Should regulators always be transparent? A bank run experiment

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Abstract

We study, using laboratory experiments, the extent to which disclosure policies about the financial health of a bank affect the likelihood of a bank run. We consider two disclosure regimes, full disclosure and no disclosure, under two scenarios: one in which the bank is on average financially solvent and another in which the bank is on average insolvent. When the bank is on average insolvent, the full disclosure regime reduces the expected likelihood of runs. In contrast, when the bank is on average solvent, the full disclosure regime increases the expected likelihood of runs. Our evidence illustrates the importance of contemporary financial disclosure regulations.

JEL Codes: C92, G21, C72, G18.
Keywords: Bank runs, Banking crises, Public policy, Information disclosure.

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1 Introduction

The stability of financial systems has been at the top of policy agendas after the 2007-2008 financial crisis. In reaction, there has been a growing consensus for increased transparency about the health of financial institutions.[1,2] Since 2015, the Basel Committee on Banking Supervision has continued its recommendations toward increased disclosure by banks about their financial state (see the BCBS report for 2015 and 2018). Currently, the Bank of England has a statutory duty to reveal when a financial institution applies for emergency funding. However, such a policy is not adopted everywhere. Most notably, the US Federal Reserve has a policy of not publicly disclosing its CAMELS ratings.[3]

In this paper, we aim to provide experimental evidence that will help discern whether or not regulators should commit themselves to revealing the health of financial institutions. Whilst we recognise that runs on financial institutions can sometimes be optimal for depositors (see Alonso, 1996), such events are nevertheless undesirable for regulators.

We base our experimental design on the Diamond and Dybvig (1983) model where a bank faces short-term liquidity constraints and uncertainty about its long-term health.[4] We consider two economic outlooks, *weak* and *strong*, differing in the distribution of returns on the bank's long-term assets, which proxy the bank's long-term health. For both types of outlooks, the distribution in returns of the bank's long-term assets includes values for which it is a dominant strategy for depositors to run (i.e., the prisoners' dilemma), as well as values for which the no run equilibrium is feasible as in the standard Diamond and Dybvig model. The former case we refer to as an insolvent bank, while the latter case we refer to as a solvent bank.[5] There is a higher chance for depositors to face the prisoners' dilemma (an insolvent bank) when the outlook is weak relative to when it is

[1]One of the main recommendations from the "Squam Lake Report" (French et al., 2010) is for regulators to increase the dissemination of collected information about financial institutions to the private sector.

[2]The Dodd-Frank Wall Street Reform and Consumer Protection Act of 2010 mandates the Federal Reserve to conduct supervisory "stress tests" on large financial institutions and publicly disclose the results by June 30th of the calendar year. However, it is not obvious as to whether such disclosure is necessarily beneficial (see Goldstein and Sapra, 2014).

[3]Supporting this contrasting view of non-disclosure, Gorton (2009) argues that the creation of the ABX.HE index precipitated the run on subprime bonds, by revealing information about beliefs concerning the riskiness of those assets.

[4]The Diamond-Dybvig model is also used to study currency attack (e.g., Obstfeld, 1995) and roll-over risk (e.g., He and Xiong, 2012; Martin et al., 2014).

[5]Hence, a run on a solvent bank is a liquidity problem rather than a solvency problem in that if all depositors delay withdrawing, then they would each receive more than they could today.

strong and, in fact, a bank with a return equal to the expected return would be insolvent in the weak outlook and solvent in the strong outlook.

To study the role of information disclosure on bank runs, we implement two regimes differing on whether depositors are informed of the returns on the bank's long-term assets. In the first regime, there is a no disclosure policy in which depositors must decide whether or not to withdraw their deposits knowing only the distribution of returns to bank's long-term assets. In the second regime, there is a full disclosure policy in which depositors know the actual returns to the long-term assets before making their withdrawal decisions.

The influence of information disclosure on bank runs is non-trivial due to the existence of multiple equilibria when the bank is solvent. This task is therefore well suited to laboratory experiments where the confounding forces such as beliefs and experiences can be carefully controlled.

Our experiment shows that information disclosure is a double-edged sword. When the outlook is weak, the no disclosure policy leads to more runs than the full disclosure policy. The opposite is true when the outlook is strong: the full disclosure policy leads to more runs than the no disclosure policy. In both cases, results are driven by behaviour at the extremes of the distribution of returns: full disclosure is beneficial when the outlook is weak because it informs depositors in the rare event it is rational not to run. In contrast, no disclosure under a strong outlook prevented runs in the rare event that returns were too low and running on the bank is a dominant strategy. Essentially, when the outlook is strong, it is beneficial to hide bad information within overall good information. When the outlook is weak, it is beneficial to allow good information to be revealed against a backdrop of overall bad information. As a whole, our results show that disclosure rules can have significant influence on bank runs.

We contribute to the body of experimental literature that studies bank runs in the spirit of the Diamond and Dybvig model (see Dufwenberg, 2015, for a survey of the literature). In particular, there are a number of studies that examine the influence of external information on depositors' withdrawal decisions. In Arifovic and Jiang (2014), the depositors observe an external signal, a random public announcement stating the "predicted" deposit withdrawals. They find that depositors are more likely to follow the unconnected external signals when parameters are such that there is high strategic uncertainty as to which equilibrium will form. Chakravarty et al. (2014) and Brown et al. (2017) look at the possibility of bank run contagions in the sense that a publicly visible run on one bank triggers a run on another. Both papers find evidence of bank run contagions when the fundamentals of two banks are linked. Consistent with the findings of Arifovic and Jiang (2014), Chakravarty et al. (2014) also find that depositors may get influenced by external information when the fundamentals are not linked.[6] Finally, there is also theoretical work on the role of announcements regarding the health of bank on bank runs (e.g., Gorton, 1985; Chari and Jagannathan, 1988; Kaplan, 2006; Dang et al., 2017; Ebert et al., 2018). We extend this literature by looking at the influence of disclosure policies (under full commitment) on the likelihood of a run on a bank.

There is a related strand of experimental literature that uses the global games (e.g., Carlsson and van Damme, 1993; Morris and Shin, 2002) paradigm to study the effects of information transparency or disclosures on coordination failures—see Goldstein and Pauzner (2005) for an application of global games in bank runs.[7] For example, Anctil et al. (2004, 2010) find that changes to transparency, modelled by the precision of players' private information, can affect coordination failures.[8] Heinemann et al. (2004) experimentally study the role of public information in global games framed as currency attacks. They consider two treatments, one where the true state is fully revealed by the public signal and the other where the true state is not revealed (i.e., players receive noisy private signals). They find that public information reduces coordination failures and increases the success likelihood of currency attacks. Finally, Banerjee and Maier (2016) use global games to investigate the granularity of the public signal on coordination failures—all players receive noisy private signals. They find that the effect of information transparency, a more granular public signal, depends on whether the public signal is "pessimistic" or "optimistic". More specifically, greater transparency increases the likelihood of coordination failure (i.e., bank runs) when the public signal is pessimistic and reduces the likelihood of coordination failure when the public signal is optimistic.[9]

The rest of the paper is organised as follows. Section 2 details our experiment design. Section 3 details the experimental procedures. Section 4 reports the experimental results. Finally, Section 5 concludes.

[6] There is also bank run literature about depositors observing withdrawals in their own bank (e.g., Schotter and Yorulmazer, 2009; Garratt and Keister, 2009; Kiss et al., 2012).

[7] In global games (Morris and Shin, 1998, 2002), a continuum of players each receive a private noisy signal about the true state of nature. The experimental literature obviously considers a finite number of players but keep the noisy private signal paradigm.

[8] In general, they find that increasing the precision of player's private information increases coordination on *risk-dominance* (Harsanyi and Selten, 1988) equilibria.

[9] The findings of Banerjee and Maier (2016) are not necessarily contradictory to our results since both studies use fundamentally different paradigms to model bank runs.

2 Experiment Design

We consider a simple two-player bank run game that is inspired by the Diamond and Dybvig (1983) model. In order to focus on the role of information disclosure, we use a two-player game so as to minimise the difficulty in evaluating the strategic uncertainty of other players.[10]

The game is summarised in Figure 1. There are two depositors, each with 400 deposited in a bank. Each depositor decides (simultaneously) to withdraw his money *early* (e) or *late* (l). The bank faces short-term liquidity constraints and uncertainty about about its long-term fundamentals. To model the long-term fundamentals, we assume that nature determines the bank to be one of eleven possible types, $\theta \in \Theta = \{\theta_1, \dots \theta_{11}\}$, with equal probability of each type. The bank collapses if any depositor withdraws early and the bank is only worth its liquidation value of 400, which is equally shared among all depositors who withdrew early. If both depositors withdraw late, the payoffs to each depositor is $R^j(\theta) \geq 0$, where $j = S, W$ denotes the long-term economic outlook that can either be *weak* (W) or *strong* (S)—the bank's long-term fundamentals are reflected in the outlook.[11] The outlook, whether it is weak or strong, is known to both depositors (not necessarily the bank's type).

The first two rows of Panels A and B of Table 1 detail the corresponding $R^j(\theta)$ for each type when the outlook is weak and strong, respectively. For example, if the outlook is weak (resp. strong) and both depositors withdraw late, each depositor receives 250 (resp. 550) when the bank's type is θ_6. Depositors face the prisoners' dilemma when $200 \leq R^j(\theta) < 400$ and the coordination game when $R^j(\theta) \geq 400$. When both depositors withdraw late, there is a 8/11 (resp. 2/11) chance of receiving less than their deposited amount when the outlook is weak (resp. strong).

Orthogonal to the above, we also consider two information regimes: *full information* and *no information*. In the full information regime, depositors observe the bank's type before they make their withdrawal decisions. In contrast, depositors in the no information regime do not observe the bank's type before making decisions (but do still know whether the outlook is weak or strong). The full and no information conditions are analogous to a setting where a regulator is

[10]When there are $n > 2$ players in the bank run game, each player must not only form beliefs about other players' actions but also beliefs about how correlated these actions may be.

[11]We are neutral as to the interpretation of types. One possibility is for θ to correspond to the probability that the bank will collapse in the long-run, even if all depositors withdrew late. In this case, $R^j(\theta) = X(1 - p^j(\theta))$ where $p^j(\theta) \in [0, 1]$ is the type θ's probability of collapsing in state j and $X > 0$ is the payoff to the depositor if the bank does not collapse.

	Withdraw Early (e)	Withdraw Late (l)
Withdraw Early (e)	200, 200	400, 0
Withdraw Late (l)	0, 400	$R^j(\theta)$, $R^j(\theta)$

Note. The values in each cell denote the payoffs to the row (Depositor 1) and column (Depositor 2) players, respectively. The variable $R^j(\theta) \geq 0$ depends on the bank's outlook $j = W, S$ and the bank's type θ. When the outlook is weak (W), $R^W(\theta)$ can take the values 0, 50, 100, ..., 500 with equal probability of each. When the outlook is strong, $R^S(\theta)$ can take the values 300, 350, ..., 800 with equal probability of each.

FIGURE 1. Bank run game.

Panel A: The weak outlook (FW game).

Type	θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7	θ_8	θ_9	θ_{10}	θ_{11}
$R^W(\theta)$	0	50	100	150	200	250	300	350	400	450	500
[i]Pure-Strategy eq.	ee	ee	ee	ee	ee	ee	ee	ee	$ee^{\square}$ $ll_{\perp}$	$ee^{\square}$ $ll_{\perp}$	$ee^{\square}$ $ll_{\perp}$
[ii]Mixed-Strategy eq.	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.20	0.33

Panel B: The strong outlook (FS game).

Type	θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7	θ_8	θ_9	θ_{10}	θ_{11}
$R^S(\theta)$	300	350	400	450	500	550	600*	650	700	750	800
[i]Pure-Strategy eq.	ee	ee	$ee^{\square}$ $ll_{\perp}$	$ee^{\square}$ $ll_{\perp}$	$ee^{\square}$ $ll_{\perp}$	$ee^{\square}$ $ll_{\perp}$	$ee^{\square}$ $ll^{\square}_{\perp}$	ee $ll^{\square}_{\perp}$	ee $ll^{\square}_{\perp}$	ee $ll^{\square}_{\perp}$	ee $ll^{\square}_{\perp}$
[ii]Mixed-Strategy eq.	1.00	1.00	0.00	0.20	0.33	0.43	0.50	0.56	0.60	0.64	0.67

Note The shaded columns in Panels A and B denote the equilibria in the NW and NS games, respectively, if the depositors are risk-neutral.
[i] Here, ee and ll denote the outcomes where both depositors withdraw early and late, respectively. Where relevant, the $\square$ and $\perp$ denote the *risk dominant* and *payoff dominant* equilibria, respectively.
[ii] The mixed-strategy refers to the probability of withdrawing early.

TABLE 1. Payoff parameters and pure strategy equilibria.

committed to always revealing the bank's type and never revealing the bank's type, respectively.

The above considerations result in a 2×2 design with the following four games: FW game (full information; weak outlook), NW game (no information; weak outlook), FS game (full information; strong outlook) and NS game (no information; strong outlook).[12] Panels A and B of Table 1 also detail the equilibrium (pure-strategy and mixed-strategy) given each type θ in the FW and FS games, respectively. The shaded columns in Panels A and B detail the equilibrium in the NW and NS games, respectively.[13]

We study each outlook separately to better understand how information disclosure about the bank's type, affects the *expected likelihood* of bank runs, that is, the ex-ante probability of a bank run before θ is resolved by nature. Intuitively, this will broadly depend on whether depositors coordinate on the ee (both withdraw early) or ll (both withdraw late) equilibrium when $R^j(\theta) \geq 400$. Harsanyi and Selten (1988) argue that this may depend on whether the equilibrium is risk dominant or payoff dominant. (these are denoted on Table 1 by the "$\square$" and "$\perp$" symbols, respectively).[14]

2.1 The impact of information disclosure

To study the impact of information disclosure when the outlook is weak (resp. strong) we focus on the NW and FW (resp. NS and FS) games, assuming risk-neutral depositors.

Weak outlook. Information disclosure reduces the expected likelihood of a bank run when depositors play the mixed-strategy equilibria or when depositors coordinate on the payoff dominance equilibrium.[15] In contrast, information disclosure has no influence on the expected likelihood of a bank run when depositors coordinate on the payoff dominance equilibrium.[16]

[12]Depositors in the NW and NW games face both strategic uncertainties as to the decisions of their peer and fundamental uncertainties as to the bank's type. In contrast, depositors in the FS and FS games only face strategic uncertainties.

[13]The behaviour in such games may resemble risk-neutral play which is identical to when the bank's type is known to be θ_6.

[14]When $R(\theta) = 600$, the risk-dominance equilibrium corresponds to the mixed-strategy prediction that depositors withdraw early with probability 1/2. However, since we already assume that investors always coordinate on one of the pure-strategy equilibria, they cannot play the mixed-strategy. As such, we assume that they play the payoff-dominance equilibria.

[15]The mixed-strategy equilibria in the NW and FW games are for depositors' expected probability of withdrawing early to be 1.00 and 0.78, respectively.

[16]Experimental research with the stag-hunt game suggests that whether people coordinate on the risk or payoff dominance equilibria can depend on the matching protocol or payoff parameters

Strong outlook. Information disclosure reduces the expected likelihood of a bank run when depositors coordinate on the risk dominance equilibrium. In contrast, information disclosure increases the expected likelihood of a bank run when depositors coordinate on the payoff dominance equilibrium or play the mixed-strategy equilibria.[17]

3 Procedures

The NW (72 subjects), FW (78 subjects), NS (74 subjects) and FS (80 subjects) treatments were conducted in 2016, recruiting from the student cohort at University of Erlangen-Nuremberg—see Table A1 of the Appendix for details about the experimental sessions. Subjects were recruited on a first come basis through ORSEE (Greiner, 2015). The sessions were programmed and conducted with *ztree* (Fischbacher, 2007).

Each experimental session consisted of parts A and B—both parts are identical. In part A (resp. B), subjects played 19 (resp. 17) rounds of the corresponding games with random matching at each round and one experimental round was randomly chosen for payment—we pool data from both parts for the analysis. When subjects received the instructions for part A, they were unaware of part B's design.[18] In each round, we also used an incentive compatible mechanism to elicit subjects' beliefs about their opponents likelihood of withdrawing early.[19] Subjects received feedback at the end of each round as to their payoffs and the bank's type—payoffs were denoted in the currency ECU. For efficient comparisons, we pre-generated four sequences of θ and applied them accordingly to the respective sessions. In addition to a €4 show-up payment, subjects' payoff from parts A and B were converted to cash at the exchange rate of 75 ECU to €1. Mean earnings in the NW, FW, NS and FS treatments were €11.86, €12.11, €16.39 and €17.96, respectively.

(see Devetag and Ortmann, 2007; Van-Huyck, 2008, for surveys). In general, people tend to pick the payoff dominant strategy more often as the *basin of attraction* of the risk dominance equilibria (Van-Huyck, 2008) decreases.

[17]The mixed-strategy equilibria in the NS and FS games are for depositors' expected probability of withdrawing early to be 0.43 and 0.53, respectively.

[18]The instructions are provided in the Appendix A. The two-part design allowed us to see if experience mattered as well as collect more data with the same number of subjects. We did not find an effect of experience so thus pooled the data.

[19]Each subject submits a "guess" $g = 0, 5, .., 100$ as to how likely his opponent will withdraw late. The payoffs from this task are $100 - 0.01g^2$ and $2g - 0.01g^2$ if the opponent withdraws early and late, respectively. These symmetric penalties ensure that subjects have an incentive to submit their truthful beliefs about their opponent's action.

4 Results

4.1 Preliminaries

We begin by examining the role of beliefs about other depositors' actions in determining withdrawal decisions. In the full information treatments there are three relevant ranges of R for which beliefs play (potentially) different roles.

- *Dominated* (DOM) range. When $R \leq 200$ it is both individually and collectively rational to withdraw early—beliefs should not play any role in decision-making.
- *Prisoner's Dilemma* (PD) range. When $200 < R < 400$, subjects are playing a prisoners' dilemma; while it is a dominant strategy for a self-interested subject to withdraw early, the same is not the case for subjects who exhibit social preferences (see Charness and Rabin, 2002; Chakravarty et al., 2016).
- *Coordination Game* (COOR) range. When $R \geq 400$, we have a coordination game, in which beliefs about the other's action is critical to determining which equilibrium should be played.

To verify this relationship, we ran a linear probability fixed effects GLS model of the decision to withdraw early on dummies for the relevant ranges of R (i.e., DOM, PD or COOR), as well as their interaction with a measure of belief about the probability of the other depositor withdrawing early for the treatments with full information. Table 2 summarises the results.[20] In the no information treatments, we only used beliefs as the sole regressor since subjects do not observe R.

We observe that the coefficients on beliefs are all positive and significant, meaning that the higher the belief on the other playing withdrawing early, the higher the likelihood of withdrawing early. In the full information treatments, we also observe that subjects are significantly more likely to withdraw early as R decreases. In the FW treatment, the coefficient on beliefs is significantly smaller when R is in the DOM ($F(1, 2725) = 59.19$, $p < 0.0001$) and PD ($F(1, 2725) = 160.14$, $p < 0.0001$) ranges than in the COOR range; in turn, the coefficient on beliefs is significantly smaller in the DOM than in the PD range ($F(1, 2725) = 27.70$, $p < 0.0001$). In the FS treatment, the coefficient on beliefs is significantly smaller when R is in the PD than in the COOR range ($F(1, 2725) = 28.75$, $p < 0.0001$).

We next consider instead a more dynamic model, where subjects respond, in an adaptive mode, to past behaviour. We therefore use early withdrawal

[20] We report cluster-robust standard errors at the subject level.

Dependent variable: Early withdrawal				
Treatment	*NW*	*FW*	*NS*	*FS*
DOM		0.596^{***} (0.0385)		
PD		0.345^{***} (0.0299)		0.452^{***} (0.0364)
Belief	0.004^{***} (0.0002)	0.009^{***} (0.0003)	0.006^{***} (0.0003)	0.008^{***} (0.0004)
Belief × DOM		-0.006^{***} (0.0005)		
Belief × PD		-0.003^{***} (0.0004)		-0.003^{***} (0.0005)
Constant	0.588^{***} 0.0188	0.124^{***} 0.0122	0.091^{***} 0.0105	0.044^{***} 0.009
Number of observations	2,592	2,808	2,664	2,880
Number of subjects	72	78	74	80
R^2	0.12	0.58	0.27	0.47

Note. Standard errors in parentheses. The "DOM" and "PD" dummy covariates refer to observations where $R \leq 200$ and $200 < R < 400$, respectively—the omitted category is the COOR range. We do not have any DOM range observations in the strong outlook treatments. The "Belief" variable refers to the subjects' belief that their opponents will withdraw early.
*** indicate $p < 0.01$.

TABLE 2. Fixed-effects GLS estimates of the role of beliefs.

decisions (subjects' own and opponent's) in the previous period as the main regressor, interacted whenever appropriate with the relevant ranges of R.

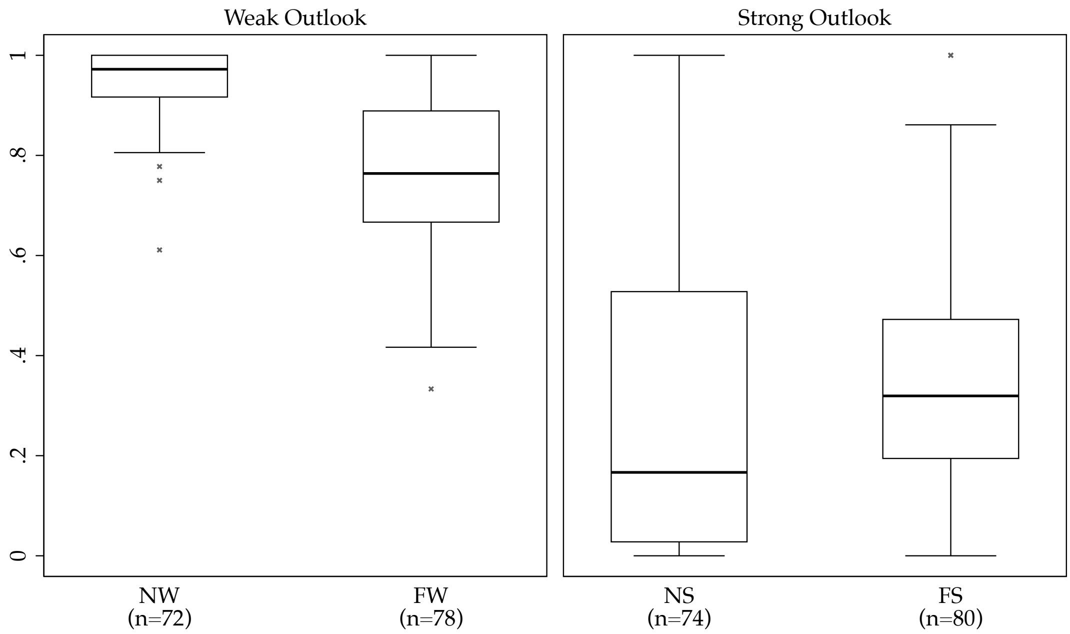
Table 3 reports the results. In the no information treatments, we find that both the subjects' previous round withdrawal decision and their previous round opponents' withdrawal decision are positively correlated (significant at the 1% level) with the present decision to withdraw early. The former correlation indicates a temporal persistence interpretation; the latter indicates a degree of social learning, in that interacting with an opponent who withdrew early may lead to an update on the beliefs about the population of players—recall that our experimental design had random matching in every round. In contrast to the above, the previous opponent's withdrawal decision has no significant influence on subjects' present withdrawal decision in the full information treatments. The estimates also review that conditional on withdrawing early in the previous round, subjects in the *FW* are more significantly less likely to withdraw early when R is in the DOM and PD ranges relative to the COOR range—the same finding applies to the *FS* treatment.

Observation 1 *Early withdrawal decisions are strongly correlated with past behaviour, the level of* R*, and their belief about their current opponent's action. They are not consistently or strongly correlated with past behaviour of other players.*

Dependent variable: Early withdrawal				
Treatment	NW	FW	NS	FS
DOM		0.767*** (0.0321)		
PD		0.623*** (0.0370)		0.587*** (0.0258)
Subject withdraws early in t-1	0.268*** (0.0181)	0.164*** (0.0282)	0.341*** (0.0181)	0.034* (0.0195)
Subject withdraws early in t-1 × DOM		−0.247*** (0.0366)		
Subject withdraws early in t-1 × PD		−1.172*** (0.0407)		−0.156*** (0.0436)
Opponent withdraws early in t-1	0.090*** (0.0173)	0.012 (0.0276)	0.139*** (0.0141)	0.014 (0.0186)
Opponent withdraws early in t-1 × DOM		0.010 (0.0367)		
Opponent withdraws early in t-1 × PD		0.001 (0.0406)		0.161*** (0.0437)
Constant	0.612*** (0.0234)	0.255*** (0.0253)	0.152*** (0.0090)	0.239*** (0.0108)
Number of observations	2,520	2,730	2,590	2,800
Number of subjects	72	78	74	80
R^2	0.15	0.40	0.52	0.24

Note. Standard errors in parentheses. The DOM and PD dummy covariates refer to observations where $R \leq 200$ and $200 < R < 400$, respectively—the omitted category is the COOR range. We do not have any DOM range observations in the strong outlook treatments.
*** and * indicate $p < 0.01$ and $p < 0.10$, respectively.

TABLE 3. Fixed-effects GLS model estimates of the determinants of early withdrawal.



Note. The left and right panels detail the boxplot distribution of f_e (i.e., a depositor's observed frequency of withdrawing early) when the outlooks are weak and strong, respectively.

FIGURE 2. Boxplot distribution of f_e in the NW, FW, NS and FS treatments.

4.2 Information disclosure and bank runs

Since a bank run occurs whenever a depositor withdraws early, the analysis needs to only focus on the depositors' propensity to withdraw early. For each depositor, define f_e as his relative frequency of withdrawing early.[21,22] Figure 2 reports the boxplot distribution f_e in all treatments.

The median f_e for the NW and NS treatments are 0.97 and 0.17, respectively. These observations suggest that when uninformed of the bank's type, most depositors chose to withdraw early when the outlook is weak and late when the outlook is strong. To see the influence of information disclosure on the *expected likelihood* of bank runs, we compare f_e in the NW and FW treatments as well as f_e in the NS and FS treatments.

Result 1 *Information disclosure (revealing the bank's type) when the outlook is weak significantly reduces the expected likelihood of bank runs.*

[21]For example, $f_e = 0.5$ implies that the subject had withdraw early in half of all his experimental rounds.

[22]For each subject, we do not find the realised frequencies of each bank's type to be significantly different (Wilcoxon Signrank, $p \geq 0.86$) from the theoretical frequencies (i.e., equal chance for each type).

Support for Result 1: We find f_e to be significantly higher in the NW relative to FW treatment (two-tailed Mann-Whitney (MW), $p < 0.001$).

Result 2 *Information disclosure (revealing the bank's type) when the outlook is strong significantly increases the expected likelihood of bank runs.*

Support for Result 2: We find f_e to be significantly lower in the NS relative to FS treatment (MW, $p = 0.003$).

To better understand Results 1 and 2, we compare depositors' behaviour in the full information regime when the bank's type is θ, against behaviour in the no information regime where the bank's type is unknown. To do so, we define $f_e(\theta)$ as a depositor's frequency of withdrawing early when the bank's type is observed to be θ.

Figure 3 details the boxplot of $f_e(\theta)$ in the FW (top row) and FS (bottom row) treatments. We also report the median f_e in the NW and NS treatments.[23] Intuitively, comparisons between the f_e of the no information treatments and $f_e(\theta)$ of the full information treatments should shed light on the influence of information disclosure at each type θ.

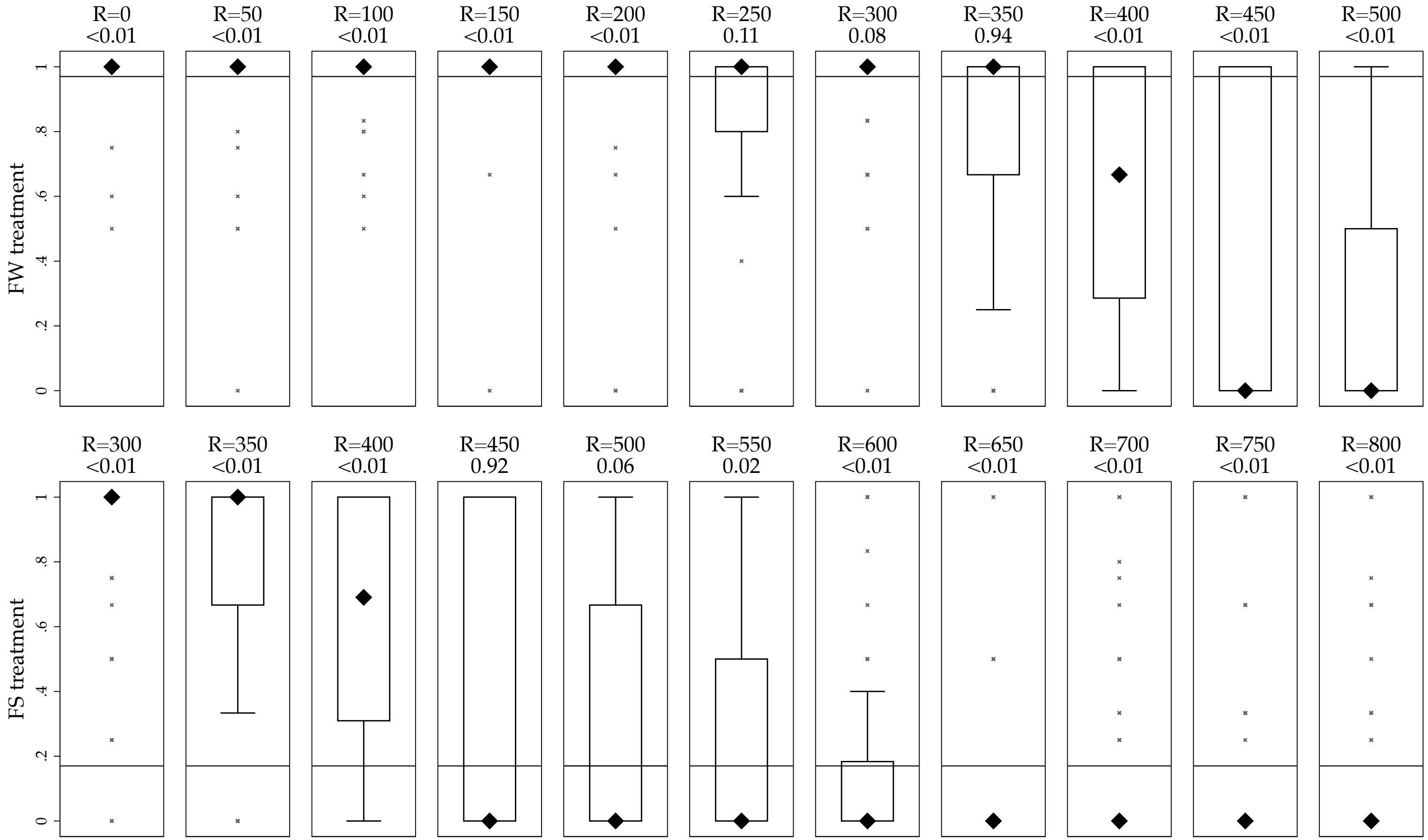
Result 3 *Information disclosure (revealing the bank's type) has mixed effects on the depositors' withdrawal decisions. In particular, information disclosure significantly increases the likelihood of bank runs for lower type banks and significantly reduces the likelihood of bank runs for higher type banks.*

Support for Result 3: Relative to f_e in the NW treatment we find $f_e(\theta)$ in the FW treatment to be significantly (MW, $p < 0.001$) higher when $R^W(\theta) \leq 200$ and significantly (MW, $p < 0.001$) lower when $R^W(\theta) \geq 400$. Relative to f_e in the NS treatment, we find $f_e(\theta)$ in the FS treatment to be significantly (MW, $p < 0.001$) higher when $R^S(\theta) \leq 400$ and significantly (MW, $p \leq 0.02$) lower when $R^S(\theta) \geq 550$.

To better understand Results 1-3, we partition the state space (i.e., the bank's type) in the FW and FS treatments into the *plus-run*, *minus-run* and *neutral-run* regions where relative to their no information counterparts, information disclosure significantly increases, significantly decreases and has no significant influence on the likelihood of bank runs, respectively.[24] The proportion of instances in the FW

[23]We do not find $f_e(\theta)$ in the FW and FS treatments to be significantly different (MW, $p \geq 0.292$) for the intersection of types where $300 \leq R^j(\theta) \leq 500$.

[24]In the FW (resp. FS) treatment, the plus-run region corresponds to the types where $R^W(\theta) \leq 200$ (resp. $R^S(\theta) \leq 400$) and the minus-run region corresponds to the types where $R^W(\theta) \geq 400$ (resp. $R^S(\theta) \geq 550$) – the remaining types correspond to the neutral-run region.



Note. Each column details the boxplot distribution of $f_e(\theta)$ in the *FW* (top row) and *FS* (bottom row) treatments for a given $R^j(\theta)$ value. The horizontal line in each panel details the median f_e in the *NW* (top row) and *NS* (bottom row) treatments. The header of each panel also details the two-tailed Mann-Whitney test p-value for the comparisons between the $f_e(\theta)$ in the full information treatment and f_e in the no information treatment.

FIGURE 3. Boxplot distribution of $f_e(\theta)$ in the *FW* and *FS* treatments.

treatment where depositors in the plus-run, minus-run and neutral-run regions withdrew early are 97%, 38% and 86%, respectively. For the FS treatment, the corresponding proportions are 77%, 14% and 31%, respectively. Finally, the proportion of instances in the NW and NS treatments where depositors withdrew early are 95% and 30%, respectively.

Clearly, Result 3 shows that information disclosure can mitigate and exacerbate the likelihood of banks runs. When the outlook is weak, information disclosure 'mitigates" in the minus-run region to a greater extent than it "exacerbates" in the plus-run. The opposite is observed when the outlook is strong where information disclosure mitigates in the minus-run region to a lesser extent than it exacerbates in the plus-run region. As a consequence, information disclosure mitigates and exacerbates the expected likelihood of bank runs when the outlook is weak and strong, respectively.

Finally, the above results also hold when we consider a depositor's frequency of withdrawing early weighted by the theoretical frequencies of each possible bank types.[25] We also draw similar findings when the analysis focuses on depositors' beliefs as to their opponents' likelihood of withdrawing early.

5 Conclusion

We add to the discussion of information disclosure in coordination games by providing experimental evidence in the context of a bank run game about how depositors respond to public information about the solvency of the bank. We show that the effects of information provision are highly dependent on the distribution of the underlying state of the world. Information provision affects behaviour at the extremes of the distribution of outcomes. That is to say, it affects behaviour in rare events (that is, bank insolvency in good times, or bank solvency in bad times).

We find that less transparency results in more runs when the expected health of the bank is fragile and less runs when the expected health of the bank is strong. In the former scenario, without information the subjects will coordinate on the run action. So if the policy maker's objective is to avoid failing banks, then clearly having a full disclosure policy would be better when the economy is weak.

A promising line of future work is to expand the ability of the regulator to communicate in two ways. First, we can make the regulator a player in the game.

[25]In doing so, we better control for the distribution of types realised by depositors in the experiment.

Our current setup is equivalent to forcing the regulator to have full commitment to either always commit to fully reveal his information or to always conceal his information. Second, we can alter these level of commitment to either restricting the regulator to always send the truth, but not restricted to which truth (a form of verifiability) or even no commitment at all (say anything even if it is lying).

References

Alonso, Irasema, "On avoiding bank runs," *Journal of Monetary Economics*, 1996, *37* (1), 73–87.

Amato, Jeffery D., Stephen Morris, and Hyun Song Shin, "Communication and monetary policy," *Oxford Review of Economic Policy*, 2002, *18* (4), 495–503.

Anctil, Regina M, John Dickhaut, Cathleen Johnson, and Chandra Kanodia, "Does information transparency decrease coordination failure?," *Games and Economic Behavior*, 2010, *70* (2), 228–241.

_ , _ , Chandra Kanodia, and Brian Shapiro, "Information transparency and coordination failure: Theory and experiment," *Journal of Accounting Research*, 2004, *42* (2), 159–195.

Arifovic, Jasmina and Janet Hua Jiang, "Do sunspots matter? Evidence from an experimental study of bank runs," Staff Working Papers, Bank of Canada 2014.

Banerjee, Sanjay and Michael Maier, "Public information precision and coordination failure: An experiment," *Journal of Accounting Research*, 2016, *54* (4), 941–986.

Brown, Martin, Stefan T. Trautmann, and Razvan Vlahu, "Understanding bank-run contagion," *Management Science*, 2017, *63* (7), 2272–2282.

Carlsson, Hans and Eric van Damme, "Global games and equilibrium selection," *Econometrica*, 1993, *61* (5), 989–1018.

Chakravarty, Surajeet, Miguel A. Fonseca, and Todd R. Kaplan, "An experiment on the causes of bank run contagions," *European Economic Review*, 2014, *72* (C), 39–51.

—, —, Sudeep Ghosh, and Sugata Marjit, "Religious fragmentation, social identity and cooperation: Evidence from an artefactual field experiment in India," *European Economic Review*, 2016, *90*, 265–279. Social identity and discrimination.

Chari, Varadarajan V. and Ravi Jagannathan, "Banking panics, information, and rational expectations equilibrium," *Journal of Finance*, 1988, *43* (3), 749–761.

Charness, Gary and Matthew Rabin, "Understanding social preferences with simple tests," *Quarterly Journal of Economics*, 2002, *117* (3), 817–869.

Cornand, Camille and Frank Heinemann, "Optimal degree of public information dissemination," *Economic Journal*, 2008, *118* (528), 718–742.

— and —, "Measuring agents' reaction to private and public information in games with strategic complementarities," *Experimental Economics*, 2014, *17* (1), 61–77.

Dang, Tri Vi, Gary Gorton, Bengt Holmström, and Guillermo L. Ordoñez, "Banks as secret keepers," *American Economic Review*, April 2017, *107* (4), 1005–29.

Devetag, Giovanna and Andreas Ortmann, "When and why? A critical survey on coordination failure in the laboratory," *Experimental economics*, 2007, *10* (3), 331–344.

Diamond, Douglas W. and Philip H. Dybvig, "Bank runs, deposit insurance, and liquidity," *Journal of Political Economy*, 1983, *91* (3), 401–419.

Dufwenberg, Martin, "Banking on experiments?," *Journal of Economic Studies*, 2015, *42* (6), 943–971.

Ebert, Michael, Joseph B. Kadane, Dirk Simons, and Jack D. Stecher, "Disclosure and rollover risk," Working Paper 2018.

Fischbacher, Urs, "z-Tree: Zurich toolbox for ready-made economic experiments," *Experimental Economics*, 2007, *10* (2), 171–178.

French, Kenneth R., Martin N. Baily, John Y. Campbell, John H. Cochrane, Douglas W. Diamond, Darrell Duffie, Anil K. Kashyap, Frederic S. Mishkin, Raghuram G. Rajan, David S. Scharfstein, Robert J. Shiller, Hyun Song Shin, Matthew J. Slaughter, Jeremy C. Stein, and René M. Stulz, *The Squam Lake report: Fixing the financial system*, Princeton University Press, 2010.

Garratt, Rod and Todd Keister, "Bank runs as coordination failures: An experimental study," *Journal of Economic Behavior & Organization*, 2009, *71* (2), 300–317.

Goldstein, Itay and Ady Pauzner, "Demand-deposit contracts and the probability of bank runs," *Journal of Finance*, 2005, *60* (3), 1293–1327.

__ **and Haresh Sapra**, "Should banks' stress test results be disclosed? An analysis of the costs and benefits," *Foundations and Trends in Finance*, 2014, *8* (1), 1–54.

Gorton, Gary, "Bank suspension of convertibility," *Journal of Monetary Economics*, 1985, *15* (2), 177–193.

__ , "The subprime panic*," *European Financial Management*, 2009, *15* (1), 10–46.

Greiner, Ben, "Subject pool recruitment procedures: Organizing experiments with ORSEE," *Journal of the Economic Science Association*, 2015, *1* (1), 114–125.

Harsanyi, John C. and Reinhard Selten, *A general theory of equilibrium selection in games*, Vol. 1, The MIT Press, 1988.

He, Zhiguo and Wei Xiong, "Rollover risk and credit risk," *Journal of Finance*, 2012, *67* (2), 391–430.

Heinemann, Frank, Rosemarie Nagel, and Peter Ockenfels, "The theory of global games on test: Experimental analysis of coordination games with public and private information," *Econometrica*, 2004, *72* (5), 1583–1599.

Hertzberg, Andrew, Jose Maria Liberti, and Daniel Paravisini, "Public information and coordination: Evidence from a credit registry expansion," *Journal of Finance*, 2011, *66* (2), 379–412.

Honoré, Bo E. and Ekaterini Kyriazidou, "Panel data discrete choice models with lagged dependent variables," *Econometrica*, 2000, *68* (4), 839–874.

Kaplan, Todd R., "Why banks should keep secrets," *Economic Theory*, 2006, *27* (2), 341–357.

Kiss, Hubert Janos, Ismael Rodriguez-Lara, and Alfonso Rosa-García, "On the effects of deposit insurance and observability on bank runs: An experimental study," *Journal of Money, Credit and Banking*, 2012, *44* (8), 1651–1665.

Martin, Antoine, David Skeie, and Ernst-Ludwig von Thadden, "The fragility of short-term secured funding markets," *Journal of Economic Theory*, 2014, *149*, 15–42.

Morris, Stephen and Hyun Song Shin, "Unique equilibrium in a model of self-fulfilling currency attacks," *American Economic Review*, 1998, *88* (3), 587–597.

_ **and** _ , "Social value of public information," *American Economic Review*, December 2002, *92* (5), 1521–1534.

Obstfeld, Maurice, "The logic of currency crises," in Barry Eichengreen, Jeffry Frieden, and Jürgen von Hagen, eds., *Monetary and Fiscal Policy in an Integrated Europe*, Springer, 1995, pp. 62–90.

Rankin, Frederick W., John B. Van-Huyck, and Raymond C. Battalio, "Strategic similarity and emergent conventions: Evidence from similar stag hunt games," *Games and Economic Behavior*, 2000, *32* (2), 315–337.

Schmidt, David, Robert Shupp, James M. Walker, and Elinor Ostrom, "Playing safe in coordination games: The roles of risk dominance, payoff dominance, and history of play," *Games and Economic Behavior*, 2003, *42* (2), 281–299.

Schotter, Andrew and Tanju Yorulmazer, "On the dynamics and severity of bank runs: An experimental study," *Journal of Financial Intermediation*, 2009, *18* (2), 217–241.

Svensson, Lars E.O., "Social value of public information: Comment: Morris and Shin (2002) is actually pro-transparency, not con," *American Economic Review*, 2006, *96* (1), 448–452.

Van-Huyck, John B., "Chapter 58 Emergent conventions in evolutionary games," in Charles R. Plott and Vernon L. Smith, eds., *Handbook of Experimental Economics Results*, Vol. 1, Elsevier, 2008, pp. 520–530.

APPENDIX

A Instructions

Table A1 details the number of participants in each session. There were two parts to the experiment, Part A (19 rounds) and Part B (17 rounds). The instructions to the relevant parts were only distributed at the start of the part. Both parts are identical.

Session	Date (Time)	Treatment	No. of subjects
1	03.06.2016 (0930)	FS	20
2	03.06.2016 (1130)	FW	20
3	01.07.2016 (0930)	NS	20
4	01.07.2016 (1130)	NW	20
5	07.07.2016 (0930)	FS	20
6	07.07.2016 (1100)	FW	20
7	07.07.2016 (1230)	NS	20
8	07.07.2016 (1445)	NW	18
9	24.10.2016 (1100)	FS	20
10	24.10.2016 (1330)	FW	20
11	26.10.2016 (0930)	NS	20
12	26.10.2016 (1300)	NW	18
13	07.11.2016 (0945)	FS	20
14	07.11.2016 (1130)	FW	18
15	09.11.2016 (1000)	NS	14
16	09.11.2016 (1130)	NW	16

TABLE A1. Details of experimental sessions.

The experiment was conducted in English. The following details the instructions for the FW (full information; weak outlook) treatment. Sentences which are unique to the strong outlook treatments will be marked in “text". Sentences which are unique to the no information treatments will be marked in “text".

A.1 Instructions: Introduction

Welcome to the experiment. Please read these instructions carefully. Your payment in this experiment will depend on your decisions and the decisions made by other people; it is therefore important you understand the rules of the experiment. In this experiment, your decisions will earn Experimental Currency Units (ECU).

75 ECU are worth €1.

At the end of the experiment, we will calculate your total ECU and convert it into euros. In addition, you will also receive a €4 show up payment.

The experiment will consist of two parts (Part-A and Part-B). The experimental design for Part-A is detailed below. We will inform you about the experimental design for Part-B once we have completed the Part-A experiment.

A.2 Instructions: Part-A

The Part-A experiment consists of at least 15 rounds. The actual number will be randomly determined by the computer but you will not know this number. At the end of Part-A, the computer will randomly choose your payoffs from one of the rounds and convert it into cash.

A.2.1 The Start of Each Round

At the start of each round, the computer will randomly match you with another player in this session. In addition, the computer will randomly generate a value for the variable R. Here, R can be any number between 0 and 500 300 and 800 in steps of 50, with each value being equally likely. The below table (Table A2) clarifies the possible values for R and the chance for each value.

Value of R	0 300	50 350	100 400	150 450	200 500	250 550	300 600	350 650	400 700	450 750	500 800
Chance	1/11	1/11	1/11	1/11	1/11	1/11	1/11	1/11	1/11	1/11	1/11

TABLE A2. Value of R.

- Both players will observe the value for R. Both players will NOT observe the value for R.
- Each player also has a saving account in a Bank worth 400 ECU.

Given the above, each player will perform two tasks. Your payoff from each task will depend on your decision and the decision of the other player. Your payoff for the round will be a combination of the payoffs from both tasks.

	Other Player withdraws Today	Other Player withdraws Tomorrow
You withdraw Today	200	400
You Withdraw Tomorrow	0	R

FIGURE A1. Task-A.

Task-A. Your first task is to decide whether you want to withdraw your money TODAY or wait until TOMORROW. The below table (Figure A1) describes how your payoff from the task will be computed.

- If both players withdraw today, you get 200 ECU (other player gets 200 ECU).
- If both players withdraw tomorrow, you get R ECU (other player gets R ECU).
- If you withdraw today and the other player tomorrow, you get 400 ECU (other player gets 0 ECU).
- If you withdraw tomorrow and the other player today, you get 0 ECU (other player gets 400 ECU).

Task-B. Your second task is to submit your guess as to how likely the other player will withdraw Tomorrow. To do so, you will submit a number between 0 and 100, in increments of 5 (i.e., 0, 5, 10, 15,...,95, 100). Here, a low number implies that it is highly unlikely for the other player to withdraw tomorrow. A high number implies that it is highly likely for the other player to withdraw tomorrow. Depending on your submitted guess and the withdrawal decision of the other player, your payoffs will be computed as follow:

For example, if your guess is 25 and the other player withdraws today, you will receive 93.75 ECU. If your guess is 90 and the other player withdraws tomorrow, you will receive 99 ECU.

Final Payoffs for the Round. Once both players have completed Task-A and Task-B, we will compute your payoffs.

Payoffs for the Round = Payoffs Task-A + Payoffs Task-B

Your guess	Other player withdraws today	Other player withdraws tomorrow
0	100	0
5	99.75	9.75
10	99	19
15	97.75	27.75
20	96	26
25	93.75	43.75
30	91	51
35	87.75	57.75
40	84	64
45	79.95	69.75
50	75	75
55	69.75	79.75
60	64	84
65	57.75	87.75
70	51	91
75	43.75	93.75
80	36	96
85	27.75	97.75
90	19	99
95	9.75	99.75
100	0	100

TABLE A3. Task-B.

A.2.2 Control questions

Here are some questions that examines your understanding of Part-A design. Please submit your answers in the computer screen.

1. There are at least 15 rounds in Part-A. (True/false)
2. You had chosen to withdraw today and the other player had chosen to withdraw tomorrow. Your Payoffs from Task-A will be ___. (0 ECU; 200 ECU; 400 ECU; R ECU)
3. You had chosen to withdraw tomorrow and the other player had chosen to withdraw tomorrow. Your Payoffs from Task-A will be ___. (0 ECU; 200 ECU; 400 ECU; R ECU)
4. You had chosen to withdraw tomorrow and the other player had chosen to withdraw today. Your Payoffs from Task-A will be ___. (0 ECU; 200 ECU; 400 ECU; R ECU)
5. You submit a Guess of 45 and the other player withdraws today. Your Payoffs from Task-B will be ___
6. Both Players will observe R. (True/false)

A.2.3 Other information

Please be reminded that the experiment in Part-A will consist of at least 15 rounds. We will inform you about the Part-B experiment was we have completed Part-A. After Part-B is completed, we will require you to complete a simple survey form. Please raise your hands if there are any questions and the experimenter will answer your questions in private.

A.3 Instructions: Part-B

Part-B of the experiment is identical to Part A.

Reminders

- The Part-B experiment consists of at least 15 rounds. The actual number will be randomly determined by the computer but you will not know this number. At the end of Part-B, the computer will randomly choose your payoffs from one of the rounds and convert it into cash.

- Both players will observe the value for R. Both players will NOT observe the value for R.
- Each player will perform two tasks (Task-A and Task-B). Your payoff from each task will depend on your decision and the decision of the other player. Your payoff for the round will be a combination of the payoffs from both tasks.