

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

Jasmina Arifovic<sup>†</sup>      Janet Hua Jiang<sup>‡</sup>

December 2, 2014

## Abstract

We investigate reactions 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 high, low and intermediate values of the coordination parameter, respectively. Strong responses to sunspots occur only in the treatment featuring the intermediate value, where strategic uncertainty is high. The policy implication is public statements must be treated with extra care during uncertain times.

JEL Categories: C92; 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 and Malik Shukayev, as well as participants at the 2013 CEA conference in Montréal, the 2013 CEF conference in Vancouver, the 2013 SAET conference in Paris, the 2014 Bank of Finland Workshop on Expectations in Dynamic Macroeconomic Models, and seminars at the Bank of Canada, University of Missouri, Concordia University and Purdue University. The support from the CIG/INET grants program is gratefully acknowledged (Arifovic 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.

<sup>†</sup>Simon Fraser University. E-mail: arifovic@sfu.ca.

<sup>‡</sup>Bank of Canada. E-mail: jjiang@bankofcanada.ca.

# 1 Introduction

Economists have long contemplated 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.<sup>1</sup> 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 key 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 irrespective of 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 efficient non-run equilibrium could depend on the realization of a sunspot variable, i.e., a commonly observed random variable unrelated to the bank's fundamental condition.

Azariadis (1981) and Cass and Shell (1983) formalize 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

---

<sup>1</sup>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.

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.<sup>2</sup> Our research questions are whether sunspots matter as predicted by the theory and under what situations they matter more. 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 or not to withdraw their money from the bank. 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 conducted by Arifovic, Jiang and Xu (2013).

In that study, Arifovic, Jiang and Xu (2013) investigate bank runs as pure coordination failures in the absence of sunspot variables. They find that whether miscoordination-based bank runs occur depends on the value of the coordination parameter,  $\eta$ , defined as the minimum fraction of depositors required to wait so that waiting entails a higher payoff than withdrawing. In particular, the value of the coordination parameter can be divided into three regions: "run", "non-run" and "indeterminacy", characterized respectively by high (with  $\eta \geq 0.8$ ), low (with  $\eta \leq 0.5$ ) and intermediate (with  $\eta = 0.6$  and  $0.7$ ) values of the parameter. 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

---

<sup>2</sup>The experimental approach is a useful complement to empirical studies of sunspot-induced financial crises. We discuss this in more detail in the next section.

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.<sup>3</sup>

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, run, and the indeterminacy regions. 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 fewer 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  $\geq x$ . As will be discussed in more detail in Section 4, formulating the sunspot variable this way helps to establish a clear correspondence between the realization of the sunspot and the action choice **if** subjects decide to use the sunspot as a coordination device. Our main question is how people respond

---

<sup>3</sup>The bank-run game (as well as many other coordination games) involves a tension between efficiency and risk. The non-run equilibrium is payoff dominant. In terms of risk, one can use the concept of risk dominance introduced by Harsanyi and Selten (1988). Temzelides (1997) and Ennis (2003) show that the non-run (run) equilibrium is risk dominant if and only if  $\eta \leq 0.5$  ( $\geq 0.5$ ). If  $\eta < 0.5$ , then the non-run equilibrium is both risk and payoff dominant so there is little strategic uncertainty. If  $\eta = 0.5$ , the two equilibria share the same level of risk but the non-run equilibrium is payoff dominant so subjects coordinate on the non-run equilibrium with little disagreement. When  $\eta = 0.8$  or  $0.9$ , there is a tension between payoff and risk concerns, and the risk concern dominates so strategic uncertainty is low too. In the case where  $\eta = 0.6$  or  $0.7$ , it is difficult to determine whether risk or efficiency is of a greater concern, giving rise to great strategic uncertainty. Heineemann, Nagel and Ockenfels (2009) conduct an experimental study to formally measure strategic uncertainty in (context-free) coordination games. One of their results is that subjects tend to disagree more on the expected behavior of others, as measured by the variance of stated beliefs, in situations in which experimental results are less predictable.

to sunspots in different economic conditions; confusion about the interpretation of the sunspot variable would confound this analysis.

We conduct six experimental sessions for each treatment. The experimental results confirm our 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 suggest that subjects tend to follow sunspots when there is great strategic uncertainty.

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 our experimental 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. When the economic situation creates great strategic uncertainty, 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. 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.<sup>4</sup>

---

<sup>4</sup>Our experimental result is largely consistent with the observation that markets seem to be very sensitive to political announcements during crises. Gade et al. (2013) offer evidence that during the period from January 2009 to October 2011, political communications had 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, during his interview with *Der Spiegel* on 22 August 2011, urged European Union policy-makers to think carefully about what impact their comments may have on the markets. In the United States, a publicly released letter by

Our study offers a new perspective on the ongoing discussion on central bank communication. Most studies in this area focus on the issue of central bank transparency, and debate what and how much the central bank should communicate to the public. Our study, however, 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.<sup>5</sup>

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 our hypothesis and discusses the experimental design. Section 5 reports and 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 that 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 to (ignore) sunspot variables when the coordination parameter takes an intermediate (extreme) value and the strategic uncertainty is high (low). Marimon, Spear and Sunder (1993) investigate expectationally driven price volatilities in experimental overlapping-generation economies. They find that subjects may follow

---

Senator Charles Schumer on 26 June 2008 that questions 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 as having helped maintain public confidence and reduce disruption to the financial system.

<sup>5</sup>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.

sunspots after training or exposure to real cycles induced by real shocks, in phase with the realization of the sunspot variable.<sup>6</sup> Duffy and Fisher (2005) consider a market game with two equilibria featuring different equilibrium prices. These two equilibria cannot be Pareto ranked: some subjects are better off in one equilibrium, whereas others are better off in the other. One of the main findings of their paper is that subjects can coordinate on a sunspot equilibrium based on a public announcement that forecasts the level of the market price in call markets. 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, and find that sunspot equilibria emerge if there are salient public signals. Finally, Arifovic, Evans and Kostyshyna (2013) examine coordination in a production economy with a positive externality that gives rise to multiple steady states (two of which are stable) with different levels of employment and productivity. They observe coordination on extrinsic announcements on the level of productivity in most of their sessions; convergence to the two stable steady states occur as well.

Another closely related branch of literature is the study of bank runs in controlled laboratory environments. Our paper focuses on the effect of the sunspot variable, a factor absent in other studies. Madiès (2006); Schotter and Yorulmazer (2009); and Kiss, Rodriguez-Lara and Rosa-Garcia (2012) discuss the effects of various ways to prevent or slow bank runs, including deposit insurance, suspension of payment, the presence of insiders and the observability of past actions. Garratt and Keister (2009) study how the occurrence of bank runs is affected by two factors: the number of withdrawal opportunities and uncertainty regarding the aggregate liquidity demand. 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). Chakravarty, Fonseca and Kaplan (2012) and Brown, Trautmann and Vlahu (2014) 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.

Our paper also contributes to the ongoing discussion on central bank commu-

---

<sup>6</sup>The sunspot variable in Marimon, Spear and Sunder (1993) takes the form of a blinking square alternating in colors on subjects' computer screens.

nication. Most of this literature focuses on the question of what to communicate, with central bank transparency being a 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.<sup>7</sup> 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 this 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 (2014) and Hichri and Trabelsi (2013) provide two experimental studies of the issue. This line of literature stresses the dual roles of public information, to convey fundamentals information and to serve 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.

Finally, we view our experimental study as a useful complement to empirical studies of sunspot-induced financial crises. 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 the general approach to the second is to regress the likelihood of a crisis event on relevant fundamental variables. If the

---

<sup>7</sup>Some issues that are still under debate include whether the central bank should deliver explicit statements on the likely future path of interest rates, and whether the central bank's decision-making process should be made more transparent, say, by the release of the minutes of its deliberations.



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 relatively easily. In our study, we clearly define and identify the sunspot and fundamental variables; we also 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 must 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 well the risk of bank failures 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 this experimental study to gain some insight into the conditions under which sunspots have a stronger impact on the economic outcome.

### 3 Theoretical Framework

The theoretical framework that underlies our study is the DD model of bank runs. In this model, the bank functions as a liquidity insurance provider pooling depositors' resources to invest in profitable illiquid long-term assets, and at the same time issuing short-term demand deposits to meet the liquidity need of depositors.<sup>8</sup> The contract requires that 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 miscoordination-based bank runs.

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. 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 must consume early). Impatient agents always withdraw, and only patient agents are "strategic" players. For the experiment, we focus on strategic players and hence all agents are patient consumers.<sup>9</sup> 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

---

<sup>8</sup>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 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.

<sup>9</sup>Madiès (2006) and Arifovic, Jiang and Xu (2013) makes the same arrangement in this regard.

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.<sup>10</sup> 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

$$\pi_1 = \min \left\{ r, \frac{N}{e} \right\}, \quad (1)$$

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

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

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

The coordination game characterized by the above payoff structure has two symmetric pure-strategy Nash equilibria.<sup>11</sup> 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  $R$ . Stationary sunspot equilibria also exist, where the economy switches between the run and non-run equilibria contingent on the realization of a sunspot variable.

---

<sup>10</sup>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 easily change the coordination parameter in a simple way.

<sup>11</sup>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.

## 4 Hypothesis and Experimental Design

In this paper, we examine whether sunspots matter as predicted by the theory (note that in the DD bank-run model, sunspot equilibria can be constructed for any  $r$  between 1 and  $R$ ), and whether there are certain economic 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  $\eta$ ) 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 experimental treatment. The coordination parameter measures the minimum fraction of depositors required to wait so that waiting entails a higher payoff than withdrawing. We can calculate  $\eta$  in two steps. First, solve for the value of  $e$ , the number of depositors who choose to withdraw, which 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, calculate  $\eta$  from the equation,

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

Note that there is a one-to-one correspondence among  $\eta$ ,  $e^*$  and  $r$ . Given  $\eta$  (or, equivalently,  $e^*$  or  $r$ ), the payoff from waiting exceeds that from withdrawing early if the fraction of depositors choosing to wait exceeds  $\eta$  (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 value of this parameter into three regions: "run" ( $\eta \leq 0.5$ ), "non-run" ( $\eta \geq 0.8$ ) and "indeterminacy" ( $\eta = 0.6$  and  $0.7$ ), characterized by high, low and intermediate values of the parameter, respectively. In the run (non-run) region, all experimental economies stay close or converge to the run (or non-run) equilibrium. In these two 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 the following hypothesis:

*When a sunspot variable is introduced into the bank-run 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 regions, 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 a huge impact on the coordination outcome.*

To test the above hypothesis, we conduct three experimental treatments with three values of the coordination parameter: 0.2, 0.7 and 0.9, which lie in the non-run, indeterminacy and run regions, respectively.<sup>12</sup> Under our hypothesis, the power of the sunspot variable is likely to be strong when  $\eta = 0.7$ , but weak when  $\eta = 0.2$  or  $0.9$ . More specifically, the experimental economy is likely to switch between the two equilibria in step with the realization of the sunspot variable in the treatment

---

<sup>12</sup>Note that although we use  $\eta$  as the treatment variable, given that there is a one-to-one correspondence among  $e^*$ ,  $\eta$  and  $r$  as discussed earlier, we could also use  $e^*$  or  $r$  as the treatment variable.

with  $\eta = 0.7$ . When  $\eta = 0.2$ , the economy is likely to be in the vicinity of the non-run equilibrium, irrespective of the announcement. When  $\eta = 0.9$ , the economy is likely to stay close to the run equilibrium, irrespective of the announcement.

Given that the main purpose of our study is to investigate how the economic condition (characterized by the coordination parameter) affects whether people choose to follow the sunspot, we try to reduce the confounding impact of other factors, such as the interpretation of the sunspot variable. To that end, we take two measures to promote a common understanding of the semantics of the sunspot variable. The first measure is to formulate the sunspot variable as a series of randomly generated public announcements that predict the number of withdrawals. In particular, the following explanation is used in the instructions to participants:<sup>13</sup>

*"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 'The forecast is that  $e^*$  or fewer 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

---

<sup>13</sup>See the appendix for the full content of the instructions for the case where  $\eta = 0.7$ .

"withdrawing is a better strategy."

We clearly state that the realization of the sunspot variable is public information and has no impact on the fundamental state of the economy (which remains constant during each session). We formulate the sunspot variable as a forecast of the number of withdrawals so that it is straightforward for subjects to translate the realization of the variable to an action choice (i.e., to withdraw if the forecast is high and wait if the forecast is low) **if** they choose to follow it. Therefore, we can be more confident that, if subjects do not coordinate on the sunspot variable, it is not because they would like to act upon its realizations but could not decide which action to take, but rather they choose to ignore the variable. Our concern is valid given a result in Duffy and Fisher (2005): if the sunspot announcement is formulated as a forecast of the equilibrium market price ("high" or "low"), subjects successfully coordinate on the sunspot equilibrium, but fail to do so if the announcement is replaced by a weather forecast ("sunshine" or "rain"). The coordination outcome in the latter case may be attributed to confusion or disagreement about the interpretation of the sunspot variable.

Our second measure to enhance the semantics of the sunspot variable is to introduce a training stage similar to Marimon, Spear and Sunder (1993); Duffy and Fisher (2005); and Arifovic, Evans and Kostyshyna (2013). The purpose of the training stage is twofold: (1) to familiarize subjects with their tasks, and (2) to expose them to the language of the sunspot equilibrium and build the correlation between the coordination outcome and the realization of the sunspot variable. To be specific, the forecast is  $e \leq e^*$  in the first three practice periods, and  $e \geq e^*$  in the second three periods. The number of withdrawals in those periods is predetermined to make the announcements self-fulfilling. The technique is a shortcut to mimic the endogenous arising of sunspots in real life: usually people would start believing in a sunspot variable only after observing some evidence about its predictive validity. Given the time constraint of laboratory experiments, such a shortcut is an effective way to quickly establish the prior belief.<sup>14</sup>

---

<sup>14</sup>There may be a concern that the clear formulation of the sunspot variable may induce subjects to respond to it too much. This concern may be lessened considering that we adopt the same measures in all three treatments, and we conjecture coordination on the sunspot variable only for  $\eta = 0.7$ , but

Six sessions of experiment are run for each of the three treatments, for a total of 18 sessions. In each session of the experiment, subjects play a repeated one-period game for 56 periods: six practice/training periods (for which they are not paid) plus 50 formal periods. In each new period, each subject starts with 1 unit of experimental money in the bank. Upon observing the realization of the sunspot variable, each decides simultaneously whether to withdraw their money from the bank or to wait. Following the spirit of the literature on sunspots, we generate the random sequence of announcements before the experiment and use the same sequence of announcements in all experimental sessions to facilitate comparison among the sessions. 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 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.

Table 1: Experimental parameters

Session	$\eta$	$r$	$e^*$	$A$ (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

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 wait and roll over their deposits through the decision screen. This screen shows a table that 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

not for  $\eta = 0.2$  or  $0.9$  (as shown in the next section, our conjecture is supported by the experimental results).



choose to withdraw. This payoff table helps to reduce the calculation burden so that subjects can focus on playing the coordination game. The decision 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 announcement, the actual number of withdrawals, the subject's decision and the subject's own payoff, both in each period and accumulatively. 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.<sup>15</sup> Each session lasted for about 50 minutes. The average earning was around \$14.

## 5 Experimental Results

Figures 1 ~ 3 plot the coordination results for each of the 18 sessions of experiment. The six sessions of the same treatment are grouped on the same page. The horizontal axis represents the time period running from  $-5$  to  $50$ . Periods  $-5$  to  $0$  are intended for practice, and 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

---

<sup>15</sup>Since the game in the experiment is fairly straightforward, it is important that the subjects have no prior experience with experiments of coordination games.

(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 (second) group contains the statistics for periods with  $A = 0$  (with  $A = 1$ ). Each group has six observations corresponding to the six experimental sessions 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 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 stay there 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 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

consistent with the announcement is 89% for  $A = 1$  and much lower at 19% for  $A = 0$ .

Figure 1: Experimental results  $\eta = 0.2$

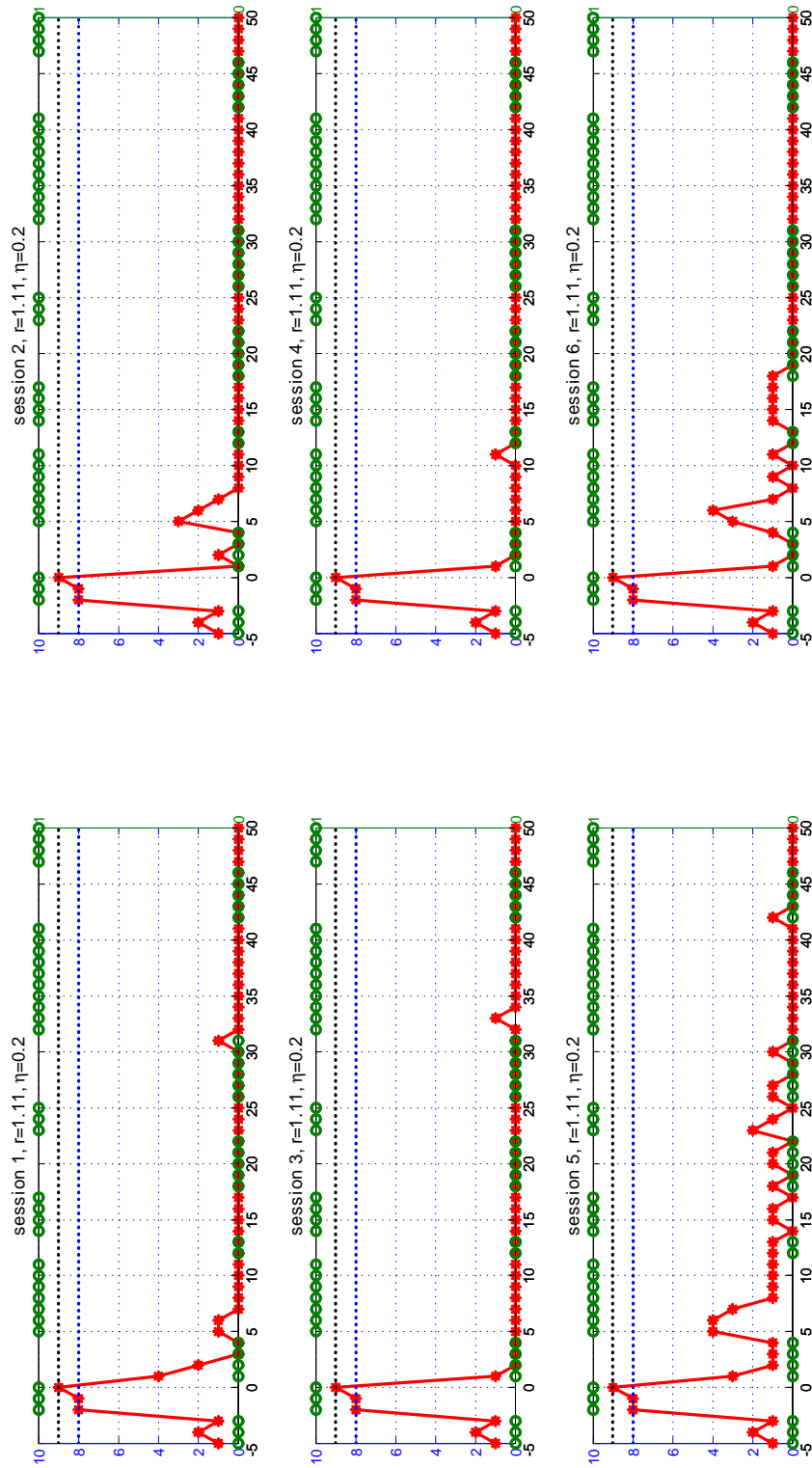


Figure 2: Experimental results  $\eta = 0.7$

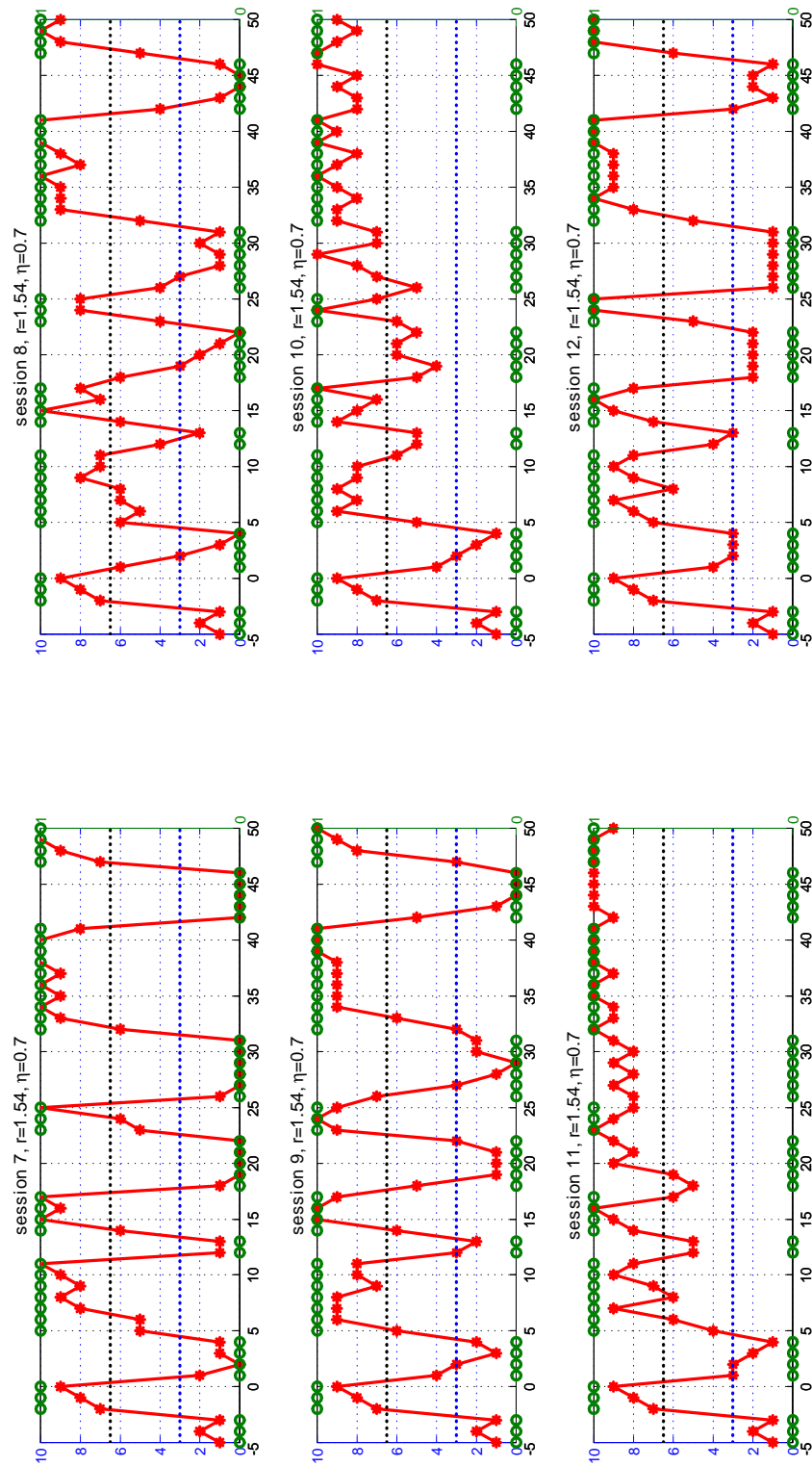


Figure 3: Experimental results  $\eta = 0.9$

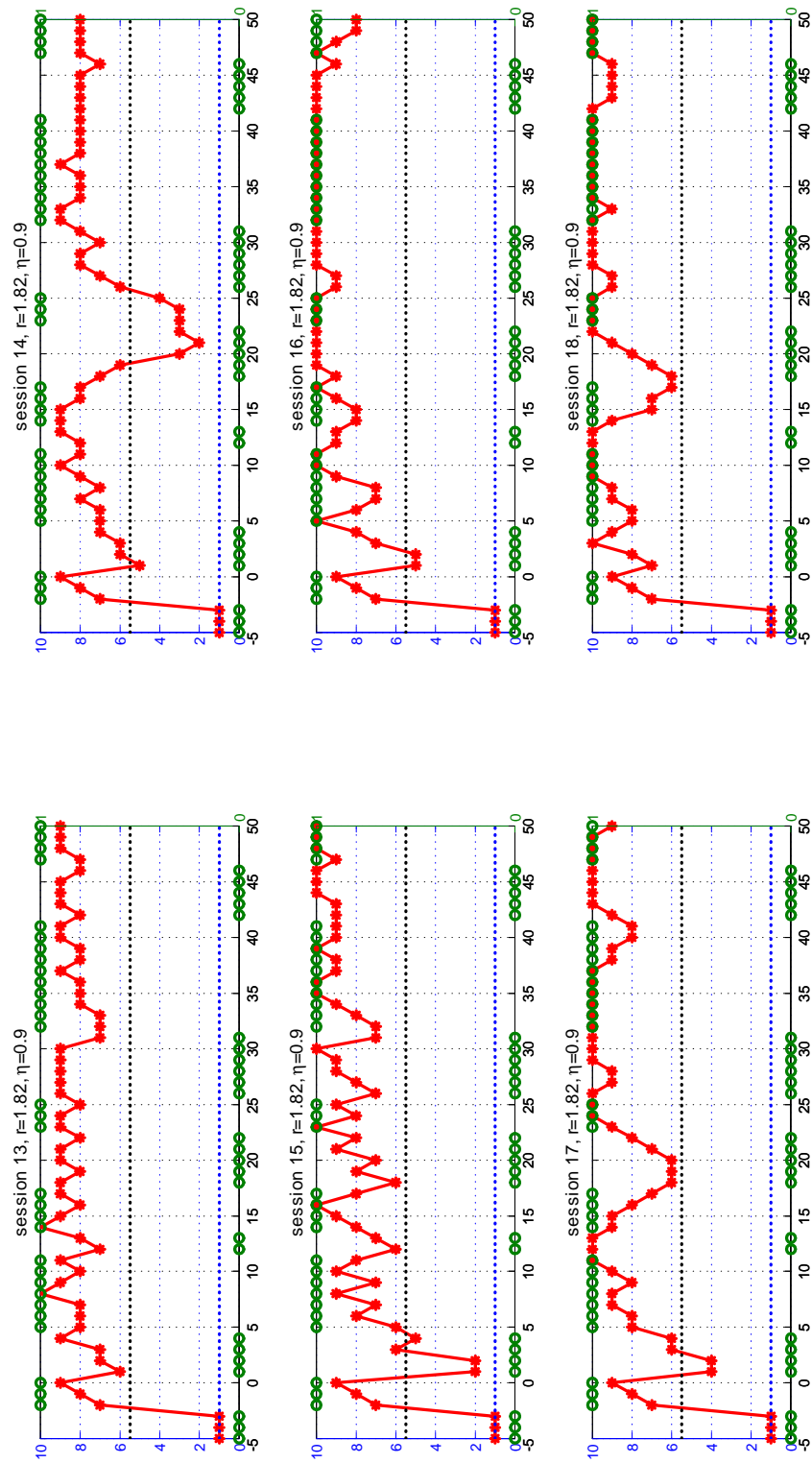


Table 2: Statistics

Session	Mean withdrawals		% Bankruptcies		% Actions consistent with announcement	
	Whole session	$A=0$ $A=1$	Whole session	$A=0$ $A=1$	Whole session	$A=0$ $A=1$
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
<b>Sessions 1-6 (<math>\eta=0.2</math>)</b>	<b>0.24</b>	<b>0.21 0.26</b>	<b>0</b>	<b>0 0</b>	<b>45</b>	<b>98 3</b>
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
<b>Sessions 7-12 (<math>\eta=0.7</math>)</b>	<b>6.15</b>	<b>3.30 8.39</b>	<b>54</b>	<b>19 82</b>	<b>76</b>	<b>67 84</b>
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
<b>Sessions 13-18 (<math>\eta=0.9</math>)</b>	<b>8.48</b>	<b>8.09 8.78</b>	<b>95</b>	<b>92 98</b>	<b>58</b>	<b>19 88</b>

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 $\eta=0.2$	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 $\eta=0.7$	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 $\eta=0.9$	A=0	6	8.09
	A=1	6	8.78
Z-value			1.601
p-value (2-sided)			10.93%

Compared to their responses 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 line 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 the 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. We can evaluate the relative riskiness of the two equilibria using the risk dominance concept introduced by Harsanyi and Selten (1988). As

shown in Temzelides (1997) and Ennis (2003), the non-run (run) equilibrium is risk dominant if and only if  $\eta \leq 0.5$  ( $\geq 0.5$ ). When  $\eta = 0.2$ , the non-run equilibrium is both payoff 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  $\eta$ , 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, 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.<sup>16</sup>

## 6 Conclusion

This paper presents 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 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

---

<sup>16</sup>The result of a strong response (here to public announcements) when there is greater strategic uncertainty is consistent with that of 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.

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, again irrespective of the realization of the sunspot variable.

Our study suggests 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. Although we conduct the study in the context of bank-run games, we expect the result to apply to other games with strategic complementarity, including currency attacks, repo runs and debt runs. The policy advice stemming from our study is that the timing and the market condition 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 significant 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., 2014. Reducing overreaction to central banks disclosure: theory and experiment, *Journal of the European Economic Association* 12, 1087-1126.

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., 2014. Contagious bank runs: experimental evidence. *European Economic Review*, forthcoming.

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 Jersey.

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.

Heinemann, F., Nagel, R., Ockenfels, P., 2009. Measuring Strategic Uncertainty in Coordination Games. *Review of Economic Studies* 76, 181-221.

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.

### Appendix: Instructions (for $r=1.54$ or $\eta=0.7$ )

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.

Period: trial 6 of 6 Remaining time [seconds]: 0

Please reach a decision!

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

Number of Withdrawals

Period

Period	Announced withdrawals	Number of withdrawals	Your Choice	Your Payoff	Your Total Payoff
-5	<=3	2	withdraw	1.54	0.00
-4	>=3	2	wait	1.73	0.00
-3	>=3	7	withdraw	1.43	0.00
-2	<=3	3	wait	1.54	0.00
-1	>=3	8	wait	0.00	0.00

The forecast is that 3 or **less** people will choose to withdraw.

Do you want to withdraw or wait?

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:

$$\text{Total payoff in ED} \times 0.1$$

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