PRELIMINARY VERSION

Does Information Make any Difference? Some Experimental Evidence from a Common-Pool Resource Game*

by

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Abstract

The effects on behavior of two different levels of information about the payoff structure are analyzed in a fifty period Common-Pool Resource game of six players with no communication. Six groups of six players played a complete information game while other six groups played the same game but without knowledge of the payoff functions. Players in the incomplete information treatment only had some qualitative information about the interdependent character of the decision situation. It will be shown that the aggregated decision patterns are remarkably similar in both treatments. After arguing that this is of especial importance to the literature on learning models, three such models are contrasted with the data. It will be concluded that the predictions of a simple extension of a learning model based on average payoffs cannot be rejected to be equal to the observed data.

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1.- Introduction

The intense field and experimental study that Common-Pool Resources (CPRs) have raised in the social sciences has been motivated for their intrinsic empirical importance as well as for constituting an attractive environment where to analyze theoretical models of individual behavior. The effects of direct and indirect communication, sanction systems, experience, the possibility of destruction of the CPR, heterogeneity among individuals, different appropriation rules and the possibility to modify the allocation rules, uncertainty in the production capacity and time dependence, are some of the questions that have been addressed in experimental research (see Ostrom, Gardner and Walker, 1994; Rocco and Warglien, 1996; Keser and Gardner, 1999; Walker and Gardner, 1992; Hackett, Schlager and Walker, 1994; Gardner, Moore and Walker, 1997; Walker, Gardner, Herr and Ostrom, 2000; Budescu, Rapoport and Suleiman, 1995; Herr, Gardner and Walker, 1997).

In this paper the types of learning models that individuals follow in repeated CPR games are studied. Up to now there is some agreement that while Nash equilibrium is a relatively good predictor of group behavior in baseline CPR experiments, it systematically fails to help the understanding of individual behavior. Typical inconsistencies with the (symmetric) Nash equilibrium are pulsing patterns of decision making that create high intertemporal variation and, on the other hand, wide heterogeneity across individual behavior (see Ostrom, 1998).

The experiment to be reported in this paper draws from the baseline game used in Ostrom, Gardner and Walker (1994; hereafter, OGW), with some modifications intended to through some light on the individual strategies adopted by players. OGW´s baseline game is symmetric with a time independent payoff structure and where the same group of players repeats the same constituent game for 20 or 30 periods with no communication. Our first concern is to significantly increment the number of periods to be played to a total of 50. It can be conjectured that players might need some time to learn with what type of players are interacting before they reach some stable pattern of decision making that leads to Nash equilibrium, or to some other outcome. Besides, as it will be the case, an important number of periods allows the use of estimation procedures, provided the number of parameters to be estimated is kept low.

Secondly, to the modeling of individual behavior is crucial to know what is the type of information players use in the course of the game. Traditional game theory bases its concepts of equilibria on the assumption that players make use of an a priori analysis of the game in order to infer a complete strategy that ultimately will end in an equilibrium. On the other hand, learning models of individual behavior are typically constructed as adjustment processes to contingencies that arise in the course of the game. The Cournot best-reply function is a clear example of the last, which constitutes a rule of adaptation that takes the group investment level in the previous round as the independent variable. Hence, in this experimental study we run two treatments, one with complete information about the payoff structure and one (the minimal information treatment) with no information at all about the payoff structure, here only some qualitative information about the nature of the game was provided. To the knowledge of the author, this treatment characterization has not been studied before. Note then that while the a priori calculation of the theoretical equilibrium is possible in the complete information treatment, only some type of adaptation rule can be used in the second treatment. The comparison of behavior in both treatments might allow us to reach some conclusions about the value of ex-ante information on payoffs. This is of relevance not only from the theoretical perspective, as explained above, but also from the policy point of view.

Therefore, apart from the symmetric Nash equilibrium, three learning models will be contrasted with the experimental data. The organization of the paper is as follows. In the following section the CPR game is introduced, while the predicted equilibrium as well as the learning models are presented in section 3. Section 4 deals with the experimental procedure, the experimental data are analyzed in section 5 and, finally, section 6 develops some concluding remarks.

2. - Description of the Game

The same six individuals play a constituent game aimed to represent the appropriation problem of a CPR for fifty periods. Players know the number of periods to be played. The game is symmetric and no communication between players is allowed. In the constituent game, players face the decision problem of distributing a fix endowment (labeled *k*) between two markets, the CPR market (market *a*) and a "sure market" (market *b*). One's payoffs from the CPR market depend on one's investment decision but also on the decisions of the rest of players. On the contrary, in the sure market, payoffs are only contingent upon one's own investment decision.

The constituent game can be denoted by $\Gamma = (N, X, u)$, where for all $i \in N = \{1,\ldots,6\}$ the strategy space is denoted by $x_i \in X_i = [5,30]$; $x = (x_1,\ldots,x_6)$ is the vector of individual investment decisions in the CPR market and therefore $(k - x_i)$ represents player i's investment in market b, being k = 35 for all $i \in N$; $X = X_1 \times \ldots \times X_6$ is the strategy space of Γ; the i-th payoff function reads as

$$u_i(x) = \left(120 \cdot \sum_{i=1}^{6} x_i - 1.165 \cdot \left(\sum_{i=1}^{6} x_i\right)^2\right) \cdot \frac{x_i}{\sum_{i=1}^{6} x_i} + (135 - 6 \cdot (35 - x_i)) \cdot (35 - x_i) \qquad (1)$$

and $u = (u_1(x), \ldots, u_6(x))$ is the payoff vector.[1] The individual strategy space is limited to the interval [5,30] for practical convenience. In this way, the possibility of reaching high negative payoffs is limited. This is of special importance in the minimal information treatment.

The first addend of (1) represents the CPR market. Note that fraction $\frac{x_i}{\sum_{i=1}^{6} x_i}$ denotes the i-th share of the CPR payoffs produced by the total group investment. The concave nature of the CPR group payoff function together with the CPR payoff share rule create a dilemma to players. On the one hand, it would be of benefit to oneself to make a large investment in the CPR market so that one's share of its payoffs will be relatively high. However, if the rest of players think in the same way, CPR group payoffs might be highly negative. Then, players could profit by restricting their investments to lower levels. However, as it will be shown in a few lines, the sure market creates incentives to do just the contrary.

The sure market, the second addend in (1), is also represented by a concave function, but this time, its returns are only dependent on one's decisions. Payoffs in this market have been specified as quadratic instead of linear (as in OGW) to avoid that payoff per unit invested in it serves as a focal point for decision-making, as it was observed in OGW (p. 121). Besides, as it can be seen in the following section, this allows for a greater difference in the predictions of the learning models of behavior considered in this paper. The maximum payoff in the sure market is attained when 11.25 talers (the experimental currency) are invested in it, obtaining a profit of 759 talers. However, note that this level of investment in the sure market implies a high investment in the CPR market (23.75 talers). That is, players are confronted with a relatively complex decision task where they have to evaluate the nature of each market and to consider the trade-off between them. Let us proceed now with the analysis of the theoretical hypotheses.

3. - Theoretical Hypotheses

3.1. - Equilibrium Prediction

In games with complete ignorance about payoff functions on the part of players, standard game theory does not provide any equilibrium prediction. Then, the following argument applies only to those games with complete information, that is, to our first treatment.

By the application of the logic of subgame perfection to our finitely repeated, time independent, complete information noncooperative game and attending to Harsanyi and Selten´s (1988) equilibrium selection theory, it can be concluded that the *Symmetric Nash Equilibrium* (SNE) of the constituent game is the *Symmetric Subgame Perfect Nash Equilibrium* of the CPR game, which constitutes, therefore, the equilibrium prediction of the CPR game. Then, let us calculate the SNE by first specifying player i´s Best-reply (B-r) function,

$$b_i(x_{-i}) = \{x_i \in X_i : u_i(x_i, x_{-i}) \geq u_i(x_i', x_{-i}) \text{ for all } x_i' \in X_i\}, \quad (2)$$

where $x_{-i} = (x_1, \dots, x_{i-1}, x_{i+1}, \dots, x_6)$. Then, the individual B-r function can be written as

$$\frac{\partial u_i(x_i, x_{-i})}{\partial x_i} = 405 - 1.165 \cdot \sum_{i=1}^{6} x_i - 14.33 \cdot x_i = 0, \quad (3)$$

$$x_i^B(x_{-i}) = 28.26 - 0.08 \cdot \sum_{\substack{j=1 \\ j \neq i}}^{6} x_j \quad (4)$$

Hence, the SNE is computed by solving the six B-r functions simultaneously. Then, regarding the complete information treatment, the theoretical prediction for each of the 50 periods is the SNE that calls for an investment of $x_i^* = 20$ for all $i \in N$ and which translates into 268 talers of profits per individual.

[1] Note that although it is stated that $X_i = [5, 30]$, in fact, the individual strategy space is limited to the real

3.2.- Best-reply function and the Cournot-reply function

Now, two of the three adjustment strategies to be analyzed are introduced. These two models share the fact that are derived from a marginal analysis of the game while the third, to be presented below, focuses on average payoffs. The first one, the B-r function, has already been introduced in the previous section. We will check whether globally or individually it can be claimed that the B-r function captures the observed pattern of decision-making through time. Note that this is not a trivial question. It can be the case that while at the group level the SNE is not supported, at the individual level B-r functions might explain (some) behavior, and the opposite is also feasible.

At the same time, a weaker formulation of the best-reply function, what it will be called the Cournot-reply (C-r) function, will be studied. In the C-r function players are payoff maximizers but with respect to the observed investment level of the rest of players in the previous round. That is, as in Cournot´s model of adaptation in oligopoly contexts, it will be checked whether a complete myopic behavior that expects to happen at time *t* what happened at time *t*-1 is a good model of individual behavior in CPR games. Then, note that regarding the formation of expectations about other's behavior, two extremes will be checked. On the one hand, with the B-r function we will assume that that what happened at time *t*, was that what was expected to happen by individuals at time *t*. That is, to this extent we will assume that players are able to perfect foresight the group investment level of the following period. At the other extreme, by the analysis of C-r functions we will assume that players are completely unable to foresight future aggregated opponents´ behavior.[2] Now, for the consideration of the individual C-r function we need to include the variable time. Then, let us first restate (2) and (4) in the following terms,

$$b_i\left(x_{-i,t}\right)=\left\{x_{it}\in X_{it}\ :\ u_i\left(x_{it},x_{-i,t}\right)>u_i\left(x'_{it},x_{-i,t}\right)\text{ for all }x'_{it}\in X_{it}\right\}, \qquad (2')$$

$$x_{it}^{B}(x_{-i,t})=28.26-0.08\cdot\sum_{\substack{j=1\\ j\neq i}}^{6}x_{jt}\,, \qquad (4')$$

numbers up to two decimals in the above interval.

[2] By considering these two extremes we omit the analysis of other adjustment models that lie in between, like for example fictitious play (Brown, 1951).

where x_{it}, $x_{-i,t}$ and X_{it} are defined as above but framed in some $t \in T = \{1,\ldots,50\}$. Then, player i´s C-r function is characterized as follows,

$$c_i\left(x_{-i,t-1}\right) = \left\{x_{it} \in X_{it} \ : \ u_i\left(x_{it}, x_{-i,t-1}\right) > u_i\left(x'_{it}, x_{-i,t-1}\right) \text{ for all } x'_{it} \in X_{it}\right\}. \tag{5}$$

Therefore,

$$x_{it}^{C}(x_{-i,t-1}) = 28.26 - 0.08 \cdot \sum_{\substack{j=1 \\ j \neq i}}^{6} x_{j,t-1}. \tag{6}$$

3.3.- Stable Melioration Strategy in Games

The third model of adaptive behavior, the Stable Melioration Strategy in Games (SMSG) is based on the analysis of average payoffs. Herrnstein (1997) and Herrnstein and Prelec (1988; 1991; 1992) developed the theory of melioration based on sound experimental research for independent and binary decision-making contexts. According to their theory, subjects behave in a way that in each period react by selecting that alternative that presents a higher average value. This adjustment process leads in the long run to the equalization of the average values of all those active alternatives (those alternatives which frequency of selection is greater than zero). This model of behavior has been theoretically extended to game-theoretic and non-binary contexts and it has been experimentally tested with supportive results using the CPR experimental data of the baseline game of OGW (Apesteguía, 2000 a, b).

While melioration theory is a theory that states the nature and the direction of adjustment, in non-binary decision contexts it does not specify per se the quantification of the reaction. Therefore, given that the average payoff functions of both markets present negative slopes, as a first approach, it is adopted the most natural specification: player i´s SMSG function derives that individual investment level resultant from the equalization of average payoffs of both markets, taking the observed investment level of the rest of players in the previous period. Therefore, it can be written that,

$$s_i\left(x_{-i,t-1}\right) = \left\{x_{it} \in X_{it} \ : \ \frac{x_{it}}{\left(k - x_{it}\right)} = \frac{V_i^a\left(x_{it}, x_{-i,t-1}\right)}{V_i^b\left(x_{it}\right)}\right\}, \tag{7}$$

where V_i^a and V_i^b are the payoff functions of the CPR market and the sure market, respectively. Then, we can now state (7) in the following terms,

$$x_{it}^S(x_{-i,t-1}) = 27.21 - 0.16 \cdot \sum_{\substack{j=1 \\ j \neq i}}^{6} x_{j,t-1}. \tag{8}$$

Therefore we will analyzed whether (4´), (6) and (8) are able to explain behavior in a CPR game of the characteristics discussed in section 3.

3.4. - Efficiency

It is important to show that SMSG represents a more efficient investment pattern, in the sense of Pareto and regarding CPR appropriators, than B-r (and C-r) function does. This can be easily proved by deriving the "Pareto-reply function". By the Pareto-reply (P-r) function we mean the determination of x_{it} so that group payoffs are maximized,

$$p_i(x_{-i,t}) = \left\{ x_{it} \in X_{it} \ : \ \sum_{i=1}^{6} u_i(x_{it}, x_{-i,t}) \geq \sum_{i=1}^{6} u_i(x'_{it}, x_{-i,t}) \text{ for all } x'_{it} \in X_{it} \right\}. \tag{9}$$

Then,

$$\frac{\partial \sum_{i=1}^{6} u_i(x_{it}, x_{-i,t})}{\partial x_{it}} = 405 - 2.33 \cdot \sum_{\substack{j=1 \\ j \neq i}}^{6} x_{jt} - 14.33 \cdot x_{it} = 0 \ , \tag{10}$$

$$x_{it}^P(x_{-i,t}) = 28.26 - 0.16 \cdot \sum_{\substack{j=1 \\ j \neq i}}^{6} x_{jt} \ . \tag{11}$$

Figure 1 shows the B-r (consequently, C-r), SMSG and P-r functions. While B-r function defines the greatest individual investment level for any given investment level of the rest of players, SMSG shows always the lowest, being the P-r function in between but closer to the

SMSG line than to the B-r line. Given the nature of $\sum_{i=1}^{6} u_i(x_{it}, x_{-i,t})$, Fig 1 means that SMSG calls for a more efficient behavior than B-r does. The symmetric solutions of the three theoretical hypotheses can be found by the intersection of the 1/5 slope line that departs from the origin, with the three reply functions. Therefore, in the symmetric solutions, the individual investment levels together with the individual payoffs for the B-r (that is, the SNE), SMSG and P-r functions are respectively (20; 268.08), (15; 527.42) and (15.58; 531.75).

4.- Experimental Procedure

This experiment was conducted in the summer of 1999 at the Laboratory for Experimental Economics at the University of Bonn. Volunteer subjects, recruited through posters on campus, were primarily undergraduate economic and law students but also students from other disciplines such as computer science or mathematics. The computerized program was developed using *RatImage* (Abbink and Sadrieh, 1995). Five sessions of eighteen subjects each were conducted. In each session, subjects were randomly divided into three independent groups of six. The first session constituted a pilot used to adjust the exchange rate of the experimental currency (the taler), the capital balance and the restrictions on investment decisions. Then, two sessions with a total of six games were conducted to test treatment I and two other sessions were conducted to test treatment II.

Instructions were handed out to subjects and read aloud. A translation to English of instructions for treatment I can be found in the Appendix. Instructions for treatment II were similar to those of treatment I; information regarding payoffs were omitted, but it was noted that while market *a* was an interdependent market, market *b* was fully determined by one's decisions, that there was not any kind of randomness and that the game was time independent. Also, the main computer screen, the one where players had to enter their investment decisions, was presented and explained to subjects. There, subjects were explained the type of information that after each round they would have available (common to both treatments). That is, information about the group investment level, one's total, average and marginal payoffs in both markets, one's total payoffs of that round and, finally, one's cumulative payoffs through the experimental rounds already played. Further, players were told that by clicking on "History", they would have access to this type of information for every experimental round already played. There, subjects were told that individual decisions were anonymous to the group. It was common knowledge that the game was symmetric.

After instructions were read and questions answered, subjects were randomly assigned to independent and visually isolated cubicles equipped with computer terminals. Once the experimental rounds were initiated, no communication between subjects was allowed. No time restrictions on the length of decision rounds were imposed. On average, a session, including the instructions phase, lasted less than 1,40h. Players were privately paid in cash right after completing the 50 experimental rounds. The capital balance was 4,000 talers in treatment I and 8,000 talers in treatment II. The exchange rate was 0.0025 DM. Average earnings were around DM 53 (about $ 27).[3]

5.- Experimental Results

5.1. - Theoretical Equilibrium and Comparison of Investment Decisions by Treatment

We begin by wondering about the predictive results of SNE. To this end see the average time series of both treatments, the detailed time series of two selected games, the distribution of investment decisions in both treatments (Figures 2-6) and Table I where some descriptive statistics can be found.

Observation 1. Although at the group level investments are slightly lower than that predicted by SNE, at the individual level players do not play the SNE.

These are not surprising results. In all of the 600 possibilities (50 rounds times 12 games), the SNE (an investment of 20 talers per each one of the 6 players) was not played any single time. The predicted group investment by the SNE (120 talers) was played the 3% of the times. Further, the variability in individual behavior shows itself as extremely large (see Fig 3-6). At the aggregate level, the observed investment level approaches to that predicted by SNE (see Table I and Fig 2). We will analyze below whether these results can be explained according to B-r or on the contrary are the consequence of aggregation of heterogeneous behavior, as it seems to be the case. Also, it is worth noting that comparing the standard deviations of the first and last third of the experiment it is seen that the variability of behavior across rounds tends to decline, although not to disappear (Table I).

[3] The experimental data will be made available upon request.

Now, let us compare results in both treatments.

Observation 2. It cannot be rejected that the mean investment decisions are equal in both treatments.

Taking the mean investment of each game in both treatments as the two series of independent observations (six for each treatment) and applying the Kolmogorov-Smirnov two sample Test, the null hypothesis of equal distributions against the alternative hypothesis of different distributions cannot be rejected at the 5% significance level ($p = 0.2$). The consistency of this finding can be tested by comparing the mean investment of each game in both treatments using the first fifteen rounds, as well as using the last fifteen rounds. It can be concluded that results do not change ($p = 0.2$ in both cases). In fact, Fig 2 clearly shows the similitude in average investment levels across periods.

Furthermore, two more games were run at the Public University of Navarre to test whether this finding could be attributed to the fact that players had information about average and marginal payoffs in both markets after each decision period. These two new games (Game 13 and 14) had a similar experimental design than those already reported in this paper. In Game 13 six players had the same information than in treatment II (minimal information treatment) and Game 14 presented as the only difference with Game 13 that players did not have information about average and marginal payoffs. It can be concluded again that the means of the investments and the aggregated tendencies through time are remarkably similar in both games.

Observation 3. The dispersion in the pattern of investment in the second treatment is greater than that observed in the first treatment.

Taking the standard deviation of each game in both treatments and applying the Mann-Whitney *U* Test, we cannot accept at the 5% significance level the null hypothesis of equal dispersions in favor of the alternative hypothesis of greater dispersion in treatment II ($p = 0.013$). Again this result does not change when the first 15 periods as well as when the last 15 periods are compared ($p = 0.001$ and $p = 0.032$).

Therefore, although with no information about the payoff structure players present a higher variation in individual behavior presumably motivated by an exploratory process of the nature of the payoff functions, at the aggregate, the investment patterns are equal. As explained in the introduction, this is an important finding for its implications to the way individual behavior is modeled in game theory. We will deal again with this issue at the end of the paper, from now on, the analysis of the models of adaptive behavior will be made at the experiment level and typically, no distinction will be made in terms of treatment.

5.2. - Adaptive Models of Individual Behavior

Let us see now whether the observed results can be ordered according to the models of learning introduced in sections 3.2. and 3.3. Note that except when explicitly stated on the contrary, the investment predictions of the theoretical hypotheses are calculated by substituting in the corresponding reply function the *observed* value of the independent variable (either $\sum_{\substack{j=1 \\ j \neq i}}^{6} x_{jt}$, or $\sum_{\substack{j=1 \\ j \neq i}}^{6} x_{j,t-1}$).

Figure 7 clearly shows that, at the aggregate level per round, the B-r and C-r functions make a much better job approaching the observed time series than SMSG does. In fact, by the end of the experiment the differences between the observed investment levels and the predictions of B-r and C-r functions tend to decline while those from SMSG tend to increase. However, no model is able to capture the observed aggregated tendency of investments through time.

Observation 4. The three theoretical hypotheses under consideration (B-r, C-r and SMSG) predict a downward tendency while the observed time series shows an upward investment tendency.

Applying the Cox-Stuart test for trend, the p values are p = 0.003, 0.004, 0.004 and 0.003, respectively. This finding is taken as a failure of the three models in explaining the aggregated data, although, clearly, the case of SMSG is the worst of the three. Hence, there is a need of a leaning model able to both, to make sufficiently good investment predictions and to correctly approach the observed tendency through time. Concretely, as stated in section 3.3., (7), the employed specification of the quantitative reactions of SMSG, was taken as a first approach. Therefore, based on the success of melioration interpreting the OGW experimental data, now, its formulation in a more general fashion is analyzed. Then, from (7) we might consider the following general formulation

$$\frac{x_{it}}{k - x_{it}} = \alpha + \beta \cdot \left(\frac{V_i^a(x_{it}, x_{-i,t-1})}{V_i^b(x_{it})} \right)^{\gamma} . \qquad (12)$$

When $\alpha = 0$ and $\beta = \gamma = 1$, the above expression is the former SMSG. For convenience, throughout this paper we will consider that $\gamma = 1$ and only estimations of α and β will be calculated. The interpretation of parameters α and β is in the line of other learning models that consider partial adjustment to a specified response (see Rassenti et al. (2000) and Kruse et al. (1994)). Then, α represents a "natural" tendency to distribute the investment endowment, a focal point, while β represents a corrector factor of α measuring the sensibility to the ratio of average payoffs.

The number of periods run in the experiment allows to divide the data into two parts, one for the estimation task and the other to test the predictive capabilities of the estimated model. In the analysis of (12), we will follow two approaches:

1. – First approach: a general estimation which will be denoted by SMSG-β. We estimate (12) as one and general reply function to all the experiment. In so doing, the data for the estimation exercise consist of the means of the games calculated using the first 39 observations (recall that for SMSG we have 49 observations). Hence, the last 10 observations are left to evaluate the predictive value of the estimation.

2. – Second approach: an individual estimation (SMSG-β_i). The above reaction function will be estimated for each of the 72 subjects. Then, for the individual estimation of (12), the first 39 individual observations will be used.

5.3. - SMSG-β

Theil´s method, a nonparametric regression procedure, is used in the estimation of parameters α and β (see Sprent (1993) and Hollander and Wolfe (1973)). The results of the estimation are $\alpha^* = 1.14$ and $\beta^* = -0.54$. According to the above interpretation of these parameters we would conclude that there is a close tendency to the equal split of the endowment, corrected by the ratio of average payoffs weighted in negative terms. The negative sign of β^* is understood because of the persistence of negative payoffs in market *a* along the experiment.

To evaluate (12) we need to reformulate it in terms of a reply function where $\sum_{\substack{j=1\\ j\neq i}}^{6} x_{j,t-1}$ would be the independent variable and x_{it} the dependent variable. With a little of algebra we obtain such an expression but in the form of a correspondence:

$$g(x_{-i,t-1}) = \left\{ x_{it} \in X_{it} : A + B \cdot \sum_{\substack{j=1\\ j\neq i}}^{6} x_{j,t-1} \pm \sqrt{(A + B \cdot \sum_{\substack{j=1\\ j\neq i}}^{6} x_{j,t-1})^2 \Big/ 4 - C} \right\}, \tag{13}$$

where

$$A = \frac{a \cdot \beta - (1+\alpha) \cdot c + (2 \cdot \alpha + 1) \cdot d \cdot k}{-2 \cdot b \cdot \beta - 2 \cdot (1+\alpha) \cdot d},$$

$$B = \frac{b \cdot \beta}{2 \cdot b \cdot \beta + 2 \cdot (1+\alpha) \cdot d} \text{ and}$$

$$C = \frac{(c - d \cdot k) \cdot \alpha \cdot k}{-b \cdot \beta - (1+\alpha) \cdot d}.$$

To specify one of the two possible values of x_{it} for any $\sum_{\substack{j=1\\ j\neq i}}^{6} x_{j,t-1}$, the criterion of taking the one resultant from the addition is adopted. Then, the reply function to consider is denoted by

$$f(x_{-i,t-1}) = \left\{ x_{it} \in X_{it} : A + B \cdot \sum_{\substack{j=1\\ j\neq i}}^{6} x_{j,t-1} + \sqrt{(A + B \cdot \sum_{\substack{j=1\\ j\neq i}}^{6} x_{j,t-1})^2 \Big/ 4 - C} \right\}. \tag{14}$$

Further, in occasions, $\sum_{\substack{j=1\\ j\neq i}}^{6} x_{j,t-1}$ is low enough to produce a negative value in $((A + B \cdot \sum_{\substack{j=1\\ j\neq i}}^{6} x_{jt})^2 \Big/ 4 - C)$. In such circumstances, we determine the predicted value of x_{it} by taking the predicted value for $x_{i,t-1}$ and in case there is not such a value, then, we substitute in

(14) the minimum integer value of $\sum_{\substack{j=1 \\ j\neq i}}^{6} x_{j,t-1}$ for which $((A + B \cdot \sum_{\substack{j=1 \\ j\neq i}}^{6} x_{jt})^2 \Big/ 4 - C)$ is positive.

It must be noted that these contingencies happened around the three per cent of the times.

Observation 5. SMSG- β supposes an important improvement in the approximation to the observed investment series.

Consider Fig 8 where the (average) predicted investments for the last ten rounds of SMSG- β, B-r and C-r functions are represented together with the (average) observed investments and, also, for illustrative purposes see Fig 9 (for all the time series). It is appreciated that the SMSG- β tendency and that observed are similar. In fact, reproducing the analysis of trend of the previous section for the case of SMSG- β, it is rejected the null hypothesis of no trend in favor of an upward trend (p = 0.001). That is, SMSG- β predicts the same tendency in investment decisions over time than the observed series presents. Let us now go into the analysis of SMSG- β_i.

5.4. - SMSG- β_i

Now, 72 pairs of (α_i, β_i) are estimated, one for each player. Because of the presence of ties between pairs of payoff ratios, an extension of Theil´s method is used. Each parameter β_i is calculated taking the mid-point of its 1% confidence interval (see Sen (1968) and Hollander and Wolfe (1973)). Table II shows a wide interpersonal heterogeneity in the estimated values of the parameters.

For the specification of the SMSG- β_i reply function, it is followed the same procedure than in SMSG- β (in this case the percentage of indeterminate events is less than the 3%).

Observation 6. The SMSG- β_i predicted investment series best approaches the observed investment series. In fact, it cannot be rejected that those and only those investment predictions of SMSG- β_i are equal to the observed investments.

Figures 10 and 11 show that the (average) predicted series by SMSG-β_i constitutes the best approximation to the (average)) observed investment series over time. In fact, the predictions of SMSG-β_i are so close to the observed ones that it cannot be statistically rejected that both are equal. That is, for each one of the theoretical hypotheses B-r, C-r, SMSG-β and SMSG-β_i we compare the means of the games calculated using the last ten predicted investments, with the means of the games calculated using the last ten observed investments. Applying the Wilcoxon signed-rank test at the 5% significance level, SMSG-β_i is the only theoretical hypothesis that cannot be rejected to be equal to the observed series ($P(T \leq 8) < 0.025$, $P(T \leq 3) < 0.025$, $P(T = 0) < 0.025$ and $P(T \leq 34) > 0.025$ for B-r, C-r, SMSG-β and SMSG-β_i, respectively).

Observation 7. SMSG-β_i is the best theoretical hypothesis in terms of predictive success. It constitutes a significant improvement in the prediction of the observed investment pattern.

Consider the following ratio:

$$r_{it}^{k} = 1 - \frac{\left| x_{it}^{P_k} - x_{it}^{O} \right|}{max\left\{ \left(x_{it}^{P_k} - 5 \right), \left(30 - x_{it}^{P_k} \right) \right\}}, \tag{15}$$

where,

$x_{it}^{P_k}$ is the prediction of theoretical hypothesis *k* for player *i* at time *t* and

x_{it}^{O} is the observed decision by player *i* at time *t*.

Then, the numerator denotes the actual absolute error in the prediction of theory *k* for player *i* and time *t* and the denominator represents the maximum possible error of $x_{it}^{P_k}$. The ratio r_{it}^{k} is bounded to be in the interval $[0,1]$, where $r_{it}^{k} = 0$ represents the widest error in prediction (the actual absolute error equals the maximum possible error in the prediction) and $r_{it}^{k} = 1$ represents an exact prediction of the event to be predicted. Therefore, r_{it}^{k} *is a measure of predictive success of theoretical hypothesis* k *for player* i *at time* t.

Now, for the predictions of theoretical hypotheses B-r, C-r, SMSG-β and SMSG-β_i, we take the last ten rounds to calculate the mean ratios of predictive success of each game.

Applying the Wilcoxon signed-rank test in the comparison of SMSG-β_i with each of the other theoretical hypotheses, at the 5% significance level the null hypothesis of equal predictive success cannot be accepted in any case, in favor of the alternative hypothesis that specifies a better predictive success on the part of SMSG-β_i ($P(T \leq 14) < 0.05$, $P(T \leq 16) < 0.05$, $P(T \leq 6) < 0.05$ for comparisons of SMSG-β_i with B-r, C-r and SMSG-β respectively). It is worth to insist on the robustness of these results. Note that we reach the same conclusion if we compare the mean ratios of predictive success calculated by considering all the data and also if we compare the theoretical hypotheses in terms of means of the absolute values of the differences between observed and predicted investments (see Table III).

5.5. - Classification of Players

In what follows it is analyzed whether players, individually, can be classified as if they were following a pattern of investment not distinct to one of the theoretical hypotheses that we are considering. The method used for this classification task can be explained as follows. For each individual, the last ten predictions of theoretical hypotheses B-r, C-r and SMSG-β_i are compared, according to the Wilcoxon signed-rank test, with the last ten observed investments. If for one player one theoretical hypothesis is taken to be equal to the observed investment pattern at the 1% significance level, then, this player is classified according to this theoretical hypothesis. If more than one theoretical hypothesis cannot be rejected to be equal to the observed series, then, to determine the classification of the player, the means of the absolute values of the differences between predicted and observed investments are calculated. Then, the subject will be classified according to that theoretical hypothesis that shows the less mean absolute value. Finally, those players for who no theoretical hypothesis is accepted to be equal to their observed investments will be left as unclassified.

Observation 8. The large majority of players (85%) are classified according to some theoretical hypothesis. SMSG-β_i is the best theoretical hypothesis explaining individual behavior.

In total, more than 50% of the subjects are classified as following a pattern of investment not distinct to that defined by SMSG-β_i, while 14% are classified according to B-r and 20% according to C-r (see Tables IV and V). See Fig. 12-14 for a comparison of the predicted and observed investment series *by category of players* for the last ten rounds. Clearly, those players classified as SMSG-β_i show the less erratic difference with the corresponding observed investment series.

Observation 9. Taking only those players that were classified above, it cannot be rejected that the predicted investment series resultant from the classification of individuals is equal to the observed series.

We take the predicted series of each individual defined according to the theoretical hypotheses specified in the above classification (then, those players not classified are set apart). We call this the "classification" series. In Fig 15 we compare it with the observed investment series (here also, those players that were not classified above are not considered) where the similitude between them can be appreciated. Now, the means of the games calculated using the last ten predictions of the classification series are compared, using the Wilcoxon signed-rank test, with the means of the games calculated using the last ten observed rounds. We conclude that at the 5% significance level it cannot be rejected the null hypothesis of equality ($P(T \leq 38) > 0.025$).

5.6. – Estimated Series

We now want to compare the observed investment series with what we will call the "estimated" series for the whole time series. The estimated series is calculated according to the following three characteristics:

(i) The reaction function of each player is defined according to Table IV. For those players not classified, their observed investments will be taken.

(ii) In the investment estimations, instead of taking the observed data to accomplish for the independent variable of the corresponding reaction functions, it will be taken the estimated data by each reaction function.

(iii) The estimated series will be computed for all the (feasible) rounds (49).

Observation 10. The estimated series cannot be rejected to be equal to the observed series.

Fig 16 shows the impressive results of the estimated series. Comparing according to the Wilcoxon signed-rank test those means of the games calculated using all the estimation series, with those means of the games calculated using all the observed data, at the 5% significance level it cannot be rejected that both are equal.

6. – Concluding remarks

We have concluded that neither the SNE, nor the B-r function (or its less demanding expression, the C-r function) are able to order the data, although their predictions are closer to the observed data than those from SMSG are. On the contrary, predictions according to SMSG-β_i, a simple extension of SMSG, best approach the observed investment series. At the aggregate level, SMSG-β_i shows the best mean ratio of predictive success and its predictions can even be taken to be equal to the observed data.

At the individual level, again, SMSG-β_i is the best theoretical hypothesis. It accomplishes nicely with more than half of the subjects. Furthermore, estimating an investment series for all the experimental rounds according to the individual classification, as in section 5.6., results in a predicted pattern of investments not statistically different from the observed one.

Finally, we want to stress the results from the comparison of treatments I and II. The equality of mean investment levels in both treatments shows an independence of investment decisions from information about the payoff structure. This remarks the importance of the study of individual adaptation models of decision making. In fact, clearly, the nice results obtained with the estimation of (12) can only be valued from the predictive perspective, not from the descriptive perspective as it was intended at the outset. That is, by the use of SMSG-β or SMSG-β_i we are obligated to argue in the *as if* fashion.

7.- Appendix: Experimental Instructions

Description of the experiment:

There are 18 participants in this room. Participants will be divided into three independent groups of six. You will not know who in the room is in your group.

The experiment in which you are participating is comprised of a sequence of 50 market periods. In each market period you will be asked to make an investment decision.

Each period you will be allocated an endowment of 35 talers. All other members of your group also have an endowment of 35 talers. Total endowment for your group is 210 talers.
You will decide each market period how you wish to invest your endowment between two investment opportunities. You are allowed to use up to two decimals in the distribution of your endowment.
The instructions that follow will describe the two investment opportunities.

Investment opportunity one: Market 1

In Market 1 you are allowed to invest a minimum of 5 talers and a maximum of 30 talers.
The payoffs you receive from Market 1 depend on the amount you invest *as well as on the amount all others in your group invest*.
You receive a percentage of the *total group payoff* dependent upon what share of the total group investment you made.
For example:
If the group as a whole invested 50 talers in Market 1 in a period in which you invested 6, you would receive 12% (6/50) of the total group payoff.
The *total group payoff* in Market 1 is explained using Table A (those participants interested in the payoff formula may find it at the end of these instructions). Let's talk about the meaning of the information given in the table.
The first column labeled "Total Talers Invested by the Group in Market 1" gives example levels of total investment by the group in Market 1. These are examples to give you a sense of the payoff from Market 1 at various levels.
The second column labeled "Total Group Payoff in Market 1" displays the actual total group payoff in Market 1 at various levels of group investment.
The third column, labeled "Average Payoff per Taler in Market 1," displays group payoff on a per taler (average) basis, at various levels of group investment.
The final column, labeled "Market 1 Additional Payoff", displays information on the rate of change in the total group payoff associated with a small change in the group investment in Market 1.

Investment opportunity two: Market 2

The rest of the 35 talers you do not invest in Market 1 are automatically invested in Market 2.
In Market 2 the payoffs you receive on investments *depend only on the amount you invest in Market 2*.
Table B displays information on your possible payoff on Market 2 at various levels of your investment in Market 2 (again, those interested in the formula may find it at the end of these pages).
The first column "Total Talers Invested by you in Market 2" gives example levels of your investment in Market 2. Note that your investment in Market 2 is defined by your endowment (35 talers) minus your investment in Market 1.
The second column labeled "Payoff from Market 2" displays your actual payoff from Market 2 at various levels of your investment.
The third column, labeled "Average Payoff per Taler in Market 2" displays your payoff at various levels of investment, but on a per taler (average) basis.
The final column, labeled "Market 2 Additional Payoff", displays information on the rate of change in your payoff associated with a small change in your investment in Market 2.

History:
During the experiment you will have the option of looking at the results of all the previous rounds by clicking on *History.*

Experiment Payoff:
For showing up you receive a 4000 talers profit. Every 100 talers equals 25 pfennig. All profits you make during the experiment will be totaled and paid to you in privacy in cash at the end of the experiment.

Thank you very much for your participation!

TABLE A

PAYOFF FROM INVESTMENTS IN MARKET 1

Total Talers Invested by Group in Market 1	Total Group Payoff in Market 1	Average Payoff per Taler In Market 1	Market 1 Additional Payoff

30	2551,5	85,05	50,1
35	2772,875	79,225	38,45
40	2936	73,4	26,8
45	3040,875	67,575	15,15
50	3087,5	61,75	3,5
55	3075,875	55,925	-8,15
60	3006	50,1	-19,8
65	2877,875	44,275	-31,45
70	2691,5	38,45	-43,1
75	2446,875	32,625	-54,75
80	2144	26,8	-66,4
85	1782,875	20,975	-78,05
90	1363,5	15,15	-89,7
95	885,875	9,325	-101,35
100	350	3,5	-113
105	-244,125	-2,325	-124,65
110	-896,5	-8,15	-136,3
115	-1607,125	-13,975	-147,95
120	-2376	-19,8	-159,6
125	-3203,125	-25,625	-171,25
130	-4088,5	-31,45	-182,9
135	-5032,125	-37,275	-194,55
140	-6034	-43,1	-206,2
145	-7094,125	-48,925	-217,85
150	-8212,5	-54,75	-229,5
155	-9389,125	-60,575	-241,15
160	-10624	-66,4	-252,8
165	-11917,125	-72,225	-264,45
170	-13268,5	-78,05	-276,1
175	-14678,125	-83,875	-287,75
180	-16146	-89,7	-299,4

TABLE B

PAYOFF FROM INVESTMENTS IN MARKET 2

Total Talers Invested by you in Market 2	Payoff from Market 2	Average Payoff per Taler in Market 2	Market 2 Additional Payoff
(35-30)=5	525	105	75
(35-29)=6	594	99	63
(35-28)=7	651	93	51
(35-27)=8	696	87	39
(35-26)=9	729	81	27
(35-25)=10	750	75	15
(35-24)=11	759	69	3
(35-23)=12	756	63	-9
(35-22)=13	741	57	-21
(35-21)=14	714	51	-33
(35-20)=15	675	45	-45
(35-19)=16	624	39	-57
(35-18)=17	561	33	-69
(35-17)=18	486	27	-81
(35-16)=19	399	21	-93
(35-15)=20	300	15	-105
(35-14)=21	189	9	-117
(35-13)=22	66	3	-129
(35-12)=23	-69	-3	-141
(35-11)=24	-216	-9	-153
(35-10)=25	-375	-15	-165

(35-9)=26	-546	-21	-177
(35-8)=27	-729	-27	-189
(35-7)=28	-924	-33	-201
(35-6)=29	-1131	-39	-213
(35-5)=30	-1350	-45	-225

Markets 1 and 2 payoff functions

MARKET 1: If we define *X* as the total number of talers invested in market 1 by all group members, we can calculate the total group payoff as: Total group payoff of Market 1 = $120 \cdot X - 1{,}165 \cdot X^2$

MARKET 2: If we define *x* as the number of talers you invest in Market 1, then, your endowment (35) minus *x* is the number of talers you invest in Market 2. We can calculate your payoff from Market 2 as:

Your payoff of Market 2 = $(135 - 6 \cdot (35 - x)) \cdot (35 - x)$

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FIGURE 1

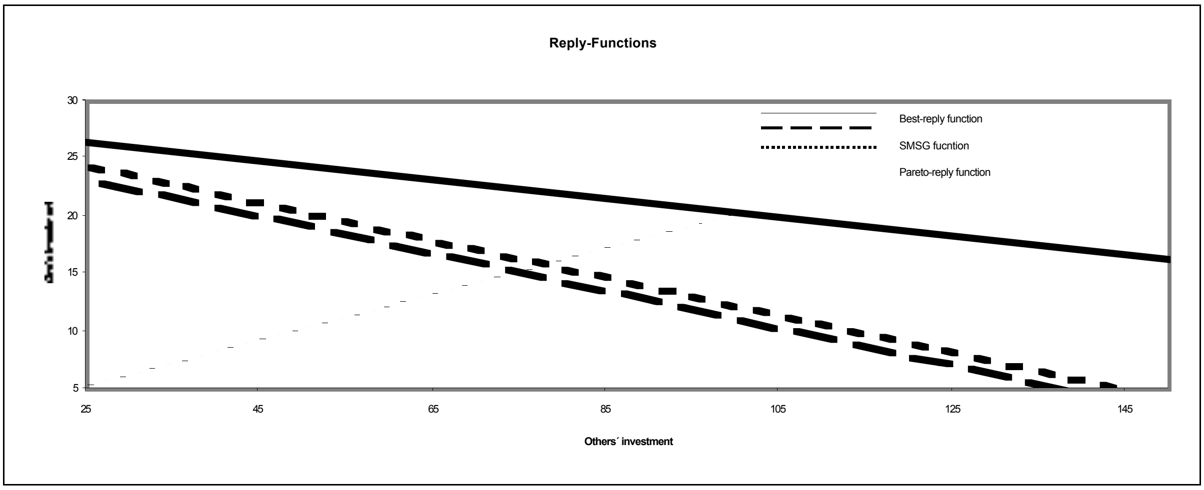
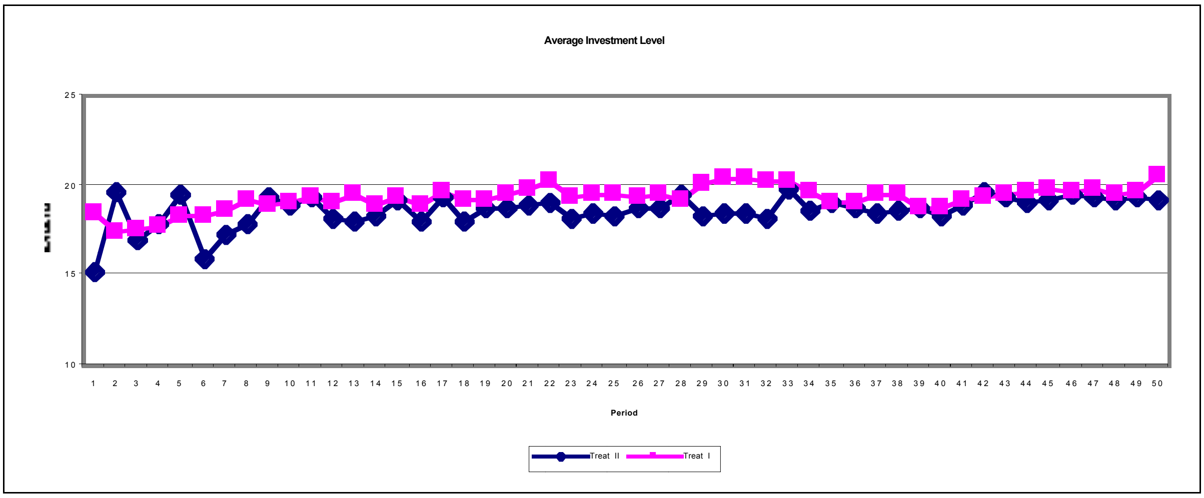


FIGURE 2



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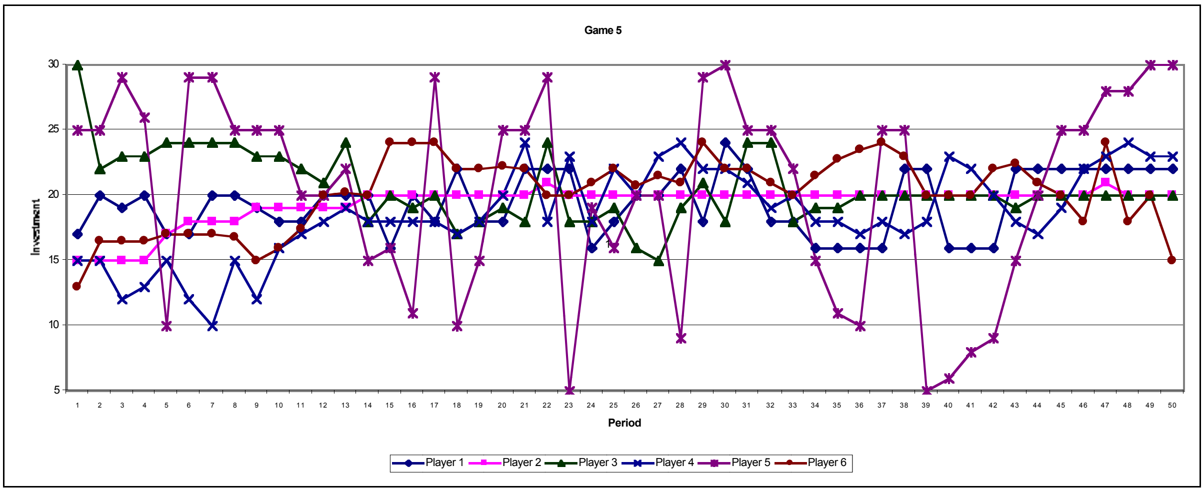

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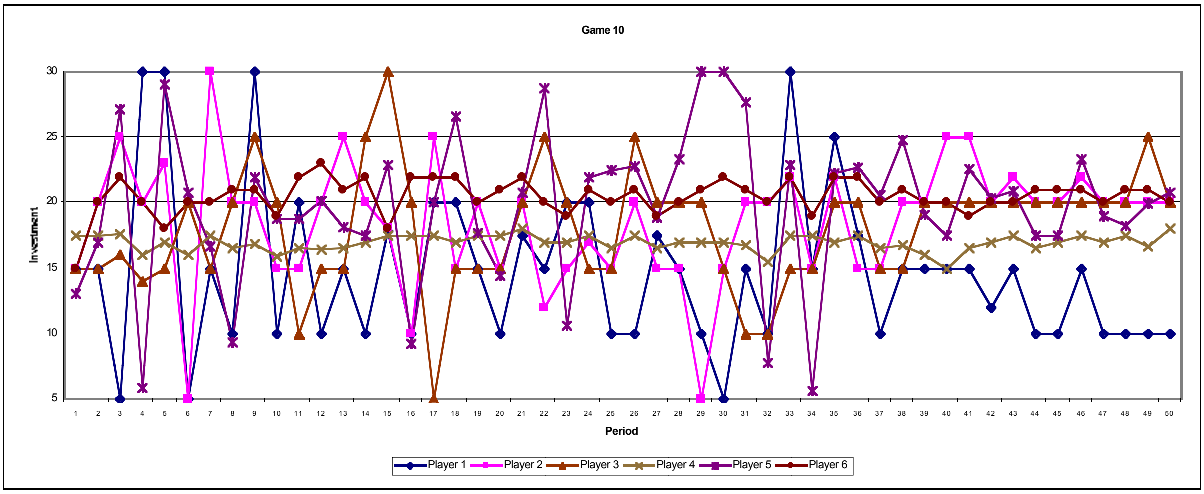

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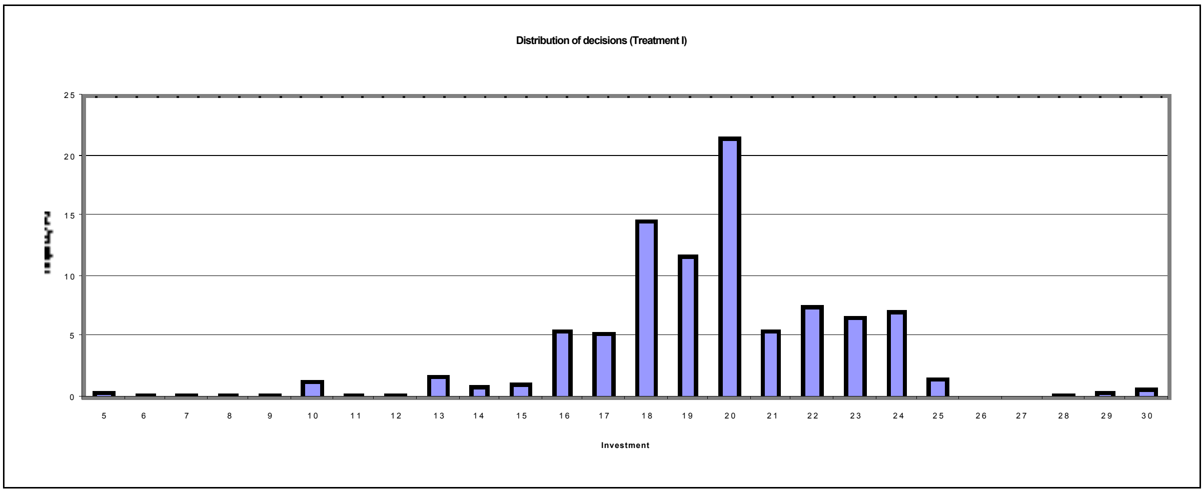

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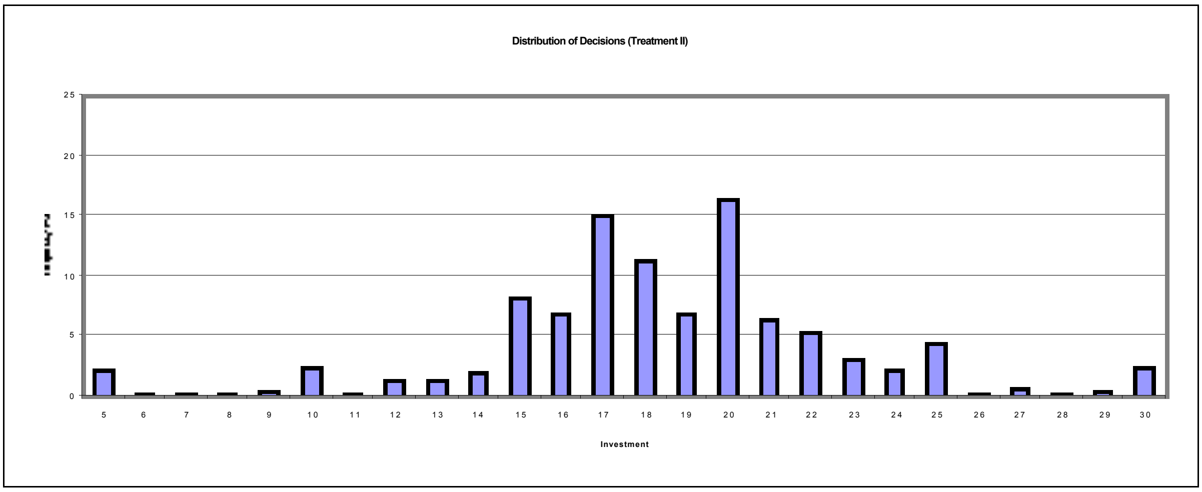

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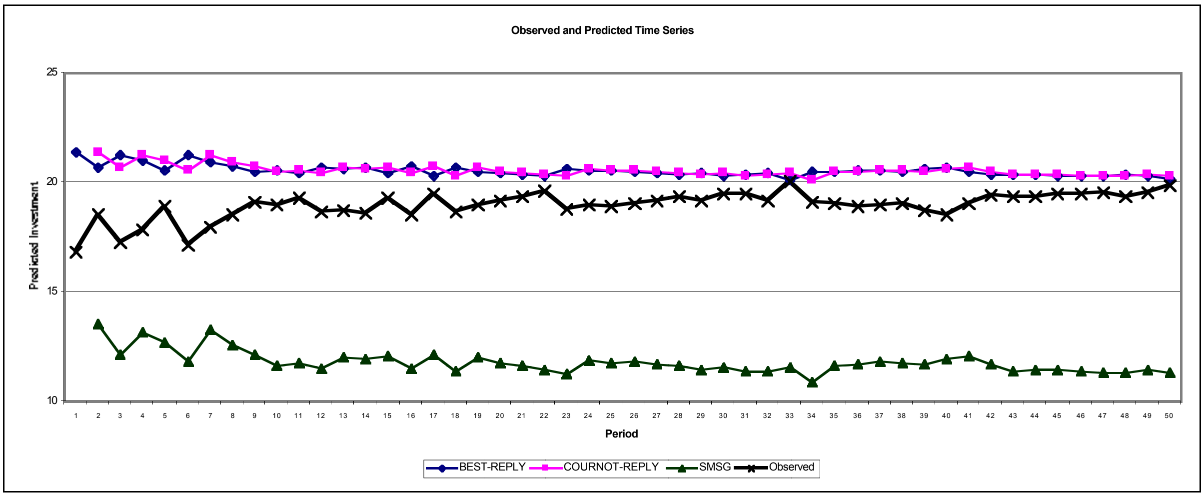

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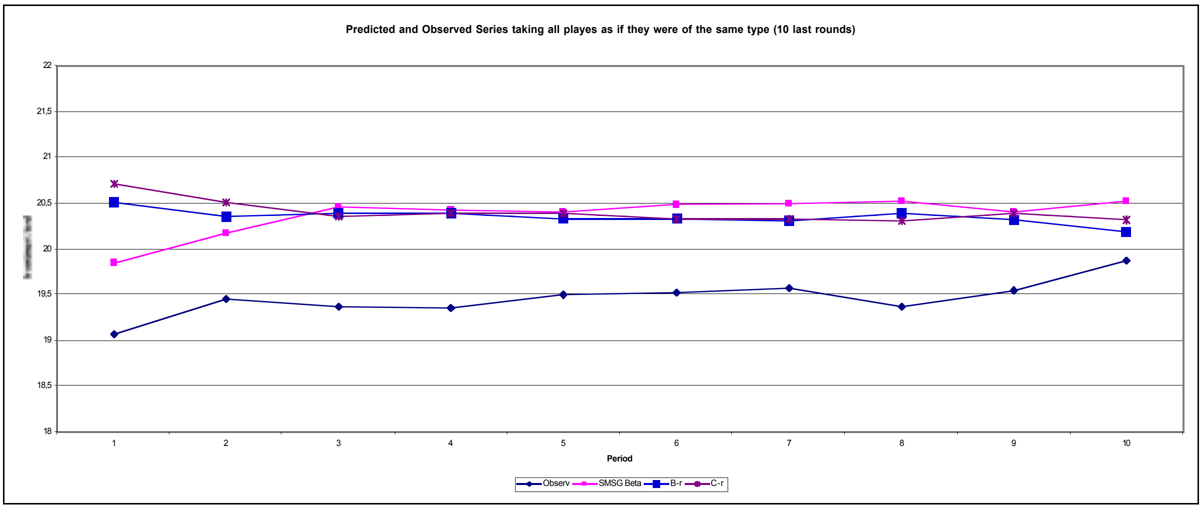

FIGURE 9

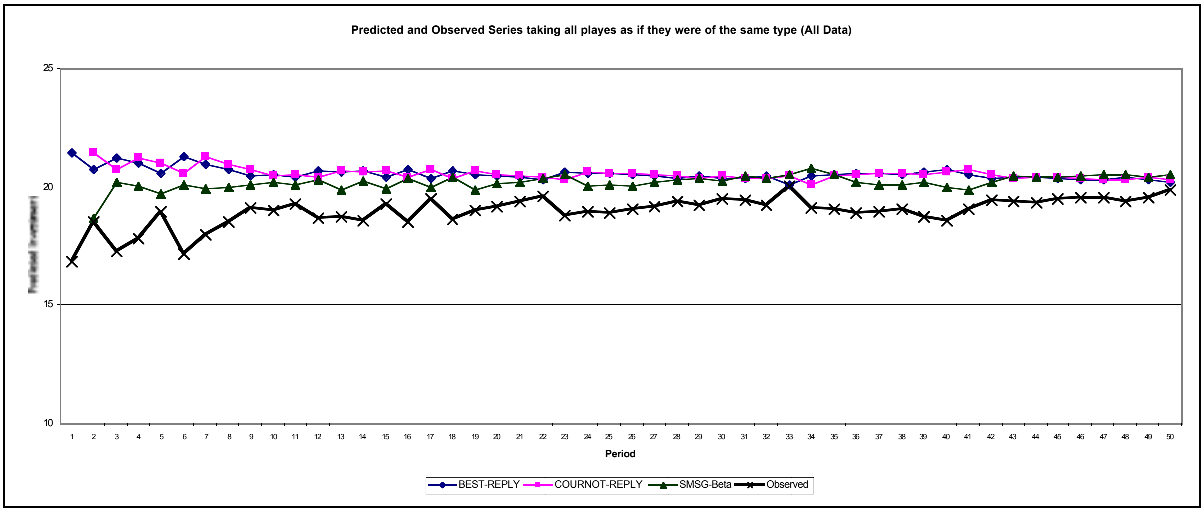

FIGURE 10

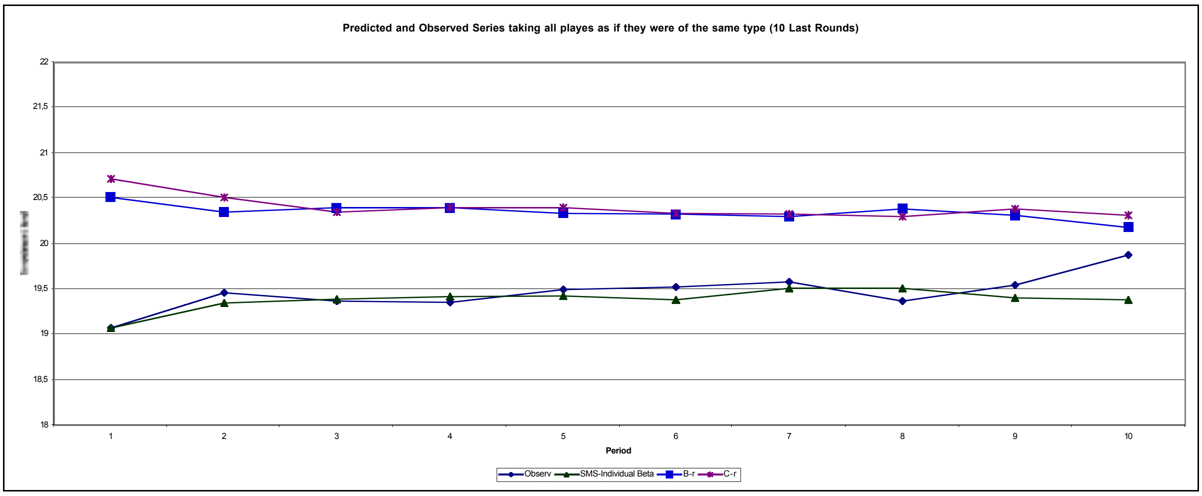

FIGURE 11

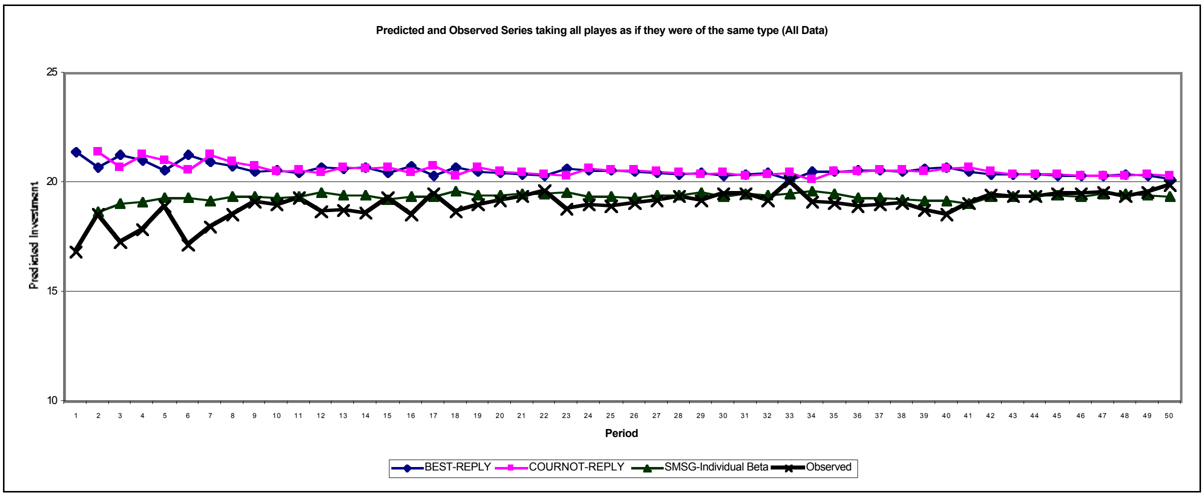

FIGURE 12

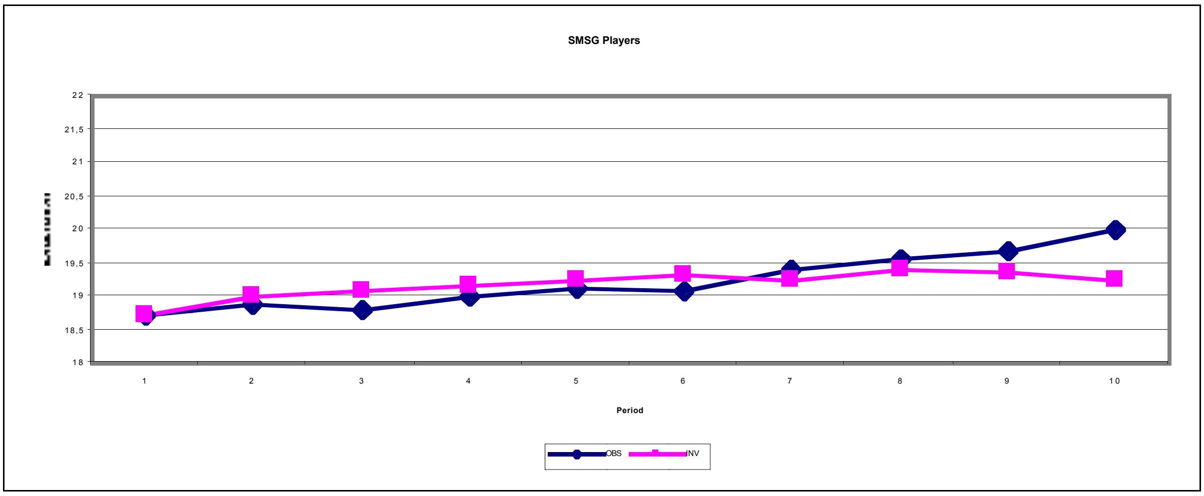

FIGURE 13

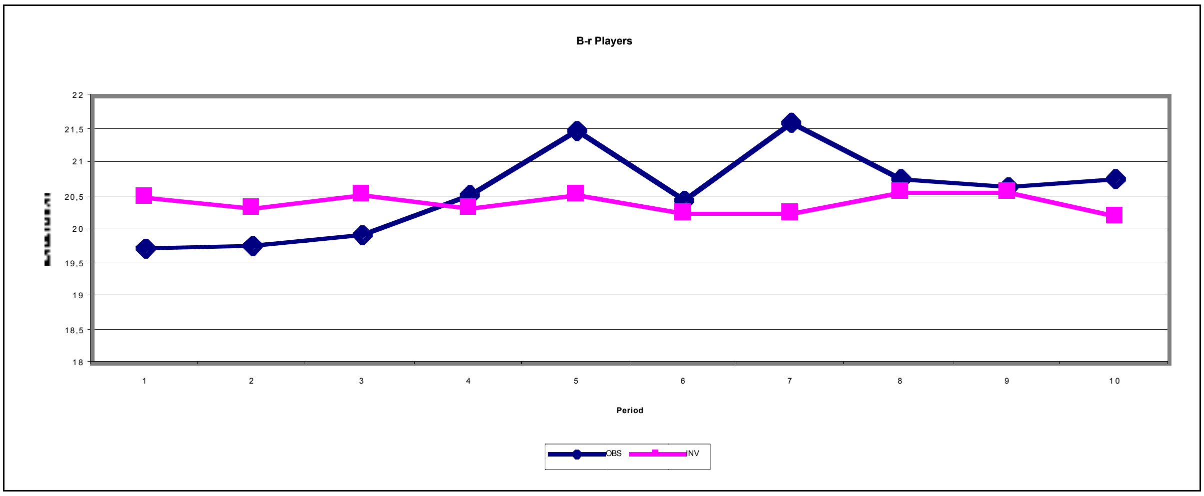

FIGURE 14

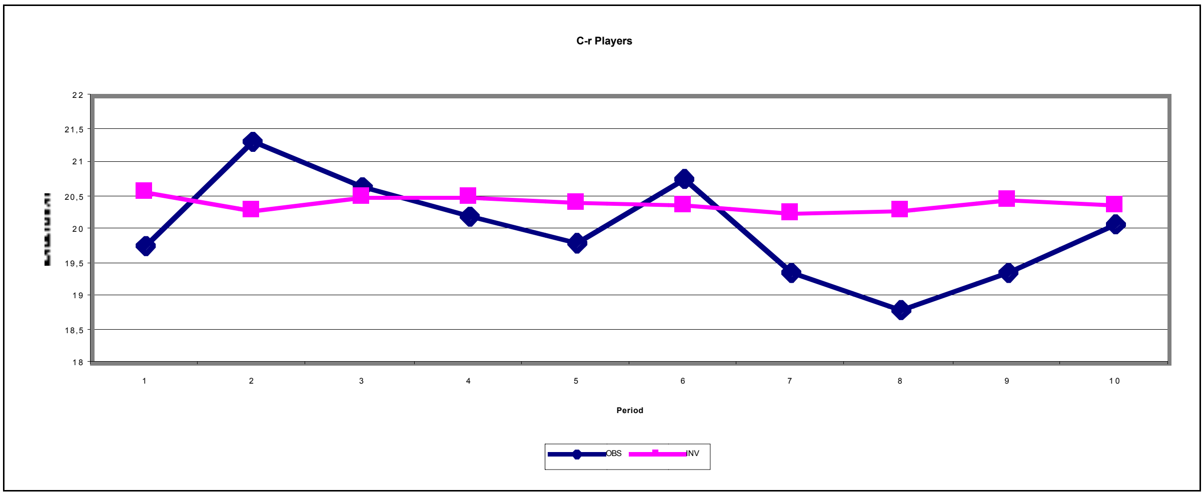

FIGURE 15

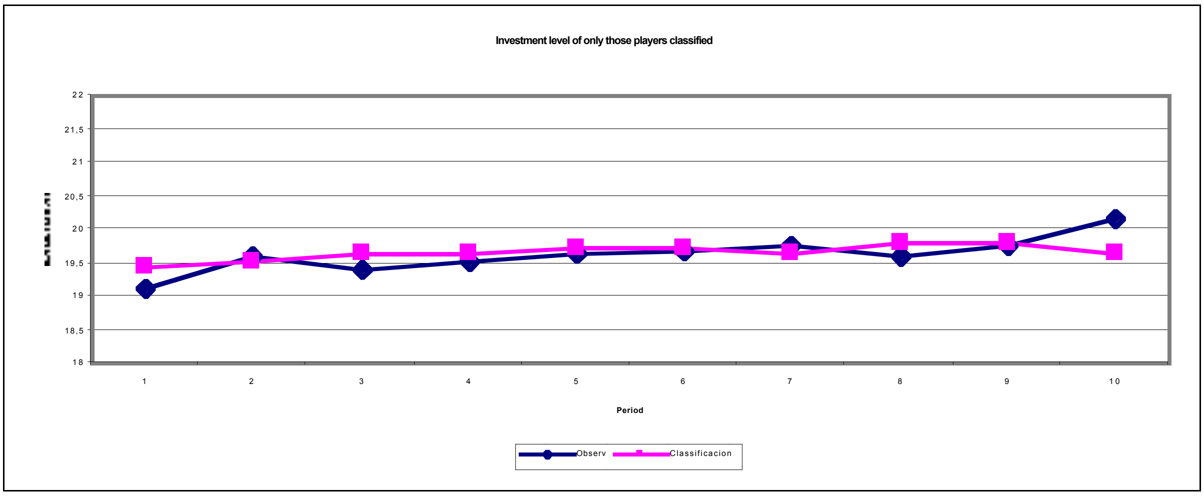

FIGURE 16

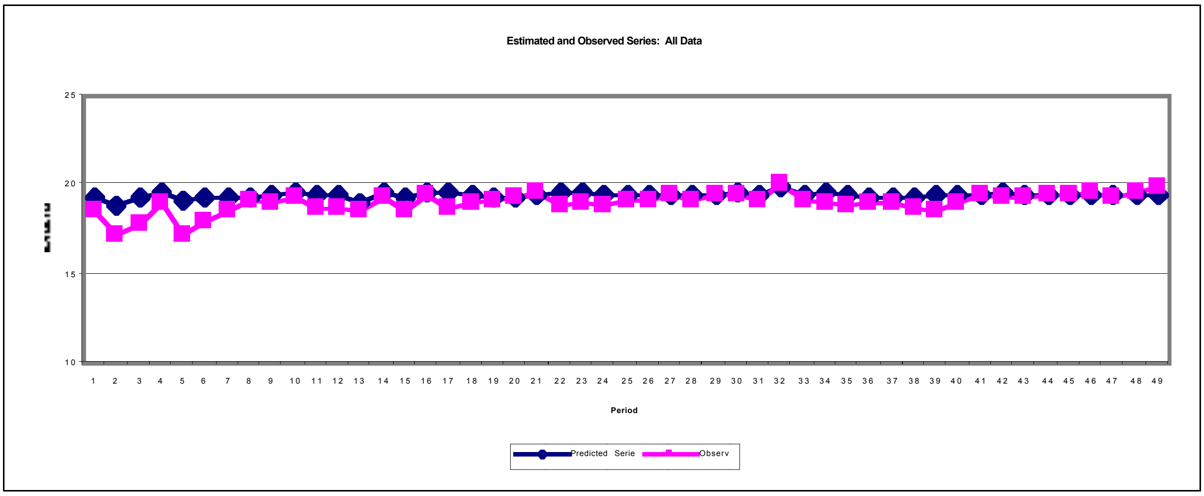

TABLE I
DESCRIPTIVE STATISTICS

GAME	1	2	3	4	5	6	TREAT I
			All Rounds				
Mean Inv	115,21	118,04	115,38	118,95	118,56	108,91	**115,84**
Stand Devi	5,68	5,65	11,51	9,94	9,67	9,47	**8,65**
			First Third				
Mean Inv	111,12	119,56	106,12	120,47	115,41	101,76	**112,41**
Stand Devi	3,12	3,673	4,14	4,25	4,19	4,43	**3,97**
			Second Third				
Mean Inv	116,02	119,44	120,08	128,03	121,59	105,91	**118,51**
Stand Devi	2,18	2,271	2,46	3,03	3,54	3,70	**2,86**
			Last Third				
Mean Inv	118,5	115,2	120,2	108,9	118,8	118,9	**116,76**
Stand Devi	2,132	2,04	2,226	2,253	4,118	2,242	**2,50**

GAME	7	8	9	10	11	12	TREAT II
			All Rounds				
Mean Inv	107,56	116,82	111,20	108,47	117,05	109,48	**111,77**
Stand Devi	12,25	8,37	11,60	11,28	9,43	8,30	**10,21**
			First Third				
Mean Inv	103,21	114,26	105,73	107,55	114,97	108,77	**109,08**
Stand Devi	6,44	5,49	4,67	5,52	6,29	4,65	**5,51**
			Second Third				
Mean Inv	109,09	118,48	113,03	107,90	117,11	107,04	**112,11**
Stand Devi	4,01	2,66	2,11	4,93	3,71	4,57	**3,66**
			Last Third				
Mean Inv	110,5	117,8	114,9	109,9	119,1	112,5	**114,13**
Stand Devi	3,659	2,306	2,519	3,713	2,373	4,304	**3,15**

TABLE II
INDIVIDUAL PARAMETER ESTIMATION

Game 1	Alpha	Beta	Game 7	Alpha	Beta
1	0,91	-0,50	1	0,96	-0,14
2	1,08	-0,24	2	1,15	-0,52
3	0,72	-1,33	3	1,03	-0,44
4	2,03	0,26	4	0,65	-0,01
5	0,91	0,11	5	1,31	-0,11
6	1,36	0,08	6	1,30	-0,09
Game 2			Game 8		
1	1,03	-0,27	1	1,34	-1,32
2	1,10	-0,45	2	0,75	-1,23
3	0,55	-1,33	3	1,11	-0,02
4	1,20	-0,63	4	1,24	-0,37
5	0,80	-1,15	5	0,94	0,11
6	1,00	-0,09	6	1,19	0,23
Game 3			Game 9		
1	0,98	-0,70	1	0,93	-0,29
2	1,04	-0,93	2	1,62	0,27
3	1,27	-0,09	3	0,93	-0,35
4	0,92	-0,13	4	1,00	0,00
5	1,31	-0,32	5	0,92	-0,28
6	1,25	-0,15	6	1,59	0,25
Game 4			Game 10		
1	1,26	-0,51	1	0,57	-0,47
2	1,70	0,06	2	1,32	-0,03
3	1,21	-0,63	3	1,00	-0,34
4	0,76	-0,36	4	0,95	0,05
5	1,26	-0,49	5	1,33	-1,34
6	1,04	-0,71	6	1,48	0,22
Game 5			Game 11		
1	0,87	-0,80	1	0,88	-1,81
2	1,33	0,00	2	1,19	-0,18
3	1,31	-0,07	3	1,40	-0,04
4	1,02	-0,12	4	1,00	-0,11
5	0,65	-2,20	5	0,77	-0,53
6	1,71	0,39	6	0,87	-0,58
Game 6			Game 12		
1	0,84	-0,07	1	0,99	0,04
2	0,91	-0,31	2	1,55	0,16
3	1,83	0,35	3	0,52	-1,30
4	1,06	0,00	4	0,96	-0,20
5	0,97	-0,27	5	0,84	0,00
6	1,20	-0,13	6	1,59	-0,35

TABLE III
PREDICTIVE SUCCESS

	B-R	C-R	Smsg-Beta	Smsg-Individual Beta
Mean Ratio Last Ten Rounds	0,85	0,86	0,84	0,88
Mean Ratio All Rounds	0,80	0,80	0,79	0,85
Mean Abs. Diff Last Ten Rounds	2,23	2,22	2,41	1,83
Mean Abs. Diff All Rounds	3,19	3,08	3,13	2,22

TABLE IV
INDIVIDUAL CLASSIFICATION

	Player 1	Player 2	Player 3	Player 4	Player 5	Player 6
Game 1	-	SMSG	SMSG	C-R	-	SMSG
Game 2	SMSG	-	-	C-R	SMSG	SMSG
Game 3	C-R	C-R	B-R	B-R	C-R	B-R
Game 4	SMSG	B-R	-	SMSG	SMSG	-
Game 5	SMSG	SMSG	SMSG	B-R	SMSG	C-R
Game 6	-	SMSG	C-R	SMSG	-	SMSG
Game 7	SMSG	C-R	SMSG	SMSG	SMSG	B-R
Game 8	-	C-R	SMSG	B-R	-	SMSG
Game 9	SMSG	SMSG	SMSG	SMSG	SMSG	SMSG
Game 10	-	SMSG	C-R	SMSG	C-R	SMSG
Game 11	SMSG	C-R	C-R	SMSG	SMSG	B-R
Game 12	B-R	C-R	B-R	SMSG	SMSG	SMSG

TABLE 5
PERCENTAGES PER TYPE OF PLAYER

	B-R	C-R	SMSG-Individual Beta	None
All Experiment	13.9	19.4	51.4	15.3
Treatment I	13.9	19.4	44.5	22.2
Treatment II	13.9	19.4	58.4	8.3