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Order of Play in Strategically Equivalent Games in Extensive Form

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Abstract: "Can we find a pair of extensive form games that give rise to the same strategic form game such that, when played by a reasonable subject population, there is a statistically significant difference in how the games are played?" (Kreps, 1990, p. 112). And if yes, "can we organize these significant differences according to some principles that reflect recognizable differences in the extensive forms?" Both questions are answered positively by reporting results from three different experiments on public goods provision, resource dilemmas, and pure coordination games.

I Introduction

Consider the two-person "Battle of the Sexes" game presented in Fig. 1. Player A has two (pure) strategies in this game labelled T and B, player B has also two strategies labelled L and R, and the payoffs are symmetric. The game has two Nash equilibrium outcomes in pure strategies (T, L) and (B, R) and one in mixed strategies. Figure 1a describes the case where player A moves first choosing between T and B. After being informed that player A completed his move, player B moves next and chooses between L and R. Player B's information set (indicated by a broken ellipse), which includes the nodes L and R, indicates that she does not know the action chosen by Player A. Fig. 1b describes the same game with the roles of A and B reversed. The strategic form of the game is depicted in Fig. 1c.

Game theory insists that the solution of the pure coordination game in Fig. 1 should be invariant to the extensive form representation. It considers all three games portrayed in Fig. 1 as games of *simultaneous play*. In particular, the theory dismisses the information in Figs. 1a and 1b, which both players share, about the chronological order of play as irrelevant. I conjecture that this information can be used by the players to help them coordinate their actions. This conjecture can be expressed precisely in statistical terms. Denote the probability of the joint outcome (B, R) by $p(B, R)$ and the probability of the joint outcome (T, L) by $p(T, L)$, and set the null hypothesis $p(T, L) = p(B, R)$. Assume that the pure coordination game, in either of its three forms, is played by each player many times in succession against different opponents with no opportunity for reputation building. Then I conjecture that the null hypothesis will not be rejected in game 1c, but will be rejected in the other two games with $p(T, L) > p(B, R)$ in game

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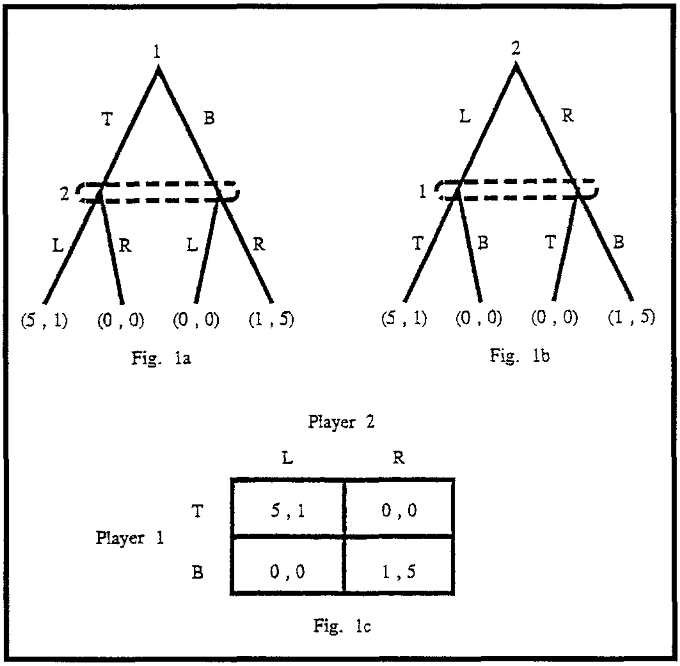

Fig. 1. A two-person coordination game in strategically equivalent extensive forms

1a and $p(T, L) < p(B, R)$ in game 1b. I contend that the null hypothesis will be rejected in games 1a and 1b because both players, who prefer (T, L) and (B, R) on (T, R) and (B, L), will use the information about the order of play to coordinate their strategies.

The example in Fig. 1 raises a fundamental issue concerning the distinction between priority in time and priority in information. We talk about priority in time – the chronological ordering of moves – if move A is known to occur before move B. We talk about priority in information (as in the definition of conditional probability) if the outcome of move A is given when move B is about to occur. Von Neumann and Morgenstern (1947) recognized the same distinction when discussing anteriority (priority in time) and preliminarity (priority in information). They realized that "Preliminarity implies anteriority, but need not be implied by it" (1947, p. 51), and that priority in time is transitive whereas priority in information need not be so. They then opted to dismiss priority in time as irrelevant to the formulation of interactive behavior, base the extensive (tree) form of a game on the notion of priority in information, and define the notion of strategy without any reference to the chronological ordering of moves.

Several researchers have recently raised the question whether the extensive form is the same as the strategic form to which it corresponds (e.g., Kohlberg & Mertens, 1986; Luce, 1992). Discussing the expected utility model for individual decision making under uncertainty and its various generalizations, Luce (1992) noted that these classes of models do not include time as a variable, whereas any empirical realization of a decision tree has a strong temporal component. He views this as a clear failing of the modeling. Although not mentioning explicitly the time variable, Kreps has raised similar questions concerning the importance of the temporal component in interactive rather than individual choice behavior:

> "Can we find a pair of extensive form games that give rise to the same strategic form such that, when played by a reasonable subject population, there is a statistically significant difference in how the games are played? And since that makes it too easy, if we find significant differences, can we organize the differences according to some principles that turn on recognizable differences in the extensive forms"(1990, p. 112).

Answers to these questions can only be determined empirically. They may depend on the nature and complexity of the game, population of players, number of players in the game, control over the players' motivation, experience gained in playing the game, and other features of the experimental design. There is ample evidence that the outcomes of experiments on interactive decisions are highly sensitive to the details of the experimental design and features of the procedure. As suggested by Fig. 1, I contend that the key to these answers is the effect of information about the chronological ordering of play. Assume that the players are ordered from 1 to n and play in this order, which is common knowledge. My main hypothesis is that even when not informed about the moves of players 1 through $j-1$, player j will assume that they take advantage of their earlier positions in the ordering and adjust her decision accordingly.

To the extent that information about priority in time, which is not captured by the notion of information set, affects interactive behavior, a most useful research strategy is to delineate the conditions under which this happens. I have opted not to compare the two extensive forms of the pure coordination game in Figs. 1a and 1b for two reasons. First, even if my conjecture is supported experimentally, it may be objected that when there are only two players in the game the sequence effects are transparent. Consequently, the results may not generalize to a larger number of players. A second possible objection is that the sequence effect, if it is established statistically, may be restricted to pure coordination games with multiple equilibria, but that it may not be generalized to other games. For this reason, I have chosen to conduct three different experiments, each involving at least three players. The first experiment[1] is concerned with resource dilemmas, the second with the provision of step-level public goods, and the third with a 3-person pure coordination game.

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[1] The resource dilemma game presented below was reported as Experiment 1 in a recent paper by Budescu, Suleiman, and Rapoport (1995). Section II focuses only on those features of the results that pertain to the main hypothesis of the present paper on order of play effects.

The paper is organized as follows. Section II describes the results of the resource dilemma study, Section III describes the results of the public goods experiment, and Section IV presents the results of the coordination game. The findings are summarized and related research is discussed in Section V.

II Experiment 1: Dilemmas with Uncertain Resource

A recent series of experiments (Budescu, Rapoport, & Suleiman, 1990, 1992; Rapoport, Budescu, & Suleiman, 1993; Rapoport, Budescu, Suleiman, & Weg, 1992; Rapoport & Suleiman, 1992; Suleiman & Rapoport, 1988), stimulated by the observation that in many common-pool problems the value of the resource is uncertain, have examined play in a single-trial n-person noncooperative game with the following structure. A group N of n players is presented with a common resource pool of variable size x. The probability distribution of the resource $f(x)$, is common knowledge. Without knowing the value of x, each player i ($i \in N$) requests r_i units from the pool ($r_i \geq 0$). The individual requests are made independently and anonymously. The individual payoffs, p_i, are determined by the following decision rule:

$$p_i = \begin{cases} r_i, & \text{if } r \leq x, \\ 0, & \text{if } r > x, \end{cases}$$

where $r = r_1 + r_2 + \cdots + r_n$ is the *total group request.*

This resource dilemma game has been investigated extensively under two different protocols of play (Harrison & Hirshleifer, 1989). Under the *simultaneous protocol* players make their requests simultaneously.[2] Under the *sequential protocol* decisions are made in a prespecified and commonly known order, such that each player knows her position in the sequence and the requests of all the players that preceded her in the sequence. Order of play is determined exogenously.[3] Thus, the simultaneous protocol induces an n-person noncooperative game with imperfect information whereas the sequential game induces a game with perfect information.

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[2] The players always participated in a computer-controlled experiment. When the simultaneous protocol was implemented, each player was only informed of the trial number, the nunber of group members (n), and the distribution of the resource for that trial ($f(x)$). The computer moved to the next trial after each player made her request. Neither the value of the resource nor the requests of the other group members were ever disclosed.

[3] It is not necessary to assign positions in the sequence exogenously. The players may be asked to bid for the positions, one at a time, or positions may be selected on the basis of their scores in a prior general knowledge test. The experiments of Hoffman, McCabe, Schachat, and Smith (in press), who compared several procedures for assigning positions in the ultimatum and dictator games, suggest that when the positions are earned rather than exogenously determined the results may be less egalitarian.

Under a third protocol of play, called the *positional order protocol*, order of play is determined exogenously as in the sequential protocol. Without loss of generality assume that the n players are ordered $1, 2, \ldots, n$. Each player j ($j = 1, \ldots, n$) is informed of her position in the sequence. However, information about the requests of the players preceding her in the sequence is withheld.

Game theory does not recognize any difference between the simultaneous and positional order protocols. When subjected to experimental testing it yields the null hypothesis of no difference in mean individual requests among the n players. The alternative one-sided hypothesis states that information about order of play will affect the mean requests of players occupying position j in the sequence. Two versions of the order of play hypothesis may be stated. The strong version recognizes no differences between the sequential and positional order protocols. It is based on the assumption that each player will make full use of her position in the sequence and assumes others to do so. Specifically, when it is her turn to play, each player will behave as if the requests of all the players preceding her in the sequence are known and that all the players following her in the sequence will behave optimally. The weak version of the order of play hypothesis asserts that only some of the players will pay attention to and take advantage of their position in the sequence. According to this hypothesis, the positional order protocol will generate mean results that fall between the results obtained under the simultaneous and sequential protocols. If x is distributed uniformly over the interval $[\alpha, \beta]$, the subgame perfect equilibrium (SPE) solution[4] for the sequential protocol yields an inverse relationship between the player's position in the sequence, j, and her request r_j. Experimental findings (Rapoport et al., 1993) provide strong support for the order of requests predicted by the SPE solution. Therefore, the weak version of the order of play hypothesis also predicts that the mean r_j will decrease in j but with a less steep slope.

Method

Subjects: The subjects were 45 undergraduate students at the University of Haifa. They were run in groups of $n = 5$. All were volunteers who listed their names on sign-up sheets, promising payoff contingent on performance. None of them had participated in a resource dilemma experiment.

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[4] If the individual utility functions are all linear and the resource is distributed uniformly over the interval $[\alpha, \beta]$, which is common knowledge, the SPE request by player j, r_j^*, is given by (Rapoport et al., 1993):

$$r_j^* = \begin{cases} 2^{n-j}\alpha - (2^{n-j} - 1)\beta - k_{j-1}, & \text{if } 0 \leq k_{j-1} \leq 2^{n-j+1}\alpha - (2^{n-j+1} - 1)\beta \\ (\beta - k_{j-1})/2, & \text{if } \beta \geq k_{j-1} > 2^{n-j+1}\alpha - (2^{n-j+1} - 1)\beta, \\ 0, & \text{if } \beta < k_{j-1}, \end{cases}$$

where $k_j = \sum_{i=1}^{j} r_i$, and $k_0 \equiv 0$.

Experimental Design: The study employed a $3 \times 5 \times 2$ within-subject design with three factors: distribution of the resource (3 levels), position in the sequence (5 levels), and the presence/absence of a post decision questionnaire (2 levels).

The three distributions of the resource had the same expected value ($\mu = 500$) but different ranges. The resource x was distributed uniformly over the interval $[\alpha, \beta]$ with $[\alpha = \beta = 500]$ in Condition 1, $[\alpha = 250, \beta = 750]$ in Condition 2, and $[\alpha = 0, \beta = 1000]$ in Condition 3.

At the beginning of each trial each group member was assigned a position (first, second, ..., fifth) determining the order of play. Positions were rotated from trial to trial. When making her request, each subject was only informed of the trial number ($t = 1, \ldots, 30$), the resource condition $(1, 2, 3)$, and her position in the sequence for the trial (1st, 2nd, ..., 5th).

Each subject participated twice in all 15 combinations of the first two factors of the design. First, all the 15 combinations were presented in a random order, which differed from one group to another (Block 1). The same 15 combinations were presented in a different random order a second time (Block 2) with each game followed by three questions. No information was given about the size of the resource, requests made by other group members, and the outcome of the game.

Procedure: The experiment was controlled by a PDP 11/73 DEC computer. The instructions explained the nature of the task, operation of the computer terminal, and payoff scheme.

The questions presented in Block 2 were:

1. Estimate the size of the resource on this trial (Conditions 1 and 2 only).
2. Give your best estimate of the total request of the players preceding you in the sequence (positions 2 to 5 only).
3. Give your best estimate of the total request of the players following you in the sequence (positions 1 through 4 only).

The subjects were told that at the conclusion of the experiment 6 of the 30 trials would be randomly selected and the number of points earned on those trials would be converted to money (30 points = 1 NIS) to determine their payoff.

Results

Individual Requests: Preliminary analyses of the individual requests (Budescu et al., in press) yielded no differences due to block. As a result, the individual requests were collapsed over the two blocks of trials to yield for each subject 15 mean individual requests, 5 in each condition. For each condition separately, the mean individual requests were organized in a 45×5 subject by position table, where the five scores in each row i are the mean requests of player i while playing in the assigned positions $1, 2, \ldots, 5$. The five scores in each row i were then converted into ranks. The nonparametric significance test for linear ranks due to

Page (1963) was then used to test the null hypothesis

$$H_0: m_1 = m_2 = m_3 = m_4 = m_5$$

against the ordered alternative (implied by the order of play hypothesis)

$$H_1 = m_1 > m_2 > m_3 > m_4 > m_5,$$

where m_j is the mean request in position j. The Page's test uses the L statistic, which is simply the sum of products of each column's predicted ranking times its column sum of ordered ranks.[5] The L test yielded a significant position effect in the predicted direction in Condition 2 ($L = 2123$, $p < .01$) and Condition 3 ($L = 2148, p < .001$), but not in Condition 1 ($L = 2051, p > .05$). Table 1 (upper

Table 1. Means (and standard deviations) of individual requests by protocol, condition, and position

		Positional Order Protocol					
Resource		$j=1$	$j=2$	$j=3$	$j=4$	$j=5$	Total
Cond. 1	M	95	92	88	81	85	441
(500, 500)	SD	(64)	(56)	(42)	(35)	(61)	
Cond. 2	M	139	110	106	113	102	570
(250, 750)	SD	(113)	(82)	(86)	(117)	(97)	
Cond. 3	M	182	164	154	117	121	735
(0, 1000)	SD	(166)	(133)	(146)	(87)	(97)	
Over	M	139	122	116	103	102	580
Condition	SD	(126)	(99)	(104)	(87)	(88)	
		Sequential Order Protocol					
Resource		$j=1$	$j=2$	$j=3$	$j=4$	$j=5$	Total
Cond. 1	M	157	137	114	89	71	565
(500, 500)	SD	(122)	(91)	(106)	(100)	(94)	
Cond. 2	M	154	98	113	108	111	585
(250, 750)	SD	(146)	(105)	(125)	(129)	(148)	
Cond. 3	M	205	170	150	115	125	765
(0, 1000)	SD	(233)	(190)	(170)	(148)	(165)	
Over	M	172	135	125	104	102	638
Condition	SD	(170)	(139)	(137)	(127)	(140)	

[5] We also subjected the individual requests to a $5 \times 3 \times 2$ position by condition by block analysis of variance (ANOVA) with repeated measures on all three factors. The ANOVA yielded two main effects. The first main effect due to condition ($F_{2,43} = 18.3, p < .01$) is of no concern to this paper. It replicates findings reported in previous studies of the resource dilemma under the simultaneous or sequential protocol (Budescu et al., 1990, 1992; Rapoport et al., 1992, 1993; Rapoport & Suleiman, 1992). The second main effect is due to the assigned position in the sequence ($F_{4,41} = 4.1, p < .01$); it shows the same predicted position effect as the L test.

panel) presents the means and standard deviations of the individual requests by condition and position.

The L test rejects the null hypothesis of no difference in mean requests between positions in Conditions 2 and 3, where the resource is uncertain. As shown by Table 1, mean requests tend to decrease with j. To decide between the strong and weak versions of the order of play hypothesis, the present results were compared to previous results obtained under the sequential protocol (Rapoport et al., 1993). This earlier study implemented exactly the same experimental procedure and recruited subjects from the same population. The only difference was that the resource dilemma game was played under the sequential rather than the positional order protocol. Table 1 (lower panel) presents the means and standard deviations of the individual requests reported by Rapoport et al. (1993).

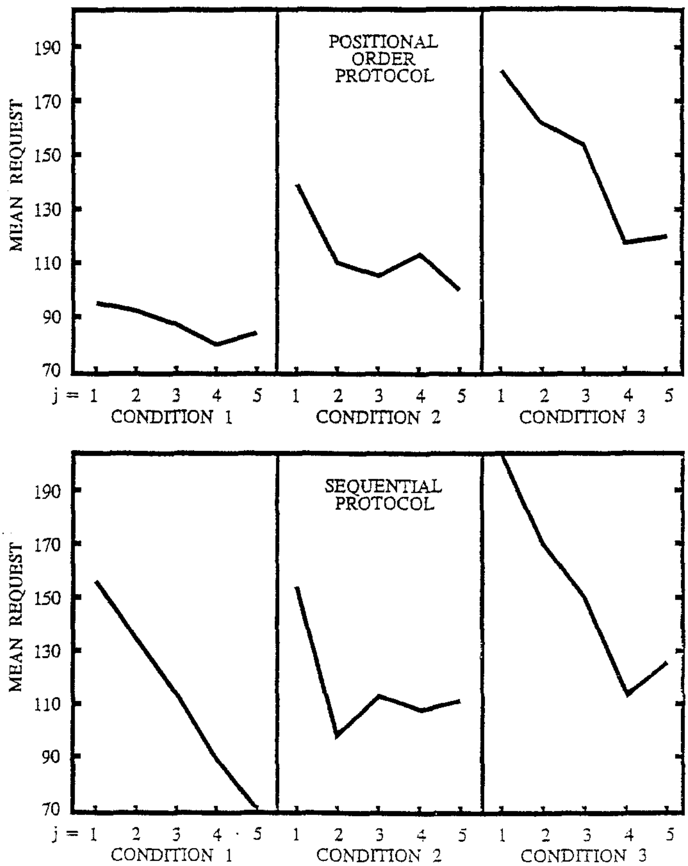

Fig. 2. Mean individual requests by position in the sequence for the positional order and sequential protocols of play

Figure 2 depicts the mean individual requests for each of the two protocols. The means are presented as before by condition and position in the sequence. Under both protocols, the mean requests decrease with position in the sequence.[6] In all three conditions, the slopes of the functions are steeper under the sequential than the postional order protocol, in support of the weak version of the order of play hypothesis.

Individual Estimates: Recall that each subject was asked on each trial in Block 2 to estimate the total request of the players preceding (Question 2) or following her (Question 3) in the (predetermined) sequence. These estimates were analyzed separately after dividing each of them by the number of the preceding (Question 2) or following (Question 3) players in the sequence. If the subjects did not perceive any effect due to position in the sequence, the derived measures should be about the same for positions 1 through 5.

The first set of derived estimates (Question 2) were subjected to a 3×4 condition by position (position 1 was omitted) ANOVA. The analysis uncovered significant effects due to condition ($F_{2,43} = 10.6$, $p < .01$) and position ($F_{3,62} = 7.1$, $p < .01$).[7]

The condition by position interaction effect was not significant. Figure 3 portrays the means of the (derived) estimates of the requests of the players preceding the pivotal player in the sequence. The pattern of the results is the same as that portrayed in Fig. 2. On the average, the actual requests of the subjects correspond rather well to what other group members are doing. Not only do the subjects lower their requests when assigned a higher position in the sequence, but they also believe that the other group members behave similarly.[8]

The same analysis was repeated with the set of estimates given in response to Question 3. A 3×4 condition by position (position 5 was omitted) ANOVA conducted on the derived estimates revealed the same significant main effect due to condition ($F_{2,43} = 14.5$, $p < .01$). However, neither the position main effect nor the condition by position interaction effect were significant.

[6] Occasionally, when the 5th player in the sequence observed that the total request of the four players preceding her in the sequence was close to β, she exercised her "veto power" and set r_5 so that $r > \beta$. Realizing that no requests could be possibly granted if $r > \beta$, she often made a relatively high request so that r exceeded β by many points. As a result, the mean requests for the 5th position under the sequential protocol are inflated. Steeper functions are obtained if the requests of the 5th player are adjusted down so that $r + 1 \leq \beta$.

[7] Similar results were obtained when the derived estimates were converted to ranks and then subjected to the nonparametric L test. The L test was conducted separately for each condition. It yielded a significant position effect in the predicted direction in Conditions 2 and 3, but not 1.

[8] The hypothesis that the estimates affected the requests is ruled out by the insignificant block effect. The alternative hypothesis that the subjects tailored their estimates to their requests cannot be ruled out. However, this hypothesis is not too plausible due to the fact that the subject was asked to estimate the total request of all the players preceding her in the sequence, not the individual requests.

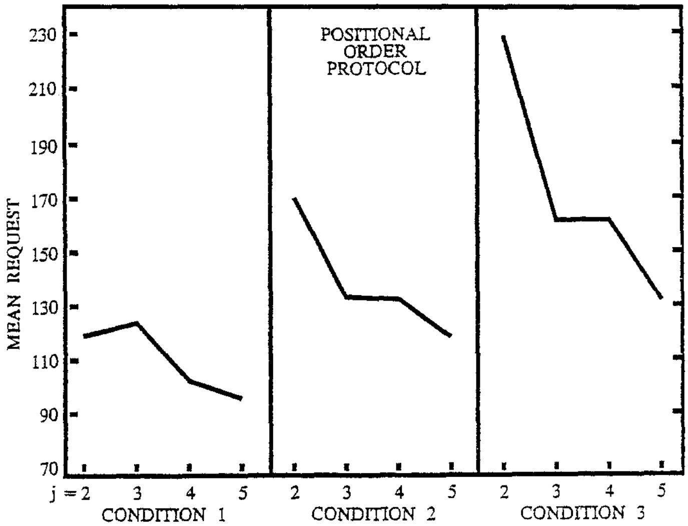

Fig. 3. Mean individual estimates of requests of players appearing earlier in the sequence

Discussion

Using a within-rather than between-subject design and, in addition, rotating positions across trials actually work in favor of the null hypothesis of no order of play effects. Rotation of positions may enhance the perception of symmetry between players – as each has the same number of opportunities to play each position – thereby inducing subjects to request equal amounts in different positions. Despite this potential bias, both the decision and estimate (from Question 2) results provide the necessary statistical evidence to reject the null hypothesis. Moreover, as required by Kreps (1990), the statistically significant differences between positions can be organized according to "principles that turn on recognizable differences in the extensive form." Information about order of play in the present study, although not augmented by information about earlier requests from other group members, induced the subjects to perceive the game as if it were played under the simultaneous protocol. Qualitatively, they followed the SPE solution for the sequential protocol (Rapoport et al., 1993) which prescribes $r_j^* > r_{j+1}^*, j = 1, \ldots, n-1$.

Whereas the analysis of the estimates from Question 2 rejected the hypothesis of no order of play effect, the analysis of the estimates from Question 3 did not. This difference seems to suggest that subjects are not involved in or capable of backward induction. Rather, they are mostly concerned with the history, not the future of the game. Experimental studies of two-person sequential bargaining with a very short horizon (see Roth, 1995, for a comprehensive review) have reached similar conclusions.

Because our analysis has focused on mean rather than individual results, there is no way of telling whether all the subjects exhibited the positional order effect in some degree or only a fraction of them treated the positional order and sequential protocols as undistinguishable. In an attempt to clarify this issue, we conducted another experiment which is described in Section III.

III Experiment 2: Provision of Public Goods

The subjects in Experiment 2 participated in a noncooperative n-person game designed to study provision of public goods when contributions are binary and the public good is all-or-none (Van de Kragt, Orbell, & Dawes, 1982; Rapoport, 1985, 1987). The game is played once by a group N of n players and has the following structure. Communication before, during, and immediately after the game is strictly forbidden. Each player i ($i \in N$) is given the same endowment (a promissory note) worth \$$e$. She must decide privately and anonymously whether to contribute her entire endowment to the benefit of the good. Partial contributions are not allowed. The public good – a prize worth \$$r$ ($r > e > 0$) – is awarded to each member of the group if at least m members contribute ($1 < m < n$); it is not provided, otherwise. The values of m, n, r, and e are common knowledge.

At the end of the game each player leaves the experiment with a payoff worth \$0, \$$e$, \$$r$, or \$$(r + e)$, as shown in Table 2. The decision not to contribute (denoted D) is not dominant; if exactly $m-1$ of the other $n-1$ players in the group contribute (C), player i is better off choosing C rather than D.

Similarly to Experiment 1, the public goods game can be played under three different protocols. Under the simultaneous protocol, players make their decisions simultaneously. Under the sequential protocol, an order of play is imposed and players are informed of their position in the order. When it is her turn to play, each player j (occupying position j in the sequence, $j = 1, \ldots, n$) is informed of the (binary) decisions of players $1, 2, \ldots, j-1$. The positional order protocol is like the sequential protocol with the only exception that information about the decisions of players $1, 2, \ldots, j-1$ is not disclosed.

Because of the symmetry of the players, only symmetric equilibria in pure strategies are considered. For the simultaneous protocol, there is a Nash equilibrium in which all players defect (D). There are additional $\binom{n}{m}$ equilibria in which m players contribute and $n-m$ defect. Of course, because communication is prohibited and the game is played once, the players have no way to coordinate

Table 2. Payoff matrix for the public goods game

Player i's Decision	Number of Other Players Choosing C $m-2$ or Fewer	Exactly $m-1$	m or More
C	0	r	r
D	e	e	$e+r$

their strategies so that m contribute and $n - m$ do not. The equilibrium solution for the sequential protocol (Erev & Rapoport, 1990) is for the first $n - m$ players in the sequence to defect and the last m players to contribute. This solution implies that under the sequential protocol the public good will be provided efficiently. Evidence supporting the equilibrium solution is reported by Erev and Rapoport (1990) and Rapoport and Erev (in press).

As in the resource dilemma game discussed in Section II, game theory does not distinguish between the simultaneous and positional order protocols. The null hypothesis states no position effect on the players' decisions. In particular, it implies that the percentage of players who choose C while occupying position j in the sequence should not be related to j. As in Experiment 1, two versions of the order of play hypothesis are considered. The strong version equates the positional order and sequential protocols; it predicts that the first $n - m$ players will choose D and the last m players will choose C. The weak version asserts that some of the players do not distinguish between the positional order and sequential protocols, whereas the others do not distinguish between the positional order and simultaneous protocols. It recognizes explicity individual differences in processing information. Therefore, the weak version implies that the percentage of contributions by players assigned position j in the order will increase monotonically in j.

Method

Subjects: Subjects were 70 male and female students at the Technion – Israel Institute of Technology. They were recruited by advertisements promising monetary reward contingent on performance in a group decision making experiment. None of the subjects had taken part in previous experiments on binary public goods. The 70 subjects were run in groups of six or seven members each, depending on the game they played, as described below.

Procedure: The subjects arrived at the laboratory individually and were each given a set of instructions and seven cards (one for each game) with the subject's I. D. number printed on their back. The subjects were instructed that they would participate in seven different games, and that they would be grouped with different players on different games. In actuality, the subjects never met their group members. They were further instructed that their task in each game would be to place the card for the game (with the game number written on its face) in one of two boxes colored blue (B) and red (R).

No reference was made to contribution or defection in order not to bias the subjects by evoking social norms or altruism. Rather, each subject was instructed that her payoff for each game would be determined as follows:

You receive 20 NIS for participation in the game.
You lose 12 NIS, if the Blue box contains more than three cards.
You gain 6 NIS, if the Blue box contains your card.

As a result, the individual payoff for each game could take one of four values:

14 NIS (Blue box contains more than 3 cards and own card is in the Blue box);
8 NIS (Blue box contains more than 3 cards and own card is in the Red box);
26 NIS (Blue box contains no more than 3 cards and own card is in the Blue box);
20 NIS (Blue box contains no more than 3 cards and own card is in the Red box).

In terms of the parameters of the game, placing a card in either the Blue or Red box corresponds to a choice of D or C, respectively. The payoff structure defines a binary public goods game (Table 2) with $n = 7$, $m = 4$, $e = 6$ NIS, $r = 12$ NIS, and an additional 8 NIS for participation ($1 = 2.7 NIS).

The subjects were instructed that on some games the two boxes would be opaque, in some only one would be opaque, and in some both would be transparent, so that they could count the number of cards already placed in each box.[9] They were further told that their position in the sequence, predetermined by the experimenter, would vary from game to game.

The subjects participated in the following seven games presented in this order:

Game 1.	Both boxes are opaque. Each player is told her position in the sequence.
Game 2.	Same as Game 1.
Game 3.	Both boxes are transparent.
Game 4.	The Red box is transparent and the Blue Box is opaque.
Game 5.	The Red box is opaque and the Blue box is transparent.
Game 6.	Same as Game 1.
Game 7.	Same as Game 1.

We discuss only Games 1, 2, 6, and 7, as they all concern the positional order protocol. Only positions 1, 2, 3, 5, 6, and 7 were assigned to the subjects in these four games. Positions 1, 3, 5, and 7 were each assigned to 12 subjects and positions 2 and 6 were each assigned to 11 subjects.

To check for the effect of positional order on the individual level, the player's positions in Games 1, 2, 6, and 7 were assigned in the following manner. If a subject was assigned to position j ($j = 1, 2, 3, 5, 6, 7$) in Games 1 or 6, she was assigned to position $8\text{-}j$ in Games 2 and 7. If a player adheres to the equilibrium solution for the sequential protocol, she should play D on two of the games (in positions 1, 2, or 3) and C on two other games (in positions 5, 6, or 7).

[9] The simultaneous protocol is implemented when both boxes are opaque. The sequential protocol is implemented when both boxes are transparent. The seven cards of each group were of different length, so that cards could be counted easily without taking them out of the box. The positional order protocol is implemented when both boxes are opaque and each player is only informed of his/her position in the sequence.

Table 3. Number and percentage of subjects choosing C when only the serial position is known

		Serial Position 1st	2nd	3rd	5th	6th	7th	Over Position
	n	12	11	12	12	11	12	70
Game 1	# C	3	2	5	4	3	3	20
	% C	25.0	18.2	41.7	33.3	27.3	25.0	28.6
Game 2	# C	1	1	2	7	3	4	18
	% C	8.3	9.1	16.7	58.3	27.2	33.3	25.7
Game 6	# C	2	1	4	4	2	6	19
	% C	16.7	9.1	33.3	33.3	18.2	50.0	27.1
Game 7	# C	1	1	3	6	6	6	23
	% C	8.3	9.1	25.0	50.0	54.5	50.0	32.9
Over Game	n	48	44	48	48	44	48	280
	# C	7	5	14	21	14	19	70
	% C	14.6	11.4	29.2	43.8	31.8	39.6	25.0

Results

Table 3 presents the number and percentage of contributions by game and position. The three bottom lines summarize the results over the four games. If the strong version of the order of play hypothesis holds, the subjects should always defect in positions 1–3 and contribute in positions 5–7. Table 3 clearly rejects this version. To test the weak version, the 70 decisions in each of the four games – one decision per subject—were categorized in a 2 × 2 contingency table of position (1–3 vs. 5–7) by decision (*C* or *D*). The null hypothesis of no association between the two dimensions of the table was rejected in Games 2 ($\chi^2(1) = 7.5, p < .05$) and 7 ($\chi^2(1) = 10.9, p < .01$), but not in Games 1 ($\chi^2(1) = 0$) and 6 ($\chi^2(1) = 1.8, p > .05$). The results suggest that support for the weak version of the order of play hypothesis was obtained only on the second iteration of the game when the two iterations were played consecutively.

Stronger support for the order of play hypothesis is obtained when the frequencies are increased by summing them over the four games. Table 3 shows that the percentage of *C* choices increased from 14.6 in position 1 to 39.6 in position 7.

The proportion of subjects who support the hypothesis can be assessed from the way positions were assigned. If a player views the positional order and sequential protocols as undistinguishable, she should switch her decision from Game 1 to 2 and from Game 6 to 7. Moreover, she should choose *C* in positions 5, 6, or 7, and *D*, otherwise. If information about serial position is perceived as irrelevant, switching should not occur. Analysis of the individual decisions in Games 1 and 2 shows that 50 of the 70 subjects made the same decision on both games, 5 subjects switched their decision in the wrong direction, and 15 switched their decision in the predicted direction. A similar analysis of the individual decisions in Games 6 and 7 shows that 42 of the 70 subjects made the same decision in both games, 4 subjects switched their decision in the wrong direction, and 24 subjects switched their decision in the predicted direction. The hypothesis that the probability of correct switch is 0.5 is rejected ($p < .05$) in both cases.

Discussion

Experiments 1 and 2 present pairs of extensive form games – referred to as the simultaneous and positional order protocols of play – that give rise to the same strategic form yet yield statistically significant differences in how the games are played. In both cases, the statistically significant differences reflect the same recognizable differences between the extensive forms. Experiment 2 adds to Experiment 1 in two different ways. First, it shows that the positional order effect is obtainable both when the player's response set includes two and infinitely many elements. Second, it allows determining the percentage of players who consider the information on order of play as relevant and determine their decisions accordingly. Although statistically significant, the positional order effect in Experiment 2 is weak, reflecting the behavior of only a minority of the players. I suspect that the effect is weak in part due to characteristics of the public goods game and the complexity of the design. Experiment 3 was designed to determine whether a simpler game with multiple equilibria would produce a stronger effect.

IV Experiment 3: A Three-Person Coordination Game

Coordination games are frequently modeled as noncooperative games with symmetric players, simultaneous move, and complete information exhibiting-multiple Nash equilibria which are Pareto rankable. The players in this class of games are better off in one equilibrium relative to another yet lack the means to coordinate their strategies to achieve the preferred outcome. If they cannot, a coordination failure occurs (Cooper, De Jong, Forsythe, & Ross, 1990). Coordination games involve no incentive problems because their efficient outcomes are supportable as equilibria. Nevertheless, playing them often involves serious difficulties (Crawford, 1991). The "Battle of the Sexes" game depicted in Fig. 1 is the simplest example of a pure coordination game with two symmetric players and two strategies. Coordination failure occurs if the game ends with the outcomes (T, R) or (B, L).

Coordination games characterize strategic interactions in a large number of settings including the design of optimal incentive schemes (Crawford, 1991) and the behavior of markets in which networking externalities figure prominently

(Cooper et al., 1990). For additional examples of social environments in which coordination games arise naturally see Schelling (1960, 1978). The traditional approach to analyze noncooperative games with multiple equilibria relies on refinements of the Nash equilibrium. However, the usual refinement techniques are not of much help in playing coordination games (Crawford, 1991). To uncover behavioral regularities or competitively test different refinements, several experiments have been designed to study pure coordination games in strategic form with two or more players (e.g., Cooper et al., 1990; Van Huyck, Battalio, & Beil, 1990, 1991; Crawford, 1991).

The purpose of Experiment 3 is neither to add to this literature nor to test alternative selection criteria for pure coordination games in strategic form. Rather, as in the previous two experiments, the major goal is to present several extensive form games which give rise to the same pure coordination game in strategic form and then search for statistically significant differences in how these extensive form games are played. With three players participating in the coordination game, Experiment 3 includes six different sequences (3!), which differ from one another in the exogenously determined order of play. As in the previous two experiments, the null hypothesis due to game theory equates all six positional order protocols with simultaneous play. The alternative hypothesis is that the order of play, which is common knowledge, is used by some or all of the players as a clue to solve the coordination problem.

Method

Subjects: The subjects were 36 male and female students from Baylor University, who volunteered to participate in a group decision making experiment for monetary reward contingent on performance. They were told that they could earn up to $45 for a two-hour experiment plus $5 for participation. None of the subjects had participated in previous experiments on pure coordination games. The subjects were run in sets of six.

Procedure: The six subjects in each set arrived at the laboratory individually. Upon arrival, they were seated in six separate cubicles. They were then instructed that they would participate in a group decision making experiment with many trials, and that on each trial they would be divided into two equal and independent groups of three players each. The instructions emphasized that group membership would be changed randomly from trial to trial so that on each trial each subject would be informed of her group (1 or 2) and her player number within the group (1, 2, or 3). There was no way of identifying the other two members of one's group or the three members of the other group on any particular trial.

The experiment included 60 trials. Group membership and player number were determined by a Latin square design.

On each trial, after learning her group number and player number, each subject was asked to choose one of three alternatives (pure strategies) labelled *a*, *b*, and *c*, by pressing the corresponding key on a computer keyboard. Decisions were made privately and simultaneously. Individual payoffs for each trial were determined according to the following payoff scheme:

Decisions			Payoffs		
Player 1	Player 2	Player 3	Player 1	Player 2	Player 3
a	a	a	$10	$6	$2
b	b	b	2	10	6
c	c	c	6	2	10

Each of the other 24 combinations of the three choices of *a*, *b*, and *c* resulted in zero payment for all three group members. After the three members of each group made their choices, the computer displayed for each subject the three decisions made by the members of her group and the corresponding payoffs for the trial.

Communication between group members was not possible. The trial-to-trial changes in group and player assignment eliminated the possibility of reputation effects.

All the subjects participated in three conditions (protocols of play) in a within-subject design.

Under the *simultaneous protocol* the three choices were made simultaneously. In particular, no information about order of play was given.

Under the *positional order protocol*, the subjects were instructed that the three decisions would be made in a prespecified and commonly known order determined by the computer. The possible orders were (1, 2, 3), (1, 3, 2), (2, 1, 3), (2, 3, 1), (3, 1, 2), and (3, 2, 1). Although they were told the order of play for each trial, information about previous decisions in that particular order was not disclosed. In particular, the subjects were instructed that under the positional order protocol

> "You will be informed about the order of making the decisions, but not about the actual decisions of the group members (if any) preceding you in the sequence. For example, supposing that the order is (2, 1, 3). Then if you are player 2 you will choose first, player 1 will choose next (without knowing player 2's choice), and player 3 will make the final choice (without knowing the actual choices already made by players 2 and 1)."

Under the *rank-order protocol*, the three choices were made in a pre-specified order, exactly as in the positional order protocol. However, the order of play was not disclosed to the players. Rather, each player was only informed of her ranking in the sequence (first, second, or third). For example, if Player 2 was assigned the third rank in the sequence, she had no way of telling whether Player 1 or Player 3 made the first choice. And if Player 1 was assigned the second rank in the sequence, she could not know whether she was preceded by Player 2 or Player 3.

The three conditions were presented in blocks of ten trials as follows. The simultaneous protocol was presented on trials 1–10 and 31–40, the positional order protocol on trials 11–20 and 41–50, and the rank-order protocol on trials 21–30 and 51–60.

Hypotheses: In the following section I shall only analyze the results from trials 11–20 (Block 1) and 41–50 (Block 2) obtained under the positional order protocol. Assume that the three decisions in the coordination game – one by each player – were made in the predetermined order (I, J, K) where $I, J, K = 1, 2, 3$, and $I/J/K$. Because information about previous decisions in the sequence is not disclosed, game theory considers the positional order protocol as a case of simultaneous move. Note also that the three players are symmetric although each prefers another equilibrium point. Consequently, the *null hypothesis* states that on each trial each of the three players will choose the three alternatives with equal probability. For the aggregate of the subjects, the null hypothesis yields the prediction

$$p(a) = p(b) = p(c) = 1/3,$$

where $p(h)$ is the probability of choosing alternative h $(h = a, b, c)$.

If the coordination game were to be played under the sequential protocol, in which each player is fully informed about the preceding decisions in the sequence, player I (the first in the sequence) should choose her best alternative, denoted by i $(i = a, b, c)$, thereby inducing the other two players to choose the same alternative in order to assure coordination. This is the only SPE solution of the game. Therefore, the strong version of the *order of play hypothesis*, which equates the positional order and sequential protocols, states that, given the predetermined order of play (I, J, K),

$$p(i) = 1, \quad i = a, b, c.$$

Assuming, as before, that only a fraction of the players would equate the positional order and sequential protocols, yields the weak version of the order of play hypothesis:

$$p(i) > 1/3, \quad i = a, b, c.$$

Two additional hypotheses can be stipulated. The *individualistic hypothesis* states that each player will choose the alternative that benefits her most (a, b, and c by Players 1, 2, and 3, respectively), The *coordination hypothesis* asserts that if during the course of the experiment the players reach one of the three equilibrium points, possibly by chance, then they will continue choosing the same alternative for the remaining trials in the experiment while disregarding the information about order of play.

Results

Each of the six possible orderings was presented at least once in Block 1 and at least once in Block 2. Because the subject's group (1 or 2) and the player number within group (1, 2, or 3) were changed from trial to trial, the results will be reported by sets rather than groups with the subjects in each set numbered from 1 to 6. With each subject making 10 decisions in each block, one on each trial, there is a total of 360 decisions in Block 1 and 360 decisions in Block 2.

Given the (predetermined) ordering (I, J, K), I shall refer to alternative i – the one most favored by the first player (I) in the sequence – as the *predicted alternative.* Table 4 presents the number of times the predicted alternative was chosen. The frequencies are presented for each subject separately and across the six subjects in each set. The top panel presents the frequencies for Block 1, the middle panel for Block 2, and the bottom panel for Blocks 1 and 2 combined. For example, Player 1 in Set 1 chose the predicted alternative on 2 of the 10 trials in Block 1 and 3 of the 10 trials in Block 2. In contrast, Player 1 in Set 3 chose the predicted alternative on all the 10 trials in each of the two blocks.

Table 4 shows that across subjects and trials the predicted alternative was chosen 221 times (61.4%) in Block 1 and 231 times (64.2%) in Block 2. Using a one-sided z-test, the null hypothesis (postulating $p = 33.3\%$) was clearly rejected in Block 1 ($z = 11.29$), $p < .0001$) and Block 2 ($z = 12.41$, $p < .0001$). The difference between the proportions of choice in Blocks 1 and 2 is not significant ($z < 1$).

The next analysis counted the number of times the predicted alternative was chosen by players holding different positions in the sequence (I, J, K). There is no evidence that position in the sequence affected the frequency of choice of the predicted alternative. Summed over trials and subjects, the predicted alternative was chosen 159 (66.3%), 151 (62.9%), and 142 (59.2%) times by the players holding positions I, J, and K, respectively.

Inspection of Table 4 shows large individual differences, with some subjects choosing the predicted alternative on only one of the ten trials in a block and others choosing it on all ten trials. To assess the consistency within subjects, I computed the product-moment correlation between the individual frequencies in Blocks 1 and 2 ($n = 36$). The computation yielded a positive and highly significant correlation ($r = 0.69$, $p < .0001$).

The null hypothesis, individualistic hypothesis, and coordination hypothesis each implies that the predicted alternative will be chosen with probability 1/3. Across the 20 trials in Blocks 1 and 2, the expected value and standard deviation of the number of choices of the predicted alternative are, therefore, 6.67 and 2.11, respectively. Adopting a very strict criterion of 17 out of 20 choices of the predicted alternative (approximately five standard deviations from the expected value), the bottom panel of Table 4 shows that the choices of 14 of 36 subjects (38.8%) can be accounted for by the positional order hypothesis. If this criterion is relaxed to 12 out of 20 trials (approximately 2.5 standard deviations), this number changes to 21 out of 36 subjects (58.3%).

Table 4. Number of choices supporting the order of play hypothesis by player and block

Block 1 (Trials 11–20)												
Set 1		Set 2		Set 3		Set 4		Set 5		Set 6		Total
s	*f*	*s*	*f*	*s*	*f*	*s*	*f*	*s*	*f*	*s*	*f*	
1	2	1	7	1	10	1	10	1	10	1	4	
2	1	2	9	2	8	2	5	2	10	2	8	
3	1	3	9	3	3	3	2	3	10	3	6	
4	2	4	9	4	10	4	4	4	3	4	3	
5	9	5	4	5	3	5	10	5	9	5	7	
6	7	6	3	6	8	6	8	6	4	6	3	
Total	22		41		42		39		46		31	221

Block 2 (Trials 41–50)												
Set 1		Set 2		Set 3		Set 4		Set 5		Set 6		Total
s	*f*	*s*	*f*	*s*	*f*	*s*	*f*	*s*	*f*	*s*	*f*	
1	3	1	8	1	10	1	10	1	10	1	1	
2	3	2	10	2	8	2	10	2	10	2	10	
3	2	3	9	3	1	3	6	3	10	3	1	
4	3	4	8	4	10	4	2	4	4	4	4	
5	3	5	10	5	2	5	4	5	10	5	10	
6	7	6	3	6	10	6	10	6	6	6	3	
Total	21		48		41		42		50		29	231

Over Block (Trials 11–20, 41–50)												
Set 1		Set 2		Set 3		Set 4		Set 5		Set 6		Total
s	*f*	*s*	*f*	*s*	*f*	*s*	*f*	*s*	*f*	*s*	*f*	
1	5	1	15	1	20	1	20	1	20	1	5	
2	4	2	19	2	16	2	15	2	20	2	18	
3	3	3	18	3	4	3	8	3	20	3	7	
4	5	4	17	4	20	4	6	4	7	4	7	
5	12	5	14	5	5	5	14	5	19	5	17	
6	14	6	6	6	18	6	18	6	10	6	6	
Total	43		89		83		81		96		60	452

Discussion

Depending on the criterion used, between 39% and 58% of the subjects used the order of play as a cue on most or all trials to coordinate their strategies. Order of play was used in the same way as in Experiments 1 and 2. Order of play was used by these subjects to achieve coordination despite the fact that coordination was not assured because not all six players in any of the six sets always used the order of play as predicted by the strong version of the order of play hypothesis. Table 4 shows that the strongest support for that hypothesis was obtained in Set 5 in Block 2 in which four of the six players always chose the predicted alternative.

However, even in this set coordination was not achieved in all the ten trials because Players 4 and 6 in this set deviated from the prediction on six and four trials, respectively.

Results not reported here show partial support for the other hypotheses. There were two subjects in Block 1 and seven subjects in Block 2 who disregarded the information about order of play and chose the same alternative on at least 9 of the 10 trials in the block. The results of these nine subjects are consistent with both the individualistic or coordination hypotheses. And there were other subjects for whom no clear pattern of choices could be discerned. Detailed analysis of the results of these subjects and the outcomes of the simultaneous and rank-order protocols are beyond the scope of the present paper.

V Discussion and Conclusions

Kreps (1990) has raised two related questions: (1) whether there exist different extensive form games giving rise to the same strategic form game that are played differently, and (2) whether these differences, if they are observed, can be accounted for by principles reflecting recognizable differences between the extensive form games. To answer these questions, I conducted three different experiments with a common methodology. Experiments 1 and 2 introduced the positional order protocol of play in which decisions are made in a prespecified order but no information about previous decisions is given, and then compared the results under this protocol to those obtained previously under the simultaneous and sequential protocols. I did not conduct the pure coordination game under the sequential protocols because the results seemed obvious. The first comparison shows that in all three experiments the simultaneous and positional order protocols yielded statistically different results. The second comparison shows that the principle organizing the difference in play between the simultaneous and positional order protocols is the ("recognizable") chronological structure of the latter protocol. A fraction of the players, whose size depends on the specific characteristics of the extensive form game, seem to regard the positional order and sequential protocols as undistinguishable. Information about the chronological ordering of moves seems to induce these players to "frame" the game as if it were played under the sequential protocol with perfect information and adjust their behavior accordingly. The results seem to apply to a variety of games and various populations of financially motivated subjects.

The effects of information about order of play, although statistically significant, are not particularly strong. The positional order protocol in Experiment 1 did not induce the same strong effects as the sequential protocol (Table 1). Only about 28% of the subjects in Experiment 2 supported the order of play hypothesis whereas the majority of the subjects regarded the information about order of play as irrelevant. And even in Experiment 3, which was specifically designed to elicit the order of play effect, the percentage of subjects exhibiting this effect ranged between 39 and 58. There is a need to compare protocols of play in other noncooperative games and under alternative designs in order to assess the scope and strength of the order of play effect.

There are at least two different interpretations of the findings of this study. The first asserts that the findings indicate the existence of cognitive cues used by players to coordinate their actions. These cues most probably reflect previous experience with the sequential protocol, which renders earlier players in the sequence more advantageous. The various examples of coordination that Schelling (1960) discusses in his book are consistent with this interpretation. Although this interpretation is quite reasonable for Experiments 2 and 3, where the simultaneous protocol gives rise to several symmetric equilibria, it seems less convincing for Experiment 1 in which there is only a single symmetric equilibrium in pure strategies under the simultaneous protocol. The "focal point" interpretation, so often invoked to account for findings which are not predictable by game theory, loses some of its explanatory power in games which do not involve choice among multiple symmetric equilibria.

A second, and potentially more damaging, interpretation is that the notion of information set is not sufficient to account for the information that reasonable players extract from their knowledge of the moves of the game. A player who knows the chronological ordering of moves in the game may form certain beliefs, which are position dependent, about the behavior of players preceding her in the sequence even without learning the decisions that they have actually made. The results presented above are insufficient to determine between these interpretations. More experiments are needed to assess the magnitude of the positional order effect in games which are not primarily concerned with coordination.

Related research was conducted by Schotter, Weigelt, and Wilson (1991), who also investigated the extent to which the mode of presentation of the game affects the way subjects play it. Their study differs from the present study in two major respects. First, Schotter et al. (1991) used two-person games with multiple equilibria. The comparison of their two frames involved the percentage of time each of the two equilibria was chosen. Secondly, and more importantly, they did not compare to each other two extensive games. Rather, the games that they chose were presented and described in a strategic form to some groups of subjects and in an extensive form with an explicit sequential structure to other groups. Like the present study, they observed in some games a dramatic difference in the behavior of the subjects depending on whether the game was presented as a matrix in which the two players move simultaneously or as a tree in which they move sequentially.

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