COMPARATIVE STATICS OF A SIGNALING GAME: AN EXPERIMENTAL STUDY*

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Abstract. In this paper a simple and basic signaling game is studied in an experimental environment. First, we check whether we can replicate some of the findings in the literature concerning equilibrium selection and the use and impact of costly signals. Second, and foremost, the comparative statics implications of the game are studied. The experimental results are related to the predictions of two competing behavioral models: a game model, in which subjects are assumed to behave in line with (refined) sequential equilibrium theory, and a decision model, in which subjects are assumed to behave as non-strategic decision makers.

The experimental outcomes replicate the finding in the literature that costly messages are sent more frequently by 'higher' sender types (whose information is such that persuasion is also profitable to the responder), and that such messages have an impact on the behavior of the responder. These results are consistent with (versions of) both the game model and the decision model. The comparative statics results, however, clearly point in the direction of the decision model. Play is most strongly affected by 'own' payoff parameters, as predicted by the decision model, and less so by opponent's payoff parameters, as predicted by the mixed strategies of the refined sequential equilibrium. Particularly, a decision model in which players are assumed to adapt beliefs about opponents' choice probabilities in response to experience in previous play, appears to succeed best in organizing the data.

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1. Introduction

> "We think that much of the potential contribution of experimental methods lies in their ability to provide serious tests of the basic comparative-static implications of hypotheses of economic interest" (Kagel and Roth, 1992)

Although there are many signaling games in the theoretical literature, relatively few have been studied experimentally (see Davis and Holt, 1993). The focus of these experimental studies is typically on reputation formation in repeated games or on equilibrium selection in one-shot games[1], where in case of the latter attention is concentrated on pure strategies. As yet, remarkably little attention has been paid in the experimental literature to the comparative-static implications of signaling games. There implications deserve a much more prominent place, in our view (as in Kagel and Roth's, see the citation above). An exception is Neral and Ochs' (1992) test of some qualitative predictions of the Kreps-Wilson model of reputation formation in the version used by Camerer and Weigelt (1988). Although their results do not differ substantially from those of Camerer and Weigelt when the same parameters are used, they show that the theory fails to account for observed behavioral variations to parameter changes (responses go in the wrong direction). The authors suggest that the poor performance of sequential equilibrium theory might be generic to games with a unique equilibrium in mixed strategies. Also others have shown reservations with respect to the plausibility of mixed strategy equilibria, because of the counterintuitive implications and the weak incentives that they would provide.[2]

In this paper the comparative-static implications of a basic (two-player, one-shot) signaling game are studied in an experimental environment. The model, which is motivated by our research on lobbying[3], has two sequential equilibria. One (pooling) equilibrium in pure strategies and one (hybrid) equilibrium in mixed strategies. Only the latter equilibrium survives all the equilibrium refinements. The aim of this study is to contribute to the literature on signaling games in the following ways. First, we want to check whether we can replicate some of the qualitative findings in that literature concerning the use and impact of signals. Second, the comparative-static implications of the game will be studied. And, finally, attention will be paid to the development of subjects' play in the experiment. We are stimulated in this respect by recent experimental

[1] Regarding the former, see, for instance, Camerer and Weigelt (1988), Jung, Kagel and Levin (1994), Neral and Ochs (1992); as regards the latter, see Banks, Camerer and Porter (1994), Brandts and Holt (1992, 1993), Cadsby, Frank and Maksimovic (1990, 1992).

[2] See, e.g., Camerer and Weigelt (1988), Holler and Høst (1990), Tsebelis (1989), Wittman (1985).

[3] See Potters and Van Winden (1992) where a more general version of the game is presented and theoretically analyzed. Apart from the topic of lobbying, the model is also relevant for the study of advertising, for example.

work concerning non-strategic and adaptive behavior in signaling games.[4] As an alternative to the game theoretic model we will study the performance of a non-strategic decision model in organizing the experimental results. In this model subjects are assumed to act as if their opponents behave probabilistically rather than strategically.

The main results of our study can be summarized as follows. First of all, (versions of) both models correctly predict a higher frequency of costly messages by 'higher' sender types and that such messages have an impact on the behavior of responders. These results replicate earlier findings in the literature. However, the decision model outperforms the game theoretic model in tracking the comparative static implications. An adaptive decision model, with subjects adapting their beliefs about opponents' choices in response to cumulative experience, succeeds best in organizing our data. The model suggests a cyclical, but stable, adjustment process, leading towards a steady state that resembles the more refined sequential equilibrium of (at most) two of the five treatments studied. These results indicate that the predictive success of sequential equilibrium theory may be an artifact of the particular parameter configuration used. As such it illustrates the importance of using multiple parameter configurations to avoid erroneous conclusions about the predictive power of a (game theoretic) model.

The organization of the paper is further as follows. In Section 2 we present the nature of the signaling game and a number of hypotheses to be tested. The experimental design is discussed in Section 3. Results are presented and analyzed in Section 4, followed by a discussion and further analysis in Section 5. Section 6 concludes.

2. Description of the game and hypotheses

In the signaling game to be studied in this paper there are two players, a sender S and a responder R. The responder has to take an action, x_1 or x_2. The payoffs that the players derive from this action depend on the realization of a stochastic 'state' variable, which can take the value t_1 or t_2. The realization of this variable is private information to S; R only knows the odds p (1-p) that the value (state) is t_2 (t_1). In the sequel, we will sometimes refer to the sender as 'type 1' or 'type 2' depending on the realization t_1 or t_2. Before R decides which action to take, S can transmit a message m to R, where m is selected from a set of feasible messages M. Transmitting a message $m \in M$ bears a fixed cost c to S only, whereas sending no message (denoted by n) is costless. Thus, the cost of a message is assumed to be independent of both the content (value) of the message and the private information of the sender.[5] Formally, for the cost of a 'signal' s it is assumed that $c(s)=0$ if $s=n$, and $c(s)=c$ if $s=m \in M$. Apart from the realization of t_1 or t_2, which is private information to

[4] For instance, Brandts and Holt (1993, 1994), Cooper et al. (1994), Partow and Schotter (1993), Mookherjee and Sopher (1994).

[5] In the context of the interaction between a lobbyist and a policy maker one could think of testifying at a congressional hearing, making a telephone call, or hiring an intermediary. Such activities bear a cost to the lobbyist which is independent of what (s)he says or knows.

the sender, every other element of the game is common knowledge.

The (normalized) payoffs over state-action pairs for sender and responder, respectively, are represented by the following matrix.

	x_1	x_2
t_1	$0,b_1$	$a_1,0$
t_2	$0,0$	a_2,b_2

In this paper attention will be concentrated on the case where $0<c<a_1<a_2$, $b_i>0$, $i=1,2$, and $p<b\equiv b_1/(b_1+b_2)$. This payoff structure implies that S, independent of his private information or 'type', prefers R to choose x_2. On the basis her prior belief, however, R is inclined to choose x_1. R will only choose x_2 if she can be persuaded that the state is (likely to be) t_2, which is also the state under which S has the largest stake to persuade R ($a_2>a_1$). Hence, the game has a clear and interpretable structure. As will be shown next though, it's (equilibrium) outcome is not at all trivial.

Let $\rho(s)$ denote R's strategy, defined as the probability that x_2 is chosen after the signal s (m or n). Let σ_i stand for S's strategy, defined as the probability that a message (signal m) is sent when the state is t_i [with $1-\sigma_i$ the probability that no message (signal n) is transmitted]. Finally, let q(s) denote R's posterior belief, defined as the probability that the state is t_2, after having received s. It is straightforward to verify that the following condition should be satisfied for sending a message to be a best response (in the sense of maximizing expected payoff):

$$\rho(m)-\rho(n) \geq c_i \equiv c/a_i \quad , i = 1,2 \tag{1}$$

In words, sending a message should increase the probability of a favorable response (x_2) by at least as much as the 'relative cost' (c_i) of sending a message.

For R, having observed s, it is the best response to choose x_2 if the posterior belief q(s) exceeds the threshold b. Applying Bayes' rule this requires:

$$\sigma_2\beta \geq \sigma_1 \qquad \text{when } s = m \tag{2a}$$

$$(1-\sigma_2)\beta \geq (1-\sigma_1) \qquad \text{when } s = n \tag{2b}$$

where $\beta\equiv p(1-b)/(1-p)b$ (<1) may be called the 'prior attractiveness of choosing x_2'. Inequality (2a) indicates that, for x_2 to be a best response, a costly message (s=m) should be 'sufficiently more likely' to come from type t_2.

In the sequel, hypotheses derived from two competing theoretical models regarding the behavior of the players will be considered: (1) a 'game model', where players are assumed to behave as gamesmen, that is, in line with game theory; and (2) a 'decision model', where players do not behave strategically, in the sense that they take as given the probabilities with which the other player chooses her or his actions. The first model seems to be a natural reference point from a theoretical point of view, given the strategic aspects of the situation for the sender and the responder. The second model, on the other hand, is in line with recent experimental studies concerning signaling games suggesting that subjects do not behave as gamesmen, but follow a non-strategic decision process (see Brandts and Holt, 1994, Partow and Schotter, 1993).[6]

Starting with the game model, there are only two sequential equilibria for the signaling game presented above (Potters and van Winden, 1992)[7]:

SE1: $\sigma_1 = \sigma_2 = 0,\ \ \rho(n) = \rho(m) = 0,$

SE2: $\sigma_1 = \beta,\ \ \sigma_2 = 1,\ \ \rho(n) = 0,\ \ \rho(m) = c_1.$

In the first equilibrium (SE1) no messages will be sent, and R will stick to x_1. As R never reacts favorably to a message - by choosing x_2 - there is no use in sending one. On the other hand, if both types of senders never send a message there is no reason for R to change her prior belief, which leads to the choice of x_1. In case of the off-equilibrium event that a message is received - in which case Bayes' rule cannot be applied - it is assumed in this equilibrium that R's posterior belief is still concentrated on t_1. Since type t_2 has the largest stake to try and persuade R ($c_2<c_1$), however, this equilibrium does not satisfy the equilibrium refinement concepts which require that off-equilibrium beliefs be concentrated on the sender type that is 'most easily' induced (has the weakest disincentive) to send an off-equilibrium signal.[8]

In the only other equilibrium (SE2) R sometimes chooses the action that is preferred by S (x_2). This is produced by the fact that a message is sufficiently more likely to come from type t_2. But this requires that the responder uses a mixed strategy which makes type t_1 indifferent, and that the latter uses a mixed strategy which makes the responder indifferent when receiving a message. That is, (1) holds with equality for i=1 and with strict inequality for i=2, while (2a) holds with equality and (2b) does not hold. Since there are no off-equilibrium events in this equilibrium, it survives all refinements.

The decision model is inspired by the doubt that laboratory subjects (can) follow the intricate thought process that underlies (refined sequential) equilibrium theory. Instead, it posits that players follow a non-game-theoretical decision process, where they act as if their opponents behave probabilistically rather

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6 Apart from the recent literature emphasizing non-strategic and adaptive behavior, the explicit introduction of an alternative to the game model in this version of the paper was inspired by the stimulating comments of the referees.

7 It is noted that, in a sequential equilibrium, every message from the set of feasible messages that is sent with positive probability will induce the same action. The intuition is that the decision to send a message implies a fixed cost c, no matter what its content is, making this content essentially equivalent to cheap talk. Consequently, without loss of generality, we can focus on one element of the set M, m say.

8 Specifically, SE1 does not survive the refinements of D1, Universal Divinity, or elimination of Never Weak Best Responses, although it does obey Cho-Kreps' Intuitive Criterion, which has no bite in our game (see Cho and Kreps, 1987, Cho and Sobel, 1990).

than strategically. They think of their opponents not as strategic players but as decision machines with fixed probabilities of behaving in a certain way. As can be read from the best response conditions (1) and (2), it will then depend on the probability beliefs concerning $\rho(s)$ and σ_i whether messages will be sent and x_2 is chosen. The decision model in this 'weak' form cannot deliver as precise predictions as the (refined) game model. Nevertheless, as will become clear below, the sharp difference in importance of the role played by own versus other player's payoff parameters makes our comparative statics design an interesting one to distinguish between the game model and the decision model.

Although one cannot reasonably expect that a theoretical model will exactly predict the behavior of subjects in an experiment, it should at least be predictive in a qualitative (directional) sense, which implies that the results should go in the direction suggested by a comparative-static analysis of the model. To that purpose, a number of hypotheses are now formulated that can be tested using the experimental data. We start out with hypotheses that are relevant for all of the parameter configurations (experimental treatments) chosen. This is followed by a set of hypotheses more specifically related to the comparative-static implications of the two theoretical models. In the sequel, we let s_i stand for the empirical frequency with which a message is sent when the state is t_i (i=1,2) and r(s) for the empirical frequency with which x_2 is chosen when signal s (=n,m) is received.

H1. No messages will be sent: $s_1=s_2=0$, and x_1 is chosen: r(n)=r(m)=0.

This outcome would be in line with the unrefined sequential equilibrium SE1 of the game model, but also with 'best response to uniform' behavior in case of the decision model, which implies that senders assume that signals do not affect choices [$\rho(m)=\rho(n)$] and responders assume that the frequency of messages is state-independent ($\sigma_1=\sigma_2$).

The following hypotheses refer to situations where (sometimes) messages are sent, and (sometimes) x_2 is chosen. For the decision model we have to assume here that subjects are to some extent able to understand the incentive structure of the opponent. More specifically, (at least some) senders are assumed to believe that the choice of x_2 is more likely after a message than after no message, that is, $\rho(m)>\rho(n)$. And (at least some) responders are assumed to believe that the probability of a message is higher when the state is t_2, that is, $\sigma_2>\sigma_1$. The former consideration seems plausible as "you have to do something to persuade a responder who is inclined to choose x_1" ($\beta<1$), and the latter because a sender of type t_2 has a greater incentive to persuade the responder ($c_2<c_1$). In the sequel, we will speak of the decision model with 'non-uniform beliefs', in that case.

H2. Messages are more frequently sent by t_2 senders: $s_2>s_1$, and responders choose x_2 more frequently in case of a message: r(m)>r(n).

This hypothesis is in line with the sequential equilibrium SE2 of the game model, as in that equilibrium

$\sigma_2 > \sigma_1$ and $\rho(m) > \rho(n)$. It can also be derived from the decision model, assuming non-uniform beliefs about the probabilities of the choices by opponents. The derivation is somewhat loose, though, in the sense that we will not be very precise regarding these beliefs. If senders (on average) believe that $\rho(m) > \rho(n)$ it can be inferred from (1) that they are more likely to send a message under t_1 than under t_2 (since $c_1 > c_2$). Similarly, if responders (on average) believe that $\sigma_2 > \sigma_1$, it can be inferred from (2) that they are more likely to choose x_2 when a message is received than when no message is received.

Hypotheses *H1* and *H2* discriminate between outcomes of the same model under different assumptions, but not between the two models. The following hypotheses, referring to the comparative-static implications of the models, give the opportunity to do so. These implications hinge on the parameters c_i and β [cf. conditions (1) and (2)], where the former reflects the 'relative cost of sending a message' for the sender of type t_i, and the latter the 'prior attractiveness of choosing x_2' for the responder. One set of hypotheses (*H3a-H5a*) concerns SE2 of the game model, the other set (*H3b-H5b*) relates to the decision model with non-uniform beliefs about the (fixed) decision probabilities of opponents [that is, $\rho(n) < \rho(m)$ and $\sigma_1 < \sigma_2$]. Assuming that these beliefs are sufficiently independent of the parameter configuration, it follows from (1) and (2) that more messages will be sent as c_i decreases, and that x_2 will be chosen more frequently if β increases. To bring out the competition between the hypotheses we will juxtapose those that pertain to the same behavioral issue.

H3a. Parameter β mainly affects s_1, in a positive way (game model).

H3b. Parameter β mainly affects $r(m)$, in a positive way (decision model).

H4a. Parameter c_1 mainly affects $r(m)$, in a positive way (game model).

H4b. Parameter c_1 mainly affects s_1, in a negative way (decision model).

H5a. Parameter c_2 has no effect (game model).

H5b. Parameter c_2 mainly affects s_2, in a negative way (decision model).

As borne out by these hypotheses, the discriminating aspect of the two models concerns the response to changes in own payoff parameters versus changes in the parameters affecting the payoff to the other player. In SE2 of the game model the behavior of subjects is mainly affected by the opponent's payoff parameters, since the mixed strategies [$\rho(m)$ and σ_1] imply that players make each other indifferent. In the decision model, on the other hand, behavior is mainly affected by own payoff parameters, as beliefs about opponent's choice probabilities are assumed to be (largely) independent of opponent's payoff parameters.

After the presentation of the experimental design in the next section, the aforementioned hypotheses will be tested against the experimental data in Section 4.

3. Experimental design

Since our focus is on the comparative statics of the game, it was decided to study five different treatments (parameter configurations). Two experimental sessions per treatment were held. No subject participated in more than one session. As the parameters β and c_1 play a crucial role in the game model as well as the decision model (H3-H4), two substantially different values for these parameters were induced (.25 and .75). In addition, we chose to vary a parameter (a_2) that according to the game model should have no impact on the outcome of the game (H5a). Table 1 summarizes the different treatments. Remaining freedom in the design of the experiment was used to set the predicted payoffs under SE2, to both the sender and the responder, equal to 2 Dutch guilders per play.[9] Since only a_2 was changed in treatment 5, as compared to treatment 2, the sender's expected payoff was necessarily somewhat different in that treatment (1.63 guilders). The details concerning the payoff parameters are presented in the Appendix.

[Table 1]

Undergraduate students were recruited as subjects through announcements in classes of the department of economics and in the weekly information bulletin of the University of Amsterdam (overall, 85% were economics majors). They were requested to participate in a two hour decision-making experiment. Subjects had not been involved in any experiment of our laboratory before.

In each session 12 subjects and one monitor (observer) were actually used, but 15 were registered to allow for no-show-ups. Upon arrival, a lottery decided who was to be the monitor, a sender or a responder. If more than 13 showed up - which was always the case - the lottery also determined who could not participate. Those students got 10 guilders and an assurance of participation in a next experimental session. Once the 12 subjects and the monitor were seated in the laboratory - at tables with partitions - the instructions were distributed and read aloud (an English translation of the instructions is provided in the Appendix). In the instructions senders and responders were, respectively, called A and B participants, and the responder's actions were labeled B1 and B2 (instead of x_1 and x_2). The 'message character' of the sender's signal was retained, however, as information transmission via announcements, messages or reports is at the heart of the subject matter of lobbying, which motivated the research (see Potters and Van Winden, 1992).

Each session consisted of 2 parts, each part beginning with one practice period followed by 10 periods (rounds) of play. Instructions for the second part were read after the first part was finished. The only difference between the parts was that subjects changed roles (senders became responders, and vice versa). In every period the senders were matched with the responders. Subjects could not know, however, whom they were paired with in any period. Matching schemes were determined randomly before the experiment under the constraint that within each part of 1+10 periods no particular pair would occur twice in a row, nor more

[9] This was approximately equal to 1.16 U.S. dollars at the time of the experiment, being January - March 1992.

than twice during the whole part. Subjects were informed about this constraint. On the record sheets (see the Appendix) codes were used for the pairings such that the subjects could not deduce the matching scheme and, equally important, would not think they could. Answers to a debriefing questionnaire did not cast doubt on the credibility of this procedure to preserve the one-shot character of the game.

In each period the game presented in the previous section was played according to the following rules. At the start of the period a small white or black disk (checker) was drawn by the monitor from an urn. Whereas the portion of black and white disks in the urn was made known to all subjects (see below), the disk drawn by the monitor was only shown, by the monitor, to the subjects playing the role of sender. After seeing the color of the disk a sender decided whether or not to send a message to the unknown responder (s)he was paired with in that period. In case of a message, the sender had to choose between the announcement (the disk is) ’white’ or ’black’. Sending a message involved a fixed cost for the sender, independent of the content of the message (announcement) and the true color of the disk. After the sender had recorded this decision on her or his record sheet, it was privately communicated (by us) to the paired responder, by marking the appropriate column of the responder’s record sheet. Subsequently, the responder had to choose between B_1 and B_2, and mark this decision on her or his record sheet. The choice was then communicated privately to the paired sender (by us) and the color of the disk was revealed to the responder (by the monitor). At the end of each period subjects calculated their own earnings and - to have an additional check on whether they understood the game - of the player they were paired with in that period. Results for the other pairs were not revealed.

Possible payoffs were presented in tables on a description form (see Appendix) and expressed in Dutch guilders. They were also projected on a wall, for all to see. To avoid any ’sequence effects’ the payoffs as well as the prior odds for the color of the disk remained the same throughout a particular session. The only difference between part one and part two was the change of the role of the subjects.

Earnings were paid, confidentially and in cash, at the end of the experiment, after the completion of a questionnaire.

4. Results

The general impression we got during the experiments was that the procedures worked well and that subjects seemed to understand and ’trust’ the instructions. The debriefing questionnaire confirmed this impression. All participants rated the instructions as ’clear’ or ’very clear’, and all confirmed that they had the idea that the procedures were in accordance with the instructions. Few questions were asked; the most frequent one was: What does ’B1’ and ’B2’ mean? (which were the labels used for the choices x_1 and x_2). Furthermore, few mistakes were made on the record sheets. The questionnaire, like the whole experiment, was anonymous in the sense that we did not use subjects’ names but only, randomly drawn, registration numbers. The experiment including questionnaire and payment lasted about two hours. Average payment was 42.92 guilders, which is about 50% more than a student would typically earn in a two hours job.

We took some effort to make sure that the lottery was in accordance with the stated priors and, more importantly, was believed to be so by the subjects. To that purpose - and contrary to other experiments (e.g., Brandts and Holt, 1992, or Camerer and Weigelt, 1988) - the draw was observed by all subjects. The disks were contained in identical opaque film cases. Upon drawing a case, the monitor would lift the top and walk past all senders to show the contents. Furthermore, at the start of the experiment the monitor was requested to empty the urn and cases and show the contents to the subjects (this was repeated when a 'suspect' sequence of colors turned up). The randomness of the draws was supported by the data. The color turned out to be black in 45 out of 80 draws with a prior odd of 1/2, and in 38 out of 120 draws with a prior odd of 1/3. The fact that we had random draws decreased, of course, to some extent experimental control. In different sessions subjects experienced different sequences of draws. This feature may have increased variability of behavior between the sessions, but we did not find any strong effects of the sequence of draws.

From now on, s_1 refers to the observed frequency of a message when the color of the disk was white (state t_1), and s_2 to the observed frequency of a message when the color was black (state t_2). Furthermore, r(m) and r(n) indicate the observed frequency that x_2 was chosen given that a message (m) or no message (n) was received.[10] Since each of the five treatments of the game was run twice, there were 10 sessions, each consisting of two parts, where each part comprised 10 periods of play by six varying pairs of subjects. In the sequel, we will report nonparametric statistical tests which treat aggregate play of individual subjects as the basic unit of observation. In each part we have 60 senders and 60 responders. Thus, for each part of each treatment there are 12 observations of s_1, s_2, r(n), and r(m). Results of more conservative tests, using the 10 session aggregates as units of observations, will be presented in footnotes.

Before we turn to statistical testing of the hypotheses, it is useful to give some idea of the variation of the frequencies *across* treatments, and of the development of the frequencies over time. Figures 1 and 2 show the development over the two parts of s_1 and s_2, and r(n) and r(m), respectively, taking togther the two sessions in each treatment and adjacent periods (two by two).[11]

[Figures 1 and 2]

As can be seen from the figures the frequencies s_1 and r(m) display a large variation across treatments, which appears to increase with the period number. The frequencies s_2 and r(n) display a smaller variation across treatments. In addition, there seems to be a tendency for s_2 to move towards 1 (except perhaps for treatment 1) and for r(n) to move towards 0. Taking all ten sessions together, the subjects in the role of

[10] No distinction will be made between 'black' and 'white' messages as the number of messages with content 'white' was too small for a powerful test. The overall fraction of such messages in part 2 - the part to be focused upon below - was only 24/354=.067.

[11] For some frequencies no observations were obtained in particular (adjacent) periods. For example, the absence of markers for periods 7-8 and 9-10 in the top line for s_1 in Figure 1 indicates that no white disk was drawn in either session of treatment 5 in any of the periods 7-10 of part 1.

sender in part 1 transmitted a costly message when the color was black (s_2) at an average rate of .713, whereas the senders in part 2 did so at an average rate of .873. The difference is significant at p=.002 with a two-tailed (Mann-Whitney) U test (n_1=n_2=60). Note that this development of s_2 is in the direction of SE2 but not SE1. Also the decline of r(n) as we move from part 1 to part 2 is significant. The responders in part 1 chose x_2 after no message at an average rate of .095, whereas the responders in part 2 did so at an average rate of .038. The difference is significant at p=.006 with a two-tailed U-test (n_1=60, n_2=56[12]).

As regards the development of behavior *within* a particular treatment, it is found that the behavioral variance decreases as we move from part 1 to part 2. For example, for each treatment (1-5) and for each of the four frequencies [s_1, s_2, r(n), r(m)] we computed the variance over the subjects in part 1 and in part 2. This gives 20 comparisons of behavioral variance between part 1 and part 2. In 15 of these, the variance in part 2 is smaller than in part 1. The decline of variance is significant at $p<.05$ with both a two-tailed sign test and a Wilcoxon match-pairs signed-ranks test (n=20).

Based on this analysis attention will be concentrated on part 2 for each treatment from now on, to avoid effects that may be due to initial confusion about the game and the initial learning phase, and to give the game model (SE2) its best chance. (None of our main conclusions depends on this restriction, however.)

Tables 2 and 3 give the average frequencies and standard deviations of s_1, s_2, r(m) and r(n) over the 12 senders and responders in part 2, for the five treatments. These tables will be referred to in testing the hypotheses presented in Section 2.

[Tables 2 and 3]

Ad *H1*. The hypothesis that no messages will be sent and x_1 will be chosen by the responder is clearly rejected by the data, as the large frequencies that a message was sent and that x_2 was chosen show. Consequently, it is rejected that players behave according to the sequential equilibrium SE1 of the game model, or play 'best response to uniform' in case of the decision model.

Ad *H2*. The hypothesis that type 2 senders transmit relatively more messages than type 1 senders is unambiguously supported by the data, as a comparison of s_1 and s_2 in Table 2 shows. Senders in part 2 sent costly messages at an average rate of .411 when the color was white, and at an average rate of .873 when the color was black. The difference is significant at $p<.0001$ with a two-tailed U test (n_1=n_2=60). The data presented in Table 3 also support the hypothesis that costly messages increase the frequency with which x_2 is chosen (the action that is favorable to the sender). The average frequency is .542 when the responder received a message [r(m)], and only .038 in case of no message [r(n)]. The difference is significant at p=.0001 with a two-tailed U test (n_1=60,n_2=56).

These results suggest that subjects did not maintain uniform beliefs regarding the choice probabilities of the other player, in contrast with the predictions by SE1 of the game model and 'best response to

[12] Four responders in part 2 always received a message and, hence, provided no observation of r(n).

uniform' behavior in case of the decision model. Subjects tried to signal by sending costly messages, and the more frequently in case they had a higher stake to do so (s_2>s_1). Moreover, sending a message had a clear impact on the behavior of responders as x_2 was chosen much more frequently in that case [r(m)>r(n)]. To find out whether SE2 of the game model or the decision model with non-uniform beliefs performs better in organizing the experimental data, we proceed with an investigation of the comparative-static implications of these models (hypotheses *H3-H5*).

Ad *H3a* and *H3b*. The data in Table 2 show that the frequency of messages by senders of type 1 increases in β, as predicted by the game model. From the row averages it can be observed that the average frequency of s_1 increases from .272 to .503, as β increases from .25 to .75. This difference, albeit not as large as predicted by SE2, is significant at *p*=.042 with a two-tailed U test (n_1=24, n_2=36). It turns out that β also has a positive effect on s_2. The average frequency of s_2 increases from .806 to .918 as β increases from .25 to .75. The difference is significant at .034 with a two-tailed U test (n_1=24, n_2=36). As predicted by the decision model, Table 3 shows a positive effect of β on r(m). Costly messages are reacted to with x_2 at an average rate of .292 when β=.25 and at an average rate of .709 when β=.75. The difference is highly significant at *p*=.0001 two-sided with a U test (n_1=24, n_2=36). Hence, the effect of β on r(m) is both larger and more significant than the effect of β on s_1 (and s_2). The data support hypothesis *H3b* of the decision model much more strongly than hypothesis *H3a* of the game model.[13]

Ad *H4a* and *H4b*. As Table 3 shows, the average frequency with which x_2 is chosen by responders increases with c_1, as predicted by the game model. From the column averages it can be seen that r(m) increases from .460 to .666 as c_1 increases from .25 to .75. Although the difference is not as large as predicted by SE2, the difference is significant at *p*=.040 with a two-tailed U test (n_1=36, n_2=24). The only other significant effect of c_1 is the one predicted by the decision model. The average rate at which messages are sent when the color is white (s_1) decreases from .559 to .189 as c_1 increases from .25 to .75. The effect is significant at *p*=.0001 with a two-tailed U test (n_1=36, n_2=24). Hence, the effect of c_1 on s_1 is both larger and more significant than the effect on r(m). Again, the hypothesis of the decision model (*H4b*) is supported more strongly than the hypothesis (*H4a*) of the game model.[14]

Ad *H5a* and *H5b*. The hypothesis derived from the game model, that c_2 has no effect on senders and responders, is rejected by the data. Table 2 shows that the average frequency of s_1 is .458 in treatment 2 and .833 in treatment 5. The increase is significant at *p*=.015 with a two-tailed U test (n_1=n_2=12). In addition, the difference between r(m) of treatment 2 (.791) and of treatment 5 (.535) is marginally significant at *p*=.089 with a two-tailed U test (n_1=n_2=12). On the other hand, the hypothesis derived from the decision

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[13] If the 10 sessions are taken as units of observation, the effect of β on r(m) remains significant at p=.019, whereas the effects of β on both s_1 and s_2 become insignificant at p=.171 with a two-tailed U test (n_1=4, n_2=6). Furthermore, the effect of ß on s_1 becomes insignificant if treatment 5 - in which a parameter irrelevant to SE2 is changed - is left out. The effect of β on r(m) remains significant, however.

[14] The same conclusion is reached when sessions are taken as units of observation, or when treatment 5 is excluded.

model, that the main effect of c_2 is on s_2, is also clearly rejected. Although the effect goes in the direction predicted by the decision model, the difference between s_2 of treatment 2 (1.00) and of treatment 5 (.925), is insignificant at p=.514 with a two-tailed U test (n_1=n_2=12). Hence, hypothesis *H5a* as well as *H5b* is rejected by the data.[15]

Summarizing, the results suggest that subjects' behavior is most strongly affected by changes in 'own' payoff parameters (*H3b* and *H4b*), as predicted by the decision model. Changes in the other player's payoff parameters are in the direction predicted by equilibrium SE2 (*H3a* and *H4a*), but these effects are smaller and less significant. The rejection of both *H5a* and *H5b* adds a negative result for both the game model and the decision model. However, combined with the tests of *H1* and *H2*, the general picture emerges that the decision model, with non-uniform beliefs, outmatches the game model in organizing the experimental data.

5. Discussion and further analysis

A further analysis of the game model

The discussion is started with a closer examination of the performance of the game model. The outcome that many (costly) messages were sent, with a clear impact on the behavior of responders, led to the rejection of the pooling equilibrium SE1 (*H1*) and directs attention towards the performance of the unique refined equilibrium SE2. A number of results turned out to be supportive for the predictions derived from this equilibrium, in a qualitative sense. First, in line with *H2*, type 2 senders transmitted significantly more messages than type 1 senders ($s_2>s_1$), and responders reacted with x_2 to a significantly larger extent in case of a message [$r(m)>r(n)$]. Second, s_2 approaches 1 and $r(n)$ goes to 0, as illustrated by Figures 1 and 2. Moreover, these frequencies are hardly affected by changes in β or c_1. Finally, there is some evidence that s_1 increases with β (*H3a*) and $r(m)$ with c_1 (*H4a*). A sympathetic reading of these results may lead to the conclusion that the game model performs rather well as a predictive model, in a qualitative sense. This is remarkable in light of the reservations met in the literature concerning mixed strategy equilibria, which refer to very weak payoff incentives and counterintuitive comparative-static implications that empirically would go into the wrong direction.

Nevertheless, even under this sympathetic reading the game model clearly fails as a predictive model in two important respects, both of which relate to the mixed strategies [σ_1 and $\rho(m)$] of SE2. First of all, play is strongly affected by changes in 'own' payoff parameters. Secondly, outcomes show a substantial spread around the predicted values.[16]

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[15] With only 4 sessions in treatments 2 and 5, no significant effects can be found when sessions are taken as units of observation.

[16] Adjustment of the sequential equilibrium theory in directions tried in the literature (e.g., risk-attitudes, homemade priors, altruism, relative money, or repeated game considerations) does not solve the problem; nor does the inclusion of psychological considerations like a 'cost of lying'. Although they help to reduce the

With respect to the first failure of the mixed strategy predictions - the reaction to 'own payoffs' - the following may be important to note. If c_1 would grow further from .75 to a value larger than 1, the unique refined sequential equilibrium SE2 would be replaced by a separating equilibrium with σ_1=0 (and σ_2=1). On the other hand, σ_1 would go to 1 if c_1 decreases further from .25 to a value smaller than zero, as always sending a message becomes a dominant strategy in that event. Thus, it may be the case that the decrease in the frequency of messages as c_1 increases from .25 to .75 is part of a more gradual adjustment to regime switches. A similar argument could hold for the observed increase of r(m) if β increases to a relatively high value. For, if β would increase further from .75 to a value larger than 1, sequential equilibrium analysis predicts that a responder will play $\rho(m)$=1 (see Potters and Van Winden, 1992). Along the same lines, one would expect that the frequency r(m) goes to zero if β decreases further from .25 to a value smaller than zero (that is, $b_2<0$), as the choice of x_1 would become a dominant strategy in that case. The results presented in Figures 3 and 4 seem suggestive of such a gradual adjustment to regime switches. In Figure 4, for instance, the outcomes of $r(m)/c_1$ for β=.25 (treatments 1 and 3) are bounded away from the predicted value of $\rho(m)/c_1=1$ in the direction of 0, which would be the predicted value for $\beta<0$. Also, the outcomes for β=.75 (treatments 2, 4, and 5) are larger than 1 and in the direction of the predicted values for $\beta>1$ (1.33 for treatment 4, where c_1=.75, and 4 for treatments 2 and 5, where c_1=.25).

[Figures 3 and 4]

Perhaps the strong rationality assumptions of the game model are inadequate when there are regime switches, such as here, that would involve 'jumpy' adjustment. As yet it is not clear, though, how these assumptions - or other assumptions, for that matter - can be relaxed to incorporate such gradual adjustment to regime switches in the game model.

The strong rationality assumptions of the model, which do not allow a distinction in a motivational sense between a tiny and a huge monetary gain or loss, may also play a role in the second failure of the mixed strategy predictions: the gap between outcomes and predicted values. From a motivational point of view such a gap is not surprising. The theoretically expected cost of a one-sided deviation from a mixed strategy is zero, whereas these costs are quite substantial for the predicted pure strategies [circa 1 guilder for a deviation from σ_2=1 and 3 guilders for a deviation from $\rho(n)$=0[17]]. But, again, it is not clear yet how such motivational factors can be taken on board (see, however, McKelvey and Palfrey, 1993).

For now, the outcome that subjects predominantly react to changes in own payoff parameters should lead to the conclusion that the decision model with non-uniform beliefs succeeds better in describing the

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average prediction error, they fail to account for the observed responses to changes in the players' own payoff parameters. Details are given in the earlier version of this paper. This outcome shows once more the importance of experiments testing the comparative-static implications of hypotheses.

[17] Incidentally, this may also explain why the average prediction error of the pure strategies of SE2 is higher for σ_2=1 (.126) than for $\rho(n)$ (.032).

experimental results; particularly, since the focus of this study is on the comparative-static implications of the two models.

History dependence and adaptive decisionmaking

There is another experimental result, however, that is of relevance here. This result concerns the presence of history dependence, which runs counter to the assumptions of the game model as well as a decision model with *fixed* non-uniform beliefs about opponents' play. History dependence was tested in a number of ways. It shows up most clearly if behavior is related to all past experience of subjects, and much less so if behavior is only related to experience in the preceding round. There is evidence that subjects are affected by cumulative experience concerning opponents' play, in a direction reminiscent of 'fictitious play'. In case of fictitious play subjects maximize expected payoffs assuming that the probability distribution of the opponent's play in the next period is the same as the observed frequency distribution of past play (for a discussion of this model, see, e.g., Milgrom and Roberts, 1991).

In the sequel we will focus on the effects of history on the frequencies, s_1 and r(m), that showed the largest variation over time and across treatments. Let $r(s)_{t-1}$ denote the relative number of times that a sender experienced the choice of x_2 in response to signal s=m,n in all past play up to period t. Furthermore, let $s_{k,t-1}$ stand for the relative number of times that a message was received by a responder when the state was t_k (k=1,2) in past play up to period t. It was examined whether type 1 senders transmitted significantly more messages in a particular period t when $r(m)_{t-1}-r(n)_{t-1}>c_1$, than in case of the reverse inequality sign [cf. condition (1)]. Similarly, for responders we examined whether significantly more often x_2 was chosen after a message when $s_{2,t-1}\beta>s_{1,t-1}$, than in case of the reverse inequality sign [cf. condition (2a)].

The outcomes of these examinations turned out to be positive, but more strongly so for responders than for senders. Furthermore, there are relatively few observations as for each observation it is required that a sender has at least once experienced a response to both a message and no message, and a responder must have experienced a signal at least once in both states. To increase the number of observations, one could assume that senders believe that $\rho(n)=0$ and that responders believe that $\sigma_2=1$, even without direct experience with these frequencies. In that case history dependence hypothesizes senders to respond positively to the sign of $r(m)_{t-1}-c_1$, and responders to the sign of $\beta-s_{1,t-1}$. These hypotheses are strongly supported by the data. For example, pooled over treatments[18] and subjects, messages are sent at a rate of .284 (48/169) when $r(m)_{t-1}-c_1<0$ and at a rate of .455 (61/134) when $r(m)_{t-1}-c_1>0$ (p=.002 with a two-tailed X^2 test). The effect on responders is even stronger. They choose x_2 at a rate of .371 (49/132) when $\beta-s_{1,t-1}<0$ and at a rate of .767 (125/163) when $\beta-s_{1,t-1}>0$ (p<.0001 with a two-tailed X^2 test).[19]

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[18] The effects, however, do not depend on the pooling of treatments.

[19] Recall that we focus here, and in the sequel, on part 2, where subjects had already played the game ten times in the other role. Contrary to part 2, in part 1 the effect of the history of opponents' play is stronger for senders than for responders. We have no good explanation for this difference, but we conjecture that it is related to the fact that the sender's preferred choice (x_2) is state-independent, whereas the

These results suggest that beliefs regarding the probabilities of the opponent's actions are adjusted in light of experience. It was decided, therefore, to investigate the performance of an *adaptive* decisionmaking model. The model allows behavior to be adjusted in response to personal experience in past play. Specifically, choices in a particular period are related to 'own' past play (to allow for some idiosyncracy or slackness) and to the cumulative experience with opponents' play. Again, attention is restricted to the frequencies s_1 and r(m). For notational convenience, state, signal and time indices are deleted.

$$\textit{probability of message given } t_1 = f[\gamma_0 + \gamma_1 s_{-1} + \gamma_2(r_{-1}-c_1)] \quad (3)$$

$$\textit{probability of } x_2 \textit{ given message} = g[\delta_0 + \delta_1 r_{-1} + \delta_2(\beta-s_{-1})] \quad (4)$$

where r_{-1} denotes the cumulative relative frequency of x_2 choices after a message and s_{-1} denotes the cumulative relative frequency of messages in state t_1, as observed by a subject up to the period under consideration. This model is attractive for the following reasons. Firstly, the model can be related to individual updating rules which link up present choices with experienced average payoffs of past choices.[20] Secondly, it enables the estimation of the extent of 'fictitious play', which should show up via the size of the interaction effects (γ_2 and δ_2), relative to the effect of own previous choices (γ_1 and δ_1). Thirdly, equilibrium SE2 is nested in the model, in the sense that $r \equiv r(m) = c_1$ and $s \equiv s_1 = \beta$ may hold in a steady state, which obtains when the probabilities at the left hand side of (3) and (4) are, respectively, equal to the cumulative relative frequencies s and r at the right hand side. It is easily seen that this requires the satisfaction of a functional relationship between, on the one hand, β, γ_0 and γ_1, and, on the other hand, c_1, δ_0 and δ_1. If these relationships are satisfied, and the model is stable, then the adaptive decision-making process would go in the direction of SE2.

We estimated a logit specification of the two equations on the individual data (of part 2), adding dummies to allow for specific treatment effects that are not picked up by the variation of β and c_1 over the treatments. To avoid the dummy trap, the treatment with the median value for the endogenous variable was used as base. For eq. (3) this was treatment 1, for eq. (4) treatment 5. The effects of these treatments are incorporated in the constant term (γ_0 and δ_0). Stepwise estimation indicated that, except for 'T5' for treatment 5 in eq. (3) and 'T1' for treatment 1 in eq. (4), no dummies for the other treatments had to be inserted. The estimated versions of eqs. (3) and (4) are (with standard errors in parentheses):

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responder's preferred choice is state-dependent. This may make it more straightforward for senders to rely on observed frequencies of responders' choice of x_2 right from the start of the experiment. Responders have to (learn to) update beliefs about the state in response to observed (state-dependent) opponents' choices, and this may be easier if you have been a sender in part 1.

[20] Letting π_{-1} stand for r_{-1} or s_{-1}, the structure of the model would follow, for instance, if the probability of a message or a choice x_2 is related to the rule $\Theta+(1-\Theta)\pi_{-1}$, in case of successful choices, and the rule $(1-\Theta)\pi_{-1}$, in case of unsuccessful choices, and the respective rules are applied at a rate of r_{-1} and $(1-r_{-1})$ for senders, and $(1-s_{-1})$ and s_{-1} for responders (cf., in this context, Mookherjee and Sopher, 1994).

$$\text{prob. message given } t_1 = f[\ -1.59 + 1.47\ T5 + 1.88\ s_{-1} + 0.77\ (r_{-1}-c_1)\ ]$$
$$(0.22)\quad (0.42)\qquad (0.37)\qquad (0.42)$$
$$n = 285,\ X^2 = 72.5,\ p < 0.0001$$

$$\text{prob. } x_2 \text{ given message} = g[\ -0.98 - 1.40\ T1 + 2.38\ r_{-1} + 2.22\ (\beta-s_{-1})\ ]$$
$$(0.31)\ (0.67)\qquad (0.43)\qquad (0.49)$$
$$n = 284,\ X^2 = 131.4,\ p < 0.0001$$

According to the X^2 statistic the adaptive decision model seems to make a highly significant contribution to the explanation of the experimental outcomes. Apart from the interaction effect in eq. (3) (p=.064) and T1 in eq. (4) (p=.037), all coefficients are significant at p<.01. Subjects clearly appear to react to the cumulative relative frequency of own and opponents' choices (which they could track on their record sheets). Again, the interaction or 'fictitious play' effect is stronger for responders.

Table 4 presents the steady state values of the cumulative frequencies obtained by solving the logit specifications of (3) and (4), after substituting s and r for the probability of sending a message and choosing x_2, respectively, and deleting the time index.[21] Two remarks are in order. First of all, it appears that these steady state values are generally not far removed from the final (period 10) frequencies in part 2, which are presented in the last two columns of the table. Second, for the two treatments with the largest relative deviation (treatment 1 and, particularly, treatment 3) the steady state values are closer to the equilibrium predictions of SE2. For the other treatments the results are nowhere close to these predictions.

[Table 4]

As noticed above, it depends on the behavioral coefficients γ_0, γ_1, δ_0 and δ_1, in combination with the environmental (experimental design) parameters β and c_1, whether the steady state values for the cumulative frequencies resemble the mixed strategy predictions of SE2. Explicit information on these relationships and some insight into the dynamics of play can (only) be obtained by using the cumulative relative frequencies s and r for each subject instead of - or as proxies for - the probabilities on the left-hand side of eqs. (3) and (4), and adopting a linear specification of f and g. This leads to the following simultaneous difference equation system:

$$s = \gamma_0 + \gamma_1 s_{-1} + \gamma_2(r_{-1}-c_1) \qquad (5)$$
$$r = \delta_0 + \delta_1 r_{-1} + \delta_2(\beta-s_{-1}) \qquad (6)$$

OLS-estimation of these equations, using the same dummies as before, gives (with standard errors in

[21] The equation system, made up by $\ln[s/(1-s)] = \gamma_0+\gamma_1 s+\gamma_2(r-c_1)$ and $\ln[r/(1-r)] = \delta_0+\delta_1 r+\delta_2(\beta-s)$, was solved by a numerical search procedure.

parentheses):

$$s = 0.05 + 0.10\ T5 + 0.80\ s_{-1} + 0.04\ (r_{-1}\text{-}c_1)$$
$$(0.01)\quad(0.02)\qquad(0.80)\qquad(0.02)$$
$$n = 285,\ adjR^2 = 0.87,\ F = 609.7,\ p < 0.0001$$

$$r = 0.13 - 0.09\ T1 + 0.79\ r_{-1} + 0.12\ (\beta\text{-}s_{-1})$$
$$(0.02)\ (0.03)\qquad(0.02)\qquad(0.02)$$
$$n = 284,\ adjR^2 = 0.87,\ F = 758.8,\ p < 0.0001$$

The outcomes show a similar degree of importance for the different explanatory variables: a relatively large effect of the lagged dependent variable, and a relatively stronger effect of the interaction term for responders. The steady state values of s and r are close to the ones obtained for the logit specification, except for r^* of treatment 1 (.20 instead of .06). The results for this treatment (s^*=.25 and r^*=.20) are very close now to the predictions of SE2 [$\sigma_1=\rho(m)$=.25]. Given the estimates of the coefficients, it turns out that the characteristic equation of the system has complex roots, with an absolute value smaller than 1 (.79). This implies that the time paths of s and r are cyclical and damped, that is, convergent to the steady state values.

In this linear model - contrary to the logit model - it can be analytically derived under which conditions the steady states will be identical to the game theoretic prediction of SE2. This turns out to be the case if the parameters β and c_1 happen to be chosen such that $\beta=\gamma_0/(1-\gamma_1)$ and $c_1=\delta_0/(1-\delta_1)$. It holds that $\beta\equiv pb_2/[(1-p)b_1]$ with $b_1\equiv b_{11}-b_{12}$ and $b_2\equiv b_{22}-b_{21}$, and $c_1\equiv c/a_1$ with $a_1\equiv a_{12}-a_{11}$, where the subscripts i and j in b_{ij} and a_{ij}, respectively, denote the state (t_1 or t_2) and the choice by the responder (x_1 or x_2). Consequently, there are obviously many picks of parameter values that would (approximately) satisfy these conditions. In our experiment this happened to be the case for treatments 1 and 3. Hence, if one had incidentally gathered information on only these two treatments, one could have been led to the (wrong) conclusion that the game model performs very well, after all, since adaptive decision making ultimately leads to outcomes that are fairly close to the predictions of the refined equilibrium.[22] This further analysis nicely illustrates once more the importance of a comparative static experimental design.

6. Conclusion

The experimental outcomes first of all replicated the finding in the literature that costly messages are sent, that they are more frequently sent by 'higher' sender types - whose information is such that persuasion is also profitable to the responder -, and that such messages have an impact on the behavior of the responder. Both the game model and the decision model used to analyze the data predicted this result. However, the

[22] In principle, the specific treatment effects, incorporated in the coefficients of the dummies, might be such that for each treatment the conditions for a development towards a steady state that is similar to a Nash equilibrium are satisfied. This, however, is clearly not borne out by our data.

observed tendency for higher sender types always to send a message, and for responders to stick to the action that was optimal according to the prior in case of no message, was sharper predicted by the game model (that is, the refined sequential equilibrium). This model failed, though, in tracking the behavior of the lower type senders and the responses to messages. Its mixed strategy predictions were not only substantially removed from the observed outcomes, they particularly missed the observed reaction to changes in own payoff parameters. It was conjectured that the former result may have to do with weak payoff incentives in case of mixed strategies, and the latter with gradual adjustment towards another parameter regime. However, as yet it is not clear how such phenomena could be incorporated in the game model. Moreover, the observed history dependence of play provided negative evidence for the game model as an explanatory model of behavior.

An adaptive decision model with beliefs regarding the opponent's likely behavior adapted in the direction of 'fictitious play', succeeded best in describing the comparative static implications and the development of play. This model was inspired by other recent experimental work (e.g., Brandts and Holt, 1993, 1994, Mookherjee and Sopher, 1994, Partow and Schotter, 1993). The analysis of this model, inter alia, showed that for fortunate choices of the environmental (experimental design) parameters - and there may be many such choices - the adaptive behavior of the players may lead to a steady state that is similar to the game theoretic predictions. In this experiment this turned out to be the case in (at most) two of the five treatments. This illustrates the importance of a comparative static design, as it prevented the apparently wrong conclusion that the game model is a good predictor of (steady state) behavior.

Important issues regarding the adaptive decision model are still open to question. First, to get at the comparative statics results, we had to make a particular assumption about the (initial) beliefs of subjects regarding opponent's choice probabilities. This assumption, that subjects are 'to some extent' able to understand the incentive structure of the opponent, appeared to be borne out by the data.[23] However, the reason why, and the precise extent to which subjects are able to understand the opponent's incentive structure is not addressed, let alone understood. Second, an important feature of the adaptive decision model and its estimated versions is that it does not necessarily lead to a (Nash) equilibrium. The full scope and implications of this feature are not completely clear yet. Finally, the robustness of the estimated relationship between present play and cumulative past experience is still an open issue. This concerns, for instance, the finding that in the estimated models present play is largely determined by *own* past play and to a lesser extent by *others'* past play. Also, for some treatments a specific effect shows up (the dummies in the estimated equations) which cannot be easily related to the payoff parameters. It remains to be seen whether these and other outcomes are robust to changes of the experimental design or the specification of the empirical model. For these reasons, we still have reservations regarding the strength of the adapative decision model in the form presented here. Nevertheless, we belief the model deserves further exploration in view of its performance in organizing the data of our comparative statics design. After all, comparative statics is at

[23] Therefore, we are careful not to dismiss observed behavior as 'irrational' or 'naive'. Also, subjects on average turned out to earn sligthly more than what was predicted by SE2.

the heart of economic analysis.

Appendix

This Appendix contains, first, the parameter values of treatments 1-5, and, second, integral translations of the Introduction, read aloud to the subjects in the reception room, the Instructions, distributed and read aloud in the laboratory, and samples of the Description (treatment 2) and Record Sheet (for participant A).

Parameter values of the treatments 1-5

a_{ki} denotes the sender's (A's) payoff and b_{ki} denotes the reponder's (B's) payoff when the color is k and B's choice is x_i, with $k \in \{w,b\}$ and $i \in \{1,2\}$. Furthermore,

$a_1 \equiv a_{w2}-a_{w1} > 0$, $a_2 \equiv a_{b2}-a_{b1} > 0$

$b_1 \equiv b_{w1}-b_{w2} > 0$, $b_2 \equiv b_{b2}-b_{b1} > 0$

p: prior probability that color is black

c: cost of a message to A

$c_i \equiv c/a_i$, $b \equiv b_1/(b_1+b_2)$; $\beta \equiv p(1-b)/[(1-p)b]$

Treat-ment	p	a_{w1}	a_{w2}	a_{b1}	a_{b2}	b_{w1}	b_{w2}	b_{b1}	b_{b2}	c	c_1	β
1	1/3	2	4	1	7	3	1	0	1	0.5	.25	.25
2	1/2	2	4	1	7	4	0	0	3	0.5	.25	.75
3	1/3	1.5	3.5	1.5	5.5	3	1	0	1	1.5	.75	.25
4	1/3	1.5	3.5	1.5	5.5	3	1	0	3	1.5	.75	.75
5	1/2	2	4	1	4	4	0	0	3	0.5	.25	.75

INTRODUCTION

You are about to participate in an experimental study of decisionmaking. The experiment consists of two parts. In total the experiment will last about 2 hours. Before you will be invited to the laboratory, we ask you to draw one envelope from this box.

In the envelope you will find your "registration number", which will be used throughout the experiment, and an indication for your role in the first part of the experiment. There are two roles: "participant A" and "participant B". In the envelope it is announced whether you have the role of participant A or B. One envelope is an exception to this rule. Instead of "participant A" or "participant B" this envelope contains the announcement "monitor". The monitor will watch us while we carry out the experiment and assist us from time to time. The monitor receives a payment of ƒ40,-.

After you have taken an envelope, you are invited to enter the laboratory and take a seat behind a table reserved for an A or B participant. As you will see clearly indicated, participants A sit together in one part and participants B in another part of the room. A separate table is reserved for the monitor.

From the moment you have drawn an envelope you are no longer allowed to talk or communicate to the other participants. If you have a question, please raise your hand and one of us will come to your table. As soon as everyone has taken his or her seat in the laboratory, we will distribute further instructions and read them aloud.

Are there any question, about what has been said up till now? If not, then the person on the left of me is now requested to first pick an envelope, open it and go the laboratory.

INSTRUCTIONS

<u>Introduction</u>

This is an experimental study of decisionmaking. Various research institutions have provided funds for this study. The instructions are simple and if you follow them carefully you may earn a considerable amount of money. All the money you earn is yours to keep. Your payoffs will be paid to you in cash, privately and confidentially, after the experiment.

We will begin by reading these instructions. Thereafter you will have the opportunity to ask questions.

Decisions and earnings

The experiment will consist of two separate parts, and each part will consist of a number of periods. In each period a **participant A** will be matched with a **participant B**. Both participants will have to take one decision during the period. The earnings for A and B depend upon the decisions made, but are codetermined by the color of a **disk**. The color of the disk can be either *black* or *white*. At the beginning of each period the color of the disk will be determined by a drawing. The *probability* that a white or a black disk is drawn will be announced to both participants. The *outcome* of the drawing, however, will only be announced to participant A. Hence, participant A knows the color, whereas B only knows the probabilities of a white and a black disk. At the beginning of each period participant A decides whether or not to send a *message* to participant B. In case of a message, there is a choice between the announcement (the disk is) *"white"* and the announcement (the disk is) *"black"*. The announcement is allowed to differ from the real color. Sending a message bears a cost to participant A; the costs of a message will be stated in guilders.

Thus, the decision by participant A, can either be a message, stating *"white"* or *"black"*, or *no* message. This decision will subsequently be communicated to participant B. Each B participant will be notified of only one decision, namely, the decision of the A participant to whom he or she has been matched in that period. After taking notice of A’s decision, participant B decides whether to react with *choice B1* or *choice B2*. This decision (choice) will then be communicated to participant A and, finally, the color of the disk will be announced to B.

The earnings of A and B are (apart form the costs of a message) determined by the disk’s color (white or black) and B’s decision. These earnings are presented in *tables* on the sheet called DESCRIPTION, which has already been distributed. You are now requested to take this sheet. In order to demonstrate that all of you have the same information, this sheet will also be projected on the wall.

First, you see the probabilities that the disk’s color is white or black. Next, it is again indicated that participant A takes a decision whether or not to send a message, before participant B determines her or his choice. In case of a message, a choice must be made between the announcements "white" and "black". The costs of a message are posted in guilders.

Finally you see two tables. The left table presents A’s earnings and the right one presents B’s. If you want to know a participant’s earnings with a particular color of the disk and a particular choice by B, you first move to the table indicating *"earnings participant A"* or *"earnings participant B"*. Then you look up the color of the disk (white or black) and you move right to the column indicating the choice of B (choice B1 or choice B2). The figures are stated in guilders. For A participants the costs of a message must be subtracted if a message was sent.

The monitor

At the beginning of each period the monitor will perform the drawing that determines the color of the disk. This color will then *privately* be communicated to the A participants.

From time to time we will ask the monitor whether we are actually conducting the experiment in the manner specified in the instructions. The monitor will be expected to answer these questions with a simple yes or no. The monitor will also assist us with the experiment. The monitor will not be permitted to communicate with the rest of you in any way.

The monitor is now requested to show the disks to the participants, in order to check whether the probability of a white and a black disk is in accordance with the probabilities stated on the sheet DESCRIPTION. [There always was one black disk and either one or two white disks. We also asked the monitor to show the urn and filmcases for the disks and turn them upside done.]

Recording of the results

Now both A and B participants are requested to pick one envelope from the appropriate box and to open the envelope.

Take the enclosed sheet, called RECORD SHEET, and put your registration number in the upper left corner. The registration number is needed to be sure that the right payments are made to the right person. On the next line you see your role (A or B) in this part of the experiment. The table is also projected on the wall.

Now, first look at the first (left) column of the table. The figures in this column indicate the period, starting with period 0 and ending with period 10. Period 0 is a practice period. The results (earnings) of this period are not included in the payments at the end of the experiment.

The next column (the second from the left) contains a codeletter. This codeletter makes it easier for us to register the results. The codeletter determines the participant in the other role you are matched with in a particular period. Each period you are matched with a different person; furthermore, in periods 1 to 10 you are matched with the same person at most twice. We have determined the sequence before the experiment in an arbitrary way, so you cannot know whom you are matched with in a any period.

Each period will proceed as follows. After the color has been determined by the monitor's draw, this color will be communicated to the A participants. They will mark this color in the column called "the color is" of their RECORD SHEET. Then participant A takes her or his decision to send or not send a message ("white" or "black") to B. Participant A will mark this decision in the column called "A's decision (message)". We will then note this decision in the RECORD SHEET of the appropriate B participant. Participant B will then make her or his decision (choice B1 or choice B2) and mark it in the column "B's decision". We will then note this decision in A's table and simultaneously, the monitor will mark the color of the disk in the column "the color is" of the B participants.

The last two columns concern the payoffs. At the end of each period you will use the tables of the sheet DESCRIPTION to determine your payoffs for that period. These payoffs must be noted in the column called "your payoffs". Finally, for the sake of completeness, a column is included in which you are supposed to register the payoffs of the participant with whom you are matched in a particular period. For A participants account must be taken of the costs of a message in case A has decided to send a message in that period.

We will also register all the information.

Summary

Each period begins with the monitor drawing the color of the disk. After the outcome has been communicated to participant A, he or she decides whether or not to send a message to participant B. After this decision has been communicated, it is B's turn to take a decision (choice B1 or choice B2), **not knowing** the result of the draw (the disk's color). Finally, B's decision is communicated to A and the disk's color to B. With this information the participants determine the payoffs for that period, on the basis of the tables on the sheet DESCRIPTION. The next periods will proceed in exactly the same way until and including period 10.

Thereafter, the sheets for part 2 of the experiment will be distributed, and the new instructions will be read.

Final Remarks

At the end of today's session you will be asked to answer some questions for the evaluation of the experiment. After that you will be called by your registration number to privately collect your payoffs in cash at the secretariat. Your payoffs are your own business: you don't have to discuss them with anyone.

It is not allowed to talk or communicate with other participants during the experiment. If you have any questions please raise your hand and one of us will come down to your table.

DESCRIPTION

(sample treatment 2)

- The urn contains one white and one black disk. Hence, the probabilities that a white or black disk are drawn are both ½.

- Participant A decides whether or not to send a message - "white" or "black" - before participant B makes her or his choice. A message bears a cost of ***f* 0.50** to participant A.

- The earnings to participant A (excluding any message cost) and participant B are presented in the tables below. The earnings are dependent upon the disk's color (the color is white or the color is black) and B's decision (choice B1 or choice B2).

earnings participant A	choice B1	choice B2
the color is white	2	4
the color is black	1	7

earnings participant B	choice B1	choice B2
the color is white	4	0
the color is black	0	3

RECORD SHEET (sample)

Your registrationnumber:
Your role is participant **A**

period	code-letter	the color is		**Your decision** (message)			B's decision		**Your payoff** (earnings minus costs)	B's payoff (earnings)
		white	black	"white"	"black"	no	choice B1	choice B2		
0	a									
1	b									
2	c									
3	d									
4	e									
5	h									
6	f									
7	g									
8	i									
9	j									
10	n									
							your total payoffs for this part:			

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Table 1. Parameter design

	c_1 = .25	c_1 = .75
β = .25	treatment 1	treatment 3
β = .75	treatment 2 (c_2 = 1/12)	treatment 4
	treatment 5 (c_2 = 1/6)	

Table 2. Average frequencies of messages across individuals when the color was white [s_1, first entry] or black [s_2, second entry]. Standard deviations and number of observations between brackets.

	$c_1 = .25$	$c_1 = .75$	row average
β = .25	.384 (.199, 12) .764 (.261, 12)	.161 (.131, 12) .847 (.241, 12)	.272 (.200, 24) .806 (.249, 24)
β = .75	.458 (.365, 12) 1.00 (.000, 12) .833 (.333, 12) .925 (.183, 12)	.217 (.212, 12) .828 (.326, 12)	.503 (.396, 36) .918 (.222, 36)
column average	.559 (.359, 36) .896 (.205, 36)	.189 (.175, 24) .838 (.280, 24)	.411 (.349, 60) .873 (.237. 60)

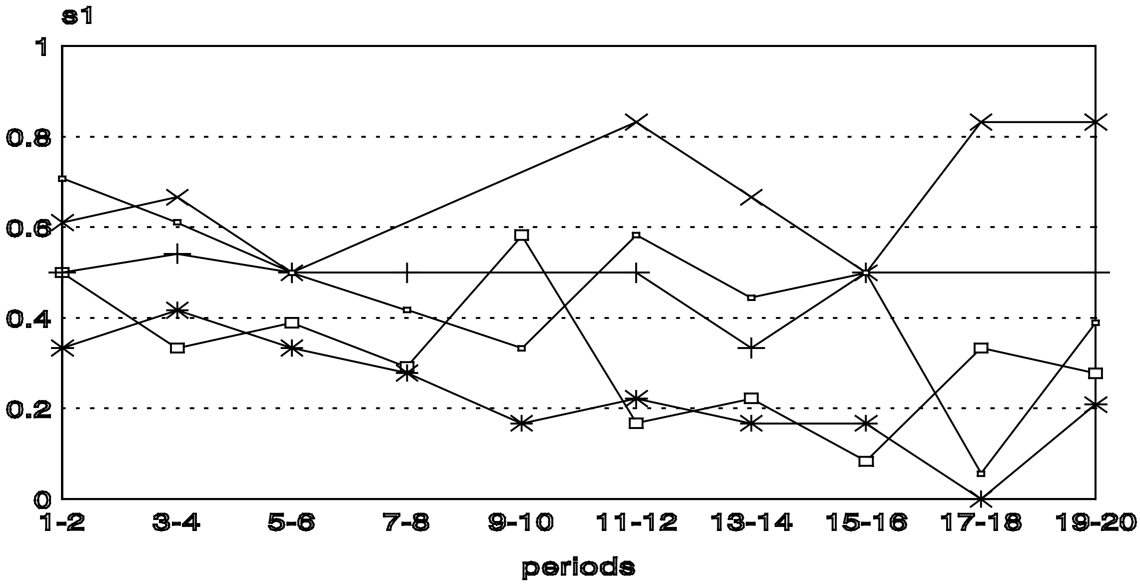
Table 3. Average frequencies of x_2 choices across individuals after no message [r(n), first entry] and after a message [r(m), second entry]. Standard deviations and number of observations between brackets.

	$c_1 = .25$	$c_1 = .75$	row average
β = .25	.017 (.081, 12) .054 (.099, 12)	.000 (.000, 12) .529 (.339, 12)	.008 (.041, 24) .292 (.344, 24)
β = .75	.030 (.101, 11) .791 (.274, 12) .111 (.333, 9) .535 (.375, 12)	.049 (.115, 12) .803 (.223, 12)	.060 (.194, 32) .709 (.315, 36)
column average	.048 (.186, 32) .460 (.408, 36)	.024 (.083, 24) .666 (.314, 24)	.038 (.150, 56) .542 (.384, 60)

Note. Four individuals did always receive a message and, hence, there is no observation of r(n).

Table 4. Steady state values (s^* and r^*) and period 10 frequencies, for s_1 and r(m), respectively.

treatment	eqs. (3) and (4) LOGIT model		eqs. (5) and (6) OLS model		part 2, period 10 frequencies	
	s^*	r^*	s^*	r^*	s_1	r(m)
1	.21	.06	.25	.20	.38	.05
2	.42	.86	.36	.84	.46	.79
3	.23	.65	.24	.62	.16	.53
4	.28	.90	.28	.88	.22	.80
5	.84	.51	.79	.59	.83	.54


s1
1
0.8
0.6
0.4
0.2
0
1-2
3-4
5-6
7-8
9-10
11-12
13-14
15-16
17-18
19-20
periods

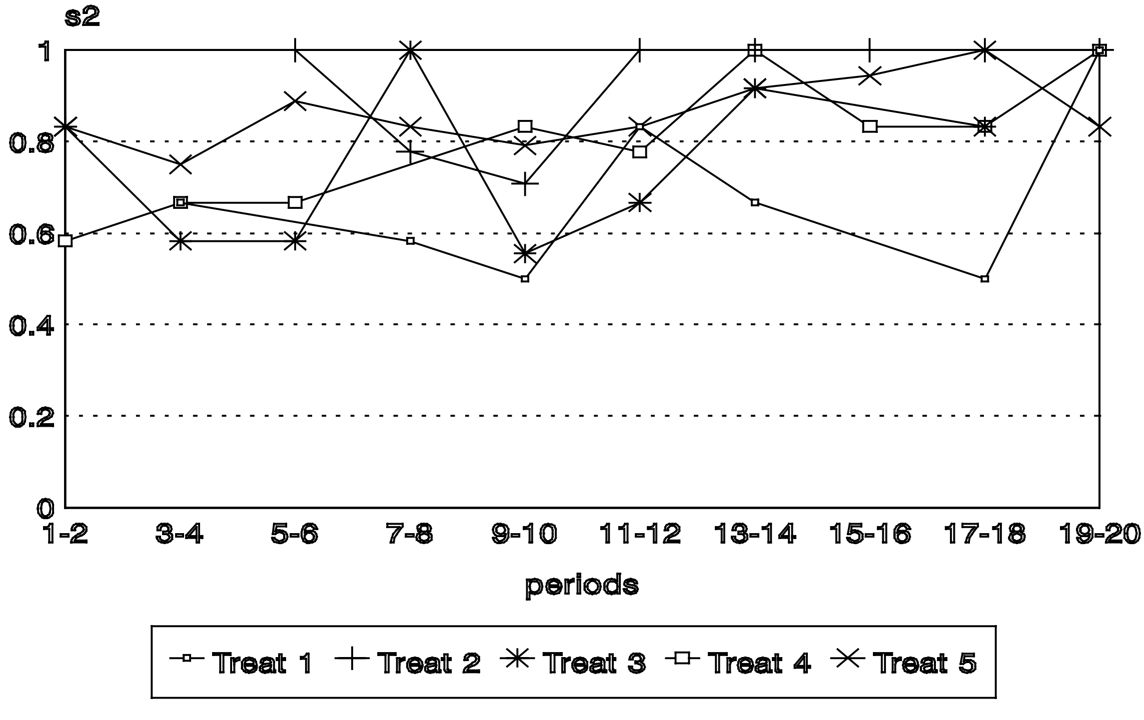
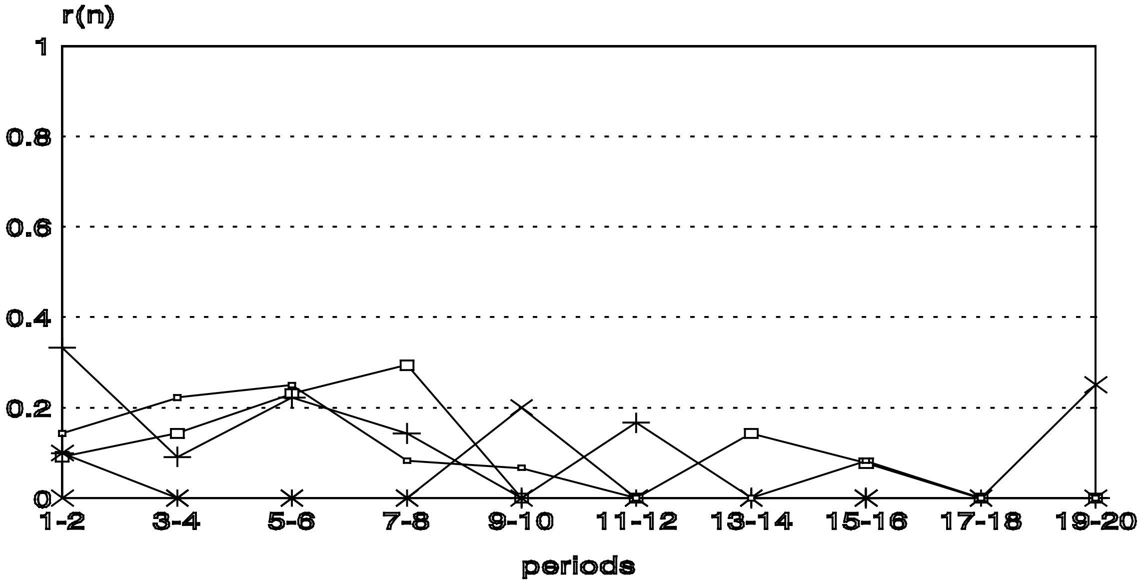


Figure 1. Development of s_1 and s_2


r(n)
1
0.8
0.6
0.4
0.2
0
1-2
3-4
5-6
7-8
9-10
11-12
13-14
15-16
17-18
19-20
periods

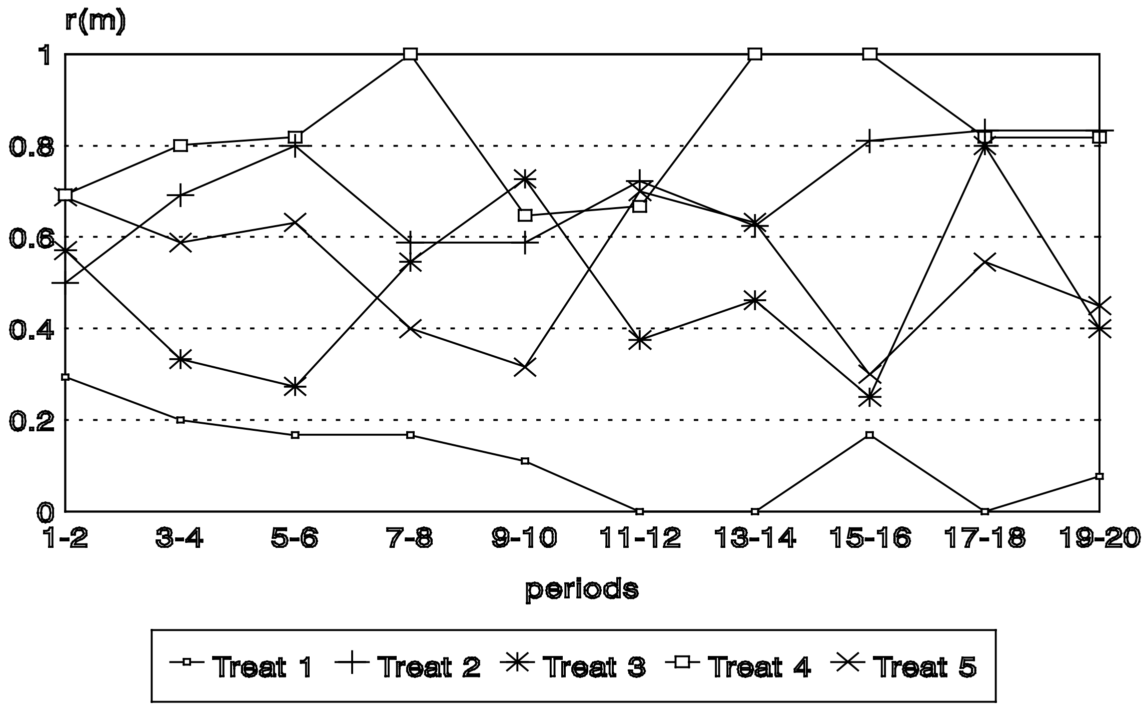


Figure 2. Development of r(n) and r(m).

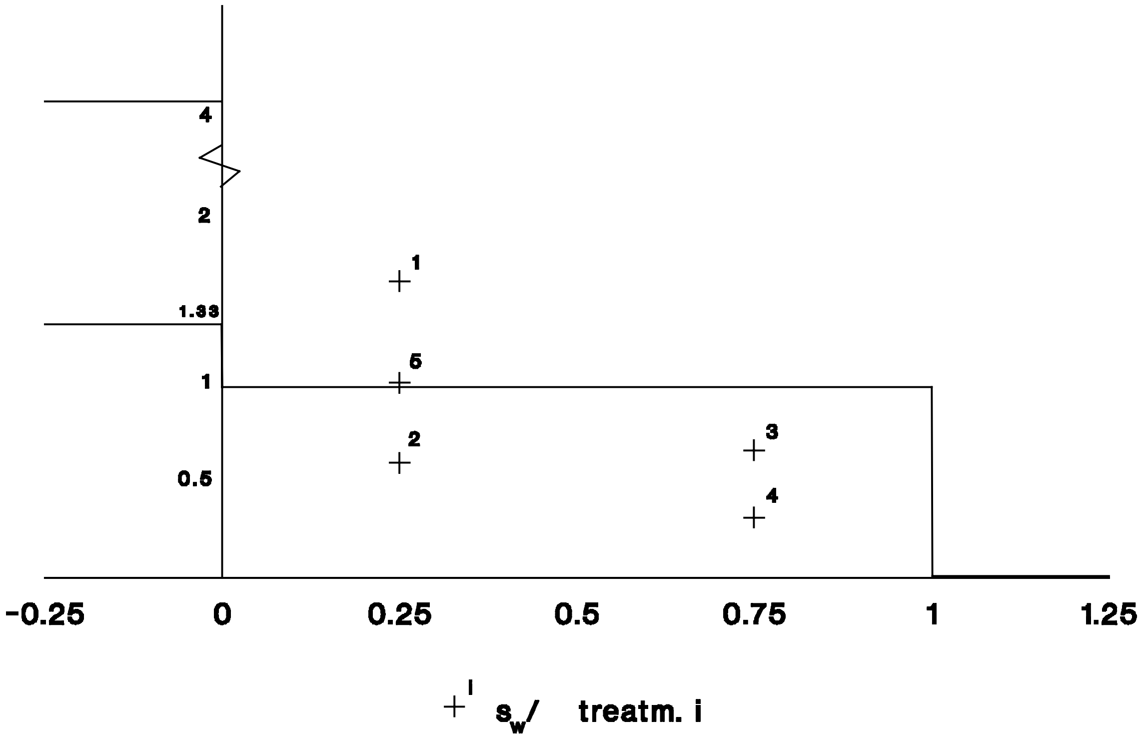


Figure 3

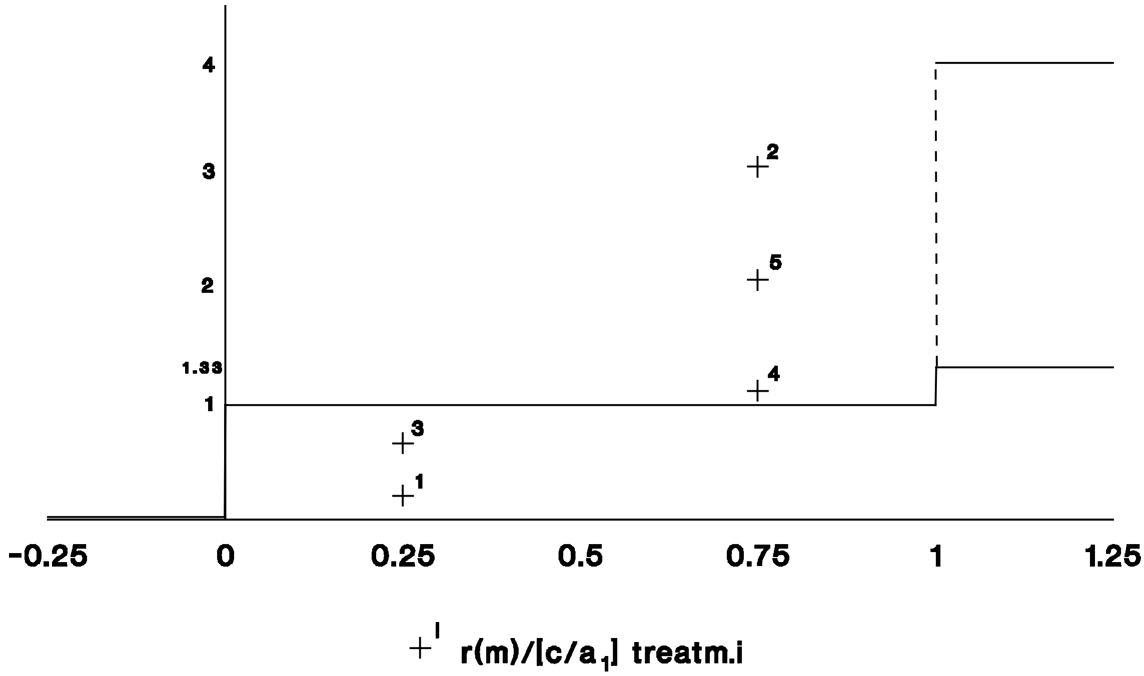


Figure 4