Credit cycles in theory and experiment*

Antoni Bosch-Domènech
Universitat Pompeu Fabra
08005 Barcelona (Spain)

María Sáez-Martí
Stockholm School of Economics
S-113 83 Stockholm (Sweden) and
Universitat Pompeu Fabra
08005 Barcelona (Spain)

*We wish to thank Fabrizio Zilibotti for helpful comments and Xavier Herrero for his assistance in programming the experiments. Financial support from the Spanish Ministry of Education and Culture under contract DGICYT PB94-0663-C03-02 is gratefully acknowledged. Maria Saez-Marti thanks the Jan Wallander and Tom Hedelius' Foundation for financial support.

Credit cycles in theory and experiment

Corresponding author:

María Sáez-Martí

Stockholm School of Economics

Box 6501

S-113 83 Stockholm (Sweden)

Abstract

We test in the laboratory the potential of evolutionary dynamics as predictor of actual behavior. To this end, we propose an asymmetric game -which we interpret as a borrower-lender relation-, study its evolutionary dynamics in a random matching set-up, and test its predictions. The model provides conditions for the existence of credit markets and credit cycles. The theoretical predictions seem to be good approximations of the experimental results.

JEL classification: C7; C9; E3.

Keywords: Cycles, evolutionary dynamics, games, experiments.

1 Introduction

Evolutionary game theory has been a hot topic of research in recent years and an important body of results is now available (see, e.g. Weibull (1995)) . Yet, experimental evidence about the relevance of the use of evolutionary dynamics in real world economic situations is still limited (see, e.g., Friedman (1996)). This paper studies theoretically, and tests experimentally, the evolutionary dynamics of a two-population asymmetric game which is interpreted as a model of borrower-lender relations.

In our model potential borrowers and lenders -who know nothing about each other's history- are randomly matched. Lenders choose to grant a loan or to invest in a safe asset. If borrowers receive a loan they invest it in a project and decide whether to exert effort. Effort, which is not contractible, positively affects the probability of success of the project. Lenders can detect shirking and enforce its punishment, but only if they engage in a costly monitoring process. If lenders decided to monitor all projects, the borrowers' payoff would be maximized by exerting effort, since shirking would certainly be detected and penalized. However if no borrower shirked, lenders would maximize profits by not monitoring any loan.

The model has two sets of Nash equilibria. One equilibrium characterized by a mixture of good and bad behavior on the borrowers' side, and with lenders randomly monitoring a positive proportion of the loans granted. This equilibrium describes a fully developed credit market since, in this case, all matches between borrowers and lenders result in a credit relation. The other equilibrium (or, more exactly, set of equilibria) is characterized by complete 'financial collapse'. When lenders expect to find many bad borrowers they prefer to invest in the safe asset and do not grant any loans. If the proportion of borrowers who would cheat -should they receive a loan- is large enough, the lenders behave optimally by not lending.

The main focus of the theory is the characterization of the dynamics under the assumption that agents follow an adaptive behavior. We assume that individuals from large populations (borrowers and lenders) are randomly matched to play repeatedly a one-shot game representing the credit relation just described. In this framework, Nash equilibria are viewed as stationary points of dynamic processes representing some kind of evolutionary adaptation. We shall assume very general dynamics whose only requirement is that *strategies with higher payoffs grow relative to those with lower payoffs.* These "payoff monotonic dynamics" can be obtained from models of imitation and learning, with individuals revising their strategies in the light of the different strategies' relative payoffs.

In the presence of this adaptive behavioral rule, cyclical patterns of credit and effort are an intrinsic feature of the impulse-response function of an economy subjected to shocks. In particular, when a shock hits the economy, reducing the probability of successful investments, potential lenders become increasingly 'scared' at the growing number of defaults which they observe and start switching out of loans into safer investments. As a result, the economy is temporarily driven away from the *good* and towards the *bad* equilibrium. However, before the complete financial collapse is reached, granting credit to borrowers may turn again profitable and the economy starts reverting towards the *good* equilibrium in which all applications for a loan are satisfied. This explanation of the credit cycles relies on the assumption that *agents are not fully rational*. If agents played Nash equilibrium strategies at any moment in time, we could only observe either a fully active or a missing credit market. But as out-of-equilibrium behavior is part of the actual play, the cycles describe the dynamic behavior of populations who learn their way to equilibrium through iterative play.

The dynamics postulated in the paper predict the existence of two absorbing sets: *i*) the set of Nash equilibria with credit collapse and *ii*) the set of states with a fully developed credit market which contains the (mixed) Nash equilibrium described above. The model also gives exact predictions of when credit crunches will take place. We run the experiment in order to discriminate between the two absorbing sets, to test whether Nash equilibrium is a good predictor of behavior and to test whether credit crunches occur as predicted by the model.

The experiment clearly rules out the credit collapse set of equilibria, and, in most cases, shows convergence to the absorbing set with full credit availability. The experiment also shows that Nash equilibrium is not a good predictor of average behaviour. This last results contradicts neither our theoretical model, since convergence to the mixed Nash equilibrium is not guaranteed under general monotonic dynamics, nor other experimental results which show the difficulty in obtaining convergence to mixed equilibria in two populations games (see Friedman (1996)). Finally, the experiment shows that credit cycles do occur as predicted by the model.

Our analysis relates to various streams of literature. The emergence of periodical episodes of credit rationing and their effects on the aggregate economic activity have been widely discussed in the macroeconomic literature. Some explanations attribute the emergence of credit cycles to changes in the value of net worth and collaterals in the hand of the borrowers. In Bernanke and Gertler (1989) temporary shocks to net worth have persistent effects on the economy due to financial market imperfections. Kiyotaki and Moore (1997) obtain endogenous credit cycles in a dynamic model where borrowers' credit limits are affected by the price of their collaterizable assets (land). The interaction between asset prices and asset limits acts as a propagation mechanism through which the initial shock in one sector is amplified and transmitted to the rest of the economy. Differently from these model, in our game-theoretical model, cycles of credit emerge from simple *evolutionary* dynamics.[1]

The paper is organized as follows: In section 2 we describe the model, characterize the equilibria and study the dynamics of the economy. In section 3 we describe the experimental set-up and the different treatments of the experiment. In section 4 we present the results of the experiment and test the predictions of the model. Section 5 concludes.

2 Model

We consider a stylized economy in which all agents are risk-neutral. There exists a safe asset in the economy that earns an exogenously given interest rate. All potential investors need to borrow a fixed amount of money W to finance a project and have no collateral. Borrowers may either exert effort, or shirk. Each project can have two outcomes (*states*): *good* or *bad*, and outcomes are publicly observable at the end of each period. Effort increases the probability that an investment is successful and has a *good* outcome. In the *good state* the investment is successful and the borrower gets revenue $H > W$, cancels the debt with the agreed payment R and earns a net profit, whereas in the *bad state* the borrower gets nothing and cannot repay the

[1] A shortcoming of our one-shot set-up is that it fails to capture the long-term nature which typically characterize borrower-lender relations. We think that our model can be regarded as a description of the inherently risky market for loans to new investors and small firms, whose access to the credit market is sporadic and result in unreliable information about their past behavior. Bernanke (1983), for instance, observes that this segment of the market was significant and important during the Great Depression. In that period, customer relations were also weakened by the fact that many borrowers were separated from their banks when these were forced to close. This caused a considerable amount of borrowers to ask for credits in banks that were new to them. There is evidence that credit rationing was particularly significant to these segments of the market.

debt.[2] Let π and $(\pi+\alpha)$ be the probabilities of good state without and with effort, respectively and let e be the disutility of the effort. Lenders can decide to grant a loan of size W or to invest the same amount of money in a safe asset which yields a gross return r. Moreover, lenders are entitled to *interim* monitor borrower's activity. By monitoring, the lender will be able to observe the effort exerted by the investor. If he detects cheating, the lender asks for his money back (without earning interest) and the borrower is liable to legal prosecution, with a non-pecuniary utility loss f. If no cheating is detected the project can continue. However, monitoring entails a cost c (as if the lender had to pay some specialized institution for this purpose).

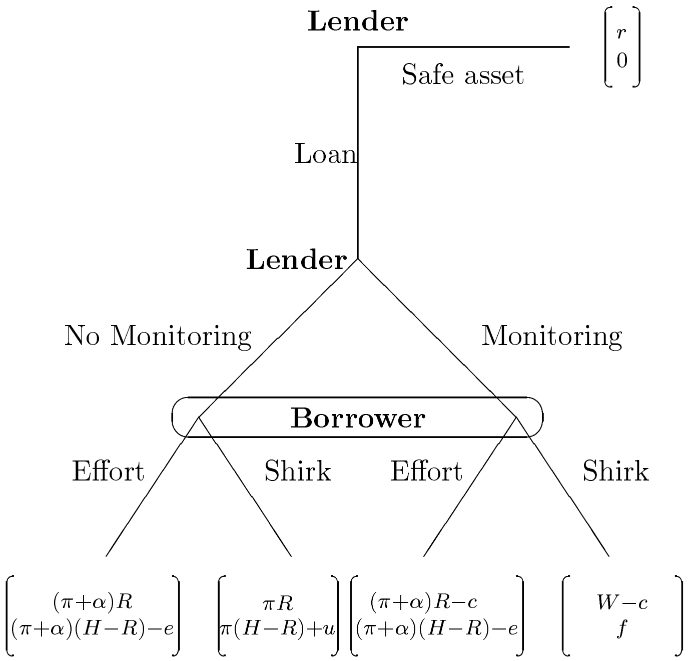

Figure 1: Borrower-Lender Game

Figure 1 is the extensive form representation of the situation described above.

The lender, therefore, decides whether to invest in a *safe asset* (SA) or to grant a *loan* (L). If the loan is granted, the lender chooses between *no monitoring* (NM) and *monitoring* (M). Observe that the lender has four pure strategies: (SA, NM), (SA, M), (L, NM) and (L, M).

[2] We will treat R as exogenous, although this can be regarded as the outcome of a more complicated contractual relation. In particular, we implicitly assume that there is no equilibrium value of R that makes the borrower's choice incentive compatible, i.e. that induces the borrower to exert effort, while giving the lender a higher expected payoff than that warranted by investing in the safe asset.

The borrower decides either to exert *effort* (E) or to *shirk* (S). The interpretation of each payoff pair is straightforward. For example, strategy (L, NM) matched with strategy E gives an expected payoff of $(\pi+\alpha)R$ to lenders (the probability of success for a honest borrower times the payment agreed in the case of success) and $(\pi+\alpha)(H-R)-e$ to borrowers (the probability of success when effort is exerted times the net profit minus the effort cost). The quantity u represents the utility to borrowers from shirking. The quantity f represents the disutility from the prosecution in the case of being caught when shirking.

	E	S
SA	$r, 0$	$r, 0$
NM	$(\pi+\alpha)R, (\pi+\alpha)(H-R)-e$	$\pi R, \pi R+u$
M	$(\pi+\alpha)R-c, (\pi+\alpha)(H-R)-e$	$W-c, f$

Figure 2: Normal form game

Figure 2 is the normal form of the borrower-lender game. Since the strategies (SA, NM) and (SA, M) are behaviorally indistinguishable, we will refer to both of them with the same label SA. For notational simplicity we will relabel (L, NM) and (L, M) as NM and M, respectively.

2.1 Equilibria

Let us assume that players can randomize over pure strategies. Let S_i be player's i strategy space and let $|S_i|$ be its cardinality. In the borrower-lender game the strategy spaces are $S_1 = \{SA, NM, M\}$ and $S_2 = \{E, S\}$. Player i's mixed strategy x_i is a vector which belongs to the $|S_i|-1$ dimensional probability simplex Δ_i,

$$\Delta_i = \{x_i \in R_+^{|S_i|} : \sum_{h=1}^{|S_i|} x_{ih} = 1\}$$

where x_{ih} is the probability assigned by x_i to the player's hth strategy.

Let x_{11}, x_{12} and x_{13} be the probabilities assigned by a lender to strategies SA, NM and M, respectively. The vector $x_1 = (x_{11}, x_{12}, x_{13})$ is a lender's mixed strategy. Notice that $x_{13} = 1 - x_{11} - x_{12}$. Let x_{21} and x_{22} be the probabilities assigned to the strategies E and S by a borrower. His mixed strategy is described by a vector $x_2 = (x_{21}, x_{22})$ with $x_{22} = 1 - x_{21}$. A mixed strategy profile is a vector $x = (x_1, x_2)$ in the mixed strategy space $\Delta = \Delta_1 \times \Delta_2$. The set Δ is a 3-dimensional polyhedron in R^5. We shall describe a mixed strategy profile by the vector $x = (x_{11}, x_{12}, x_{21})$.

We assume that payoffs satisfy the following conditions:

(c.1) $(\pi + \alpha)R - c > r > W - c > \pi R$.

(c.2) $(W - c - \pi R)((\pi + \alpha)R - W) > (r - (W - c))(W - \pi R)$.

(c.3) $(\pi + \alpha)(H - R) - e > f$.

(c.4) $\alpha(H - R) - e < u$.

Condition $(c.1)$ guarantees that when the borrower exerts effort, the lender's most profitable strategy is NM followed by M and SA, whereas when the borrower shirks the ordering is strictly reversed. Conditions $(c.1)$ and $(c.2)$ together guarantee that every strategy in S_1 is a strict best-reply for some values of x_{21}. Condition $(c.3)$ guarantees that, when the lender monitors, exerting effort is the best-reply for the borrower. Condition $(c.4)$ guarantees that, when the lender doesn't monitor, to shirk is the best-reply for the borrower. Notice that the optimal strategy of the borrowers depends only on the ratio of non monitored loans over total loans, $x_{12}/(1 - x_{11}) \equiv \bar{x}_{12}$, since the payoff to E and S is the same when the lenders invest in the safe asset.

If payoffs satisfy conditions $(c.1)$-$(c.4)$, the Borrower-Lender Game has a set of Nash equilibria with two components,

(i) a mixed equilibrium $x^* = (0, x_{12}^*, x_{21}^*)$ where

$$x_{12}^* = \frac{(\pi + \alpha)(H - R) - e - f}{\pi(H - R) + u - f} \text{ and } x_{21}^* = \frac{(W - c) - \pi R}{W - \pi R} \tag{1}$$

with $x_{12}^* \in (0, 1)$ by condition $(c.4)$, $x_{21}^* \in (0, 1)$, $\delta x_{12}^*/\delta\pi > 0$, $\delta x_{12}^*/\delta\alpha > 0$ and $\delta x_{21}^*/\delta\pi < 0$.

(ii) A set $C = \{(x_1, x_2) \in \Delta_1 \times \Delta_2 : x_{11} = 1 \text{ and } x_{21} \leq \hat{x}_{21}\}$ where

$$\hat{x}_{21} = \frac{r - (W - c)}{(\pi + \alpha)R - W} \tag{2}$$

$\hat{x}_{21} \in (0, 1)$ by condition $(c.1)$, $\delta\hat{x}_{21}/\delta\alpha < 0$ and $\delta\hat{x}_{21}/\delta\pi < 0$.

It is important to notice that SA is the lenders' best strategy when the proportion of borrowers who exert effort is below $\hat{x}_{21}$. This critical *threshold* will play a crucial role in our characterization of the dynamics, since it will allow us to determine the conditions under which credit cycles will emerge.

The mixed equilibrium, which is subgame perfect, corresponds to the existence of credit. All equilibria in C imply no credit. Under our restrictions on the payoffs, any equilibrium belonging to C, which corresponds to the absence of credit, is Pareto dominated by the singleton equilibrium.

The problem of the existence of credit therefore reduces to studying an equilibrium selection problem in game theory. In the following section we follow an evolutionary approach.

2.2 Dynamics

Rather than assuming that we have two players randomizing over pure strategies, we assume that there are two large populations of boundedly rational players, playing pure strategies, which are randomly matched. In this view a mixed strategy in population i is a population profile $x_i \in \Delta_i$ with $x_{ih} \geq 0$ denoting the relative frequency of the hth pure strategy in population i.

We assume a very general type of continuous dynamics, *payoff monotonic*, which ensure that more profitable strategies increase relative to less profitable strategies. This type of dynamics can be obtained from models of imitation and learning (Friedman (1992) and Weibull (1995)). We could assume, for instance, that players can observe a sample of contemporaneous interactions and imitate more profitable strategies. Lenders could meet and talk about businesses, and borrowers tell each other their credit experiences.

We describe evolution of the state of the economy, (x_{11}, x_{12}, x_{21}), by a system of differential equations (time indices suppressed)

$$\dot{x}_{ih} = x_{hi} g_{ih}(x) \qquad \forall i \in \{1,2\}, h \in S_i, x \in \times\Delta_i$$

where g_{hi} is the growth rate of pure strategy h in population i.[3] Under these dynamics, both Δ and its interior int(Δ) are invariant and extinct strategies stay extinct forever.

[3] We assume, as it is standard, that i) g is Lipschitz continuous on Δ and ii) $\sum_{h \in S_i} \dot{x}_{ih} = \sum_{h \in S_i} x_{hi} g_{ih}(x) = 0$, $\forall i \in \{1,2\}, x \in \times\Delta_i$. Existence and uniqueness of a solution is guaranteed by the Picard-Lindelf theorem.

Under payoff monotonic dynamics,

$$\pi_{ih}(x) > \pi_{ik}(x) \Longleftrightarrow g_{ih}(x) > g_{ik}(x) \tag{3}$$

for all $h, k \in supp\{x_i\}$; where $\pi_{ih}(x)$ is the expected payoff to a player from population i who employs strategy h in state x. Notice that the ordinal relationship applies only to nonextinct strategies; for extinct strategies $g_{ih}(x) = 0$.

Since several strategies will coexist at any time, including strategies which are not current best–replies and agents are randomly matched, the expected payoff to each strategy will depend on the probability of matching with each of the strategies played by the opponent population. In a world with many honest borrowers, to lend without monitoring is likely to be a successful strategy. In a world with almost all dishonest borrowers the best one can do is to invest in the safe asset. The state space, with the Nash equilibrium components, is represented in Figure 3. The states where the credit market is fully developed ($x_{11} = 0$) correspond to the floor of the polyhedron, which contains the mixed equilibrium. The set of Nash equilibria with credit collapse is the thick segment, C, on the edge where $x_{11} = 1$. The arrows along the edges of the polyhedron show the associated directions of the vector field for any monotonic dynamics. We have also drawn the directions of the vector field on the face where $x_{11} = 0$.

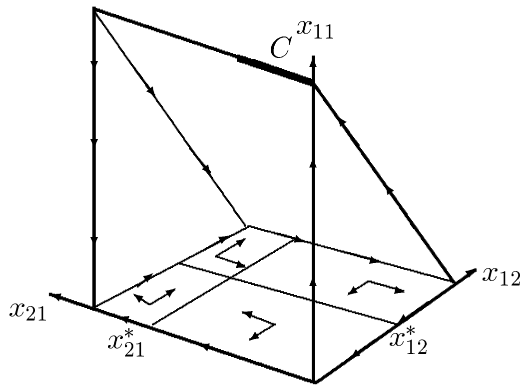

Figure 3: State space and equilibria.

In order to characterize the dynamics we need to study the stability properties of the absorbing sets of the system. We assume that some players tremble, mutate or experiment. Alternatively we could assume that new players, who know nothing about the economy, come along and play arbitrary strategies. The trembles' role is to resurrect extinct strategies and to perturb the rest points of the dynamics. Lemmata 1 and 2 in the appendix characterize the dynamic properties of set C and of the face of the polyhedron $F = \{x \in \Delta : x_{11} = 0\}$, which contains the mixed equilibrium. Lemma 1 shows that mutations which are intensive enough in monitored loans will drive the state of the system out of the set of credit collapse equilibria

Under payoff monotonic dynamics, the behavior in the face F, when there are no mutations or experimentation, can be of three types: 1) convergent to the mixed equilibrium, 2) closed orbits around the equilibrium point and 3) convergent to the boundary of F. Figure 4 represents the different dynamics on the face F (with $x_{11} = 0$), the mixed equilibrium x^*, and the value $\hat{x}_{21}$ (equation 5). On the horizontal dimension we plot the proportion of non monitored loans and on the vertical the proportion of borrowers who exert effort. The dashed line is the critical value $\hat{x}_{21}$. In all three cases the dynamics are clockwise. In case 1 the mixed equilibrium is asymptotically stable; in case 2 the dynamics are characterized by closed orbits around the equilibrium point; case 3 shows monotonic dynamics under which the mixed equilibrium is asymptotically unstable and the dynamics in the face F converge to the boundary.

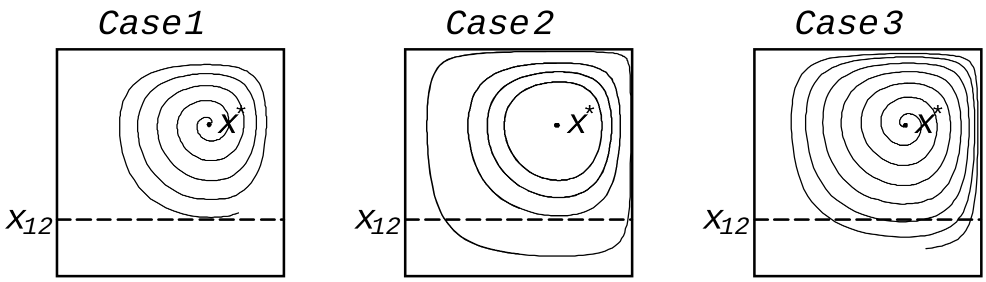

Figure 4: Dynamics on face F

In Lemma 2 we show that the face F is reflecting for low levels of effort, and absorbing for high levels of effort. Conditions (c.1) and (c.2) guarantee that investing in the safe asset is the lenders' best strategy for efforts below $\hat{x}_{21}$, and it is the worst strategy for efforts above $x'_{21} = (r - \pi R)/\alpha R$, with $\hat{x}_{21} < x'_{21} < x^*_{21}$. Under payoff monotonicity, "mutations" involving SA will spread if they occur when $x_{21} \leq \hat{x}_{21}$ and will be killed-off when $x_{21} \geq x'_{21}$. The behavior for intermediate values of x_{21} depends on the particular specification of the dynamics. Observe that as the proportion of SA increases so does the proportion of monitored loans over total loans, since due to the payoff monotonicity and assumptions (c.1) and (c.2) M grows relative to NM when

$x_{21} \leq x^*_{21}$. As monitored loans grow relative to non monitored loans, the advantage of shirking over exerting effort disappears and effort starts growing. The process of credit contraction will be reverted if a state with $x_{21} \geq x'_{21}$ is reached.

The following proposition exploits the reflecting nature of the face F and gives conditions for the existence of credit cycles.

Let $\mathcal{M}$ be the set of all payoff monotonic dynamics and $\mathcal{M}_1$ the set of monotonous dynamics for which x^* is the α-limit of any state in the interior of F, i.e. the dynamics bend outward (case 3).

PROPOSITION 1. *Assume that dynamics are payoff monotonic and that agents experiment with non-played strategies.*

i) *If dynamics belong to $\mathcal{M}_1$ the economy may exhibit credit cycles.*

ii) *For any dynamics belonging to $\mathcal{M}/\mathcal{M}_1$ there exist a set of initial conditions such that the economy may exhibit credit cycles.*

Proof. See Appendix.

Figure 5 shows a simulation with replicator dynamics.[4] Under replicator dynamics all strategies which get a higher than average payoff have positive rates of growth and those with higher payoff grow faster. The mixed equilibrium is a center point which is neutral, neither asymptotically stable nor unstable (case 3 in Figure 4) (see Hofbauer and Sigmund (1988)).

Consider a state such as a in figure 5 with a high proportion of good borrowers and non monitored loans. Under monotonous dynamics, both S and NM will grow: in a population with many good borrowers from the lenders' point of view, it is better to grant loans without paying the monitoring costs, while when there is little risk of being caught cheating is better. The system will move East and reach states characterized by a high rate of cheating and bankruptcy. In those states the outside option turns out to be relatively profitable and the system falls into

[4] Under replicator dynamics the rate of growth of population share x_{ih} is given by

$$g_{ih}(x) = (\pi_{ih}(x) - \bar{\pi}_i(x)) \forall i \in \{1, 2\}, h \in S_i, x \in \times \Delta_i$$

where $\bar{\pi}_i(x)$ is the average payoff in population i. Justifications to the use of the replicator dynamics to the modelling of learning are found in Cabrales (1992), Binmore and Samuelson (1993b), Börgers and Sarin (1997) and Schlag (1998). See Samuelson and Zhang (1992) for the properties of replicator dynamics which are shared by monotonic dynamics.

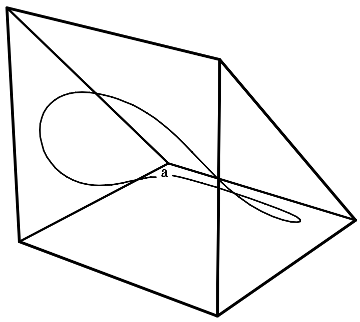

Figure 5: Credit cycle

a progressive credit crunch. Notice, however, that this process does not lead to the complete disappearance of credit activity. It is destined to revert to a new stage of credit expansion accompanied by a reduction of the rate of bankruptcy.

An implication of the previous result is that shocks can generate credit cycles. For instance, a shock that reduces the probability of success tends to generate credit cycles since its effect is to increase $\hat{x}_{12}$ and to make the economy more vulnerable to the invasion of SA. Assume, for the sake of simplicity, that the economy is initially in the mixed equilibrium and that a shock which changes the payoff matrix and the equilibria, although not their topological properties, hits the economy. The initial equilibrium is no longer stable and we can observe credit cycles as illustrated in Figure 6, which shows a simulation in which the initial equilibrium a becomes unstable after the shock.

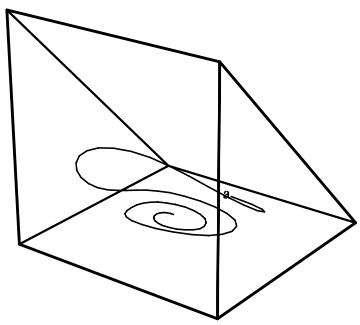

Figure 6: Post-shock behavior

Credit cycles are observed before the economy reaches a new long run equilibrium with higher proportion of monitored loans and of 'good' borrowers. Observe that the new mixed equilibrium is asymptotically stable in the face F. Notice that we have generated cycles with dynamics which are "convergent" in the face F. These dynamics are the "least favorable" for generating credit cycles, since we cannot guarantee that values below $\hat{x}_{21}$ are reached (see case 1 in Figure 4).

2.3 Summary of the theoretical results

In the previous subsection we have studied the behaviour of the economy under very general evolutionary dynamics. We have established the existence of two absorbing sets: i) a set of Nash equilibria with credit collapse (set C) and ii) the set of states with a fully developed credit market (set F) which contains a unique (mixed) Nash equilibrium. In this equilibrium there is a mixed of good and bad borrowers, and the lenders, who grant all loans, monitor a positive proportion of them. We have also shown that there exists a critical value for the proportion of borrowers exerting effort, $\hat{x}_{21}$, below which lenders prefer to invest in the safe asset. If such or a lower proportion of good borrowers is reached, a drainage of funds from loans into safer investments will be observed. An implication of this result is that shocks that occur when the economy is in the absorbing set with fully developed credit market, can generate credit cycles.

In what follows we present the results of an experiment which reproduces in the laboratory the situation described in the model. The experiment will allow us to select one of the two absorbing sets and to tests empirically the predictions of our theoretical model about credit crunches' occurrences.

3 Experiment

3.1 Experimental set up[5]

3.1.1 Generalities

As in the theoretical model, there exist two sets of experimental subjects, A and B. Each period, a random pairwise procedure matches individuals (whose identities are kept confidential) in both

[5]The description follows the usual protocol, as in Friedman (1996) p. 10.

sets, approximating a series of 2-player non-repeated games. An individual in A, a lender, can each period either invest in a low return, r, safe asset (SA) or lend, at a fixed return, R, to the individual in B, a borrower, with whom she has been matched. Since the identity of the two matched individuals is unknown to them, the interest rate charged for the loan cannot be made dependent on the borrowers history, and it is assumed to be always the same. Now, lenders can choose to monitor (M) the use of the credit in order to detect possible fraudulent behavior, but this monitoring entails a cost, c. Borrowers, on the other hand, can either "shirk" (S) or exert "effort" (E).

The experiment consist of a sequence of 13 laboratory sessions (without preliminary pilot sessions), lasting from 60 to 90 minutes each, using profit motivated subjects. Payoffs are calibrated to result in average earnings of about Peseta 2,000 (about \$14) per hour per subject. Realized earnings depend on chosen actions and typically vary from Peseta 500 (US \$4), to Peseta 3,500 (\$27) per session. All subjects are given written instructions (available from the authors on request) in a neutral language that does not mention the interpretation of their roles as borrowers or lenders, nor does it include any reference to lending, consuming or investing. The instructions contain information about the mechanics of the experiment and about the subject's payoffs, which depend, as it is made explicit, on her decisions and the decisions of the matched pair. In the instructions, subjects are not informed about payoffs of any other subjects. Previous to the beginning of the sessions, subjects receive about 15 minutes training on the computer. In each session, 12 or 14 undergraduate subjects interact for an undisclosed number of periods.[6]

All sessions have in common that, in each period, the subjects, seated at visually isolated terminals, review historical data and take actions from a menu of two possible actions for borrowers (which we interpret as effort (E) and no effort (S)) and three possible actions for lenders (which we interpret as invest in the safe asset (SA), lend without monitoring (NM) and lend with monitoring (M)). The choices of all subjects are sent to a central processor that computes the outcomes. The historical data that appear on their screens, after each period,

[6]We intended to use 14 subjects in all sessions. Failure of a computer in one session and failure to attract the required 14 subjects in another, resulted in two sessions (10 and 11) with only 12 subjects. Additionally, in order to see whether our averages were affected by the small number of observations, in Sessions 3, 9, 10 and 11, we forced subjects to make three choices per period, as if we had 42 subjects participating. We fail to see any effects of this procedure. We kept sessions to a minimum of 32/34 periods, and some sessions went up to 62 periods.

are their previous decision and payoff and the previous decision and payoff of another subject, chosen randomly, in their group (either A or B).

In all sessions, the payoff function is defined for a set of parameters that satisfy the conditions $(c.1) - (c.2)$ of the theoretical model. The abstract payoff matrix used is the same as in the normal form game showed in Figure 2, but subjects only see as the elements of the matrix the *expected* payoffs that result from the operations stated there. These payoffs are the same for each group of subjects. In some sessions, a shock occurs in mid-session resulting in a change in the payoff matrix.[7] The remaining sessions (1, 5 and 9) do not include a shock and, consequently, the payoff matrix stays the same during the whole session. When a shock exists, the payoffs are chosen to separate as clearly as possible the pre and post shock mixed Nash equilibria predicted by the model.[8]

3.1.2 Treatment

The treatment is the payoff: We want to observe the effects of changes in payoffs. We organize the experiment in three groups of four sessions, each with a different starting payoff matrix. Among the four, one session, serving as a baseline, does not include a shock, or payoff change, in midsession. These shocks originate in a modification of one or several of the parameters that affect the expected payoff -like the probability of success with or without effort- in the normal form game matrix. In addition, a Session 13 was organized to observe the effect, if any, of reversing the order of the payoff matrices with respect to Sessions 10, 11 and 12. Table 1 summarizes the experimental set-up.

[7] In Sessions 2, 6, 7 and 8, the shock was announced and the new payoff matrix was made public. In the remaining sessions with shocks, the shock was not announced and the new payoff matrix was never made public, but subjects were told that the payoff matrix would change during the session without warning. We have failed to see any systematic difference between the two treatments. In particular we fail to see, as one would have expected, more experimenting on the subjects' part when the new payoff matrix was not explicitly given. These changes, plus the ones reported in footnote 5, were introduced to check for robustness, as we replicated the sessions with these variations.

[8] In sessions 1, 2, 3 and 4, the equilibrium values before and after shock for NM were considered to be too close, and the payoffs were subsequently changed so that the distance between equilibria increased.

Group	Session	Payoffs	Periods	Number of Subjects
1	1	P1	32	14
1	2	P1/P2	17/32	14
1	3	P1/P2	17/32	14
1	4	P1/P2	26/62	14
2	5	P3	50	14
2	6	P3/P4	20/50	14
2	7	P3/P4	21/50	14
2	8	P3/P4	23/50	14
3	9	P5	30	14
3	10	P5/P6	17/34	12
3	11	P5/P6	17/34	12
3	12	P5/P6	16/62	14
-	13	P6/P5	17/34	14

Table 1. Summary of the sessions' basic features.

1) The payoffs' column indicates the different payoffs used in the experiment. A slash means that a shock occurred in the session, resulting in different initial and final payoffs. Sessions 1, 5 and 9, acting as baselines, do not have any shock. Note that in Session 13, the order of payoffs was reversed with respect to Group 3 sessions. 2) When the number of periods is separated by a slash, the first figure indicates the period when the shock occurred, and the second the total number of periods.[9]

Our main goal is to test whether, as predicted by the payoff monotonous dynamics of the model, credit crunches occur at the critical threshold. We also want to check whether Nash is a good predictor of average behavior and whether the observed dynamics show any degree of convergence towards Nash. Finally we use the experiment to discriminate between the two sets of equilibria of the game.

[9] Session 7 includes a cost of changing strategies with the purpose of reducing the volatility of the market.

4 Experimental results

4.1 Payoff salience

Since the experiment involves quite a few sessions, we want to begin by checking that the sessions are taking place in a stable experimental setting, unaffected by the different subject pools or the different experimental situations. To this end, we compare sessions that share the same initial payoffs looking at the average frequencies of the different strategies before any shock occurs. For those sessions without shock, we will only compare averages for the same number of periods as in the first part of the sessions with shock.

Payoff P1				**Payoff P3**				**Payoff P5**			
Session	x_{11}	$\bar{x}_{12}$	x_{21}	Session	x_{11}	$\bar{x}_{12}$	x_{21}	Session	x_{11}	$\bar{x}_{12}$	x_{21}
1	.12	.58	.69	5	.21	.56	.25	9	.29	.35	.55
2	.12	.68	.74	5b	.09	.80	.49	10	.27	.29	.49
3	.14	.64	.73	6	.09	.78	.60	11	.28	.54	.44
4	.10	.65	.63	7	.09	.78	.49	12	.26	.48	.26
				8	.07	.74	.51				
Average	.12	.62	.70	Average	.11	.73	.47	Average	.28	.48	.26
SDV	.02	.07	.05	SDV	.06	.10	.13	SDV	.01	.12	.13

Table 2: Table of frequencies[10]

Sessions grouped according to payoffs. First part of sessions. x_{11} (Safe asset) ; $\bar{x}_{12}$ (Non monitored loans over total of loans); x_{21}(Effort).

In broad terms, see Table 2, one can say that average frequencies of SA (x_{11}) and NM/NM+M ($\bar{x}_{12}$) remain more similar within groups than between groups, confirming some basic stability of the experimental set-up and indicating, as well, that payoffs have an effect on outcomes, what may be called salience.[11] Specifically, if we leave aside Session 5, which does not fit squarely in any of the three groups, SA has frequencies in the range 10-14% per cent for P1, in the range

[10] The original Session 5 was interrupted by a computer failure. The result was a short session, so we decided to run it again. We call 5 the new session and we label the old session as 5b.

[11] This effect is called "dominance" in Friedman and Sunder (1994). We do not use this name to avoid confussion with "payoff dominance" as used in game theory.

7-9% for P3, in the 26-29% range in P5. Similarly we observe that $\bar{x}_{12}$ are in the 52-65% range for P1, in the 74-80% range for P3, in the 29-48% range for P5.

When we turn to borrowers and we observe their effort strategy, differences among groups of sessions are less marked but still clearly discernible. P1 has frequencies in the 63-74% range, P3 in the 49-60% range and P5 in the 26-55% range. The conclusion is that stability of the experimental environment and payoff salience seem to be verified.

4.2 Which absorbing set?

The game presented in the theory part of the paper has two differentiated sets of Nash equilibria. One is a set of equilibria with credit collapse, the second being a full credit situation with some loan monitoring and effort. In the experiment the situation of credit collapse was never reached. The worst case represents a credit crunch of about 75% of the credit potential, which occurs in one period of Session 4 and in one period of Session 12. In the experiment a "serious" credit crunch meant usually a credit reduction of 50-60%, still quite a long way from the credit collapse. On the other hand, situations with full credit availability abound and, as we will see soon, convergence to full credit availability is not uncommon.

The first conclusion of the experiment is, therefore, to question the likelihood of a credit collapse equilibria

4.3 Convergence to full credit availability

The set of Nash equilibria with credit collapse is not selected in the experiment, but is the face F an attractor in the dynamics of the credit market? Our general model only claims attractor capability for the full credit strategy, i.e., we should observe a tendency to go to the floor of Figure 3. But cycles of effort and monitoring could be either converging or diverging. The following table reports the convergence results for the safe asset. The aim of this test is to see whether we can say that observed behavior converges to the fully developed credit market or not.

We say that state x converged to x^* at time t' with a pre-selected tolerance bound b if

$$\frac{1}{T-t}\sum_{t}^{T}|x(t)-x^*| \leq b \text{ for all } t \geq t'$$

where T is the last period. When sessions have shocks, we run the test for the two subsessions. Following Friedman (1996) we choose $b = 1/n$ (tight convergence) and $b = 2/n$ (loose convergence), where n is the number of subjects in each set A and B.[12] Observe that the tight criterion will yield convergence from period t onwards as long as no more than one subject deviates, on average, from the equilibrium strategy, while the loose criterion allows for, at most, two deviating subjects on average.

Session	**Periods**	**Pre-shock**	**Periods**	**Post-shock**
1	1-32	T(1), L(1)	-	-
2	1-16	T(1), L(1)	17-32	T(22), L(17)
3	1-16	T(16), L(15)	17-32	No convergence
4	1-25	T(1), L(1)	26-62	T(26), L(26)
5	1-52	No convergence	-	-
6	1-19	T(19), L(1)	20-50	T(50), L(20)
7	1-20	T(1), L(1)	21-50	T(21), L(21)
8	1-22	T(1), L(1)	23-50	T(46), L(23)
9	1-30	L(30)	-	-
10	1-16	No convergence	17-34	No convergence
11	1-16	No convergence	17-34	T(31), L(25)
12	1-25	No convergence	26-62	T(34), L(26)
13	1-16	T(16), L(1)	17-34	L(11)

Table 3. Convergence towards full credit availability ($x_{11} = 0$).

T(t) and L(t) stand respectively for tight and loose convergence from period t onwards. Of course, T(t) implies L(t).

In the pre-shock part, out of thirteen sessions, five show strong convergence to full credit availability from the very beginning, a total of eight show strong convergence from some period onwards, a total of nine show some sort of convergence, and only four show no convergence. In the post-shock part, out of ten sessions, seven show strong convergence, another one shows loose convergence, and only two sessions show no convergence. We interpret this result as showing

[12] Our criterion for convergence differs from Friedman's in that we check for convergence from every period onwards, while he does it for the whole session (or half session). As explained in footnote 5, n=7 except in sessions 3, 9, 10 and 11, when n=21.

behavioral convergence towards the full credit equilibrium, as predicted by the payoff monotonic dynamics of our model.

4.4 Nash as an approximation

As we have seen in section 2.2, payoff monotonic dynamics do not guarantee convergence to the mixed equilibrium, but is the Nash equilibrium with full credit availability a good approximation of the average frequency of strategies?

Whether Nash fails to approximate the average frequencies is a matter of opinion, difficult to settle since we do not have an alternative concept of equilibrium to compare with. In spite of it, we think that Nash fails since it is not capable, in most cases, to predict in what direction the frequency of strategies is going to move when Nash varies as payoffs are changed. If we look at effort, the equilibrium values in the pre-shock sessions of the three groups are 22%, 54% and 71%, while the average frequencies stay, very broadly, around 50%, 70% and 50% respectively. Similarly for the post-shock parts of the three groups of sessions, with equilibrium values at 41%, 47% and 78% and average behavior around 53%, 35% and 78%.

	Pre-Shock							Post-Shock						
Session	x^*_{11}	x_{11}	x^*_{12}	x_{12}	$\bar{x}_{12}$	x^*_{21}	x_{21}	x^*_{11}	x_{11}	x^*_{12}	x_{12}	$\bar{x}_{12}$	x^*_{21}	x_{21}
1	0	.08	.93	.46	.52	.54	.69	-	-	-	-	-	-	-
2	0	.12	.93	.60	.68	.54	.74	0	.21	.91	.55	.69	.78	.76
3	0	.14	.93	.55	.64	.54	.73	0	.21	.91	.36	.45	.78	.80
4	0	.10	.93	.66	.65	.54	.63	0	.06	.91	.49	.50	.78	.76
5	0	.26	.79	.37	.49	.22	.30	-	-	-	-	-	-	-
5b	0	.09	.79	.72	.79	.22	.49	-	-	-	-	-	-	-
6	0	.09	.79	.71	.78	.22	.60	0	.14	.77	.70	.81	.41	.54
7	0	.09	.79	.71	.78	.22	.49	0	.11	.77	.63	.71	.41	.57
8	0	.07	.79	.69	.74	.22	.51	0	.24	.77	.51	.67	.41	.49
9	0	.22	.40	.26	.34	.71	.60	-	-	-	-	-	-	-
10	0	.28	.40	.21	.29	.71	.49	0	.18	.50	.49	.50	.47	.49
11	0	.26	.40	.35	.47	.71	.26	0	.15	.50	.44	.50	.47	.44
12	0	.26	.40	.35	.47	.71	.26	0	.17	.50	.43	.52	.47	.11
13	0	.08	.50	.43	.48	.47	.63	0	.14	.40	.27	.33	.71	.67

Table 4. Table of equilibria frequencies and average frequencies

x_{11} (Safe asset), x_{12} (Non Monitored Loans), $\bar{x}_{12}$ (Non monitored loans with respect to total loans), x_{21} (Effort). A star denotes equilibrium values.

Things look better with respect to Non monitored loans over total loans ($\bar{x}_{12}$), but not quite. Equilibrium values at 40% and 79% seem to be close to actual frequencies of about 40% and 75%, but when equilibrium moves up to 93%, observed frequencies move down to about 60%. In the post shock part of the three groups of sessions, we have equilibrium values at 50%, 77% and 91%, with averages in the range of 50%, 75% -quite good- and 45% -quite bad.

4.5 Cycles

The evolutionary model presented in the paper predicts that there exist a threshold, $\hat{x}_{21}$, such that, when effort falls below it, a credit crunch takes place. Table 5 reports the values of $\hat{x}_{21}$ corresponding to the six different payoffs of the experiment.

Payoffs	$\hat{x}21$
P1	.24
P2	.46
P3	.15
P4	.36
P5	.40
P6	.23

Table 5.Values of the threshold $\hat{x}_{21}$ for the different payoffs

Although our general dynamics predict the possibility of credit crunches, it does not predict their magnitude. We turn now to see how this qualitative prediction fares in our experiment (see figures in the Appendix):

Group 1: In Session 1 (with no shock) and in the pre-shock part of the rest of sessions in this group, the threshold $\hat{x}_{21}$ is .24. Since average effort stays always above this level, no credit crunch should be observed according to the model, and *no credit crunch is observed*. After the shock, the threshold $\hat{x}_{21}$ moves up to .46, average effort crosses this level, and *we observe credit crunches* of more than 50% in Sessions 2 and 4 and of about 65% in Session 3.

Group 2: The second group of sessions is characterized by a very low effort threshold $\hat{x}_{21}$ =.15. In many periods of Session 5, a session with no shock, actual effort reaches the threshold and we observe, as predicted, many periods of *credit contraction* to availability levels around 60%, and as many as five periods in which credit availability falls to lows of about 40%. In the pre-shock part of the remaining sessions (6, 7 and 8), effort never falls as low as 15% (except in one period of Session 7) and *no fall in credit availability is observed* (except in one period of Session 6). After the shock, the threshold raises to .36, and effort falls twice below it in Session 6, and twice in Session 8. Only in one of the cases, in each session, we observe that credit falls below 60%. In Session 8, which charges a cost for changing strategies, this credit contraction lasts for as many as 7 periods. In Figure 7 we show effort and monitoring cycling in the neighborhood of their equilibrium values in session 8 and how, after the shock which raises $\hat{x}_{21}$, observed effort crosses the threshold.

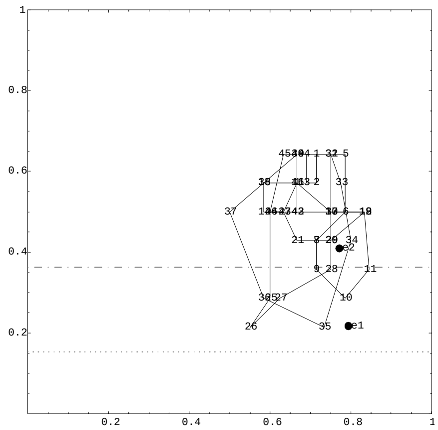

Figure 7: Path of (x_{12}, x_{21}) in Session 8. The shock occurs in period 23, raising $\hat{x}_{21}$ from .15 to .36, as shown by the horizontal lines; e1 and e2 indicate, respectively, the pre-shock and post-shock equilibria.

Group 3: To the third group of sessions corresponds an initial threshold of .4 and a post-shock threshold of .23. Session 9 (the section without shock) begins with effort near the threshold and credit availability below 60% in several periods. After period 10, effort remains above the threshold and, as predicted, credit begins a *slow recovery* with a clear trend towards full credit availability. In Sessions 10 and 11, with effort staying at about the same level before and after the shock, *credit availability is higher* in the second part of the sessions, as predicted by the model, due to the fall in the threshold. In the whole of Session 12, observed effort is very low, while *credit availability stays low* in the pre-shock part (in fact, the lowest credit availability of the whole experiment is reached in this part of the session), increasing in the post-shock phase. But this higher credit availability takes place in spite of effort falling below the threshold, contrary to what the model's prediction. Finally, if we turn to Session 13, which *inverts* the order of the payoff matrices, the model predicts *more credit availability* in the pre-shock part than in the post-shock, and this is what is observed: the only significant credit crunch occurs in the second part, after effort falls close to 40%.

Our conclusion is that, except in the second part of Session 12 and, ambiguously, in the second part of Sessions 6 and 7, the model is a good guide to predict when credit crunches are going to be more likely in the 13 sessions of the experiment.[13]

5 Conclusions

In this paper we have presented an asymmetric game which we interpret as representing a lender-borrower relation. The game has two sets of Nash equilibria: an equilibrium with full credit availability and a set of equilibria with credit collapse. Both types of equilibria can be reached under payoff monotonic dynamics. The experiment has helped us to discriminate in favor of the full credit equilibrium.

The experiment has also confirmed that Nash equilibrium strategies are not a good predictors of the average behavior in asymmetric games, as pointed out by Friedman (1996).

The evolutionary model presented makes very precise predictions about credit crunch occurrences. These predictions are, in essence, confirmed experimentally.

Diverging or converging cycles of effort and monitoring are all possible with general payoff monotonic dynamics. This may be a drawback of using such a general model. But that a general model can make precise predictions on when credit crunches will occur, and that these predictions are essentially substantiated by the experiment, seems to give added credibility to the evolutionary approach taken here.

References

Bernanke, B., and M. Gertler (1990): "Financial fragility and economic performance," *Quarterly Journal of Economics*, pp. 87–114.

Börgers, T., and R. Sarin (1997): "Learning Through Reinforcement and Replicator Dynamics," *Journal of Economic Theory*, 77, 1–14.

Cabrales, A. (1993): "Stochastic Replicator Dynamics," University of California, San Diego.

Friedman, D. (1992): "Evolutionary Games in Economics," *Econometrica*, 59, 637–666.

[13]In Session 5b, the session that a computer failure stopped midway, credit availability also shows the behavior that the model would have predicted.

Friedman, D. (1996): "Equilibrium in Evolutionary Games: Some Experimental Results," *Economic Journal*, 106, 1–25.

Friedman, D., and S. Sunder (1994): *Experimental Methods.* Cambridge University Press.

Hofbauer, S., and K. Sigmund (1988): *The Theory of Evolution and Dynamical Systems.* Cambridge University Press, Cambridge.

Kiyotaki, N., and J. Moore (1997): "Credit Cycles," *Journal of Political Economy*, 105, 211–248.

Ritzberger, K., and J. Weibull (1995): "Evolutionary Selection in Normal-Form Games," *Econometrica*, 63, 1371–1399.

Samuelson, L., and J. Zhang (1992): "Evolutionary Stability in Asymmetric Games," *Journal of Economic Theory*, 57, 363–391.

Schlag, K. (1998): "Why Imitate, and If so, How? A Bounded Rational Approach to Multi-Armed Bandits," *Journal of Economic Theory*, 78, 130–156.

Weibull, J. (1995): *Evolutionary Game Theory.* MIT Press, Cambridge, Mass.

6 Appendix

6.1 Proofs.

LEMMA 1. *C is not stable.*

Proof. Consider the state $(1, 0, \hat{x}_{21} - \delta)$ $(\delta \geq 0)$ in C and an ϵ-proportion of mutants who play NM and M in proportions γ and $(1-\gamma)$, respectively. At $(1-\epsilon, \gamma\epsilon, \hat{x}_{21} - \delta)$ $\dot{x}_{21} > 0$ for all $\gamma/(1-\epsilon) < x^*_{12}$, $d/dt(x_{11}/x_{13}) > 0$ and $\dot{x}_{12} < 0$. At $(1-\epsilon, \gamma\epsilon, \hat{x}_{21} + \delta)$, $d/dt(x_{11}/x_{13}) < 0$ for all $\gamma \in [0, 1]$. QED

LEMMA 2. *For any payoff monotonic dynamics, the face D is reflecting for $x_{21} \leq \hat{x}_{21}$ and absorbent for all $x_{21} \geq x'_{21}$, with*

$$\hat{x}_{21} = \frac{r - (W - c)}{(\pi + \alpha)R - W} < \frac{r - \pi R}{\alpha R} = x'_{21} < x^*_{21} \tag{4}$$

Proof. For any monotonous dynamics $\dot{x}_{11} > 0$ $(\dot{x}_{11} < 0)$ at all $x = (\epsilon, x_{12}, x_{21})$ with $x_{21} \leq \hat{x}_{21}$ $(x_{21} \geq x'_{21})$ and $\epsilon \in (0,1)$ since by $(c.1)$ and $(c.2)$ SA is the most (least) profitable strategy for all $x_{21} < \hat{x}_{21}$ $(x_{21} \geq x'_{21})$. QED

Proof to proposition 1. (i) Let us assume that the dynamics belong to $\mathcal{M}_1$ and that the economy is at the mixed equilibrium. Consider a perturbation in t such that $x(t) \in F$ and $x(t) \neq x^*$. Under any dynamics in $\mathcal{M}_1$ the system will swirl outwards and reach a state with $x_{21} \leq \hat{x}_{21}$. By lemma 2, $\dot{x}_{11} > 0$ if SA happens to be played. In the process of credit contraction the proportion on monitored over non monitored loans is increasing, $d/dt(x_{13}/x_{12}) > 0$, by conditions $(c.1)$ and $(c.2)$ and monotonicity. A state is reached at which $\dot{x}_{21} > 0$, by monotonicity and conditions $(c.3)$ and $(c.4)$. The process of credit rationing slows down and is reverted when $x_{21} > x'_{21}$, by lemma 2. A state in F is reached and a new credit cycle arises after a period of fully developed credit market. (ii) Consider all the states $x(0) \in \Delta$ such that $x(t) \in F' = \{x \in F : x_{21} \leq \hat{x}_{21}\}$ for some $t \geq 0$. Apply the argument in (i). QED

6.2 Payoff matrices

Numbers are in Lab units, which will be converted, after each session, at a fixed exchange rate, into pesetas.

	E	S
SA	300, 0	300, 0
NM	540, 170	180, 190
M	490, 170	240, -100

Payoffs P1

	E	S
SA	300, 0	300, 0
NM	420, 110	60, 130
M	370, 110	240, -100

Payoffs P2

	E	S
SA	250, 0	250, 0
NM	540, 170	180, 240
M	360, 170	230, 140

Payoffs P3

	E	S
SA	250, 0	250, 0
NM	465, 133	105, 202
M	285, 133	230, -100

Payoffs P4

	E	S
SA	70, 50	70, 50
NM	120, 100	0, 250
M	100, 100	50, 0

Payoffs P5

	E	S
SA	50, 50	50, 50
NM	140, 125	0, 250
M	100, 120	35, 0

Payoffs P6

6.3 Dynamics of credit and effort.

In the following figures we plot the dynamics for total credit (⧫ ⧫), effort (⋆ ⋆), equilibrium values (in the mixed equilibrium) of total credit (− · − · −) and effort (− − −−) and the critical threshold $\hat{x}_{21}$ (− · · · − ··)

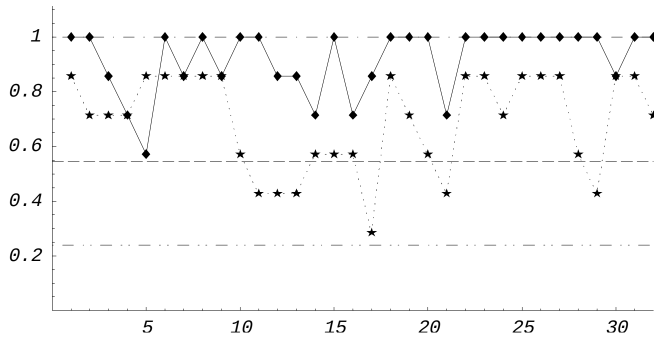

Figure 8: Session 1

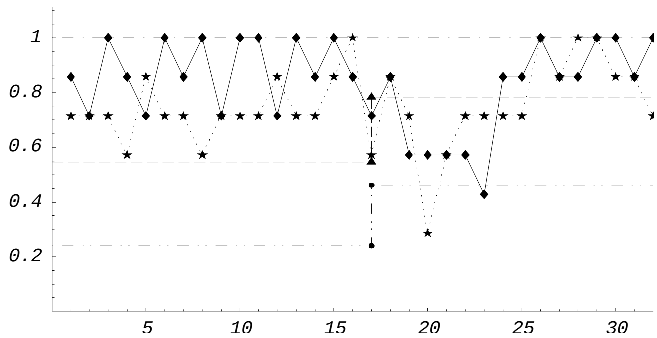

Figure 9: Session 2

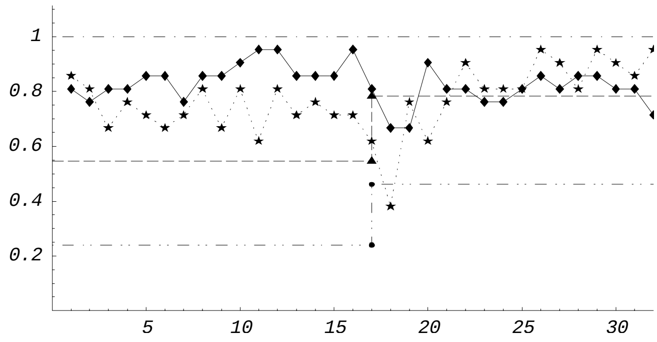

Figure 10: Session 3

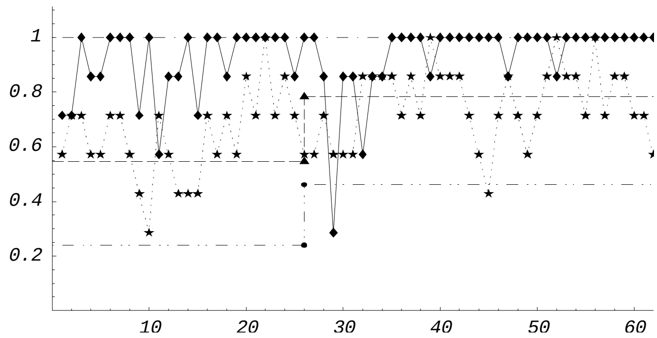

Figure 11: Session 4

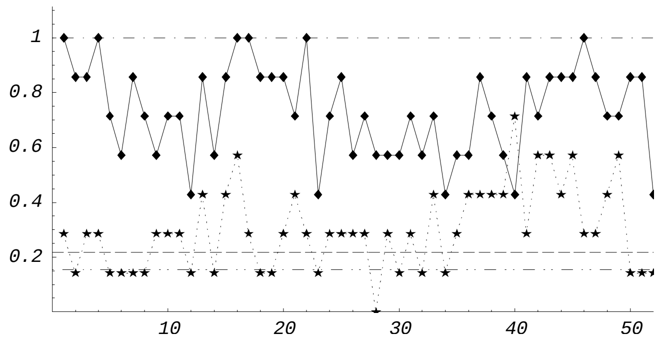

Figure 12: Session 5

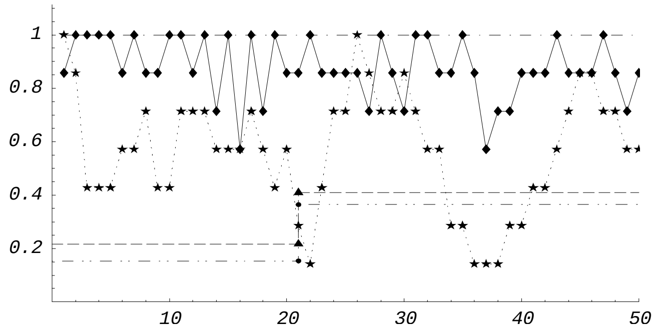

Figure 13: Session 6

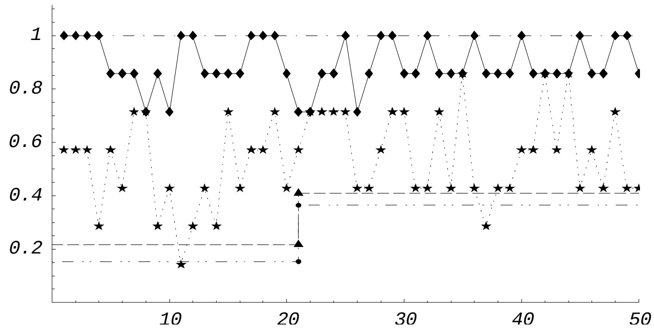

Figure 14: Session 7

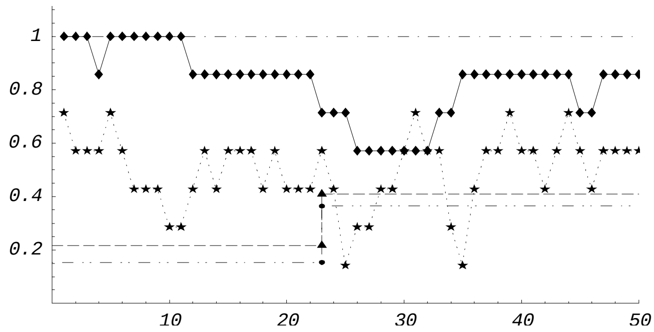

Figure 15: Session 8

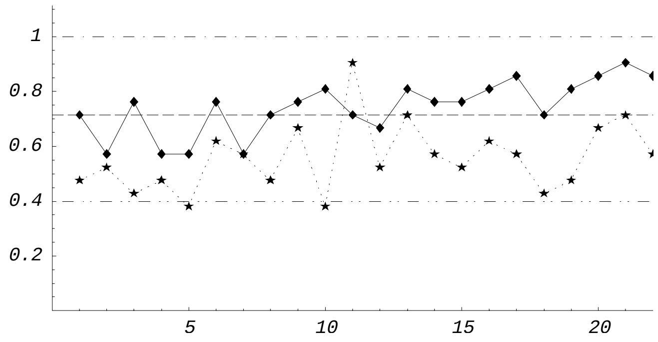

Figure 16: Session 9

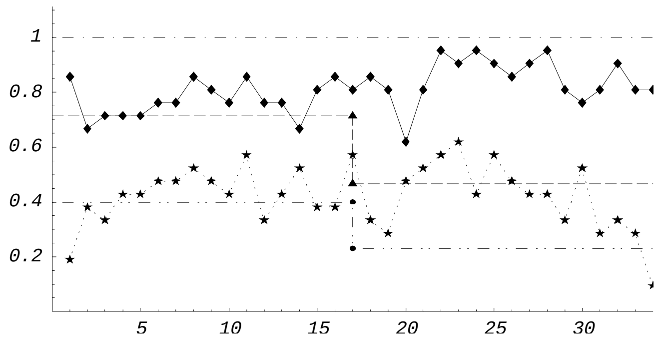

Figure 17: Session 10

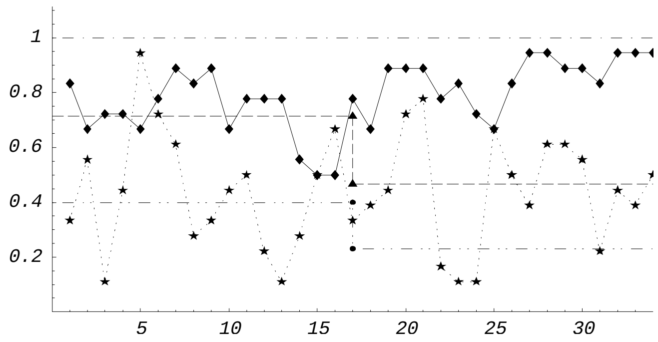

Figure 18: Session 11

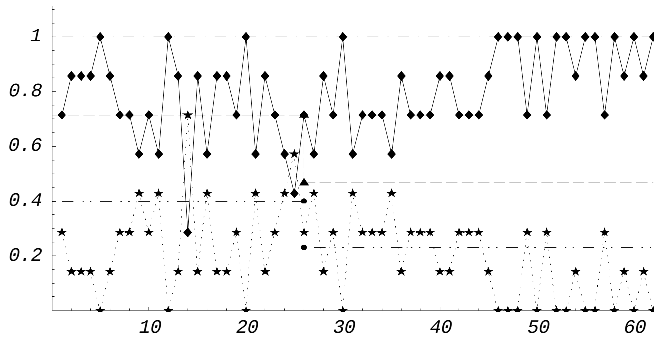

Figure 19: Session 12

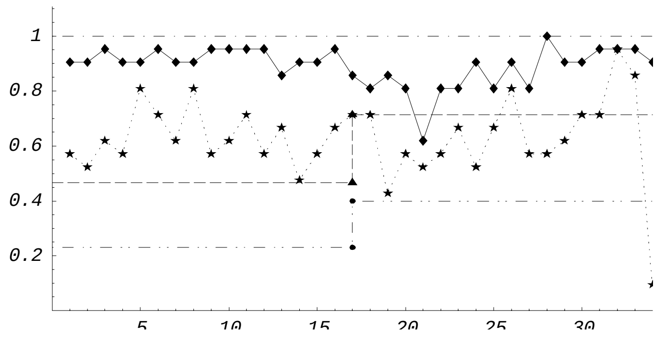

Figure 20: Session 13