Efficient Investment via Assortative Matching in One-Shot Games: Theory and Evidence

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Abstract

This paper studies pre-commitment investment strategy in a one shot game, where agents seek to form matches in the presence of an assortative matching rule. We show that a bimodal distribution of investment arises in equilibrium where most players select high levels of investment —achieving a pareto superior solution— meanwhile few stay at the lower bound —the trivial NE. The experimental evidence obtained supports our predictions and shows that the median investment levels are remarkably high, close to 91 percent of the initial endowment. This result is novel as one shot games have generally been unable to produce such high levels of cooperation (efficiency).

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1 Introduction

Interactions between multiple parties are central to the outcome of joint projects: marriages, employer-employee relationships, student-university matches or joint-ventures by firms. In all these scenarios, the involved parties hope to form the best possible match in order to maximize potential benefits. However, when pre-commitment is required, the outcome is not always obvious. For instance, in a joint-venture situation, firms may have misaligned incentives that lead them to shirk and “free-ride" on the investment of others. A number of institutions or incentive compatible mechanisms have been suggested to overcome this problem. We propose a matching rule that unites agents with similar investment choices, which we then formally analyze and contrast with experimental evidence.

The pre-commitment investment decision can be characterized by a one-shot Prisioner's Dilemma (PD) or a one-shot public goods game where the Nash Equilibrium (NE) is not a socially optimal outcome. To enhance efficiency, we introduce an assortative group formation. This mechanism could be implemented in the form of a third-party who has knowledge regarding investment levels of both sides and is able to match players accordingly. This process is an idealization of a pure assortative matching, where we abstract from any matching errors.

Our game is also a variation of a matching tournament, where players can choose to invest in a partnership. In Becker (1973), Cole, Mailath and Postlewaite (1992) and others,[1] the agents possess heterogenous characteristics (e.g. rich/poor or low-skilled/high-skilled) and compete to be matched with other players with certain desirable traits. This process yields an endogenous group formation, with assortative matching arising as an equilibrium condition. In our game, the agents do not have any ex-ante distinguishing characteristics, and thus look to a third-party to unite similar types based on strategy choices. The resulting pairs are formed according to investment rank while the payoff is calculated using pairwise investment levels. Thus, for each individual, the payoff depends negatively on own investment level and positively on the partner's. Notice that this setup can also be interpreted as a linear public goods game with group size equal to two, using a pre-specified matching rule. The solution of the game suggests that in addition to the trivial NE — where investment levels stay at the lower bound— there also exist a mixed ε-equilibrium in which higher levels of investment can be sustained.

To empirically test the existence of these equilibria and to study how human behavior approximates these predictions, we conduct a laboratory experiment using two treatments: assortative matching (AM) and random matching (RM). The experimental evidence shows

[1] Other studies that include ex-ante investment decisions Peter and Siow (2002), Cole, Mailath and Postlewaite (1995), Hopkins (2012) and Hoppe, Moldonavu and Sela (2009). The last three studies incorporate signaling into the matching process.

that investment levels support the existence of a mixed ε-equilibrium , and that investments are roughly doubled when compared to RM. This result is novel as one shot games have generally been unable to produce high levels of cooperation (efficiency) as noted by Cooper et al. (1996).[2]

The rest of the paper is organized as follows: section 2 reviews past experimental literature, while section 3 describes the game and proposes a solution. Section 4 introduces the experimental design and hypotheses while section 5 discusses the results. Lastly, section 6 concludes with a summary and avenues for future research.

2 Literature Review

Numerous studies have previously analyzed the stability of cooperative equilibria in Prisoners' Dilemma (PD) type games. Generally, the findings suggest that cooperation is not fully sustainable unless the game is infinitely repeated or otherwise incorporates incentive compatible features that induce cooperation on part of the players (Cooper et al. 1996). In this paper, we introduce a mechanism that enhances cooperation using group formation, or assortative matching, thus leading to a more efficient outcome. It will be noted the connections of our work to the most closely related laboratory studies.

The motivation behind group formation is to mitigate the free-rider problem commonly found in public goods games, and to unite similar player types. The game we present differs from past experimental designs by introducing one stage group formation. Through this approach, investment decisions —contributions— affect group formation in the current period *only*. In public goods literature, group formation is usually modeled as a separate stage of the game and it can take either exogenous or endogenous form. In the first case, the experimenter applies a pre-determined rule based on contribution history and which may or may not be known to participants, while in the second case the participants are able to form or leave groups at their own will.[3]

A number of these studies have found evidence that group formation enhances cooperation, though not without limitations. The results indicate that some groups maintain statistically higher contributions rates compared to others sometimes leading to a bimodal distribution of contribution levels. In terms of exogenous group formation, Page, Putterman, and Unel (2005) study the interaction of four person groups (initially randomly assigned) over 20 rounds. Following every three periods, there is a regrouping, where each player rates all other participants based on the public information about average con-

[2]The results suggest that while reputation models are unable to fully explain observed cooperation in one-shot games (above 20 % over 400 observations in the last ten periods), the presence of altruists without reputation building is insufficient to explain the higher cooperation rates in finitely repeated games.

[3]For a overview of the literature, see Chaudhuri (2010) and Charness and Kuhn (2011).

tribution. The four people with the highest sum of mutual ratings amongst all groups go on to form the first group. The same procedure determines the second and third groups, with the leftovers forming the last group. The authors find that the average contribution improves from 38 to 70 percent. Gunnthorsdottir, Houser, McCabe, (2007) secretly sort people into high and low contribution groups and find similar results.

Ehrhart and Keser (1999) were among the first to consider a public-goods game with endogenous group formation. In their setup, nine participants were randomly placed into three initial groups. Each person was then told the sizes and average contributions for each group, and could unilaterally decide, at a fixed cost, to switch groups or to form a new (one person) group. While this approach lead to some improvement, free-riders began to chase more cooperative players. Notice that under endogenous group formation, feedback is closely related to reputation building —repeated interaction, which is absent in our approach. The structure of our game leads to anonymous matches, formed by a pre-specified matching algorithm.

It is also of interest to note that assortative matching does not always lead to a Pareto superior outcome as discovered by Friedman and Rich (1998) through laboratory experiment comparing matching market institutions to uniform price markets. In their setup, total surplus is constant in any match that results in a transaction, while in our game players' choices in any given match affect the total surplus as well as its division.

3 The game

The game is played by a population of $2n$ players, $i = \{1, 2, \ldots 2n\}$, who seek to form a match with a high-contributing counter-party. While neither side has much information regarding possible partners, each player must pre-commit to an investment level prior to being matched. The investment can take on any integer multiple of 10 between zero and an initial endowment b, $x_i \in [0, b]$. The game payoffs are computed as follows

$$\pi_i(x_i, x_{j(i)}) \quad = \quad b - x_i + \gamma \cdot EM_{j(i)} \tag{1}$$

where π_i refers to individual payoff, b is the initial endowment and it is equal to 100, γ refers to the marginal impact of the counter-party and it is equal to 5, and player i's expect match $EM_{j(i)}$ depends on the ranking of actions, which are sorted from lowest to highest, breaking any ties randomly. This implies a match between players ranked 1 and 2, 3 and 4; ....; $2n-1$ and $2n$. Thus, the investment decisions have a direct negative effect on payoffs and an indirect effect on determining the quality of the match. Notice that this game can be expressed as a standard public goods game in which the group size is two and the marginal per capita return (MPCR) is 0.83 (=5/6).[4] .

The equilibrium concept used to solve this game will be *symmetric* NE equilibrium. Let's denote $F(x)$ the distribution of investment choices.

Theorem 1. *Pure NE (trivial NE): All players choose to invest at the lower bound of zero. Therefore F(0)=1.*

Proof. In this case, $EM = 0$ and any positive deviation of investment choice leads to a payoff lower than the payoff at the trivial NE (equal to 100). □

Is it possible to achieve higher payoffs and efficiency? We focus on a bimodal distribution such that mass at the upper extreme is much higher compared to the mass at the lower extreme and show that a deviator is indifferent between selecting either 0 —the lower bound— and 100 —the upper bound. More formally, let's denote G_h the probability that h players select 0 as investment level and $2n-1-h$ choose higher levels. G_h is defined as a binomial distribution where the probability of success is given by $F(x)$, or $G_h = \binom{2n-1}{h} F^h (1-F)^{2n-1-h}$. Then, a deviator will be indifferent between selecting either extreme at the *symmetric* NE equilibrium $F(x)$ and any deviation from either extreme will lead to a lower payoff. Thus, the game with payoffs as (1) with eight players ($n = 8$) and discrete investment choices —grid size equal to 10— has the following symmetric mixed NE

Theorem 2. *Efficient (mixed) NE: Players contribute zero with probability* 0.04 *and* 100 *with probability* 0.96*.*

Proof. Let's denote the payoff of a deviator playing at 0 as $\pi(0)$ and it is given by:

$$\pi(0) = 100 - 0 + 500 \cdot [G_0 + (1/3) \cdot G_2 + (1/5) \cdot G_4 + (1/7) \cdot G_6]$$

Recall that 100 is the initial endowment, 0 is the investment choice and the last term is the expected match. The deviator playing at 0 could be matched with a high investment type when an even number of players (out of 7) select the lower bound of zero. For instance, when two players out of seven select zero, the probability of being "lucky" and encounter a high type is 1/3.

Similarly, we can define the payoff of a deviator playing at the upper bound of 100,

$$\pi(100) = 100 - 100 + 500 \cdot [G_0 + (6/7) \cdot G_1 + G_2 + (4/5) \cdot G_3 + G_4 + (2/3) \cdot G_5 + G_6]$$

[4] In the standard public goods game, each member of a group, i, voluntarily contributes x_i 'tokens' out of her endowment, b to a common account. Each member's payoff is then just $(b - x_i) + a/N \cdot (\sum_i x_i)$, where N is group size and a is the efficiency gain from public provision. After simple algebra, we can rewrite the payoff as $\pi_i = 100/6 - x_i + 5/6 \cdot (x_i + x_j)$, where $5/6 = a/N$, the MPCR.

In this case, a high deviator will find a similar high type for sure when an even number of players (out of 7) select the lower bound and with a probability lower than one when there is an odd number of players selecting the lower bound.

By definition of NE, $\pi(0) = \pi(100)$ and this is true when $F(0) = 0.04$, which also implies that $\pi(0) = \pi(100) = 484.69$. Then, consider investment choices 10 and 90 given that seven players are mixing according to $F(0) = 0.04$. Deviations from the lower extreme are less costly compared to the upper extreme. More importantly, both deviations do not lead to a higher payoff. Thus,

$$\pi(90) = 100 - 90 + 500 \cdot [G_0 + G_2 + G_4 + G_6] = 403.15$$

and

$$\pi(10) = 100 - 10 + 500 \cdot [G_0 + G_2 + G_4 + G_6] = 483.15$$

Notice that moving away from zero, the probability of encountering a high type is bigger. However, this action does not lead to a higher payoff. □

Our primary equilibria of interest is the Efficient NE. Assortative matching provides an incentive to invest at the upper bound, leading to a Pareto superior outcome. A different equilibrium may appear when the grid size is different than 10. In particular in the continuous game, the solution concept should imply an epsilon equilibria in which the payoff differential between either extreme is not significant.

An altogether different approach to the game is to use a random matching rule. In this case, the match which affects the payoff (1) is independent of i's investment decision. Thus, the equilibrium will be the trivial NE in which $x_i = x_j = 0$. In the next section, we present our experimental design to test the predictions of the game under the two alternative matching rules.

4 Experimental design and hypotheses

4.1 Experimental design

The experiment employed UCSC undergraduate students, who participated in one of the two treatments: assortative (AM) and random (RM). Each subject was assigned to one cell throughout the session. Each session included eight subjects and was comprised of 30 periods, where two were designated practice rounds and the remaining 28 were used to accumulate points, later to be converted to cash.

Each period allowed for maximum of 120 seconds, with the actual time dependent on how quickly the subjects chose to move on to the next round. The subjects were never told the total number of periods, but rather that they would play some indeterminate number of games. In total, 48 subjects participated in AM treatment while 32 subjects were assigned to RM treatment.[5] All subjects were recruited using the ORSEE system (Greiner, 2003). The game was encoded using z-tree software (Fischbacher, 2007). The average earnings were \$10.50 in the AM treatment and \$11.05 in the RM treatment, with an average session lasting about 30 minutes.[6]

At the beginning of every period, each subject faced a screen displaying the following information: (i) period number, (ii) cumulative payoffs so far in present time, (iii) respective payoff functions and (iv) a box to enter the strategy and a button to confirm the selected strategy.[7] After being prompted to enter a desired investment level, the subject had to confirm his/her chosen strategy. Following confirmation by all players, the subjects were then paired up according to an assortative or a random matching rule —depending on treatment— that stayed the same throughout the session. Notice that our experimental design does not constraint the investment choices to integers $x = \{0, 10, \ldots, 90, 100\}$ in order to avoid any biases in the decising making.

Under AM treatment, the strategies were ranked and then paired in a descending order. That is, the first and second highest investment levels were paired together, followed by the third and fourth highest paired together, and so forth. In the case of equal ranks, the order is randomized. Under RM, the players were matched randomly regardless of strategy.

Furthermore, in both treatments, the subjects received feedback via strategy history displayed on the bottom of the screen. The information displayed includes own strategy and that of their counterpart. However, note that this information did not identify the counterpart, but merely their input and payoff. Therefore, the game retained the anonymity required to replicate a one-shot game.

4.2 Hypotheses

Hypothesis 1. *Under random matching, we expect the strategies to approach the lower bound of zero.*

The lower bound of zero is the predicted trivial NE. When deciding on their respective strategies, each player has a reason to decrease investment until it approaches the lower bound of zero. While this result should be particularly strong under random matching rule, extensive experimental literature suggest that players will never quite reach this lower

[5] Although the panel is unbalanced, the results from the RM treatment confirm the earlier findings of low cooperation rates.

[6] Show-up fees were different when used to calculate the final payoffs for participants, two and five dollars respectively, however the actual show up fee for those who did not get to participate was five dollars unilaterally.

[7] Detailed instructions and z-tree screenshots can be found in Appendix.

bound.[8]

Hypothesis 2. *Under assortative matching, we expect the strategies to approach the Efficient mixed NE.*

Ruling out the trivial NE due to lack of experimental evidence, we concentrate on the mixed NE. Our experimental results will shed more on light whether cooperation can be sustained with assortative matching.

Table 1: Summary of equilibria and experimental predictions

Panel (a): Main theoretical predictions

	Median x	$F(x=0)$	Expected payoff	Efficiency
Trivial	0	1.00	100	20 %
Efficient	100	0.04	500	100 %

Panel (b): Investment by pairs

	Pair 1	Pair 2	Pair 3	Pair 4
Trivial	0	0	0	0
Efficient	84	100	100	100

Note: The efficiency is computed in terms of the median choice as percentage terms of 500 (the pareto outcome).

Before we present our results, we summarize the different equilibria and hypotheses in Table 1. We also translate the equilibria in terms of the predicted investment levels by pairs —see panel (b). The trivial NE implies that all pairs select the lower extreme meanwhile the efficient mixed NE corresponds to the three highest pairs playing the upper extreme and the lowest pair choosing to invest 84.[9]

5 Results

We begin by looking at Figure 1 which uses pooled data in side by side comparison of the AM and RM treatments. The pairs are sorted from one to four, with the lowest rank indicating the lowest investment choice. In the AM treatment, the subjects are highly cooperative, with top two pairs —pairs three and four— choosing maximum investment levels. While the second pair never actually stabilizes at the maximum investment level, it does not deviate too far from it. The last pair invests a bit higher than the experimental prediction in panel (b) of Table 1. In the RM treatment, the behavior is a bit more volatile,

[8] For instance, see Cooper et. al. (1996) for competing models of reputation and altruism in PD one-shot games.

[9] The investment choice of rank 1 is computed as the probability of meeting a high type divided by the probability of being at the lowest pair$((1-0.04)*8-6)/8 = 0.21$ divided by $2/8 = 0.25$.

displaying a significant drop-off in cooperation during early periods. Despite this decline, we never observe complete unraveling where cooperation stabilizes at the lower bound of zero.[10] Essentially, there is a stark contrast in subject behavior between the two treatments, which we illustrate below with the help of a few figures and formal hypothesis testing.

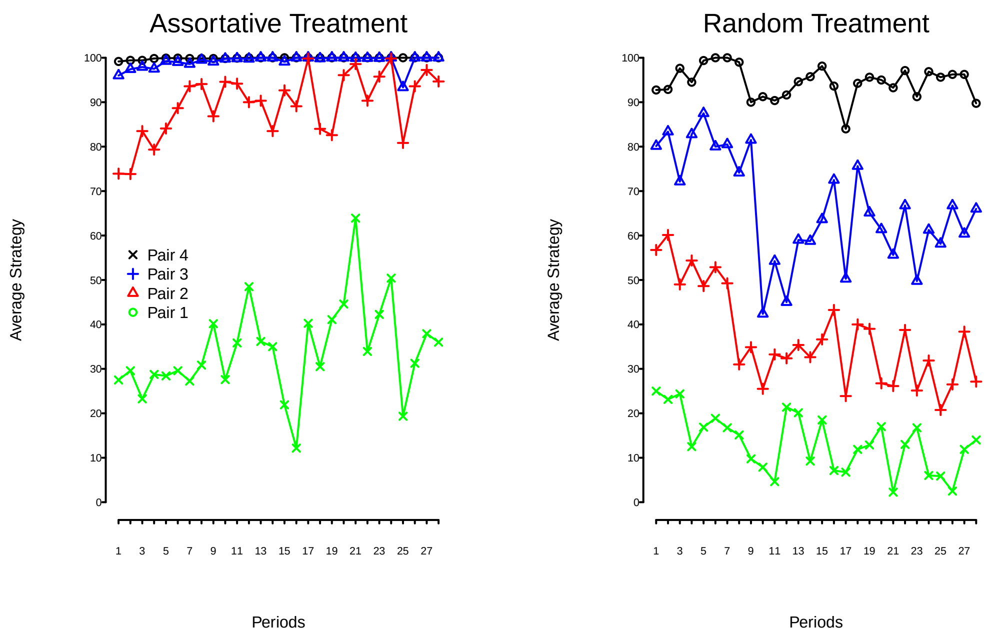

Figure 1: Group (pair) strategy per period (average-pooled data)

The contrast between the investment decisions in the two treatments is further highlighted in Figure 2 which displays the CDF of individual decisions. The median strategy of a subject per session in AM is equal to 91.36 while the median strategy in RM is much lower at 53.30. In other words, half of the subjects stay close to the upper bound in the first treatment meanwhile approximately half of the subjects in RM choose investment levels lower than 50. Further, we concentrate on median rather than mean strategy choices due to large discrepancy between high and low investment decisions. In both treatments, the median is larger compared to the mean, suggesting that the low investment choices of the "free-riders" might understate the overall investment levels.

Next, we present Table 2, which summarizes the basic statistics of subject data —the mean and the median— and includes a measure of efficiency —calculated as actual payoff over maximum possible payoff. The efficiency under AM is over 20 percentage points higher than under RM. Therefore it appears that assortative matching does indeed lead to a Pareto superior outcome —see the predicted efficiency levels in Table 1. Following this rule, the subjects are able to approach the social maximum as measured by total combined

[10]It should be noted that the pairs displayed in RM are not actual pairs, but rather pairs that would occur had we applied assortative rule to the strategy choices of this group.

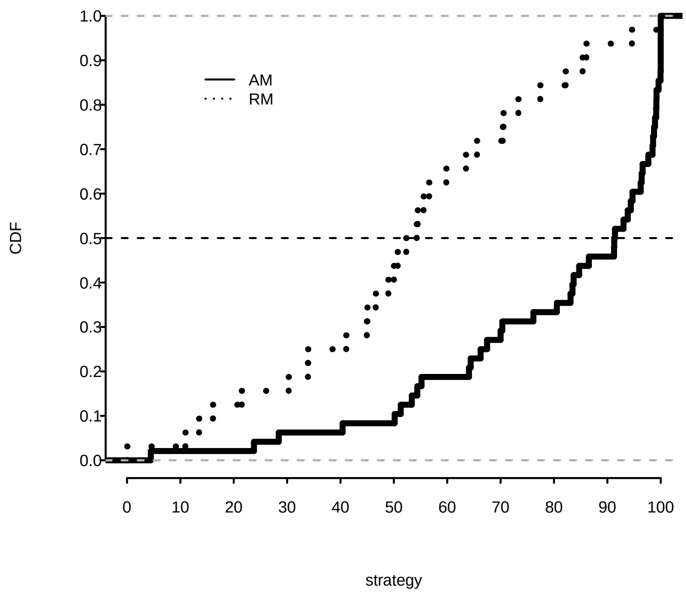

Figure 2: CDF of individual investment (subject data)

payoffs.

Finally, we test our hypotheses with the help of the Wilcoxon test —see Table 2. Under RM treatment, we reject that mean investment level is equal to zero and under AM treatment, we reject that mean investment level is equal to 100. Comparing both treatments, we test and reject the null hypothesis that the mean investment for AM is equal to or lower than that of RM. Therefore, we can conclude that AM first order stochastically dominates RM (p-value equal to 2.2e-16). We summarize our results as follows

Result 1. *The investment levels observed under assortative matching are significantly higher than investment levels observed under random matching.*

Result 2. *The assortative matching protocol leads to higher rates of efficiency —defined as actual payoff over maximum possible payoff— when compared to the random encounters.*

6 Discussion

In this paper, we presented a game that required a pre-commitment to strategy under two alternative matching mechanisms: assortative and random. Under the assortative matching, our game can be viewed as a matching tournament where players seek to form partnerships with high contributing types. Our numerical simulations show that a bimodal distribution —in which a large number of players select the upper bound and few choose

Table 2: AM and RM statistics and hypothesis testing

	Mean	Median	Efficiency	Wilcoxon Test Null hypothesis	p-value
RM	52.80	53.30	62.24	$H_0 = 0$	2.2e-16
AM	80.64	91.36	84.51	$H_0 = 100$	2.2e-16
AM-RM	—	—	—	$H_0 \leq 0$	2.2e-16

Note: The data used in the analyses is by subject except for efficiency, which is computed as a percentage of the paired Pareto optimal outcome.

the lower bound— arises as the most efficient equilibrium. We corroborate that this equilibrium can be sustained with experimental evidence, though not without some important qualifications.

One group (out of predicted three) does not reach the upper extreme though it still maintains high levels of investment. Furthermore, the lowest ranked pair invests at levels slightly higher than predicted. This is consistent with other experimental evidence that found mean contributions to be higher than zero in public goods games. Similarly, in the random treatment, we do not observe convergence to the predicted trivial NE, implying that unraveling is incomplete.

The value of the investment observed for the highest ranked pairs in the assortative treatment is remarkably higher when compared to similar public goods experiments. In our game, the median investment choice surpasses 90 percent of the initial endowment. The numerical solution suggests that this result can be challenged when the impact of others on individuals payoff is lower. Therefore, whether the human subjects will remain at the pareto superior solution or move to the trivial NE remains unclear.

We hope that our experimental findings are just the beginning of a further, more rigorous examination of this class of games. Shedding further light on subject behavior in one-shot games will almost certainly lead to more “efficient" outcomes in a wide range of situations such as joint ventures, or marriages, where repeated interaction between same players is not likely to occur.

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Appendix

A. Instructions - Assortative treatment

Welcome! This is an economics experiment. If you pay close attention to these instructions, you can earn a significant sum of money, which will be paid to you in cash at the end of the last period. Please remain silent and do not look at other participants' screens. If you have any questions, or need assistance of any kind, please raise your hand and we will come to you. If you disrupt the experiment by talking, laughing, etc., you may be asked to leave and may not be paid. We expect and appreciate your cooperation today.

The Basic Idea

The experiment will be divided into a number of periods and in each period you will be matched with another player according to your strategy. In each period you and your counterpart will secretly select strategies and at the end of the period the combination of your and your counterpart' strategy will determine your earnings for the period. Your earnings are computed by the following function:

Earnings = 100 - YOUR STRATEGY + 5 * OTHER

Your earnings are symmetric with your counterpart's. In particular, if you and your counterpart both choose the same strategy, then you will both earn the same amount.

Step by step

After everyone decides on a strategy between 0 and 100, the computer will match you with a counterpart according to the rank of the strategies. In other words, the first and second highest strategies will be matched together, then the third and fourth highest strategies and so forth. The earnings are computed with the earning function described above. This function will not change over the course of the experiment.

The screen display

Figure 3 shows the computer display you will use to make decisions. At the top of screen is the time left as well as the number of the current period. There are also two panels. The left panel gives you information about the earnings function. The right panel allows you to enter your strategy. After you write the input desired, you have to press CONFIRM. Figure 4 shows the computer display with the matches and earnings. The screen will list all the matches formed during the period as well as the strategies.

Earnings

Your earnings will be given in points. Your points will accumulate over the course of the experiment. The screen will always display your "Earnings" for each period on the bottom. It will also list all strategies chosen during that period. You will be paid cash for points earned at a rate written on the white board at the front of the room.

Frequently asked questions

Q1. Is this some kind of psychological experiment with an agenda you haven't told us? Answer. No. It is an economics experiment. If we do anything deceptive or don't pay you cash as described then you can complain to the campus Human Subjects Committee and we will be in serious trouble. These instructions are meant to clarify the game and show you how you earn money; our interest is simply in seeing how people make decisions.

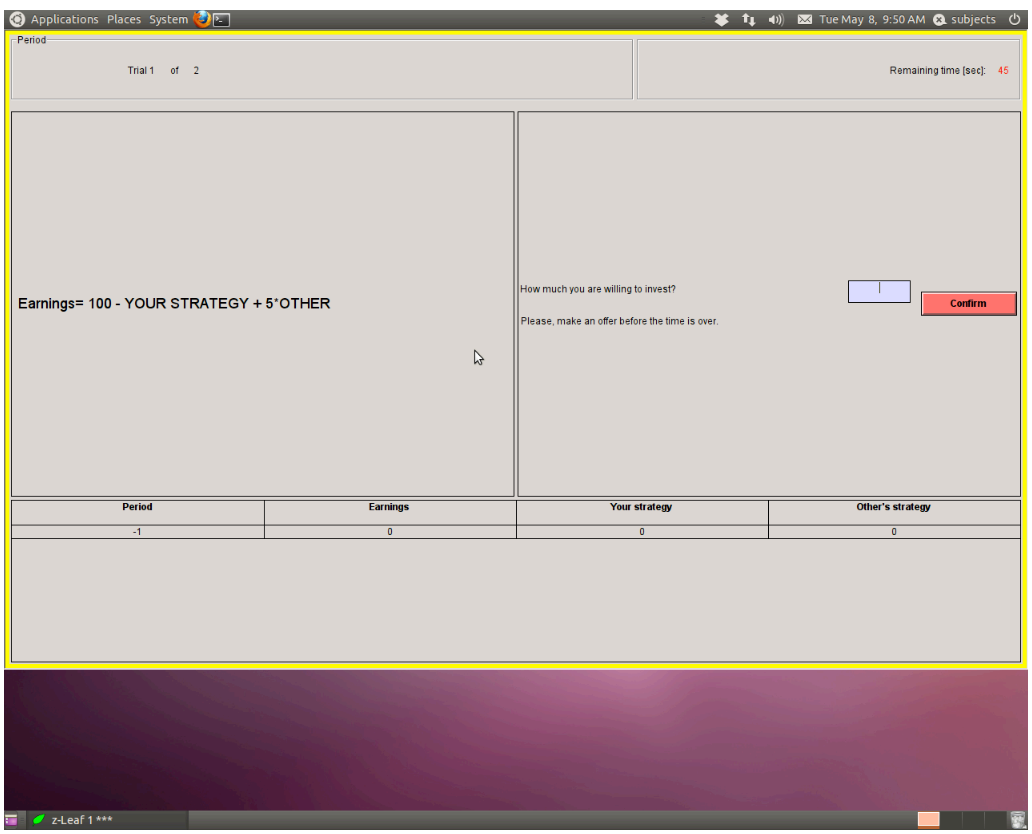

Figure 3: Screen shot 1

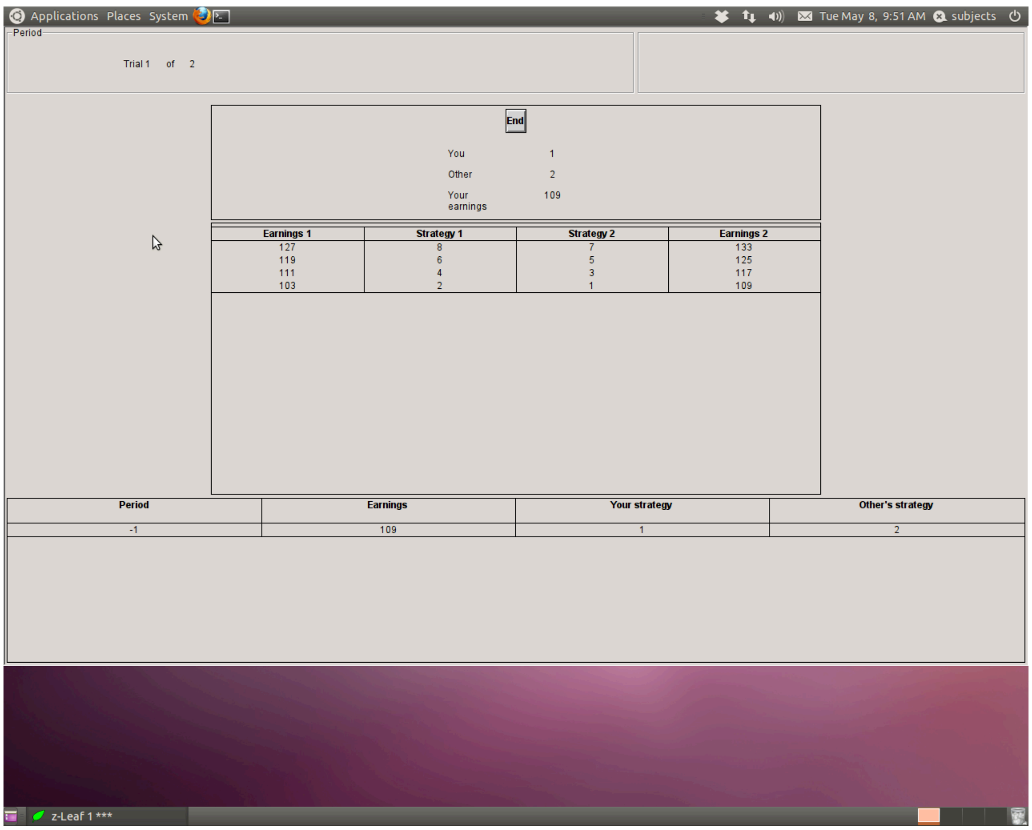

Figure 4: Screen shot 2