = 2$ (48 occurrences). The $Y = 1$ rule predicts that subjects will withdraw in both these cases, while the $Y = 2$ rule predicts that they will not. In fact, subjects withdrew in these cases only 12% and 27.1% of the time, respectively. Hence, subjects who make it through the first withdrawal opportunity tended not to withdraw as predicted by the $Y = 1$ rule.

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[16] The graph shows pooled data from the two sessions for each trial. The decision to pool the data is justified on the grounds that there is no statistically significant difference (at the 95% level) in the linear relationship between each data set. We wish to point out, however, that visually it appears that the proportion of panicky subjects rose more quickly in session 2 than in session 1.

5 No Risk of Bank Failures from Forced Withdrawals

We now examine the second stage of each session, where the bank can withstand three withdrawals without defaulting on its obligations to the remaining depositors. In this case, an individual depositor will lose money by not withdrawing only if *all* of the other depositors withdraw. This change qualitatively affects the impact of forced withdrawals. In stage 1, there was a 1/8 probability that forced withdrawals alone would cause the bank to fail, leaving all remaining depositors with nothing. Here, there is *no* chance that the bank will fail if there are no voluntary withdrawals. The bank can now meet up to four early withdrawal requests with full payment to the withdrawers.

Overall withdrawal rates were substantially lower in the second stage than in the first, meaning that there is less variation in individual behavior both within and across treatments. Moreover, we ran fewer rounds in the second stage, in part because the lower withdrawal rate made each round more expensive to run. As a result, our results in this section are not as precise as those in Section 3. Nevertheless, as we describe below, the results are revealing and are entirely consistent with those for the first stage.

5.1 Equilibrium Analysis

The set of equilibria of the model is largely unaffected by the change from stage 1 to state 2 payoffs. There are, however, some changes in the details of the strategy profile corresponding to the payoff-dominant equilibrium. Because of the broad similarities with the analysis of equilibrium in Section 3.1, we keep our discussion here brief.

A. No Forced Withdrawals. With a single withdrawal opportunity, there continue to be two exactly two pure-strategy Nash equilibria: a payoff dominant equilibrium in which all players choose N and a panic equilibrium in which all player choose W. The only change in this case is that the payoff players receive in the panic equilibrium is slightly higher.

In the treatment with three withdrawal opportunities, the strategy space is slightly larger than before because the game no longer ends when there are three withdrawal requests. A player's strategy set is still given by (1), but the set A is now equal to $\{0, 1, 2, 3\}$. There is again a payoff-dominant subgame-perfect equilibrium in which no player withdraws; the complete strategy corresponding to this equilibrium is $s_I = N$, $s_{II}(a_I) = N$ if $a_I \leq 3$, and $s_{III}(a_{II}) = N$ if $a_{II} \leq 3$. There is also a panic equilibrium in which all players withdraw in the first opportunity. As in the earlier case, these are the only pure-strategy subgame-perfect equilibria when there are no forced withdrawals.

B. Forced Withdrawals. With forced withdrawals and a single withdrawal opportunity, the change in payoffs again has no effect on the set of equilibria. There continue to be exactly two pure-strategy equilibria: a payoff-dominant equilibrium in which no player voluntarily withdraws and a panic equilibrium in which all players withdraw.

When there are three withdrawal opportunities, the change in payoffs leads players to have a higher panic threshold in the payoff-dominant equilibrium. The strategy profile in this equilibrium is now given by $s_I = N$, $s_{II}(a_I) = N$ if $a_I \leq 2$, and $s_{III}(a_{II}) = N$ if $a_{II} \leq 3$, which corresponds to the $Y = 3$ variable cutoff rule. The calculations demonstrating that this strategy profile is indeed a subgame-perfect equilibrium are presented in Appendix D. There is also a panic equilibrium in which everyone withdraws at the first opportunity.

5.2 Observed Behavior

A. No Forced Withdrawals. There were very few voluntary withdrawals in either treatment. The payoff dominant equilibrium was observed in 15 out of 16 games in the treatment with a single withdrawal opportunity (there was one withdrawal in the opening round of session 2). It was observed in 12 out of 16 games in the treatment with 3 withdrawal opportunities, and 76 out of 80 subjects (95 percent) played strategies consistent with the payoff dominant equilibrium. As in the first stage, having multiple withdrawal opportunities has a positive effect on withdrawal rates in the absence of forced withdrawals, but the difference is not significant. None of the banks in which withdrawals occurred defaulted on the promise to pay $1.50 to remaining depositors. Hence there were no observed instances of bank failures going into the rounds with forced withdrawals.

B. Forced Withdrawals.

Voluntary withdrawal rates were low in both treatments and there was no significant variation across rounds in subjects' tendency to play strategies consistent with one equilibrium or the other. The lower two lines in Figure 4 compare the voluntary withdrawal rate in sessions with a single withdrawal opportunity to that in the first opportunity of the sessions with three withdrawal opportunities. The rates in the figure represent the percentage of subjects whose play was consistent with the panic equilibrium in each of these treatments.[17] With multiple withdrawal opportunities, addi-

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[17] The percentages are based on the number of subjects that were eligible to withdraw in each round (i.e., were not forced). The actual frequencies are 2 of 26, 4 of 30, 3 of 31 and 2 of 30 for the case of 1 opportunity and 2 of 38, 1 of 37, 2 of 39, and 3 of 34 for the case of 3 opportunities.

tional voluntary withdrawals occurred after the first opportunity. However, these withdrawals were, for the most part, consistent with the payoff-dominant equilibrium strategy, which is the cutoff rule $Y = 3$. The top line in Figure 4 shows that the vast majority of play in the multiple-opportunity case was indeed consistent with the $Y = 3$ rule.

A single bank run occurred in the sessions with one withdrawal opportunity, while two bank runs occurred in the sessions with multiple withdrawal opportunities. Keeping in mind the small sample sizes, we interpret these results as follows. First, bank runs do occur in the presence of forced withdrawals, even when there is no chance that these withdrawals alone will exhaust the bank's funds. Second, the data are at least consistent with the results from Section 3, which showed bank runs to be more likely in the case of multiple withdrawal opportunities.

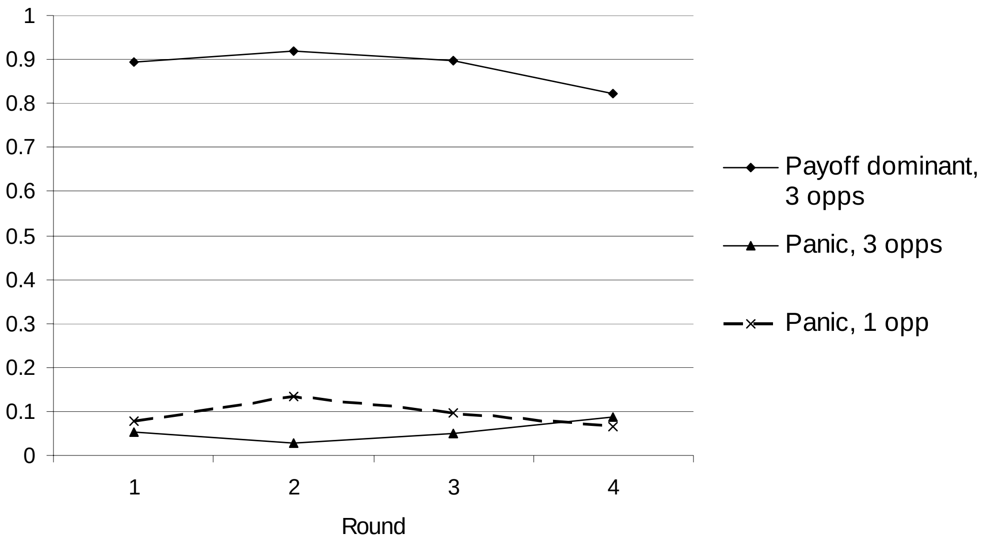

Figure 4: Equilibrium strategies; No risk case.

6 Conclusions

Our experiment and the analysis of the resulting data generate several key insights into breakdowns in coordination and the occurrence of bank runs. First, there is strong evidence that the ability of people to coordinate on the payoff-dominant equilibrium is sensitive to the presence of aggregate uncertainty about fundamental withdrawal demand, even when this uncertainty alone poses little or no threat to the solvency of the bank. The random forced withdrawals in our model mimic the type of uncertainty that is likely to be present under unfavorable macroeconomic conditions or in times of financial distress. Of course, some caution is required in extrapolating these results to consumer behavior during financial crises. The repeated play aspect of the experiment is somewhat artificial, and this is where the strongest treatment effect was observed. Nevertheless, the finding that individuals coordinate on the payoff-dominant equilibrium less frequently in the presence of aggregate uncertainty is interesting and potentially important.

Second, it matters whether subjects are given multiple opportunities to withdraw (with feedback) or a single opportunity. Initially, subjects were equally likely to withdraw at the first opportunity in both treatments, but exposure to bank runs had a greater (positive) effect on future withdrawals in the treatment with multiple withdrawal opportunities. This result indicates that the standard approach of modelling bank runs using a one-shot, simultaneous-move game may not be the most appropriate one. Moreover, the results suggest that in countries where people have a history of exposure to financial crises, withdrawal behavior might depend on the system in place for providing withdrawal opportunities and on the informational flow regarding the withdrawal activity of others.

Finally, the analysis of withdrawal behavior in the treatment with multiple withdrawal opportunities generates insight into individual decision making in a dynamic environment with uncertainty. We tested various cutoff rules for characterizing individual decisions in this setting. The experiment was specifically designed to differentiate between two such rules, one of which was consistent with Bayesian updating and one of which was not. We found that the cutoff rule associated with Bayesian updating outperformed the other rule. This effect disappeared over time, as increased rates of immediate withdrawals eventually made the panic rule – withdraw immediately – a superior predictor. This does not suggest that subjects stopped updating, however. Rather, it suggests they stopped believing that others would play their part of the payoff-dominant equilibrium, as coordination broke down and bank runs became more prevalent.

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Appendix A

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Bank Deposit Experiment
INSTRUCTIONS

This experiment has been designed to study decision-making behavior in groups. If you follow the instructions carefully and make good decisions, you may earn a considerable amount of money. The participants may earn different amounts of money in this experiment because each participant's earnings are based partly on his/her decisions and partly on the decisions of other group members. The money you earn will be paid to you, in cash, at the end of the experiment. Therefore, it is important that you do your best. A research foundation has contributed the money to conduct this study.

Description of the Task

You and four other people each have 1 dollar deposited in an experimental bank. You must decide whether to request to withdraw your $1 or leave it deposited.

How much money you will receive depends on your own decision and on the decisions of the other four people in your group. This is explained below.

Withdrawal Decision. You will see the chart below on your computer screen when the experiment begins. How much you receive if you make a withdrawal request or how much you earn by leaving your money deposited depends on how many other people in your group place withdrawal requests. The chart lists the payoffs for all the possible numbers of requests. The word "hypothetical" is used in the chart because you do not know how many withdrawal requests will be made when you make your decision. If ONE or TWO withdrawal requests are made, each requester will receive $1 and the remaining depositors will get $1.50. If THREE or more withdrawal requests are made, each requester will receive $1 or less, as shown in the chart, and the remaining depositors will get $0.

Hypothetical number of new withdrawal requests	Amount each requester would receive	Payment to each remaining depositor
0	not applicable	$1.50
1	$1	$1.50
2	$1	$1.50
3	$1	$0
4	$0.75	$0
5	$0.60	Not applicable

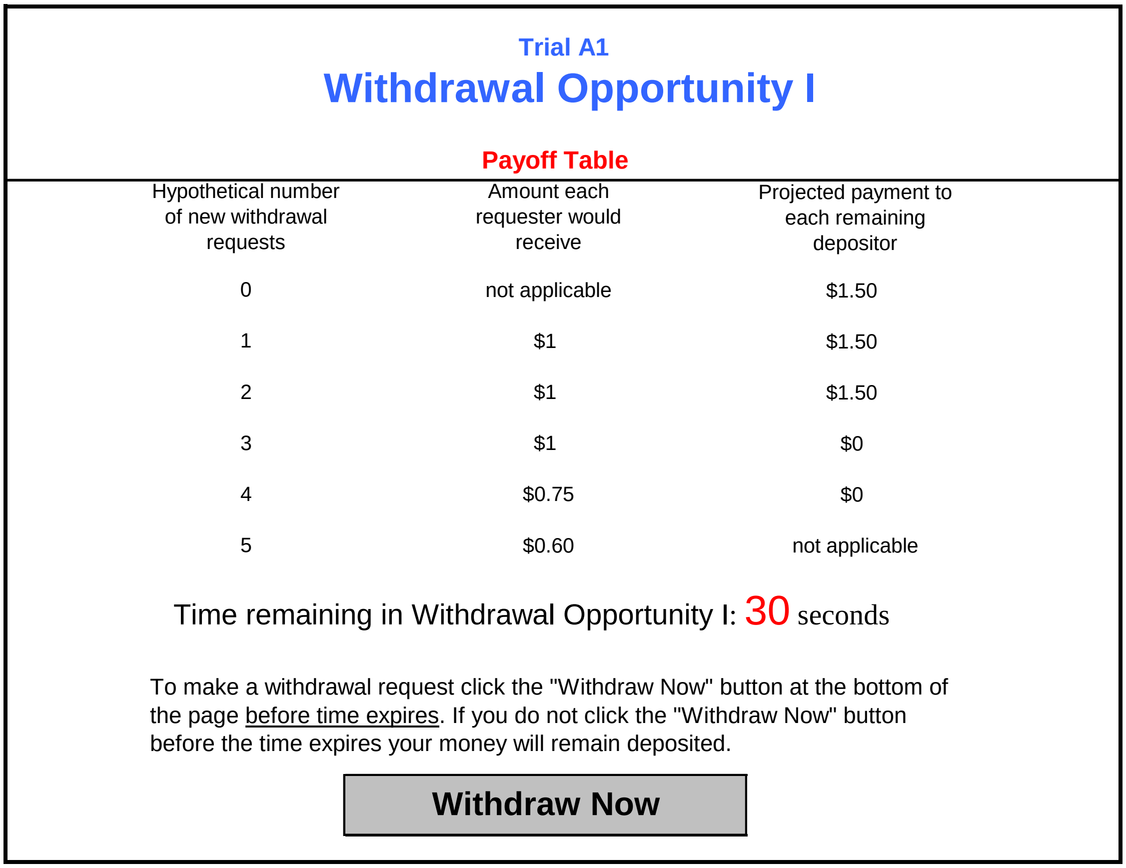
Where do these payoffs come from? It is not important that you fully understand how the numbers are determined. However, the underlying story is that the account manager has invested the $5 from the experimental account in assets that cannot be converted to cash before the end of the trial without paying a penalty. The dollar amounts you see reflect the ability of the account manager to meet her obligations of paying requesting individuals $1 (if possible) during the withdrawal opportunity and up to $1.50 to remaining depositors at the end of the trial.

Procedure

You will perform the task described above numerous times. Each time is called a trial. Each trial is completely separate. That is, you will start each trial with $1 in the experimental bank. You will keep the money you earn in every trial. At the end of each trial, your earnings for that trial and your total earnings will appear on your computer screen.

You do not play with the same people each trial. New groups of five are formed randomly every trial from the twenty people participating in the experiment.

At the beginning of each trial, you will be shown a screen similar to the pictorial representation below. The title “Withdrawal Opportunity I” will be on your screen, suggesting that there might be additional withdrawal opportunities (i.e., II, III, etc.). This is not the case. There is only ONE withdrawal opportunity per trial.



Trial A1

Withdrawal Opportunity I

Payoff Table

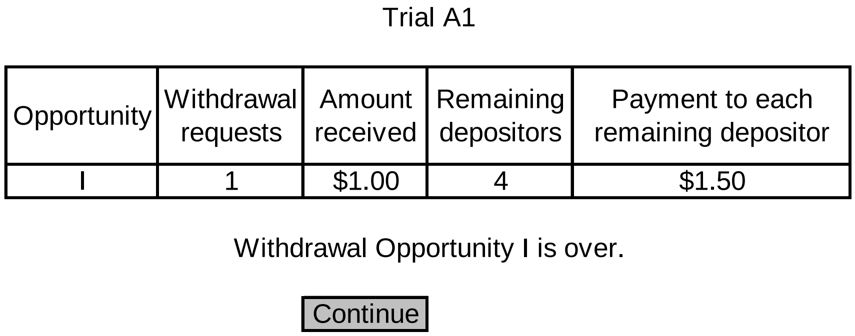
Hypothetical number of new withdrawal requests	Amount each requester would receive	Projected payment to each remaining depositor
0	not applicable	$1.50
1	$1	$1.50
2	$1	$1.50
3	$1	$0
4	$0.75	$0
5	$0.60	not applicable

Time remaining in Withdrawal Opportunity I: 30 seconds

To make a withdrawal request click the "Withdraw Now" button at the bottom of the page before time expires. If you do not click the "Withdraw Now" button before the time expires your money will remain deposited.

You can make a withdrawal request by clicking the “Withdraw Now” button before time expires. You will be given 30 seconds to make your decision. If you do not click the “Withdrawal Now” button, your money will remain deposited.

At the end of each trial you will see a summary that lists the number of withdrawal requests that were placed during the trial, the amount each requester received, the number of remaining depositors, and the payment to remaining depositors. A pictorial representation of a possible summary following Trial A1 is provided below.



Trial A1

Opportunity	Withdrawal requests	Amount received	Remaining depositors	Payment to each remaining depositor
I	1	$1.00	4	$1.50

Withdrawal Opportunity I is over.

The other people in the experiment will also view the same screens.

You will also see a summary that lists your earning for the trial and your cumulative earnings for the experiment (not including the show-up fee).

Trial Variations

There are two types of trials. Type A trials are played as described above. In Type B trials, some people may be randomly chosen and forced to withdraw. The specific rules for the type B trials will be discussed as these trials are reached during the experiment.

Payment at the End of the Session

You will participate in a maximum of 19 trials. The first two trials will be unpaid practice trials. At the end of the entire experiment, the supervisor will pay your earnings to you in cash.

Please remember, communicating with other people during the experiment is strictly forbidden.

Thank you for your participation.

TRIAL SUMMARY

Trail A1-A2: no forced withdrawals (unpaid)

Trails A3-A4: no forced withdrawals

Trials B1-B8: At the beginning of EACH trail there is a 3/8 chance that one depositor will be forced to withdraw, a 3/8 chance that two depositors will be forced to withdraw, and a 1/8 chance that three depositors will be forced to withdraw. When they occur, forced withdrawals are randomly assigned.

New payoffs

Hypothetical number of new withdrawal requests	Amount each requester would receive	Payment to each remaining depositor
0	not applicable	$1.50
1	$1	$1.50
2	$1	$1.50
3	$1	$1.50
4	$1	$0
5	$0.80	Not applicable

Trial A5: no forced withdrawals (unpaid)

Trials A6-A7: no forced withdrawals

Trials B9-B12: These trials use the same rules as B1-B8, but with new payoffs. At the beginning of EACH trail there is a 3/8 chance that one depositor will be forced to withdraw, a 3/8 chance that two depositors will be forced to withdraw, and a 1/8 chance that three depositors will be forced to withdraw. Once again, any forced withdrawals are randomly assigned.

Appendix B

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Bank Deposit Experiment

INSTRUCTIONS

This experiment has been designed to study decision-making behavior in groups. If you follow the instructions carefully and make good decisions, you may earn a considerable amount of money. The participants may earn different amounts of money in this experiment because each participant's earnings are based partly on his/her decisions and partly on the decisions of the other group members. The money you earn will be paid to you, in cash, at the end of the experiment. Therefore, it is important that you do your best. A research foundation has contributed the money to conduct this study.

Description of the Task

You and four other people each have $1 deposited in an experimental account. You must decide whether to request to withdraw your $1 at any one of THREE withdrawal opportunities you will be given, or leave it deposited in the account.

How much money you will receive if you make a withdrawal request or if you leave your money deposited depends on the withdrawal decisions of the other four people in the experiment. This is explained below. Withdrawal opportunities are numbered using roman numerals I through III.

Withdrawal Opportunity I. Below is a chart that you can use to figure out the payoffs associated with your withdrawal decision in Withdrawal Opportunity I. You will see this chart on your computer screen when the experiment begins. Remember, how much you receive if you make a withdrawal request or how much you earn by leaving your money deposited depends on how many other people place withdrawal requests. The chart gives you payoffs for all the possible numbers of requests. The word "hypothetical" is used in the chart because you do not know how many withdrawal requests will be made when you make your decision. If TWO or fewer withdrawal requests are made then each requester with receive $1 and each remaining depositor will have a projected payment of $1.50. The projected payment is the amount each remaining depositor will receive if there are no more withdrawal requests in the remaining two withdrawal opportunities. If there are future withdrawals, remaining depositors might get less, as the following charts will show. If THREE or more withdrawal requests are made then each requester will receive $1 or less as shown in the chart, and the remaining depositors will get $0.

Hypothetical number of new withdrawal requests	Amount each requester would receive	Projected payment to each remaining depositor
0	not applicable	$1.50
1	$1	$1.50
2	$1	$1.50
3	$1	$0
4	$0.75	$0
5	$0.60	not applicable

Withdrawal Opportunity II. The payoff chart for Withdrawal Opportunity II depends on the number of withdrawal requests made in Withdrawal Opportunity I. Below is the payoff chart that would apply if **1** withdrawal request were made during Withdrawal Opportunity I. Now the highest possible number of new requests is 4, so the chart has 1 less row then before. The projected payment assuming ONE or fewer withdrawal requests is $1.50. However, now if there are TWO or more withdrawal requests remaining depositors get $0. The amount each requester receives is $1 for up to two new withdrawals and less than that for more than two withdrawals, as shown in the chart.

Hypothetical number of new withdrawal requests	Amount each requester would receive	Projected payment to each remaining depositor
0	not applicable	$1.50
1	$1	$1.50
2	$1	$0
3	$0.67	$0
4	$0.50	not applicable

Withdrawal Opportunity III. The payoff chart for Withdrawal Opportunity III depends on the number of withdrawal requests made in withdrawal opportunities I and II. At the beginning of Withdrawal Opportunity III you will again see a payoff table that reflects the previous withdrawals and shows the projected payments corresponding to any additional withdrawals. Now, since this is the last withdrawal opportunity, the projected payments corresponding to each hypothetical number of new withdrawal requests will be the actual payments.

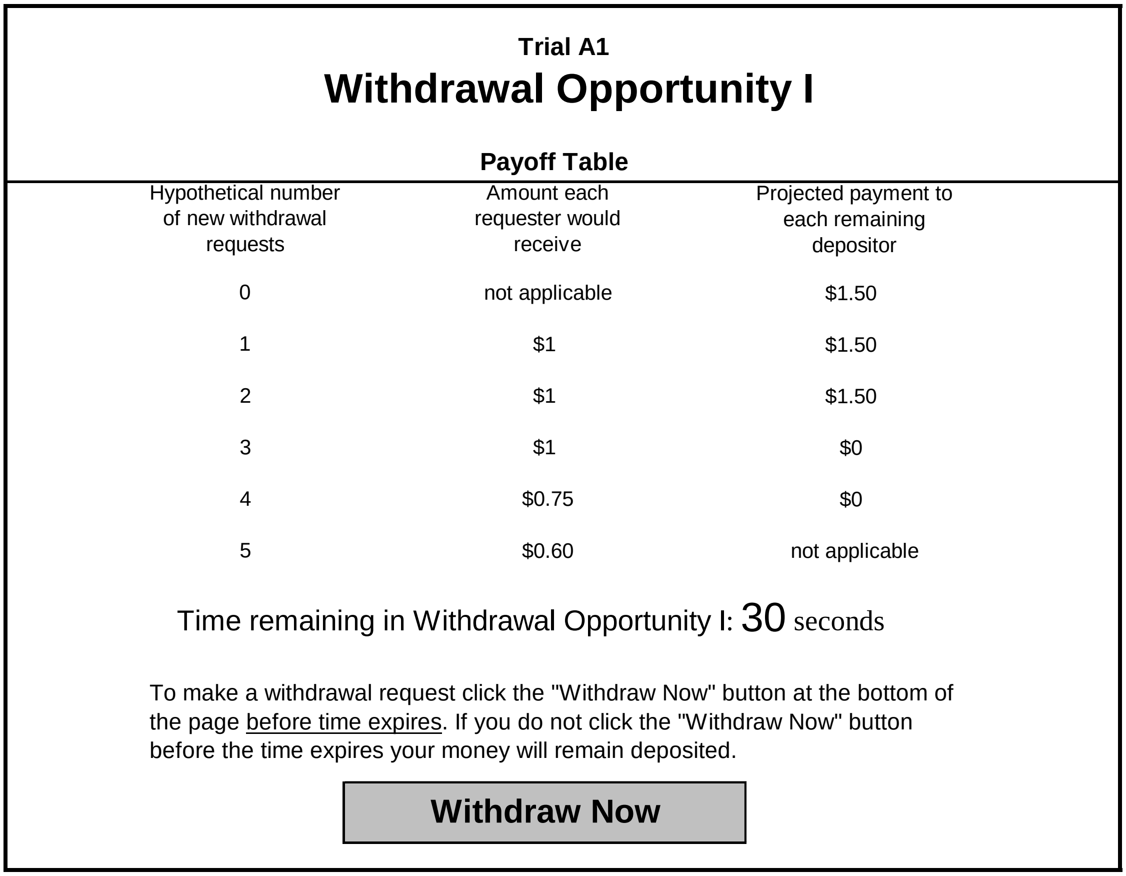
Where do these payoffs come from? It is not important that you fully understand how the numbers are determined. However, the underlying story is that the account manager has invested the $15 from the experimental account in assets that cannot be converted to cash before the end of the trial without paying a penalty. The dollar amounts you see reflect the ability of the account manager to meet her obligations of paying requesting individuals $1 (if possible) during the withdrawal opportunities and up to $1.50 to remaining depositors at the end of the trial.

Procedure

You will perform the task described above numerous times. Each time is called a trial. Each trial is completely separate. That is, you will start each trial with $1 in the experimental account. You will keep the money you earn in every trial. At the end of each trial, your earnings for that trial and your total earnings will appear on your computer screen.

You do not play with the same people each trial. New groups of five are formed randomly every trial out of the twenty people participating in the experiment.

At the beginning of each withdrawal opportunity, you will be shown a screen similar to the pictorial representation below.



Trial A1

Withdrawal Opportunity I

Payoff Table

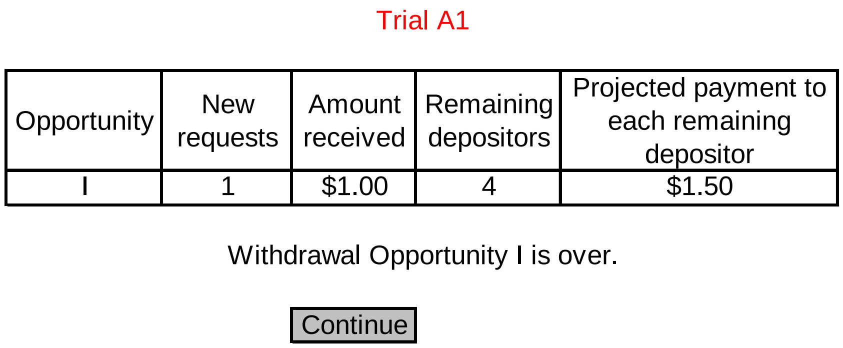
Hypothetical number of new withdrawal requests	Amount each requester would receive	Projected payment to each remaining depositor
0	not applicable	$1.50
1	$1	$1.50
2	$1	$1.50
3	$1	$0
4	$0.75	$0
5	$0.60	not applicable

Time remaining in Withdrawal Opportunity I: 30 seconds

To make a withdrawal request click the "Withdraw Now" button at the bottom of the page before time expires. If you do not click the "Withdraw Now" button before the time expires your money will remain deposited.

You can make a withdrawal request by clicking the “Withdraw Now” button before time expires. At each withdrawal opportunity you will be given 30 seconds to make your decision. If you do not click the “Withdrawal Now” button your money will remain deposited and you will either advance to the next withdrawal opportunity. If it is Withdrawal Opportunity III the trial will end and you will receive the payoff to remaining depositors.

At the end of each withdrawal opportunity you will see a summary that lists the number of new withdrawal requests that were placed during that opportunity, the amount each requester received, the number of remaining depositors, and the projected payment to remaining depositors. A pictorial representation of a possible summary following Withdrawal Opportunity I is provided below.



Trial A1

Opportunity	New requests	Amount received	Remaining depositors	Projected payment to each remaining depositor
I	1	$1.00	4	$1.50

Withdrawal Opportunity I is over.

The other people in the experiment will also view the same screens.

At the end of each trial you will see a summary that lists your earning for the trial and your cumulative earnings for the experiment (not including the show-up fee).

Trial Variations

There are two types of trials. Type A trials are played as described above. Type B trials involve a randomly determined number of forced withdrawals each withdrawal opportunity. The specific rules for the type B trials will be reviewed as these trials are reached during the experiment.

Payment at the End of the Session

You will participate in a maximum of 19 trials. The first two trials will be unpaid practice trials. At the end of the entire experiment, the supervisor will pay you your earnings in cash.

Please remember, communicating with other people during the experiment is strictly forbidden.

Thank you for your participation.

TRIAL SUMMARY

Trail A1-A2: no forced withdrawals (unpaid)

Trails A3-A4: no forced withdrawals

Trials B1-B8: At the beginning of EACH withdrawal opportunity there is a 50% chance that one of the remaining depositors will be forced to withdraw. When they occur, forced withdrawals are randomly assigned.

New payoffs

Hypothetical number of new withdrawal requests	Amount each requester would receive	Projected payment to each remaining depositor
0	not applicable	$1.50
1	$1	$1.50
2	$1	$1.50
3	$1	$1.50
4	$1	$0
5	$0.80	not applicable

Trial A5: no forced withdrawals (unpaid)

Trials A6-A7: no forced withdrawals

Trials B9-B12: These trials use the same rules as B1-B8, but with new payoffs. At the beginning of EACH withdrawal opportunity there is a 50% chance that one of the remaining depositors will be forced to withdraw. Once again, any forced withdrawals are randomly assigned.

Appendix C

Optimal Actions with Bayesian Updating, Liquidation Value = .6.

Withdrawal Opportunity III

Number of previous withdrawals	Posterior prob of a forced withdrawal in this opportunity	Expected payoff from not withdrawing			Expected payoff from withdrawing			
		# of forced withdrawals		Expected payoff	# of forced withdrawals		Expected payoff	**Optimal Action**
		0	1		0	1		
0	0.44	1.50	1.50	1.50	1.00	1.00	1.00	**not withdraw**
1	0.43	1.50	1.50	1.50	1.00	1.00	1.00	**not withdraw**
2	0.40	1.50	0.00	0.90	1.00	0.50	0.80	**not withdraw**

Withdrawal Opportunity II

Number of previous withdrawals	Posterior prob of a forced withdrawal in this opportunity	Expected payoff from not withdrawing			Expected payoff from withdrawing			
		# of forced withdrawals		Expected payoff	# of forced withdrawals		Expected payoff	**Optimal Action**
		0	1		0	1		
0	0.44	1.45	1.44	1.44	1.00	1.00	1.00	**not withdraw**
1	0.43	1.44	0.92	1.21	1.00	1.00	1.00	**not withdraw**
2	0.40	0.92	0.00	0.55	1.00	0.50	0.80	**withdraw**

Withdrawal Opportunity I

Number of previous withdrawals	Posterior prob of a forced withdrawal in this opportunity	Expected payoff from not withdrawing			Expected payoff from withdrawing			
		# of forced withdrawals		Expected payoff	# of forced withdrawals		Expected payoff	**Optimal Action**
		0	1		0	1		
0	0.44	1.40	1.19	1.31	1.00	1.00	1.00	**not withdraw**

Game ends if there are 3 withdrawals. Players factor in probability of being forced to withdraw in future rounds when calculating expected payoff to not withdrawing. Optimal actions are determined under the assumption that all other agents do not withdraw unless withdrawing is a dominant strategy. Situations that are shaded necessarily represent off-equilibrium behavior.

Appendix D

Optimal Actions with Bayesian Updating, Liquidation Value = .8.

Withdrawal Opportunity III

Number of previous withdrawals	Posterior prob of a forced withdrawal in this opportunity	Expected payoff from not withdrawing			Expected payoff from withdrawing			**Optimal Action**
		# of forced withdrawals		Expected payoff	# of forced withdrawals		Expected payoff	
		0	1		0	1		
0	0.44	1.50	1.50	1.50	1.00	1.00	1.00	**not withdraw**
1	0.43	1.50	1.50	1.50	1.00	1.00	1.00	**not withdraw**
2	0.40	1.50	1.50	1.50	1.00	1.00	1.00	**not withdraw**
3	0.33	1.50	0.00	1.00	1.00	0.50	0.83	**not withdraw**

Withdrawal Opportunity II

Number of previous withdrawals	Posterior prob of a forced withdrawal this period	Expected payoff from not withdrawing			Expected payoff from withdrawing			**Optimal Action**
		# of forced withdrawals		Expected payoff	# of forced withdrawals		Expected payoff	
		0	1		0	1		
0	0.44	1.45	1.44	1.44	1.00	1.00	1.00	**not withdraw**
1	0.43	1.44	1.42	1.43	1.00	1.00	1.00	**not withdraw**
2	0.40	1.42	1.00	1.25	1.00	1.00	1.00	**not withdraw**
3	0.33	1.00	0.00	0.67	1.00	0.50	0.83	**withdraw**

Withdrawal opportunity I

Number of previous withdrawals	Posterior prob. # of forced w/d this period = 1	Expected payoff from not withdrawing			Expected payoff from withdrawing			**Optimal Action**
		# of forced withdrawals		Expected payoff	# of forced withdrawals		Expected payoff	
		0	1		0	1		
0	0.44	1.40	1.38	1.39	1.00	1.00	1.00	**not withdraw**

Game ends if there are 4 withdrawals. Players factor in probability of being forced to withdraw in future rounds when calculating expected payoff to not withdrawing. Optimal actions are determined under the assumption that all other agents do not withdraw unless withdrawing is a dominant strategy. Situations that are shaded necessarily represent off-equilibrium behavior.