Do Sunspots Matter? Evidence from an Experimental Study of Bank Runs*

Jasmina Arifovic† Janet Hua Jiang‡

March 17, 2014

Abstract

We investigate the reaction to sunspots in a bank-run game in a controlled laboratory environment. The sunspot variable is a series of random public announcements predicting withdrawal outcomes. The treatment variable is the coordination parameter, defined as the minimum fraction of depositors required to wait so that waiting entails a higher payoff than withdrawing. We conduct treatments with a high, low and intermediate value of the coordination parameter, respectively. Although theory predicts sunspot equilibria exist in all treatments, strong responses to sunspots only occur in the treatment featuring the intermediate value of the coordination parameter where strategic uncertainty is high.

JEL Categories: C91; C92; D80; E58; G20

Keywords: Bank Runs; Sunspots; Experimental Studies; Financial Crises; Strategic Uncertainty; Public Announcements

*We appreciate comments and suggestions from Toni Ahnert, Gabriele Camera, Timothy Cason, Luba Peterson, Julian Romero, Yaroslav Rosokha, Malik Shukayev and participants at the 2013 CEA conference in Montréal, the 2013 CEF conference in Vancouver and the 2013 SAET conference in Paris, and seminars at the Bank of Canada, University of Missouri, Concordia University and Purdue Univerisity. The support from the CIGI/INET grants program is gratefully acknowledged (Arifovic's grant #5533). Heng Sok has provided excellent research assistance. The views expressed in this paper are those of the authors. No responsibility for them should be attributed to the Bank of Canada.

†Simon Fraser University. E-mail: arifovic@sfu.ca.

‡Bank of Canada. E-mail: jjiang@bankofcanada.ca.

1 Introduction

Economists have long been contemplating whether financial crises can be ascribed to factors other than weak economic fundamentals. For example, Friedman and Schwartz (1963) attribute banking crises during the Great Depression to non-fundamentals, because the crises were not preceded by a significant deterioration in macroeconomic fundamentals. The 1997-98 Asian financial crisis spurred a huge debate about whether the crisis was driven by weak fundamentals or self-fulfilling prophecies.[1] In light of the recent global financial turmoil, the debate as to whether some of the crisis events are due to non-fundamental factors is likely to persist for a long time.

The seminal paper by Diamond and Dybvig (1983, hereafter DD) establishes the theoretical possibility that non-fundamental factors could be responsible for crisis outcomes. DD focus on bank runs, but the mechanism described in their model applies more broadly to other types of financial crises, such as currency crises (Obstfeld 1996), debt runs (He and Xiong 2012) and repo runs (Martin, Skeie and von Thadden 2014). A main feature of the model is the existence of strategic complementarity: when depositors withdraw money from a bank, they deplete the bank's capital, reducing the amount available for depositors who come later. The strategic complementarity leads to multiple equilibria, including a crisis equilibrium where all depositors run on the bank disregarding their liquidity need. As a result, even banks with healthy assets could fail. DD suggest (without formal modelling) that the selection between the bank-run equilibrium and the good equilibrium could depend on realizations of a sunspot variable, i.e., some commonly observed random variable unrelated to the bank's fundamental condition.

Azariadis (1981) and Cass and Shell (1983) formalized the analysis of sunspot equilibria. They show that in an environment that gives rise to multiple self-fulfilling rational expectations equilibria, sunspot equilibria also exist where the realization of the sunspot variable affects agents' beliefs or expectations, and, in turn, their choices and equilibrium outcomes. In other words, although sunspots have no direct impact on the economy's fundamental parameters, such as preferences, endowments or technologies, they may function as a coordination device and indirectly affect the economy through the expectations channel. For formal equilibrium analysis of sunspot-induced financial crises, see Waldo (1985); Freeman (1988); Loewy (1991); Cooper and Ross (1998); Cole and Kehoe (2000); Peck and Shell (2003); Ennis and Keister (2003); Aghion, Bacchetta and Banerjee (2004); and Gu (2011).

In this paper, we test the sunspot theory of financial crises through a controlled laboratory study. The research questions that we are interested in are "do sunspots matter as predicted by the theory?" and "are there certain situations where sunspots matter more?"

[1] For example, Corsetti, Pesenti and Roubini (1999a,b), Dooley (2000), and Burnside, Eichenbaum and Rebelo (2001) emphasize the role of weak fundamentals, while Radelet and Sachs (1998), Chang and Velasco (2000), and Schneider and Tornell (2004) stress the role of self-fulfilling prophecies.

We conduct our experimental analysis in the context of the bank-run game studied in DD. There are several reasons why we chose this framework. First, the game is simple and easy to implement in the laboratory: subjects make a binary choice whether to withdraw their money from the bank or not. Second, the game involves multiple equilibria that can be Pareto ranked, so the coordination result has important welfare implications. Third, as mentioned earlier, the mechanism in the DD model applies to other types of financial crises, such as currency crises, debt runs and repo runs. We expect the lessons from this study to apply to other run behaviors as well. Finally, our specific hypothesis and design, which we introduce below, is inspired by a recent experimental study of bank runs by Arifovic, Jiang and Xu (2013).

Arifovic, Jiang and Xu (2013) investigate bank runs as pure coordination failures in the absence of sunspot variables. They find that the occurrence of miscoordination-based bank runs depends on the value of the coordination parameter, defined as the minimum fraction of depositors required to wait so that waiting entails a higher payoff than withdrawing. In particular, the values of the coordination parameter can be divided into three regions: the "run" region, the "non-run" region and the "indeterminacy" region, characterized by high, low and intermediate values of the parameter, respectively. When the coordination parameter lies in the run (non-run) region, strategic uncertainty is low: subjects are almost unanimous in their choices, and all experimental economies stay close or converge to the run (non-run) equilibrium. In games with the coordination parameter located in the indeterminacy region, subjects are much less certain as to what the "right" choice is; as a result, the outcomes of the experimental economies vary widely and become difficult to predict.

Extrapolating from the result in Arifovic, Jiang and Xu (2013), we conjecture that if a sunspot variable is introduced to the bank-run game, its power as a coordination device is likely to be weak if the coordination parameter lies in the run or the non-run region, but strong if the parameter is in the indeterminacy region. In other words, sunspots matter more if there is great strategic uncertainty. We conduct three experimental treatments to test the hypothesis. Each treatment is characterized by a different value of the coordination parameter that corresponds to the non-run region, the run region, and the indeterminacy region. All three games have a sunspot equilibrium where agents coordinate their actions on realizations of a sunspot variable. In our experiment, the sunspot variable takes the form of a sequence of randomly generated announcements forecasting how many people will choose to withdraw. The content of an announcement is either: (1) a forecast that x or more people will choose to withdraw, or (2) a forecast that x or less people will choose to withdraw. The value of x is such that it is optimal to withdraw if and only if the number of withdrawals is $\geq x$.

We conduct six sessions of the experiment for each treatment. The experimental results confirm the hypothesis. Subjects do not react to the sunspot announcement for the non-run (run) values of the coordination parameter, with all six experimental economies quickly converging to non-run (run) equilibria despite the sunspot announcement. For the treatment with the value of the coordination parameter in the indeterminacy region, subjects follow the sunspot announcement throughout the whole session in four out of six experimental economies. In the other two sessions, subjects follow the sunspot variable initially, but coordination on the variable is not strong enough in early periods, and the economies converge to the run equilibrium in the end. The results show that subjects tend to follow sunspots when there is great strategic uncertainty.

Our study suggests that people are more susceptible to mood swings when they face great strategic uncertainty. In those situations, a publicly observable announcement by the government, an influential public figure or a newspaper may serve as a coordination device and have a huge impact on people's choices. Our experiment considers the extreme case where the publicly observed variable contains no information on the fundamental condition of the economy and affects the economy purely through the expectations channel as a coordination device. However, we expect that the result that people tend to react more strongly to public announcements in times of uncertainty would continue to hold in cases where the public announcement provides some information on the condition of the economy. The policy advice stemming from our study is that extra attention should be paid to the wording of public statements during uncertain times, such as a crisis event, because the impact of public statements tends to be much stronger in those situations.

Our result that people tend to respond more strongly to public announcements is largely consistent with the observation that markets seem to be very sensitive to political announcements during crises. Gade et al. (2013) show evidence that during the period from January 2009 to October 2011, political communications have a quantifiable effect on the sovereign bond spreads of Greece, Ireland and Portugal over the German Bund, with an increase in positive (negative) words contributing to a reduction (rise) in yield spreads. In line with our policy suggestion, the Dutch Finance Minister, J.K. de Jager, urged European Union policy-makers to think carefully about what impact their comments may have on the markets during his interview with Der Spiegel on 22 August 2011. In the United States, a publicly released letter by Senator Charles Schumer on 26 June 2008 that questioned the viability of IndyMac was blamed for inducing panic among the bank's depositors. During the 9/11 terrorist attacks, the Federal Reserve announced reassuring messages over Fedwire that the fund transfer system was "fully operational" and would remain open until "an orderly closing can be achieved." This measure is acclaimed to have helped maintain public confidence and reduce disruption to the financial system.

Our study also contributes to the ongoing discussion on central bank communication. Most studies focus on the issue of central bank transparency, and debate what and how much the central bank should communicate to the public. Our study discusses public communication from a different perspective, suggesting that, besides the content, the timing and market environment of communication are also important: public statements tend to be more influential during times of uncertainty.[2]

We view our experimental study of sunspot-induced financial crises as a useful complement to empirical studies. Testing the sunspot theory of financial crises involves two tasks: (1) identifying the sunspot variable, and (2) determining whether an economic outcome is affected by non-fundamental factors. The empirical literature usually skips the first task, and makes serious attempts at the second task. The general approach is to regress the likelihood of a crisis event on relevant fundamental variables. If the regression produces a significant unexplained residual, then it is taken as evidence that non-fundamental variables play an important role in generating crises. See, for example, Boyd et al. (2014) and Calomiris and Mason (2003) for the analysis of banking crises, and Rose and Svensson (1994) and Jeanne (1997) for the analysis of currency crises.

In his survey of the empirical literature on financial crises, Goldstein (2012) mentions that the ideal way to capture non-fundamental induced crises would be to show how agents change their choices in response to their beliefs about what other agents will choose, but that field data offer very few such observations. In contrast, such situations can be created in the laboratory in a relatively easy way. In our experimental study, we clearly define/identify the sunspot and fundamental variables, and ensure that the sunspot variable is not directly related to the fundamentals and affects the economic outcome only through the expectations channel as a coordination device. We directly examine the effect of the sunspot variable by fixing the fundamentals and allowing only the sunspot variable to vary over time. In the case of empirical studies using field data, the task has to be carried out with special care to mitigate the potential problem of omitted variables.

In addition, empirical studies have generated different conclusions on the contribution of non-fundamentals. For example, Calomiris and Mason (2003) regress the likelihood of individual bank failure during the Great Depression on fundamentals, including the attributes of individual banks and the exogenous local, regional, and national economic shocks. They find that fundamentals explain the risk of bank failures well in three crises (late 1930, mid-1931, and late 1931), but the crisis in early 1933 saw a large unexplained increase in the risk of bank failures. Given that empirical studies reach different conclusions on the effect of non-fundamental variables, we can use the experimental study to gain some insight into the conditions under which sunspots have a stronger impact on the economic outcome.

The rest of the paper is organized as follows. Section 2 discusses related literature. Section 3 describes the theoretical framework that underlies the experiment. Section 4 introduces the hypothesis and discusses the experimental design. Section 5 reports and

[2] See Woodford (2005) for a general discussion on the communication of monetary policies, and Morris and Shin (2002) for the social value of the central bank's public disclosure of information on the state of the economy in the presence of private information. We provide a more detailed review of this literature in the next section.

analyzes the experimental results. Section 6 concludes.

2 Related Literature

Our paper is closely related to experimental studies of sunspots. Marimon, Spear and Sunder (1993), Duffy and Fisher (2005), and Fehr, Heinemann and Llorente-Saguer (2012) consider models with multiple equilibria that are Pareto equivalent or cannot be Pareto ranked. As with our paper, Arifovic, Evans and Kostyshyna (2013) provide evidence of sunspot equilibria in the context of a model with multiple equilibria that can be Pareto ranked. Our study has a different focus, which is to investigate the power of sunspots as a coordination device in different economic situations characterized by the coordination parameter. We find that subjects tend to react (ignore) to sunspot variables when the coordination parameter takes an intermediate (extreme) value and the strategic uncertainty is high (low).

Marimon, Spear and Sunder (1993) study expectationally driven price volatilities in experimental overlapping-generation economies. They find that subjects may follow sunspots (in the form of a blinking square aternating in colors on subjects' computer screens), but only after being trained or exposed to real cycles induced by real shocks in phase with the realization of the sunspot variable. Duffy and Fisher (2005) consider a market game with two equilibria featuring different equilibrium prices. The two equilibria cannot be Pareto ranked: some subjects are better off in one equilibrium, whereas others are better off in the other equilibrium. They find that in call markets, subjects can coordinate on a sunspot equilibrium based on a public announcement that forecasts the level of the market price. Fehr, Heinemann and Llorente-Saguer (2012) study a two-player coordination game with a continuum of Nash equilibria, all of which have the same payoff. They find that sunspot equilibria emerge if there are salient public signals. Arifovic, Evans and Kostyshyna (2013) study coordination in a production economy with a positive externality that gives rise to multiple steady states with different levels of employment and productivity. They observe coordination on extrinsic announcements on the level of productivity in most of their sessions. In some of the sessions, convergence to the stable steady states occurred as well.

Another closely related literature is the study of bank runs in controlled laboratory environments. Our study focuses on the effect of the sunspot variable, which is absent in all other experimental studies of bank runs. Madiès (2006) provides the first experimental study of miscoordination-based bank runs within the framework of the DD model, with an emphasis on the effectiveness of alternative ways to prevent bank runs. Garratt and Keister (2009) study the effects of uncertainty regarding the aggregate liquidity demand and the number of withdrawal opportunities. Schotter and Yorulmazer (2009) examine how the speed of withdrawals is affected by the number of opportunities to withdraw and the existence of insiders in a dynamic bank-run game. Klos and Sträter (2013) test the prediction of the global game theory of bank runs developed by Morris and Shin (2001) and Goldstein and Pauzner (2005). Kiss, Rodriguez-Lara and Rosa-Garcia (2012) study the effects of deposit insurance and observability of previous actions on the emergence of bank runs. Chakravarty, Fonseca and Kaplan (2012) and Brown, Trautmann and Vlahu (2012) investigate how runs spread across two different banks through contagion. See Dufwenberg (2013) for a more detailed review of the experimental literature on bank runs.

Finally, our paper complements existing studies on central bank communication. Most of the literature focuses on the question of what to communicate, with central bank transparency being the recurring topic. Our study suggests that in addition to the content, the timing and market environment of communication are also important: public statements tend to have a stronger impact during times of great uncertainty. There is a large and growing literature on the communication of monetary policies, the full review of which is beyond the scope of our paper. See Woodford (2005) for a general discussion, and Blinder et al. (2008) for a survey of the theoretical and empirical works on the topic.[3] Recently, some experimental work has also been done on monetary policy communication; see, for example, Kryvtsov and Petersen (2013).

Another area of research on central bank communication follows the model developed by Morris and Shin (2002) to examine the social value of public information on the fundamental state of the economy (for further theoretical treatment of the topic, see Amato, Morris and Shin 2002; Hellwig 2005; Svensson 2006; Morris and Shin 2007; Angeletos and Pavan 2007; and Cornand and Heinemann 2008). Baeriswyl and Cornand (forthcoming) and Hichri and Trabelsi (2013) provide two experimental studies of the issue. This line of literature stresses the dual roles of public information conveying fundamentals information as well as serving as a coordination device. The welfare effect of increased public disclosures is ambiguous when private agents also have access to independent sources of information. In our experiment, the fundamental state of the economy is public information, and the focus of our study is on the coordination role of public announcements. In addition, our study provides insight into the situations in which public announcements are more influential.

3 Theoretical Framework

The theoretical framework that underlies our study is the DD model of bank runs. In this model, the bank has a role of a liquidity insurance provider that pools depositors' resources to invest in profitable illiquid long-term assets, and at the same time issues short-term demand deposits to meet the liquidity need of depositors.[4] The contract requires that

[3] Some issues that are still under debate include: Should the central bank deliver explicit statements on the likely future path of interest rates? Should the central bank's decision-making process be made more transparent, say, by the release of the minutes of its deliberations?

[4] For optimal contracting in the DD framework, please refer to Green and Lin (2000, 2003), Andolfatto, Nosal and Wallace (2007), Andolfatto and Nosal (2008) and Ennis and Keister (2009a, 2009b, 2010). The first

agents deposit their endowment with the bank. In return, agents receive a bank security, which can be used to demand consumption early (at date 1) or late (at date 2). The bank promises to pay $r > 1$ to depositors who choose to withdraw at date 1. Resources left after paying early withdrawers generate a rate of return $R > r$, and the proceeds are shared by all who choose to roll over their deposits and wait until date 2 to consume. The critical feature of the demand deposit contract is the presence of strategic complementarity: when depositors withdraw money from the bank, they deplete the bank's capital, reducing the amount available for depositors who come later. This strategic complementarity leads to multiple equilibria and bank runs induced by coordination failures.

To conduct the experiment, we keep this main feature of the DD model, but simplify the original model along two dimensions to facilitate the experimental design.[5] First, in the original model, agents are subject to liquidity shocks and become either patient consumers (who are indifferent between consuming early or late) or impatient consumers (who have to consume early). Impatient agents always withdraw, and only patient agents are "strategic" players. For the experiment, we focus on strategic players so that all agents are patient consumers.[6] Second, we abstract from the sequential service constraint for simplification and assume instead that if the bank does not have enough money to pay every withdrawer the promised short-term rate, r, it divides the available resources evenly among all depositors who demand to withdraw. The sequential service constraint is not essential for the existence of multiple equilibria; the fact that $r > 1$ is sufficient to generate a payoff externality and panic-based runs.[7] In the experiment, we have N subjects playing the roles of depositors, each starting with one unit of money deposited with the bank and choosing to withdraw early or wait. With the above simplifications, the payoff to a depositor who chooses to withdraw is

$$\pi_1 = \min\left\{r, \frac{N}{e}\right\}, \tag{1}$$

where e is the number of depositors who choose to withdraw and the payoff for those who choose to wait is

$$\pi_2 = \max\left\{0, \frac{N - er}{N - e}R\right\}. \tag{2}$$

Note that if $e > \hat{e} \equiv N/r$, the bank will not have enough money to pay all those who decide to withdraw the promised rate r, and those who choose to wait will receive zero payoff.

three papers show that the multiple-equilibria result disappears if more complicated contingent contracts – as compared with the simple demand deposit contracts in DD – are used. Ennis and Keister (2009a, 2009b, 2010) show that the multiple-equilibria result is restored if the banking authority cannot commit not to intervene in the event of a crisis, or if the consumption needs of agents are correlated.

[5] Arifovic, Jiang and Xu (2013) make the same set of simplifications to the demand deposit contract.

[6] Besides Arifovic, Jiang and Xu (2013), Madiès (2006) makes the same arrangement in this regard.

[7] DD derive the optimal short-term rate r^* in their original paper. For our experimental study, we do not use the optimal rate r^*. Instead, we set r to be values greater than 1. As will become clear in the next section, there is a one-on-one correspondence between r and our main treatment variable, the coordination parameter. Using r as a control variable allows us to change the coordination parameter in a simple way.

The coordination game characterized by the above payoff structure has two symmetric pure-strategy Nash equilibria.[8] In the run equilibrium, every depositor chooses to withdraw and run on the bank, expecting others to do the same. As a result, $e = N$, and everybody receives a payoff of 1. In the non-run equilibrium, every depositor chooses to wait, expecting others to do the same. In this equilibrium, $e = 0$, and everybody receives a payoff of R. There also exist stationary sunspot equilibria, where the economy switches between the run equilibrium or the non-run equilibrium contingent on the realization of a sunspot variable.

4 Hypothesis and Experimental Design

In this paper, we examine whether sunspots matter as predicted by the theory (note that in the bank-run model, sunspot equilibria can be constructed for any r between 1 and R), and whether there are certain situations where sunspots matter more. The specific design and hypothesis are inspired by an earlier experimental study by Arifovic, Jiang and Xu (2013), who investigate how the level of coordination requirement (denoted as η) affects the occurrence of bank runs as a result of pure coordination failures in the absence of sunspot variables.

The fundamental condition of the economy, captured by the long-term return, R, and the short-term repayment rate, r, is public information. The value of R is fixed throughout the experiment. The short-term rate r is set to match our main treatment variable, the coordination parameter, which remains fixed in each treatment of the experiment. The coordination parameter measures the level of coordination that is required for agents who choose to wait to receive a higher payoff than those who choose to withdraw. It is calculated as the fraction of depositors who choose to wait that equalizes the payoffs to the two strategy choices. We can calculate η in two steps. First, solve for the value of e, the number of depositors who choose to withdraw, that equalizes the payoffs associated with withdrawing and waiting,

$$r = \frac{N - er}{N - e} R,$$

and denote it by e^*. Thus, e^* is given by

$$e^* = \frac{R - r}{r(R - 1)} N.$$

Second, η can be calculated from the equation,

$$\eta = 1 - \frac{e^*}{N} = \frac{R(r - 1)}{r(R - 1)}.$$

Note that there is a one-on-one correspondence among η, e^* and r. Given η (or, equivalently,

[8] There is also a symmetric mixed-strategy equilibrium where each depositor chooses to wait with a probability between 0 and 1, and the expected payoffs from the two strategies are equalized.

e^*or r), the payoff from waiting exceeds that from withdrawing early iff the fraction of depositors choosing to wait is larger than η (or, equivalently, if the number of depositors choosing to withdraw is less than e^*).

Arifovic, Jiang and Xu (2013) find that in the absence of sunspot variables, the performance of the economy depends on the value of the coordination parameter. In particular, they divide the values of the coordination parameter into three regions: the run region ($\eta \leq 0.5$), characterized by high values of the parameter; the non-run region ($\eta \geq 0.8$), characterized by low values of the parameter; and the indeterminacy region ($\eta = 0.6$ and 0.7), characterized by intermediate values of the parameter. In the run (non-run) region, all experimental economies stay close or converge to the run (or non-run) equilibrium. In these regions, subjects perceive little strategic uncertainty and have a good idea about their own choices and those of other subjects. It is also easy for subjects to reach a consensus so that all experimental economies stay close or converge to the run (or non-run) equilibrium. In contrast, when the coordination parameter lies in the indeterminacy region, subjects become much less certain about other subjects' strategies and what the *right* choice is. As a result, the outcomes of the experimental economies vary widely and become difficult to predict.

In view of these results in Arifovic, Jiang and Xu (2013), we conjecture that when a sunspot variable is introduced into the game, its power as a coordination device will depend on the coordination parameter. Subjects are likely to ignore the sunspot variable if the fundamental lies in the run and non-run region, in which case there is little strategic uncertainty. On the other hand, if the coordination parameter is such that there is great strategic uncertainty, subjects will actively look for a coordination device; in this case, the sunspot variable may become a powerful coordination device and have huge impact on the coordination outcome.

To test our hypothesis on the effect of the sunspot variable, we conduct three experimental treatments with three values of the coordination parameter. The value of η is equal to 0.2, 0.7 or 0.9, which lies in the non-run region, the indeterminacy region and the run region, respectively.[9] Our hypothesis is that the power of the sunspot variable is likely to be high when $\eta = 0.7$, but low when $\eta = 0.2$ or 0.9. More specifically, the economy is likely to switch between the two equilibria in phase with the realization of the sunspot variable in the treatment with $\eta = 0.7$. When $\eta = 0.2$, the economy is likely to stay at the non-run equilibrium irrespective of the announcement. When $\eta = 0.9$, the economy is likely to stay at the run equilibrium disregarding the announcement.

While formulating the sunspot variable, we draw a useful lesson from previous experimental studies of sunspots, all of which suggest that the occurrence of sunspot equilibria

[9] Note that although we use η as the treatment variable, following the discussion in the previous section that there is a one-on-one correspondence among e^*, η and r, we could also use e^* or r as the treatment variable.

requires a common understanding of the semantics of the sunspot variable. As summarized in Duffy and Fisher (2005), semantics has three ingredients. First, a sunspot variable must have realizations that are public. Second, a sunspot variable can be a coordinating device only if its meaning is transparent. Third, there must be some training periods during which subjects believe that the sunspot variable is actually correlated with market outcomes. Marimon, Spear and Sunder (1993) discover that without such training, subjects will not respond to the sunspot variable. Duffy and Fisher (2005) find that subjects successfully coordinate on the sunspot equilibrium if they experience six periods of training, and if the sunspot announcement is formulated as a forecast of the equilibrium market price ("high" or "low"). In contrast, if training is skipped, and if the announcement is replaced by "the forecast is sunshine" or "the forecast is rain", subjects fail to coordinate on the sunspot equilibrium.[10]

In our experiment, the sunspot variable is a series of randomly generated public announcements that predict the number of withdrawals. The value of the sunspot variable is shown to all subjects. More specifically, the following explanation is included in the instructions (refer to the appendix for the experimental instructions):

"*In each period, an announcement will show up in the lower right section of the screen to forecast the number of withdrawal requests for this period. The announcement will be either 'The forecast is that* e^* *or more people will choose to withdraw,' or that 'The forecast is that* e^* *or less people will choose to withdraw.' Everybody receives the same message. The announcements are randomly generated. There is a possibility of seeing either announcement, but the chance of seeing the same message that you saw in the previous period is higher than the chance of seeing a different announcement. These announcements are forecasts, which can be right or wrong. The experimenter does not know better than you how many people will choose to withdraw (or wait) in each period. The number of withdrawals is determined by the decisions of all participants. Your actual payoff depends only on your own choice and the choices of other participants.*"

The value of e^* is the number of subjects requesting to withdraw that equalizes the payoff to both strategies. Note that it is optimal to withdraw if and only if the number of withdrawals, e, is $\geq e^*$. In the following, we use A to denote the sunspot announcement, with $A = 0$ corresponding to the announcement of a low number of withdrawals, or $e \leq e^*$, and $A = 1$ corresponding to the announcement of a high number of withdrawals, or $e \geq e^*$. The announcement $A = 0$ is equivalent to "waiting is a better strategy," and the announcement $A = 1$ is equivalent to "withdrawing is a better strategy."

In each session of the experiment, subjects play a repeated one-period game for 56 pe-

[10] Marimon, Spear and Sunder (1993) show that subjects can learn to respond to a sunspot variable in the form of a blinking square cycling in different colors. However, the effect of the sunspot variable seems to weaken as the experiment continues. One potential reason may be that the meaning of the sunspot variable is not salient enough.

riods. Each subject starts a new period with 1 unit of experimental money in the bank. Upon observing the realization of the sunspot variable, the subjects decide simultaneously whether to withdraw their money from the bank or to wait. Each session consists of six practice periods and 50 formal periods. During the practice periods, subjects familiarize themselves with the task that they are requested to perform. Given that all existing experimental studies of sunspots emphasize the importance of training in inducing a reaction to sunspots, we also use the practice periods to build the correlation between the coordination outcome and the realization of the sunspot variable. The forecast is that $e \leq e^*$ in the first three practice periods, and $e \geq e^*$ in the second three practice periods. The numbers of withdrawals in those periods are predetermined to make the announcements self-fulfilling.

We ran six sessions of experiment for each of the three treatments, for a total of 18 sessions. To facilitate comparison among different sessions, we follow Arifovic, Evans and Kostyshyna (2013) to generate the random sequence of announcements before the experiment and use the same sequence of announcements in all sessions of the experiment. The sunspot announcements follow a Markov process in which the probability of observing the same announcement in the next period is 0.8. We adopt a persistent shock sequence to make the experimental environment more stable. With a low switching probability of 0.2, the environment is more likely to remain the same for an extended period of time, instead of switching frequently back and forth between the two announcements. The average number of A in the 50 formal periods is 0.56, with slightly more announcements of high withdrawals. Table 1 lists the parameters used for each experimental treatment.

The program used to conduct the experiment is written in z-Tree (Fischbacher, 2007). At the beginning of a session, each subject is assigned a computer terminal. In each period, each subject starts with 1 experimental dollar in the bank and decides whether to withdraw or to wait and roll over their deposits through the decision screen. The computer screen shows the payoff table, which lists the payoff that an individual will receive if he/she chooses to withdraw or wait given that $n = 1 \sim 9$ of the other 9 subjects choose to withdraw. The payoff table helps to reduce the calculation burden for the subjects so that they can focus on playing the coordination game. The screen also provides the history of the experiment with a graph of the total number of withdrawals in all past periods and a history table that shows the history of the announcements, the actual number of withdrawals, the subject's decision, the subject's own payoff in each period and the subject's cumulative payoff. The sunspot announcement is located right above the buttons "withdraw" and "wait," which subjects click on to input their withdrawal decisions. Once all the decisions are made, the total number of withdrawals is calculated. Subjects' payoffs are then determined by equations (1) and (2). Communication among subjects is not allowed during the experiment. The experiment was run at the Economic Science Institute, Chapman University, Orange, USA, from fall 2012 to winter 2013.[11] Each session lasted for about 50 minutes. The average

[11] Since the game in the experiment is fairly straightforward, it is important that the subjects have no

earning was around \$14.

5 Experimental Results

Figure 1 plots the coordination results for each of the 18 sessions of experiment. The horizontal axis represents the time period running from -5 to 50. Periods -5 to 0 are the practice periods. Periods 1 to 50 are the formal periods. The solid line with dot markers graphed against the left vertical axis depicts the time path of the number of withdrawals. The upper dashed line is e^* used for the announcement. The lower dashed line is $\hat{e}$, at which the bank becomes bankrupt or runs out of money to meet withdrawal requests. The announcement (A) is represented as circles against the right vertical axis.

Table 2 shows three statistics, the average number of withdrawals, the percentage of bankruptcies, and the percentage of individual subjects' choices that are consistent with the announcement; i.e., to withdraw (wait) if the announcement is that $e \geq (\leq)\ e^*$. We provide the statistics for each session and for each treatment (in bold face), derived as the average of the session statistics. For each statistic, we calculate the values for the whole session, periods with $A = 0$ and periods with $A = 1$ (excluding the practice periods).

To further capture the effect of the sunspot announcement on the average number of withdrawals, we run a rank-sum test of the average number of withdrawals associated with the two types of sunspot announcements for each of the three treatments. The first group contains the statistics for periods with $A = 0$, and the second group contains statistics for periods with $A = 1$. Each group has six observations corresponding to the six sessions of experiment run for each treatment. The test results are given in Table 3.

We first check the results for the treatment with $\eta = 0.2$. In this treatment, the number of withdrawals is hardly affected by the sunspot announcement. All six experimental economies quickly converge to the non-run equilibrium. The treatment average number of withdrawals is very small for both types of announcements: 0.21 for $A = 0$ and slightly higher at 0.26 for $A = 1$. A rank-sum test between the average number of withdrawals for the two types of announcements shows that the two cases have exactly the same rank sum. The two-sided (one-sided) p-value is 100% (50%). In other words, in terms of the average number of withdrawals, the two samples cannot be distinguished from each other. There are no bankruptcies with either announcement. The probability that individual choices are consistent with the announcement is very high at 98% for $A = 0$, but very low at 3% for $A = 1$.

For the treatment with $\eta = 0.9$, the effect of the sunspot variable on the number of withdrawals is also very weak (though stronger than in the treatment with $\eta = 0.2$). All six experimental economies converge to the vicinity of the run equilibrium by period 30 and

prior experience with experiments of coordination games.

stay close to the equilibrium afterwards. The average value of withdrawals is very high, with both types of announcements at 8.09 for $A = 0$ and slightly larger at 8.78 for $A = 1$. The rank-sum test between the average number of withdrawals for the two announcements suggests that subjects tend to withdraw more often with $A = 1$, generating a p value of 10% (5%) if a two-sided (one-sided) test is used. However, the difference between the average number of withdrawals is quite small, at 0.69. The probability of bankruptcies is very high with both types of announcements: 92% with $A = 0$, and 98% with $A = 1$. The percentage of individual choices that are consistent with the announcement is 89% for $A = 1$, and much lower at 19% for $A = 0$.

Compared to the treatments with $\eta = 0.2$ and 0.9, subjects respond strongly to the sunspot variable in the treatment with $\eta = 0.7$. The rank-sum test of the average number of withdrawals under the two types of announcements generates a very small p-value of 0.39% (0.20%) if a two-sided (one-sided) test is used. The difference between the treatment average number of withdrawals when $A = 0$ and when $A = 1$ is very high, at 5.09. The effect of the sunspot variable is therefore both statistically and economically significant.

The effect of the sunspot announcement is particularly strong in sessions 7, 8, 9 and 12, where the experimental economy switches between the two equilibria in phase with the announcement throughout the whole session. When $A = 0$, the experimental economy stays close to the non-run equilibrium, with the average number of withdrawals at between 0.36 and 2.14. When $A = 1$, the economies stay close to run equilibrium, with the average number of withdrawals at between 7.79 and 8.54. There are no bankruptcies when $A = 0$, but frequent bankruptcies when $A = 1$ (between 71% and 86%). The percentage of individual choices that are consistent with the announcement is high for both $A = 0$ (at between 79% and 96%) and $A = 1$ (at between 78% and 85%).

In sessions 10 and 11, the power of the sunspot announcement is weaker than in sessions $7, 8, 9$ and 12, but still stronger than in the other two treatments. The two experimental economies respond to the sunspot in early periods up until period 26 in session 10 and period 20 in session 11. However, during two earlier episodes of low announcement (periods $12 - 13$ and periods $18 - 22$), the number of withdrawals does not drop enough to confirm the announcement. In later periods, subjects stop responding to the sunspot variable and continue withdrawing their money from the bank, and the two economies converge to the vicinity of the run equilibrium. The performance of the two economies in the second half mimics the situation where $\eta = 0.9$. The difference between the average number of withdrawals under the two types of announcements is 2.41 in session 10 and 1.66 in session 11. The percentage of individual strategies that are consistent with the announcement is high for $A = 1$ (88% in session 10 and 85% in session 11), but much lower for $A = 0$ (40% in session 10 and 29% in session 11). Bankruptcies occur frequently (86% of the time in both sessions) when $A = 1$. For the announcement $A = 0$, there is still a high incidence of bankruptcies (45% of the time in session 10 and 64% of the time in session 11). The different performance of the experimental economy in treatment with $\eta = 0.7$ (sessions 10 and 11 versus the other four sessions) suggests that a strong and persistent correlation between the coordination result and the sunspot variable is required to make the sunspot variable believable.

To summarize, subjects tend to disregard the sunspot announcement when $\eta = 0.2$ and 0.9, but have a strong tendency to follow the sunspot variable when $\eta = 0.7$. In the bank-run game (and many other coordination games), there is often a tension between efficiency and risk. The non-run equilibrium is more efficient associated with a higher payoff. As pointed out in Arifovic, Jiang and Xu (2013), the riskiness of the non-run equilibrium can be captured by the coordination parameter: a higher value of the parameter implies a higher level of risk. As shown in Temzelides (1997) and Ennis (2003), the non-run equilibrium is risk dominant if and only if $\eta < 0.5$.[12]

When $\eta = 0.2$, the non-run equilibrium is both payoff dominant and risk dominant, which means that there is no tension between efficiency and risk. As a result, there is minimal strategic uncertainty, and subjects almost unanimously choose to wait and ignore the sunspot announcement of a high level of withdrawals. When $\eta = 0.9$, the non-run equilibrium is payoff dominant but the run equilibrium is risk dominant, so there is some tension between efficiency and risk. With a high value of η, risk is the dominating concern. The extent of strategic uncertainty is small, and most subjects opt for the safe choice to withdraw, disregarding the announcement of low withdrawals. When $\eta = 0.7$, some tension exists as well. However, unlike the case with $\eta = 0.9$, where the risk concern dominates the efficiency concern, it is not clear whether efficiency or risk is of a greater concern. This creates great strategic uncertainty as subjects hesitate over whether to withdraw or wait. In this situation, an extraneous sunspot variable is more readily accepted as a coordination device.[13]

6 Conclusion

This paper conducts an experimental study of how people react to sunspots in the context of a bank-run game. The sunspot variable consists of a sequence of random forecasts on the number of withdrawals. Our main treatment variable is the coordination parameter, which measures the amount of coordination required to generate enough complementarity among depositors who wait so that they earn a higher payoff than those who choose to withdraw.

We have run three treatments characterized by three different values of the coordination

[12] Risk dominance is introduced by Harsanyi and Selten (1988) as an equilibrium selection criterion.

[13] The result of a strong response (here to public announcements) when there is greater strategic uncertainty is consistent with the result in Ahnert and Kakhbod (2014). They study a model of global games of regime change, where agents can pay a cost to acquire information on the fundamental state of the economy. They show that agents are more likely to acquire information when the common prior on the fundamental state is closer to an intermediate value, in which case the strategic uncertainty is higher.

parameter: 0.2, 0.7 and 0.9. When the coordination parameter is equal to 0.7, in which case there is great strategic uncertainty, subjects respond strongly to the sunspot variable, with four out of six sessions switching between the run and non-run equilibria conditional on the sunspot announcement. In contrast, the sunspot variable is largely ignored in the other two treatments where there is little strategic uncertainty: when $\eta = 0.2$, all (six out of six) experimental economies quickly reach the non-run equilibrium irrespective of the sunspot announcement; when $\eta = 0.9$, all (six out of six) experimental economies converge to the run equilibrium disregarding the realization of the sunspot variable.

The results of our study suggest that in economic situations with great strategic uncertainty, agents are susceptible to mood swings and tend to respond strongly to public comments or announcements from the government, a public figure such as a well-known blogger, or news media. In our experimental setting, the public announcement is a sunspot variable unrelated to (and with no information on) the fundamental condition of the economy. Nonetheless, the announcement functions as a coordination device and has a great impact on the economic outcome. We expect that the result that people tend to respond more strongly to public announcements in times of great uncertainty would carry through if the public announcement contains some information on the fundamental state of the economy. In addition, although we conduct the study in the context of bank-run games, we expect the result would also apply to other games with strategic complementarity, such as currency attacks, repo runs and debt runs. Another policy suggestion is that the timing and the market situation of public announcements matter (in addition to the content of the announcement). While the effect of the announcement tends to be weak if the economic condition is such that there is little uncertainty, it is likely to be huge in times of uncertainty. In the latter case, public announcements should be treated with extra care, because these messages are likely to be used by the public as a coordination device.

References

Aghion, P., Bacchetta, P., Banerjee A., 2004. A corporate balance-sheet approach to currency crises, Journal of Economic Theory 119(1), 6-30.

Ahnert, T., Kakhbod, A., 2014. Information, amplification, and financial crisis. Manuscript.

Amato, J., Morris, S., Shin, H. S., 2002. Communication and monetary policy. Oxford Review of Economic Policy 18(4), 495-503.

Andolfatto, D., Nosal, E., 2008. Bank incentives, contract design and bank-runs. Journal of Economic Theory 142, 28-47.

Andolfatto, D., Nosal, E., Wallace, N., 2007. The role of independence in the Diamond-Dybvig Green-Lin model. Journal of Economic Theory 137, 709-715.

Angeletos, G.-M., Pavan, A., 2007. Efficient use of information and social value of information. Econometrica 75(4), 1103-1142.

Arifovic, J., Evans, G., Kostyshyna, O., 2013. Are sunspots learnable in a general equilibrium model? An experimental investigation. Bank of Canada Working Paper 2013-14.

Arifovic, J., Jiang, J.H., Xu, Y., 2013. Experimental evidence of bank runs as pure coordination failures. Journal of Economic Dynamics and Control 37(12), 2446-2465.

Azariadis, C., 1981. Self-fulfilling prophecies. Journal of Economic Theory 25, 380-96.

Baeriswyl, R., Cornand, C., Reducing overreaction to central banks disclosure: theory and experiment, forthcoming in Journal of the European Economic Association.

Blinder, A., Ehrmann, M., Fratzscher, M., de Haan, J., Jansen, D.-J., 2008. Central bank communication and monetary policy: a survey of theory and evidence. Journal of Economic Literature 46(4), 910-45.

Boyd, J.H., Gomis-Porqueras, P., Kwak, S., Smith, B.D., 2014. A user's guide to banking crises. Annals of Economics and Finance 15(2), 800-892.

Brown, M., Trautmann, S., Vlahu, R., 2012. Contagious bank runs: experimental evidence. De Nederlandsche Bank Working Paper No. 363.

Burnside, C., Eichenbaum, M., Rebelo, S., 2001. Prospective deficits and the Asian currency crisis. Journal of Political Economy 109(6), 1155-1197.

Calomiris, C., Mason, J.R., 2003. Fundamentals, panics, and bank distress during the depression. American Economic Review 93, 1615-1647.

Cass, D., Shell, K., 1983. Do sunspots matter? Journal of Political Economy 91, 193-227.

Chakravarty, S., Fonseca, M. A., Kaplan, T. R., 2012. An experiment on the causes of bank run contagions, University of Exeter Discussion Paper 12/06.

Chang, R., Velasco, A., 2000. Financial fragility and the exchange rate regime. Journal of Economic Theory 92(1), 1-34.

Cole, H.L, Kehoe, T.J., 2000. Self-fulfilling debt crises. Review of Economic Studies 67, 91-116.

Cooper, R., Ross, T.W., 1998. Bank runs: liquidity costs and investment distortions. Journal of Monetary Economics, 41, 27-38.

Cornand, C., Heinemann, F., 2008. Optimal degree of public information dissemination. Economic Journal 118(518), 718-734.

Corsetti, G., Pesenti, P., Roubini, N., 1999a. Paper Tigers? A Model of the Asian Crisis. European Economic Review 43, 1211-1236.

Corsetti, G., Pesenti, P., Roubini, N., 1999b. What Caused the Asian Currency and Financial Crisis? Japan and the World Economy 11, 305-373.

Diamond, D.W., Dybvig, P.H., 1983. Bank runs, deposit insurance, and liquidity. Journal of Political Economy 91, 401-419.

Dooley, M. P., 2000. A model of crises in emerging markets. Economic Journal 110(460), 256-272.

Duffy, J., Fisher, E.O., 2005. Sunspots in the laboratory. American Economic Review 95, 510-529.

Dufwenberg, M., 2013. Banking on experiments? University of Arizona working paper series.

Ennis, H., 2003. Economic fundamentals and bank runs. Federal Reserve Bank of Richmond Economic Quarterly 89, 55-71.

Ennis, H., Keister, T., 2003. Economic growth, liquidity, and bank runs. Journal of Economic Theory 109, 220-45.

Ennis, H., Keister, T., 2009a. Bank runs and institutions: the perils of intervention. American Economic Review 99, 1588-1607.

Ennis, H., Keister, T., 2009b. Run equilibria in the Green-Lin model of financial intermediation. Journal of Economic Theory 144, 1996-2020.

Ennis, H., Keister, T., 2010. Banking panics and policy responses. Journal of Monetary Economics 54, 404-419.

Fehr, D., Heinemann, F., Llorente-Saguer, A., 2012. The power of sunspots: an experimental analysis. Working paper, Technische Universität Berlin.

Fischbacher, U., 2007. Z-Tree: Zurich toolbox for ready-made economic experiments. Experimental Economics 10(2), 171-178.

Freeman, S., 1988. Banking and the provision of liquidity. Journal of Business 61, 45-64.

Friedman, M., Schwartz, A.J., 1963. A monetary history of the United States: 1867–1960. Princeton University Press, Princeton, New Jersy.

Gade T., Salines, M., Glöckler, G., Strodthoff, S., 2013. Loose lips sinking markets?: the impact of political communication on sovereign bond spreads. ECB Occasional Paper Series 150.

Garratt, R., Keister, T., 2009. Bank runs as coordination failures: an experimental study. Journal of Economic Behavior and Organization 71, 300-317.

Goldstein, I., 2012. Empirical literature on financial crises: fundamentals vs. panic. in The Evidence and Impact of Financial Globalization, edited by Gerard Caprio (Elsevier, Amsterdam), 523-534.

Goldstein, I., Pauzner, A., 2005. Demand deposit contracts and the probability of bank runs. Journal of Finance 60(3), 1293-1327.

Green, E.J., Lin, P., 2000. Diamond and Dybvig's classic theory of financial intermediation: what's missing? Federal Reserve Bank of Minneapolis Quarterly Review 24, 3-13.

Green, E.J., Lin, P., 2003. Implementing efficient allocations in a model of financial intermediation. Journal of Economic Theory 109, 1-23.

Gu, C., 2011. Noisy sunspots and bank runs. Macroeconomic Dynamics 15, 398-418.

Harsanyi, J., Selten, R., 1988. A general theory of equilibrium selection in games. Cambridge: MIT Press.

He, Z., Xiong, W., 2012. Dynamic debt runs. The Review of Financial Studies 25, 1799-1843.

Hellwig, C., 2005. Heterogeneous information and the welfare effects of public information disclosures. UCLA mimeo.

Hichri, W., Trabelsi, E., 2013. Central bank transparency and information dissemination: an experimental approach. SSRN working paper 1336.

Jeanne, O., 1997. Are currency crises self-fulfilling?: A test. Journal of International Economics 43, 263-286.

Kiss, H.J., Rodriguez-Lara, I., Rosa-Garcia, A., 2012. On the effects of deposit insurance and observability on bank runs: an experimental study, Journal of Money Credit and Banking,1651-1665.

Klos, A., Sträter, N., 2013. How strongly do players react to changes in payoff parameters in an experimental bank run game? Working paper, University of Kiel.

Kryvtsov, O., Petersen, L., 2013. Expectations and monetary policy: experimental evidence. Bank of Canada Working Paper 2013-44.

Loewy, B.M., 1991. The macroeconomic effects of bank runs: an equilibrium analysis. Journal of Financial Intermediation 1, 242-256.

Madiès, P., 2006. An experimental exploration of self-fulfilling bank panics: their occurrence, persistence and prevention. Journal of Business 79, 1836-1866.

Marimon, R., Spear, S.E., Sunder, S., 1993. Expectationally driven market volatility: an experimental study. Journal of Economic Theory 61, 74-103.

Martin, A., Skeie D., von Thadden, E.L., 2014. Repo runs. Review of Financial Studies. In print.

Morris, S., Shin, H. S., 2001. Rethinking multiple equilibria in macroeconomic modelling. NBER Macroeconomics Annual 15, 139-161.

Morris, S., Shin, H. S., 2002. Social value of public information. The American Economic Review 92(5), 1521-1534.

Morris, S., Shin, H. S., 2007. Optimal communication. Journal of the European Economic Association 5(2-3), 594-602.

Obstfeld, M., 1996. Models of currency crises with self-fulfilling features. European Economic Review 40, 1037-1047.

Peck, J., Shell, K. 2003. Equilibrium Bank Runs. Journal of Political Economy 111, 103-23.

Radelet, S., Sachs, J., 1998. The East Asian Financial Crisis: Diagnosis, Remedies, Prospects. Brookings Paper 28(1), 1-74.

Rose, A.K., Svensson, L.E.O., 1994. European exchange rate credibility before the fall. European Economic Review 38, 1185-1216.

Schneider, M., Tornell, A., 2004. Balance sheet effects, bailout guarantees and financial crises. Review of Economic Studies 71, 883-913.

Schotter, A., Yorulmazer, T., 2009. On the dynamics and severity of bank runs: an experimental study. Journal of Financial Intermediation 18, 217-241.

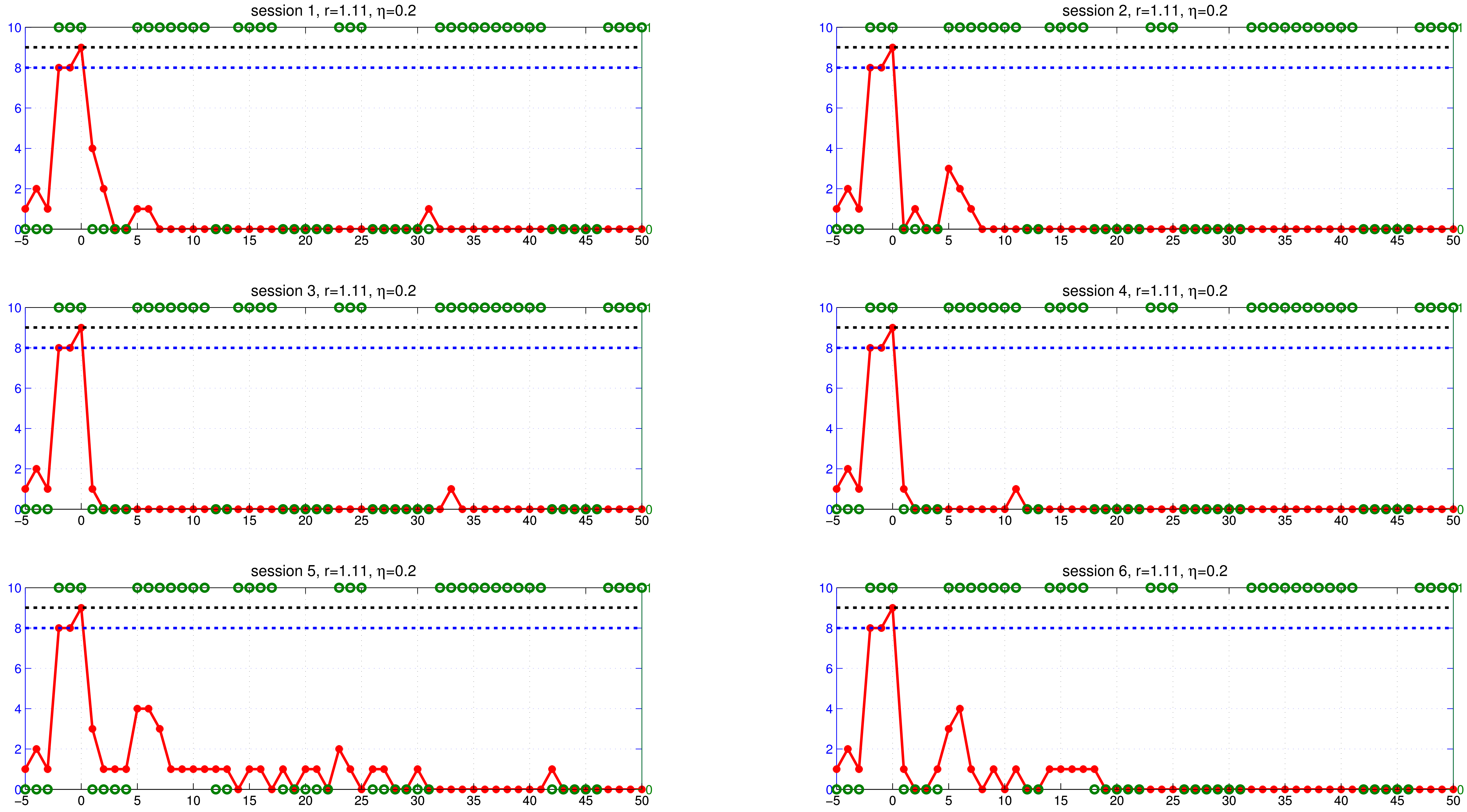
Svensson, L.E., 2006. Social value of public information: Morris and Shin (2002) is actually pro-transparency, not con. American Economic Review 96(1), 448-452.

Temzelides, T., 1997. Evolution, coordination and banking panics. Journal of Monetary Economics 40, 163-183.

Waldo, G.D., 1985. Bank runs, the deposit-currency ratio and the interest rate. Journal of Monetary Economics 15, 269-277.

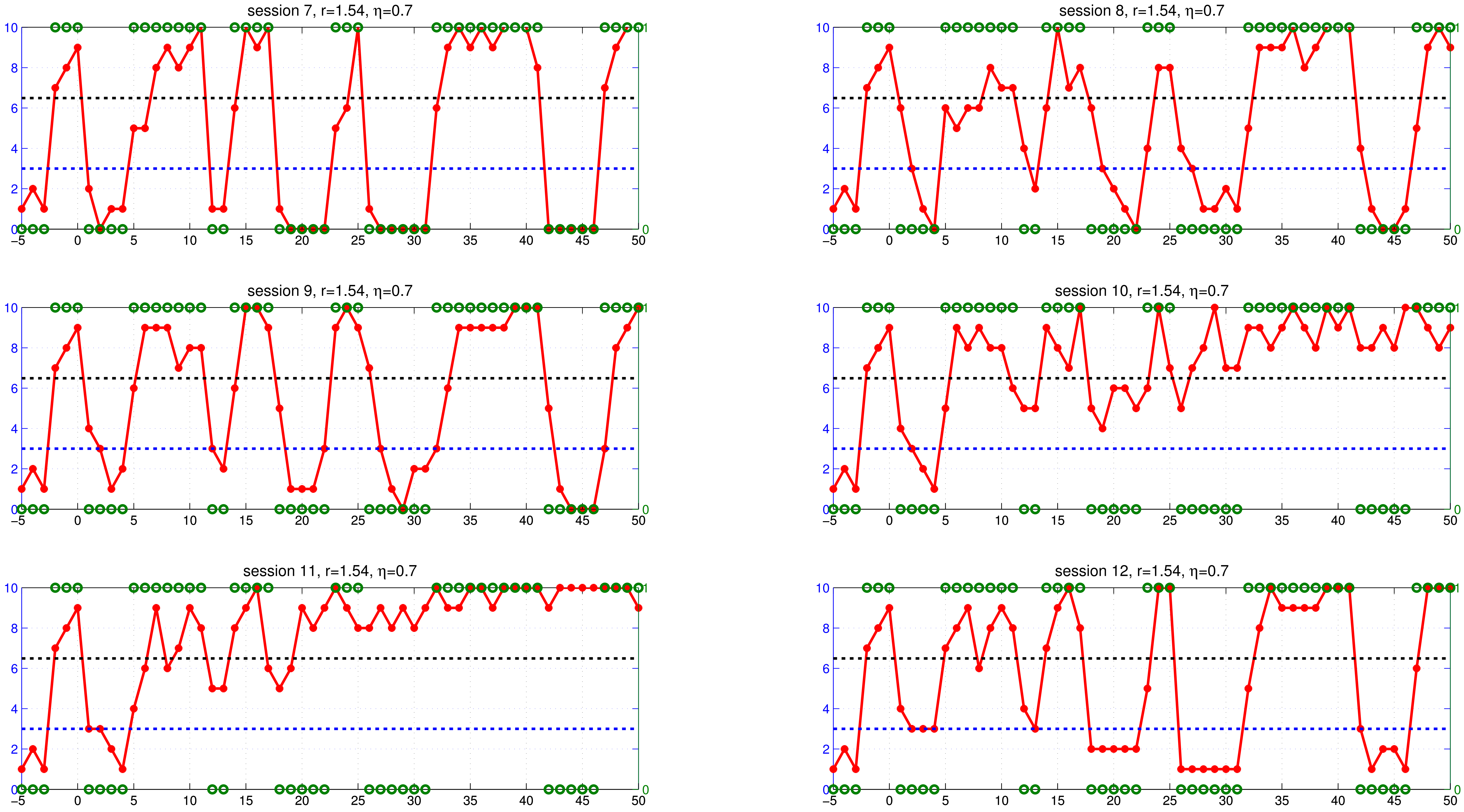
Woodford, M., 2005. Central bank communication and policy effectiveness. Paper given at the 2005 Symposium of the Federal Reserve Bank of Kansas City at Jackson Hole, The Greenspan Era: Lessons for the Future.

Figure 1: Experimental Results



continued...

Figure 1 (continued): Experimental Results



continued...

Figure 1 (continued): Experimental Results

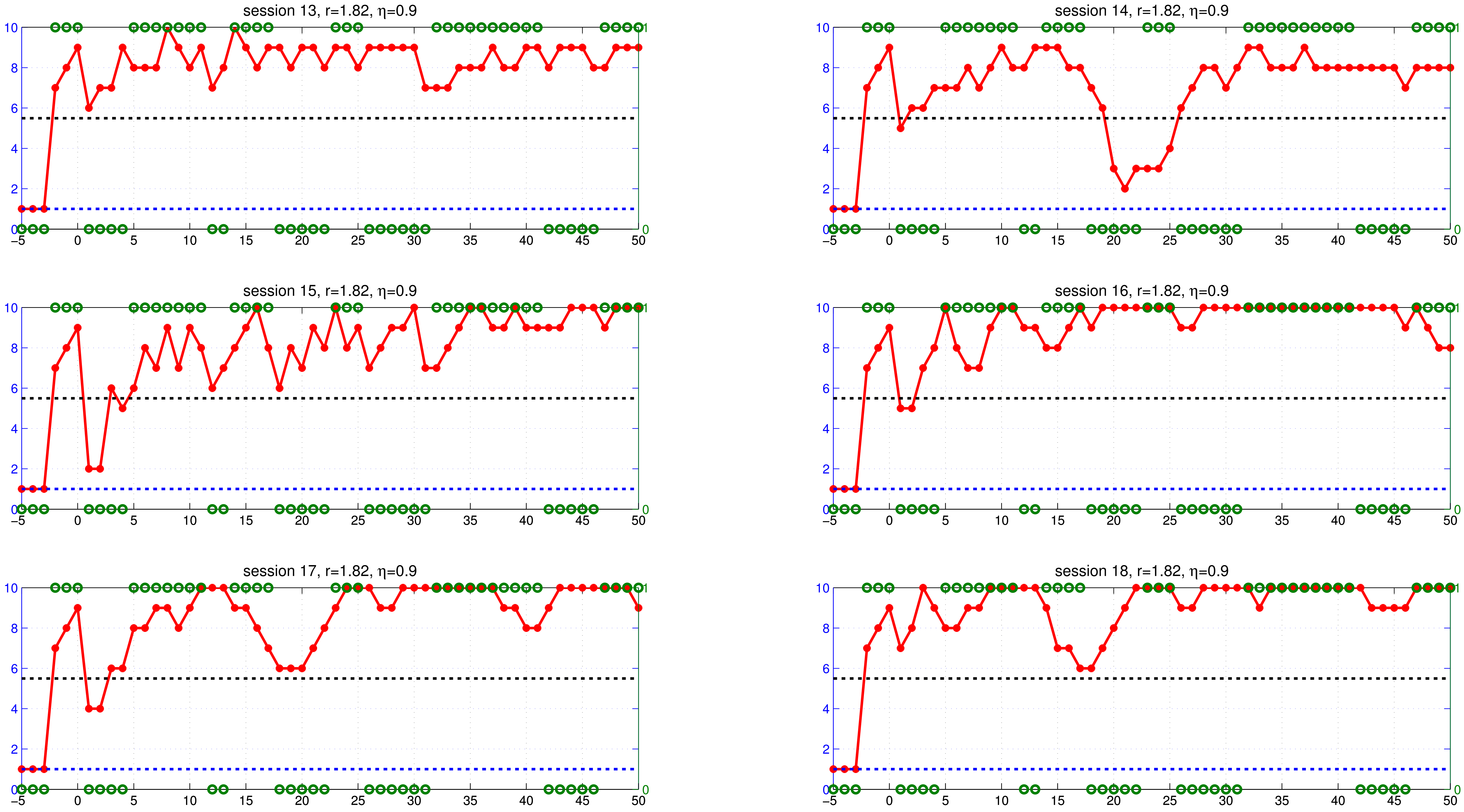


Table 1: Experimental parameters

Session	η	r	e^*	A (practice)	e displayed (practice)	Mean A (formal)
1-6	0.2	1.11	8	000111	121889	0.56
7-12	0.7	1.54	3	000111	121789	0.56
13-18	0.9	1.82	1	000111	111789	0.56

Table 2: Statistics

Session	Mean withdrawals: Whole session	Mean withdrawals: *A=0*	Mean withdrawals: *A=1*	% Bankruptcies: Whole session	% Bankruptcies: *A=0*	% Bankruptcies: *A=1*	% Actions consistent with announcement: Whole session	% Actions consistent with announcement: *A=0*	% Actions consistent with announcement: *A=1*
1	0.18	0.32	0.07	0	0	0	43	97	1
2	0.14	0.05	0.21	0	0	0	45	100	2
3	0.04	0.05	0.04	0	0	0	44	100	0
4	0.04	0.05	0.04	0	0	0	44	100	0
5	0.70	0.68	0.71	0	0	0	45	93	7
6	0.34	0.14	0.50	0	0	0	46	99	5
Sessions 1-6 (η=0.2)	**0.24**	**0.21**	**0.26**	**0**	**0**	**0**	**45**	**98**	**3**
7	4.90	0.36	8.46	44	0	79	90	96	85
8	5.28	2.09	7.79	40	0	71	78	79	78
9	5.60	2.14	8.32	48	5	82	81	79	83
10	7.40	6.05	8.46	70	45	89	65	40	85
11	8.02	7.09	8.75	76	64	86	62	29	88
12	5.68	2.05	8.54	48	0	86	83	80	85
Sessions 7-12 (η=0.7)	**6.15**	**3.30**	**8.39**	**54**	**19**	**82**	**76**	**67**	**84**
13	8.40	8.27	8.50	100	100	100	55	17	85
14	7.16	6.59	7.61	86	82	89	58	34	76
15	8.18	7.45	8.75	94	86	100	60	25	88
16	9.20	9.05	9.32	96	91	100	56	10	93
17	8.72	8.18	9.14	96	91	100	59	18	91
18	9.20	9.00	9.36	100	100	100	57	10	94
Sessions 13-18 (η=0.9)	**8.48**	**8.09**	**8.78**	**95**	**92**	**98**	**58**	**19**	**88**

Table 3: Rank-sum test of the effect of the sunspot announcement on the average number of withdrawals

	Announcement	Sample size	Average number of withdrawals
Treatment with $\eta=0.2$	A=0	6	0.21
	A=1	6	0.26
Z-value			0
p -value (2-sided)			100%
	Announcement	Sample size	Average number of withdrawals
Treatment with $\eta=0.7$	A=0	6	3.30
	A=1	6	8.39
Z-value			2.887
p -value (2-sided)			0.39%
	Announcement	Sample size	Average number of withdrawals
Treatment with $\eta=0.9$	A=0	6	8.09
	A=1	6	8.78
Z-value			1.601
p -value (2-sided)			10.93%

Appendix: Instructions (for r=1.54 or η=0.7)

Today you will participate in an experiment in economic decision making. You will be paid for your participation. There is a show-up fee of $7. The additional amount of cash that you earn will depend upon your decisions and the decisions of other participants. You will be earning experimental currency. At the end of the experiment, you will be paid in dollars at the exchange rate of 10 experimental currency units = $1.

Since your earnings depend on the decisions that you will make during the experiment, it is important to understand the instructions. Read them carefully. If you have any questions, raise your hand and the experimenter will come to your desk and provide answers

Your Task

You and 9 other people start with 1 experimental dollar (ED) deposited in an experimental bank. You must decide whether to withdraw your 1 ED or wait and leave it deposited in the bank. The bank promises to pay **1.54** EDs to each withdrawer. After the bank pays the withdrawers, the money that remains in the bank will be **doubled,** and the proceeds will be divided evenly among people who choose to wait. Note that if too many people desire to withdraw, the bank may not be able to fulfill the promise to pay **1.54** to each withdrawer. In that case, the bank will divide the 10 EDs evenly among all withdrawers and those who choose to wait will get nothing.

Your payoff depends on your own decision and the decisions of the other 9 people in the group. Specifically, how much you receive if you make a withdrawal request or how much you earn by waiting depends on how many people in the group place withdrawal requests.

On the last page, you can find the payoff table that lists the payoffs associated with the two choices – to withdraw or to wait – **if n** of the **10** subjects request to withdraw. Let's look at two examples:

Example 1.

Suppose **2** subjects choose to withdraw (and 8 choose to wait).

If you choose to withdraw, your payoff is 1.54, and if you choose to wait, your payoff is 1.73.

Example 2.

Suppose **8** subjects choose to withdraw (and 2 choose to wait).

If you choose to withdraw, your payoff is 1.25, and if you choose to wait, your payoff is 0.

Note that you are not allowed to ask other participants what they will choose. You must guess what other people will do – how many of the other 9 people will withdraw – and act accordingly.

Announcement

In each period, an announcement will show up in the lower right section of the screen to forecast the number of withdrawal requests for this period.

The announcement will be either

- "The forecast is that 3 or **more** people will choose to withdraw", or that
- "The forecast is that 3 or **less** people will choose to withdraw".

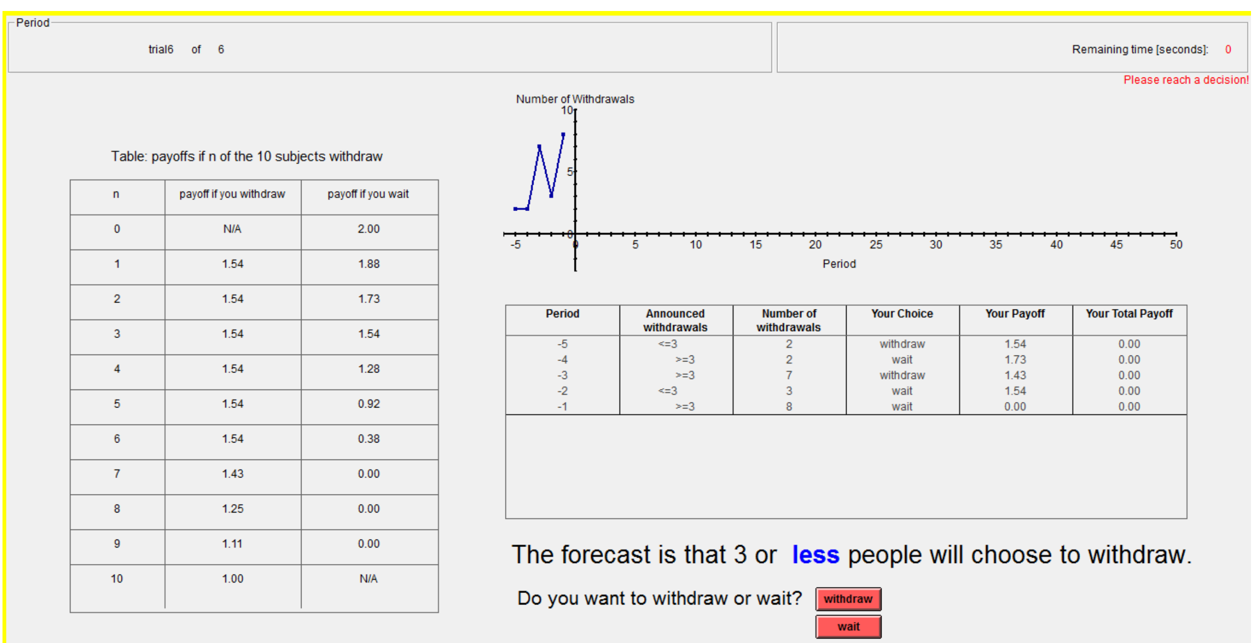
Everybody receives the **same** message. The announcements are randomly generated. There is a possibility of seeing either announcement, but the chance of seeing the same message that you saw in the previous period is higher than the chance of seeing a different announcement. These announcements are forecasts, which can be right or wrong. The experimenter does not know better than you how many people will choose to withdraw (or wait) in each period. The number of withdrawals is determined by the decisions of all participants. Your actual payoff depends only on your own choice and the choices of other participants.

Number of Periods

This experimental session consists of **50** periods.

Computer Instructions

In each period, you start with 1 ED in the experimental bank and make a withdrawal decision using a computer screen. An example screen is shown below.



The header provides information about what period you are in and the time remaining to make a decision. After the time limit is reached, a flashing reminder, "please reach a decision", will appear. For your convenience, the same payoff table as the one on the last page of the instructions is shown on the left section of the screen.

You choose to withdraw money or wait by clicking on one of the two red buttons either "withdraw" or "wait".

The screen also provides information about the history of the experiment:

- A graph of the total number of withdrawals in all past periods
- History table that provides: the history of the announcements, the actual number of withdrawals, your decision, your payoff in each period, and your cumulative payoff

Practice Periods

Before we formally start the experiment, you will have the chance to practice your decision making for **six** periods. This is an opportunity for you to become familiar with the task you will perform during the experiment. Your choice in the practice period does **not** count toward your total earnings in the experiment.

Payoff

At the end of the entire experiment, the experimenter will pay you in cash. Your earnings in dollars will be:

Total payoff in ED x 0.1

Table: payoffs **if** *n* of the 10 subjects **withdraw**

n	payoff if you withdraw	payoff if you wait
0	n/a	2.00
1	1.54	1.88
2	1.54	1.73
3	1.54	1.54
4	1.54	1.28
5	1.54	0.92
6	1.54	0.38
7	1.43	0.00
8	1.25	0.00
9	1.11	0.00
10	1.00	n/a