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THE ROLE OF INFORMATION IN BARGAINING: AN EXPERIMENTAL STUDY[1]

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A fundamental assumption in much of game theory and economics is that all the relevant information for determining the rational play of a game is contained in its structural description. Recent experimental studies of bargaining have demonstrated effects due to information not included in the classical models of games of complete information. The goal of the experiment reported here is to separate these effects into components that can be attributed to the possession of specific information by specific bargainers, and to assess the extent to which the observed behavior can be characterized as equilibrium behavior. The results of the experiment permit us to identify such component effects, in equilibrium, including effects that depend on whether certain information is common knowledge or not. The paper closes with some speculation on the causes of these effects.

1. INTRODUCTION

A FUNDAMENTAL ASSUMPTION in much of game theory (as well as in much of economics) is that the structural description of a game and the (possibly cardinal) utility functions of the players together constitute all the relevant information needed to determine rational play. Indeed, games in which the players possess this information are called games of *complete* information.

Recent experimental studies of bargaining strongly support the contention that, even in games of complete information, information absent from the classical models of games can nevertheless systematically influence their outcomes. The present study is intended to further explore this phenomenon, both to help indicate directions in which a descriptive theory of bargaining must be modified, and to help clarify what implications this phenomenon has for theories primarily intended as prescriptive models of bargaining among perfectly rational players.

Specifically, previous experiments revealed an effect of information in bargaining which cannot be explained by existing models. In the present paper, we report an experiment, the primary goal of which is to separate this effect into components that can be identified as resulting from the possession of specific information by specific individuals. A secondary goal is to assess the extent to which the behavior observed can be characterized as *equilibrium* behavior, and therefore cannot be attributed to simple inexperience among the experimental subjects.

We do not present here a new theory of bargaining, but examine in detail certain phenomena which existing theory cannot account for, in order to indicate

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directions in which new theory must be developed. While it is not yet standard practice to test economic theories with experimental data, bargaining is a subject well suited to the endeavor, both because there is a well developed body of deductive theory, and because, being an activity which can take place between as few as two agents, it readily lends itself to reliable experimental investigation.

The next section reviews two earlier experiments (Roth and Malouf [**8**], and Roth, Malouf, and Murnighan [**10**]), and discusses their implications. Section 3 reports the new experiment, designed to answer questions raised by the results of the previous experiments. Some of these questions are related to recent theoretical developments in the study of information, specifically the concept of "common knowledge."

2. EARLIER EXPERIMENTS

In order to test theories that depend on the von Neumann–Morgenstern expected utilities of the players, experiments must permit the utility functions of the participants to be determined. A class of games which makes this possible was introduced in Roth and Malouf [**8**].

In each game of that experiment, players bargained over the *probability* that they would receive a certain monetary prize, possibly a different prize for each player. Specifically, they bargained over how to distribute "lottery tickets" to determine the probability that each player would win his personal lottery (i.e., a player who received 40 per cent of the lottery tickets would have a 40 per cent chance of winning his monetary prize and a 60 per cent chance of winning nothing). If no agreement was reached in the allotted time, each player received nothing. So a player received his prize only if an agreement was reached on splitting the lottery tickets in an allowable way, and if he won the ensuing lottery. Otherwise he received nothing. We will refer to games of this type, in which each player has only two possible monetary payoffs, as *binary lottery games*.

To interpret the feasible outcomes of a binary lottery game in terms of each player's utility for money, recall that if we normalize each player's utility function so that the utility for receiving his prize is 1, and the utility for receiving nothing is 0, then his utility for any lottery between these two alternatives is the probability of winning the lottery; i.e., an agreement giving a player p per cent of the lottery tickets gives him a utility of p.[2] A change in the prizes is therefore equivalent to a change in the scale of the players' utility functions.

Since the set of feasible utility payoffs to the players in such a game equals the set of allowable divisions of lottery tickets, binary lottery games can be used to

[2]Note that we consider the feasible set of utility payoffs to be defined in terms of the utility function of each player for the lottery which he receives, independently of the bargaining which has achieved this lottery, and even independently of the lottery which his opponent receives. In doing so, we are taking the point of view that, while these factors may influence the utility of a bargainer for the agreement eventually reached, the description of any effect which this has on the agreement reached belongs in the model of the bargaining *process*, rather than in the model of the bargaining *situation*.

experimentally test theories which depend on the set of feasible utility payoffs. Note that the set of feasible utility payoffs does not depend on the size of the prizes. Thus if the players know the allowable divisions of lottery tickets, the game is one of complete information, regardless of whether each player also knows the size of the other's prize.

Following Nash [**6**], two-player bargaining games are modelled by a pair (S, d), where d is a point in the plane, and S is a compact convex subset of the plane. The interpretation is that S is the set of feasible expected utility payoffs, any one of which can be achieved if both players agree. If no agreement is reached, the disagreement point d results. In a binary lottery game normalized as above, S is the set of allowable divisions of lottery tickets, and d is the point $(0,0)$.

Nash proposed that bargaining be modelled by means of a function called a *solution*, which selects a feasible outcome for every bargaining game. If B denotes the class of all two-player bargaining games, a solution is a function $f: B \to R^2$ such that $f(S, d)$ is an element of S. Thus a solution is a model of bargaining which depends only on the information about the underlying game[3] contained in the model (S, d). Nash characterized a particular solution to the bargaining problem, which, along with others, has subsequently been the object of considerable study (cf. Roth [**7**]). Since a solution depends only on the pair (S, d), any solution is a model that predicts that the outcome of a binary lottery game will not depend on whether the players know their opponent's prize.

The experiment reported in Roth and Malouf [**8**] was designed to test this hypothesis, among others. Participants played binary lottery games with either *full information* or *partial information*. In the full information condition, each player was informed of the value of both his opponent's prize and his own. In the partial information condition, each player was informed only of his own prize.[4]

The outcomes observed in the two conditions exhibited dramatic differences. Outcomes in the partial information condition tended to be extremely close to an equal division of the lottery tickets, while outcomes in the full information condition shifted significantly towards equal expected monetary payoffs; i.e., when the bargainers had full information and unequal prizes, agreements tended to give a higher probability of winning to the player with the smaller prize. Since

[3] In order to insure that such a theory of bargaining would depend only on the information about preferences contained in a player's utility function, Nash further proposed that a solution should be independent of the scale of the players' utility functions. Any solution possessing this property predicts that the outcome of a binary lottery game should not depend on the size of the prizes; i.e. it predicts that two games which differ only in the size of the prizes will result in the same agreement.

[4] Players were seated at isolated computer terminals, and allowed to communicate by teletype, but were unaware of their opponents' identity. (The only limitations on free communication were that players were prevented from identifying themselves, or from discussing the monetary value of their prizes in the partial information condition.) The bargaining process consisted of the exchange of messages and of (numerical) proposals, and terminated in agreement when a proposal was accepted or in disagreement if no proposal had been accepted after 12 minutes. The methods used to implement the experiment are essentially those of the experiment described in Section 3 except that, there, players were free to make any (true or false) statements they wished about the prizes, in all information conditions.

the set of allowable lottery divisions, and hence the set of feasible utility payoffs, is not affected by the information condition, the observed difference between the two conditions suggests that theories which depend only on the pair (S, d) are insufficiently powerful to capture the complexity of this kind of bargaining.[5]

Other classical models describe a game in greater detail. The *strategic* (or normal) form of a game includes not only a description of the set of feasible utility payoffs, but also the players' strategy choices. In the games described above, strategy choices concern the formulation of messages and proposals. Since players' strategies depend on the information they possess, we must consider whether the observed results can be accounted for by the different strategies available in the two information conditions.

The experiment reported in Roth, Malouf, and Murnighan **[10]**, designed to address this question, involved binary lottery games whose prizes were stated in terms of an intermediate commodity. Each bargainer was told that the prizes would be expressed in "chips" having monetary value, and each player played four games under either *high*, *intermediate*, or *low* information conditions. In each condition, each player knew the number of chips in his own prize and their monetary value, but each player's information about his opponent's prize varied with the condition. In the high information condition, players knew both the number of chips in their opponent's prize and their value. In the intermediate information condition, players knew the number of chips in their opponent's prize, but not their value. In the low information condition, players knew neither the number of chips in their opponent's prize, nor their value. In the latter two conditions, players were prevented from communicating the missing information about the prizes. The games were counterbalanced in the sense that, in two of the games, the player with the higher number of chips also had a higher value per chip (and hence a higher value prize), while in the other two games, the player with the higher number of chips had a lower value per chip and a lower value prize.

The experiment took advantage of two kinds of strategic equivalence relations. First, binary lottery games whose prizes are expressed in both chips and money, played in the low information condition of this experiment, are strategically equivalent[6] to binary lottery games with the same monetary prizes whose prizes are expressed in money alone, played in the partial information condition of the previous experiment. Under the rules of the low and partial information conditions, any legal message in one kind of game would be legal in the other, so the strategy sets are the same for both kinds of games, as are the utility functions and the underlying set of alternatives.

[5] And, of course, the observed dependence of the outcomes on the magnitude of the prizes demonstrates that factors other than the players' preferences over lotteries are at work (cf. footnote 3).

[6] When we say two games are strategically equivalent, we essentially mean they can both be represented by the same strategic form. Thus any theory of games which depends only on the strategic form of a game yields the same predictions for strategically equivalent games. This is discussed at greater length in Roth, Malouf, and Murnighan **[10]**.

Second, games expressed in both chips and money played under the intermediate information condition of this experiment are strategically equivalent to games expressed in money alone played under the full information condition of the previous experiment, if the values of the prizes in each money game are in the same proportion as the numbers of chips in the prizes in the corresponding chip game. Again, any legal message in one kind of game can be transformed into a legal message in the other kind of game by substituting references to chips for references to money (or vice versa) in any message concerning the value of the prizes.

Thus if the observed difference between the partial and full information conditions of the previous experiment was due to the different strategy sets available to the players, then a similar difference should be observed between the low and *intermediate* information conditions of this experiment. The "strategic hypothesis" predicts that games in the low information condition should lead to agreements in which the players receive approximately equal probabilities of winning their prizes, while games in the intermediate information condition should lead to agreements giving the player with the smaller number of chips a significantly higher probability than his opponent of winning his prize.

Alternatively, the difference between information conditions observed in the previous experiment may be due to social conventions among the bargainers, rather than to changes in their strategy sets. In conflicts involving a wide range of potential agreements, social conventions may serve to make some agreements and demands more credible than others. Thus this hypothesis views the low variance observed in the partial information condition as evidence that the agreement giving players an equal chance of winning their prizes is supported by a social norm that inclines both players to believe that their opponent may not accept less. The shift towards equal expected monetary payoffs observed in the full information condition is viewed as evidence that when information about the monetary value of the prizes is available, the agreement giving the players equal expected payoffs is also supported by such a convention, so the bargaining focuses on resolving the difference between two credible positions.[7]

By "social conventions," we mean customs or beliefs commonly shared in a particular society. To be commonly shared, such conventions must concern familiar quantities. By stating the prizes in terms of an unfamiliar artificial commodity ("chips") which conveys no information about more familiar quantities such as the value of a given prize or a player's probability of winning it, this experiment introduced a quantity about which no social conventions apply. The "sociological hypothesis" predicts, therefore, that information about the number of chips in each prize would not affect the bargaining: the low and high information conditions of this experiment should replicate the partial and full information conditions of the previous experiments, respectively, and the intermediate information condition should not differ significantly from the low information condition.

[7] Informal analysis of transcripts of the negotiations lends support to this hypothesis.

The observed results strongly supported the sociological hypothesis. Results in the low and high information conditions essentially replicated those observed in the partial and full information condition of the previous experiment, and intermediate information outcomes did not differ significantly from those in the low information condition (i.e., in the intermediate information condition, agreements tended to give both players equal probabilities, regardless of the size of their prize in chips). Thus information about the artificial commodity, chips, did not affect the outcomes in the same way as did strategically equivalent information about money.

3. A NEW EXPERIMENT

In the games played in the partial information condition of Roth and Malouf [**8**] and in the low information condition of Roth, Malouf, and Murnighan [**10**], neither bargainer knew his opponent's prize, while in the games played in the full information condition of R&M, or in the high information condition of RM&M, both bargainers knew their opponent's prize. The difference between the outcomes in the different information conditions could be an effect which depends on (i) whether the player with the higher prize knows both prizes; (ii) whether the player with the lower prize knows both prizes; or (iii) an interaction which occurs only when both players know both prizes. The experiment reported next is designed to separate out these possible effects.

Also, in the previous experiments, it was "common knowledge" whether the bargainers knew one another's prizes. Information is common knowledge in a game if it is known to all of the players, and if, in addition, every player knows that all the players know, and that every player knows the others know that *he* knows, and so forth. (The concept of common knowledge is formalized in Aumann [**1**] and Milgrom [**4**].) In general, two bargainers can be thought of as having common knowledge about an event if the event occurs when both of them are present to see it, so that they also see each other seeing it, etc. For the purposes of this experiment, a set of instructions provides common knowledge to the bargainers if it contains the information that both of them are receiving exactly the same instructions.

Information which is common knowledge does not have "deniability": neither player can credibly deny that he knows it. The experiment described below is designed to distinguish the effects of this kind of deniability by manipulating whether each player's awareness or ignorance of his opponent's prize is common knowledge. In addition, the players are given sufficient scope for strategic manipulation to permit at least a preliminary assessment of whether the observed outcomes result from equilibrium behavior.

Design of the Experiment

Each game of this experiment was a binary lottery game in which one player had a $20 prize and the other a $5 prize, and in which all possible divisions of lottery tickets were allowable. In all conditions of the experiment, each player

TABLE I

DESIGN OF THE SHARED-INFORMATION COMMON-KNOWLEDGE EXPERIMENT

Information	Common Knowledge	Non-Common Knowledge
Neither player knows both prizes	1	5
Only the \$20 player knows both prizes	2	6
Only the \$5 player knows both prizes	3	7
Both players know both prizes	4	8

knew at least his own prize. Each player played three identical games, against different, anonymous opponents.[8]

The experiment used a 4(information) $\times$ 2(common knowledge) factorial design (see Table I). The information conditions were: (1) *neither knows* his opponent's prize; (2) the \$20 *player knows* both prizes, but the \$5 player knows only his own prize; (3) the \$5 *player knows* both prizes, but the \$20 player knows only his own prize; and (4) *both players know* both prizes. The second factor made this information common knowledge for half the bargaining pairs, and not common knowledge for the other half. For instance, when the \$20 player is the only one who knows both prizes, then the (common) instructions to both players in the common knowledge condition reveal that the \$20 player will know both prizes and that the \$5 player will know only his own in the game about to be played. In the non-common knowledge condition, the \$20 player still knows both prizes, and the \$5 player still knows only his own prize, but both players are told that the other bargainer *may or may not know* their prize. After each bargaining session, players were assigned new opponents, with the same information, common knowledge, and prizes.

This design is intended to permit the observation of effects due to subtle changes in the information available to the players. For instance, conditions 1 and 4, as numbered in Table I, closely resemble the study of Roth and Malouf [**8**], in which agreements reached in condition 1 clustered around a 50-50 split of lottery tickets, while agreements reached in condition 4 tended towards agreements giving the players equal expected monetary gains (i.e., in this game, 20 per

[8] Analysis of the results across the three games indicated that sequential play had no effects even approaching significance on the agreements reached or on the number of disagreements. Thus the remaining analyses pooled the results of each individual's three plays.

cent of the lottery tickets to the $20 player and 80 per cent to the $5 player). The difference between the two conditions is that the prizes are private information in condition 1 and common knowledge in condition 4. If the difference in the outcomes in these two conditions is primarily due to the fact that players can compare their payoffs in condition 4, then the observed outcomes in condition 4 should resemble those observed in condition 8, where the prizes are both known to both players but not common knowledge. But if the difference between the observed outcomes in conditions 1 and 4 is substantially influenced by the fact that common knowledge is 'undeniable,' then the outcomes observed in condition 8, where the shared information is deniable, should be significantly different from those observed in condition 4. The results in the other conditions can be interpreted in a similar manner.

Methods

Each participant was seated at a visually isolated terminal of a computer system, called PLATO, which has advanced graphic displays and interactive capability. Participants were seated at scattered terminals throughout a room containing over 70 terminals, and received all of their instructions and conducted all communication via the terminal. Subjects were drawn from an introductory business administration course taken primarily by college juniors. Pretests were run with the same subject pool to make sure that the instructions were clear.

Background information including a brief review of probability theory was presented first. The procedures for sending messages and proposals were then introduced. A proposal was a pair of numbers, the first being the sender's probability of receiving his prize and the second the receiver's probability. The use of the computer enabled any asymmetry in the presentation to be avoided. The proposal was displayed on a graph of the feasible region, along with the expected monetary value of each proposal.[9] Bargainers could cancel a proposal before its transmittal. Proposals were binding on the sender, and an agreement was reached whenever one of the bargainers returned a proposal identical to the one he had just received.

Messages were not binding. Bargainers could send any message they wished, with one exception. To insure anonymity, the monitor intercepted any messages that revealed the identity of the players. Intercepted messages were returned to the sender's terminal with a note that participants were not permitted to identify themselves.

To verify their understanding of the rules, subjects were given some drills followed by a simulated bargaining session with the computer. Then subjects were paired at random and the bargaining started.

Every pair matched a player with a $5 prize against one with a $20 prize. All instructions were presented prior to the start of the first game. In the Common

[9] In each information condition, PLATO displayed the expected monetary value which the player would receive from any proposal he made or received. The opponent's expected value was only displayed in those conditions in which the player knew his opponent's prize.

Knowledge conditions, the instructions stated that the players were both reading the same instructions, and that certain private information would be presented to them at the end of the instructions. Thus, for example, in the \$20 Player Knows/ Common Knowledge condition, both players were instructed that one player's private information would include both prizes while the other player's private information would include only his own prize. When the players received their private information, the \$20 player was told both prizes and reminded that the \$5 player knew only his own prize, and the \$5 player was told only his own prize, and reminded that his opponent knew both prizes. The distribution of information in the other Common Knowledge conditions was handled in a similar manner. In all four of the Non-Common Knowledge conditions, the instructions concerning the private information stated simply that each player's private information might or might not include his opponent's prize.[10]

At the end of 12 minutes or when agreement was reached (whichever came first), the subjects were informed of the results of that game and were asked to wait until all the other bargainers finished. Subsequent games used new random pairings. At no point were players aware of what other participants were doing, or of their opponent's identity.

The bargaining process consisted of the exchange of messages and proposals. Participants were instructed that "your objective should be to maximize your own earnings by taking advantage of the special features of each session." Only if the bargainers reached agreement on what percentage of the lottery tickets each would receive were they able to participate in the lottery for the particular game being played. All transactions were automatically recorded.

The lotteries were held after all the games were completed, and each player was informed of the outcomes and the amount of his winnings. A brief explanation of the purpose of the experiment was then given, and the subjects were offered the opportunity to record comments or questions, and were directed to the monitor who paid them.

Results

The negotiation process recorded in the exchange of messages and proposals revealed considerable strategic manipulation. The \$20 player, for instance, most often made no mention of the prizes; but if it was common knowledge that the \$5 player did not know both prizes, the \$20 player often misrepresented his prize. (One typical example: "I know that your prize is \$5. Mine is only \$2. I should get

[10] In all conditions, the last sentences of the common instructions were the following. "Up to this point, you and the other bargainers saw the same instructions. Now we will give you some private information." Depending on the condition, the players also received one of the following reminders after the private information had been presented. "The other bargainer does not know your prize and is aware that you don't know his prize." "The other bargainer does not know your prize and is aware that you know his prize." "The other bargainer knows your prize and is aware that you don't know his prize." "The other bargainer knows your prize and is aware that you know his prize." "The other bargainer may or may not know your prize and is not aware that you know his prize." "The other bargainer may or may not know your prize, and is not aware that you don't know his prize."

more than 50 per cent.") The $5 player, on the other hand, often revealed information when he knew the $20 player's prize. Both strategies appeared to be generally disbelieved. The frequency and timing of misrepresentation and the content of messages and proposals provide a rich source of data for analysis of the negotiations, albeit beyond the scope of this paper. The remainder of this section concentrates on the bargaining outcomes as measured by the percentage of lottery tickets which each player obtained in the different conditions.

The data were analyzed two ways, with disagreements excluded from the sample and with disagreements included. Prior to analysis of variance on the 4 (information conditions) by 2 (common knowledge conditions) by 2 (players) design, distributions were inspected to determine whether they conformed to the assumptions of analysis of variance. For only the agreements reached, the data for the $20 players' outcomes in the Neither Knows and the $20 Player Knows conditions are negatively skewed (see Figures 1 and 2). Far more agreements give the $20 player a 50 per cent chance in the lottery than anything else. In the $5 Player Knows and Both Know conditions, the data is neither normal nor unimodal, but bi-modal, with the two modes at or close to 20 per cent and 50 per cent for the $20 players' outcomes (see Figures 3 and 4). Although the skewed distributions might be analyzed with standard analysis of variance techniques and little distortion of the findings, the bimodal distributions are much more difficult. Indeed, using the means of these conditions as indicators of central tendency distorts the character of the data. Thus, although means are reported, they should be interpreted cautiously, in light of the underlying distributions observed. All statistical comparisons among the conditions used the Mann–Whitney U test, also called Wilcoxon's analysis of summed ranks. This test can be used for any distribution of data.

Frequency of Agreements in Terms of the Percentage of Lottery Tickets Obtained by the $20 Player

FIGURE 1.

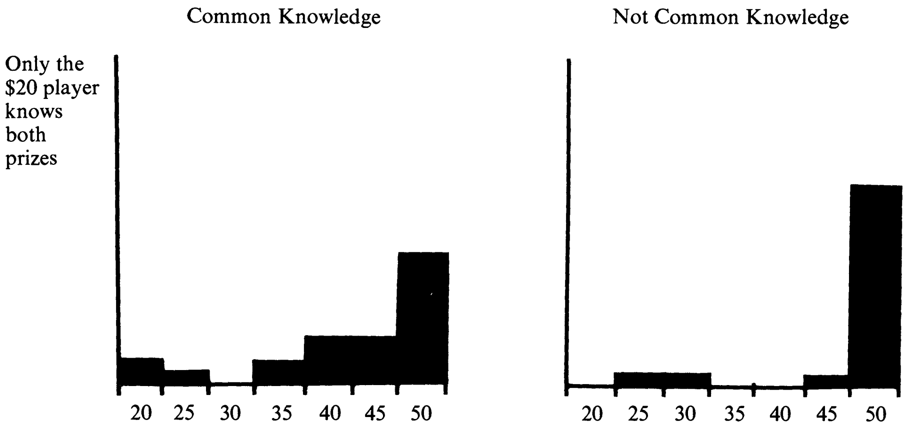

FIGURE 2.

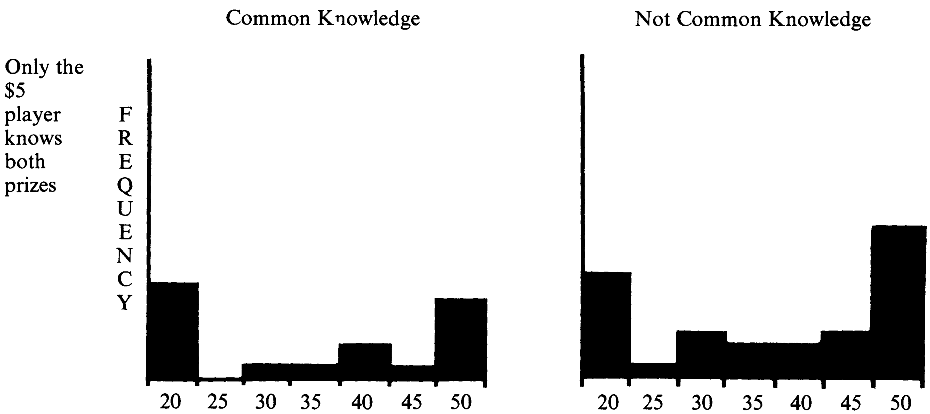

FIGURE 3.

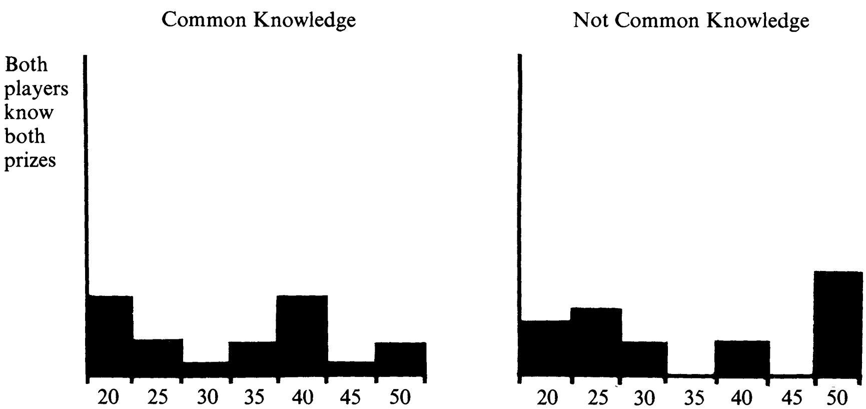

FIGURE 4.

TABLE II

MEAN OUTCOMES TO THE $20 AND $5 PLAYERS IN EACH INFORMATION/COMMON KNOWLEDGE CONDITION WHEN AGREEMENTS WERE REACHED (DISAGREEMENTS EXCLUDED)

Information	Common Knowledge		Non-Common Knowledge	
Neither player knows both prizes	48.8	51.2	47.5	52.5
Only the $20 player knows both prizes	43.6	56.4	49.1	50.9
Only the $5 player knows both prizes	33.6	66.4	37.2	62.8
Both players know both prizes	30.8	69.2	34.3	65.7

NOTE: Outcomes are the mean lottery percentages obtained by the $20 players (expressed first) and the $5 player when they reached agreement.

The data clearly differed across the conditions. If one inspects the means shown in Tables II and III, for agreements only and for the outcomes of all interactions including disagreements, differences among the information conditions are obvious. When only the agreements are considered (Table II), the Neither Knows and the $20 Player Knows conditions depart little from 50-50 agreements. Giving the $5 player information about the $20 player's prize (in the $5 Player Knows and Both Know conditions) results in considerable movement toward a 20-80 agreement. Indeed, the movement toward 20-80 in these four conditions (for both common and not common knowledge) moves just past the midpoint between 50-50 and 20-80.

Table IV displays the number of disagreements in each condition. Comparisons among conditions showed that there were more disagreements in condition 7 (the $5 Player Knows/Not Common Knowledge condition) than in all of the other conditions ($F(1,258) = 6.16$, $p < .02$) and that conditions 7 and 8 (the $5 Player Knows/Not Common Knowledge and Both Know/Not Common Knowledge conditions), when combined, were also significantly different ($F(1,258) = 7.27, p < .01$) from the others.

Comparisons using the Mann–Whitney U test were conducted on the data represented in Table III, primarily within a Common Knowledge/Player condition and across information conditions (i.e., within the columns of the table). The comparisons indicate simpler differences in the not common knowledge conditions than the common knowledge conditions. Two other comparisons, not displayed in the table, were also conducted. The outcomes of the $20 player when only he knew his opponent's prize were compared to the outcomes of the

TABLE III

MEAN OUTCOMES TO THE $20 AND $5 PLAYERS IN EACH INFORMATION/COMMON KNOWLEDGE CONDITION OVER ALL INTERACTIONS (DISAGREEMENTS INCLUDED AS ZERO OUTCOMES)

	Common Knowledge		Not Common Knowledge	
Information	$20 Player	$5 Player	$20 Player	$5 Player
Neither player knows both prizes	41.6_{ab}	43.3_{c}	43.5_{a}	48.2
Only the $20 player knows both prizes	34.9_{bc}	45.1_{bc}	40.9_{a}	42.4
Only the $5 player knows both prizes	27.2_{c}	53.6_{ab}	25.0_{b}	42.0
Both players know both prizes	27.2_{c}	56.4_{a}	25.5_{b}	48.8

NOTE: Within a column, means with common subscripts are *not* significantly different from one another using the Mann–Whitney U test ($\alpha = .01$); none were significantly different in the Not-Common-Knowledge conditions for the $5 player.

$5 player when only he knew. In the common knowledge condition, the unique information held by the $5 player led to significantly higher outcomes than those of the $20 player. The same comparison in the not common knowledge condition did not reveal a significant difference.

The unaggregated agreements are presented in Table V.

TABLE IV

FREQUENCY OF DISAGREEMENTS

Information	Common Knowledge		Not Common Knowledge	
Neither player knows both prizes	4/24	(14%)	3/36	(8%)
Only the $20 player knows both prizes	6/30	(20%)	4/24	(17%)
Only the $5 player knows both prizes	5/26	(19%)	18/55	(33%)
Both players know both prizes	5/30	(17%)	9/35	(26%)

NOTE: m/n indicates m disagreements out of n games played, with the percentage of disagreements given in parentheses.

TABLE V

UNAGGREGATED AGREEMENTS

Information	$20–$5 Lottery Percentages: Common Knowledge				Not Common Knowledge			
	45-55	50-50	50-50		45-55	60-40	45-55	
	50-50	40-60	50-50		50-50	50-50	50-50	
	50-50	50-50	50-50		45-55	58-42	50-50	
Neither	51-49	60-40	50-50		40-60	50-50	50-50	
player	45-55	37-60			50-50	50-50	50-50	
knows	50-50	50-50			50-50	30-70	50-50	
both	50-50	45-50		23 agreements	40-60	40-60	50-50	33 agreements
prizes	50-50	50-50			40-60	30-70	40-60	
	50-50	50-50		4 disagreements	50-50	50-50	50-50	3 disagreements
	50-50			(14%)	56-44	50-50	55-45	(8%)
					52-48	40-60	50-50	
	50-50	46-54	45-55		23-77	50-50		
	50-50	45-55	50-50		50-50	50-50		
Only	50-50	47-53	50-50		50-50	50-50		
the $20	50-50	35-65	15-85		30-70	45-55		
player	40-60	65-35			50-50	70-30		
knows	35-65	40-60			50-50	50-50		
both	57-43	50-50			$50\frac{1}{2}$-$49\frac{1}{2}$	48-52		
prizes	55-45	39-61		24 agreements	55-45	55-45		20 agreements
	48-52	40-60			51-49	50-50		
	25-75	20-80		6 disagreements	50-50			4 disagreements
				(20%)	55-45			(17%)

	10-90	45-55		50-50	35-65	40-60	
	40-60	50-50		40-60	20-80	50-50	
	35-65	50-50		25-75	35-65	45-55	
Only	50-50	20-80		50-50	50-50	45-55	
the $5	40-60	$47\frac{1}{2}$-$52\frac{1}{2}$		20-80	45-55	15-85	
player	10-90	20-80		50-50	50-50	40-60	
knows	20-80	49-51		50-50	30-70	$27\frac{1}{2}$-$72\frac{1}{2}$	
both	20-80			20-80	50-50	$27\frac{1}{2}$-$72\frac{1}{2}$	
prizes	30-70			55-45	20-80	21-79	
	20-80			50-50	20-80		
	50-50		21 agreements	50-50	35-65		37 agreements
	10-90			45-55	30-55		
	50-50		5 disagreements	20-80	50-50		18 disagreements
	40-60		(19%)	20-80	49-51		(33%)
	20-80	25-75		25-75	50-50		
	20-80	30-70		15-85	30-70		
	15-85	33-67		25-75	40-60		
Both	20-80	40-60		30-70	50-50		
players	20-80	40-60		25-75	25-75		
know	15-85	40-60		40-60	25-75		
both	20-80	40-60		50-50	20-80		
prizes	25-75	50-50		50-50	$47\frac{1}{2}$-$52\frac{1}{2}$		
	25-75	35-65		40-60	50-50		
	40-60	45-55	25 agreements	10-90	50-50		26 agreements
	40-60	50-50		20-80	50-50		
	35-65	40-60	5 disagreements	20-80	25-75		9 disagreements
		46-54	(17%)	30-70	50-50		(26%)

Discussion

First, consider the agreements only. The results in conditions 1 and 4 of the experiment—the Neither Knows/Common Knowledge and the Both Know/Common Knowledge conditions—replicate the results of Roth and Malouf [**8**]. When neither player knew his opponent's prize, agreements tended to divide lottery tickets equally, and when both players knew both prizes, the observed agreements gave the $5 player a significantly higher share of the lottery tickets. The same can be said of conditions 5 and 8—the Neither Knows/Not Common Knowledge and the Both Know/Not Common Knowledge conditions.

The agreements observed in the other conditions permit us to conclude that the shift from equal-split agreements to agreements favoring the $5 player is primarily caused when the $5 player learns that his opponent has a $20 prize. That is, the agreements observed in conditions 1, 2, 5, and 6, in which the $5 player knows only his own prize, are all close to equal-split agreements. They are different from the agreements observed in conditions 3, 4, 7, and 8, in which the $5 player knows both prizes. These agreements, which are not significantly different from one another, all give the $5 player more than half the lottery tickets. Thus the primary variable influencing the mean agreement reached is whether the $5 player knows both prizes.

The case of disagreements is somewhat more complex. The highest frequency of disagreements was observed in Condition 7, in which it was not common knowledge that only the $5 player knew both prizes. (It is easy to see why this should be so, since in this condition the $5 player knows that he has the smaller prize, the $20 player doesn't know it, but the $5 player doesn't know that the $20 player doesn't know it). In conditions 7 and 8, the two conditions in which it was not common knowledge that the $5 player knew both prizes, the frequency of disagreements was significantly higher than in the other conditions. Thus in the non-common knowledge conditions there is a tradeoff between the higher payoffs demanded by the $5 player when he knows both prizes (as reflected in the observed agreements), and the number of agreements actually reached (as reflected in the frequency of disagreement). This kind of tradeoff was not observed in the common knowledge conditions. A consequence of this (discussed in detail below) is that in the non-common knowledge conditions, in which the players had considerable scope for strategic manipulation, the observed behavior appears to be in equilibrium, while in the common knowledge conditions, in which the players had less scope for strategic manipulation, the observed behavior does not appear to be in equilibrium. It will be convenient to discuss the common knowledge conditions separately from the non-common knowledge conditions, since different kinds of strategies are available to the players in the two sets of conditions.[11]

[11] In analyzing the equilibrium properties of the observed outcomes, we will obviously not be able to analyze the complete strategy sets of the players, since these strategy sets are infinite, involving as they do the choice of both the content and timing of messages. Instead, we will consider whether *observed* strategies were in equilibrium, by considering whether the behavior observed by either kind of player in any condition could have profitably been substituted for the behavior observed by either kind of player in any other condition.

In the four common knowledge conditions, neither player can pretend not to know his opponent's prize when he knows it, or pretend to know his opponent's prize when he doesn't, since these facts are common knowledge. However, when it is common knowledge that exactly one of the players knows both prizes, then that player is free to make any assertion about his own prize, without fear of (confident) contradiction. Thus the $20 player, when he alone knows both prizes, is free to behave in precisely the same way as the $5 player, when *he* alone knows both prizes: the strategy set of the player who alone knows both prizes is not affected by the size of this prize. (And the player who knows only his own prize also has essentially the same strategy set regardless of his prize.) Thus the results in the common knowledge conditions probably do not result from Nash equilibrium behavior, since the overall mean payoff (agreements plus disagreements) to the $20 player when he alone knows both prizes (34.9) is significantly less that the corresponding payoff to the $5 player (53.6). That is, the benefit to the player who knows both prizes of insisting on a larger share of the lottery tickets (as the $5 player did in this position) was not offset by a corresponding increase in the frequency of disagreement, so we can reasonably expect that the $20 players could have increased their overall payoffs by also adopting this strategy.

In the four non-common knowledge conditions, the players have different opportunities for strategic behavior. They cannot misrepresent their own prizes as freely, since they cannot be sure that their prize is unknown to their opponent.[12] But, since neither player knows if his opponent knows both prizes, a player who knows both prizes is always free to behave precisely as if he knew only his own prize. (Of course a player who does not know his opponent's prize cannot behave *precisely* as if he did, since, for instance, he cannot state his opponent's prize). If the observed behavior in these conditions is in equilibrium, it must not be the case that players who do not know their opponent's prize do better on average than those who do, since, if this were the case, a player who knew both prizes could profit from adopting the strategy he would have used if he knew only his own prize. (And, to the extent that a player who does not know his opponent's prize *can* behave as if he did, equilibrium requires that players who do know their opponent's prize do no better on average than those who do not).

First consider the $20 players in the non-common knowledge conditions. A $20 player whose opponent knew both prizes (i.e. in conditions 7 and 8) received a mean overall payoff of 25.5 if he knew his opponent's prize (condition 8) and 25.0 if he didn't (condition 7), which are not significantly different from one another (cf. Table III). A $20 player whose opponent knew only his own prize (i.e., in conditions 5 or 6) received a mean overall payoff of 40.9 if he knew his opponent's prize (condition 6) and 43.5 if he didn't (condition 5) which also do not differ significantly from one another. Thus a $20 player who managed to find

[12]In any event, unlike the common knowledge conditions, in the non-common knowledge conditions there is no significant difference between the mean overall payoff of the $20 player when he alone knows both prizes (40.9) and the mean overall payoff of the $5 player when he alone knows both prizes (42.0).

out whether his opponent knew both prizes[13] could not improve his overall payoff by acting as he would have if his own information about his opponent's prize were different. And a \$20 player who thought it was equally likely that his opponent did or didn't know that his prize was \$20 faced a fifty-fifty gamble of receiving 25.5 or 40.9 if he knew the \$5 player's prize, or a fifty-fifty gamble between 25.0 or 43.5 if he didn't, and, since these two gambles do not significantly differ, he also could not improve his expected overall payoff by acting as he would have if his own information about his opponent's prize were different.

The situation faced by the \$5 players in the non-common knowledge conditions was slightly different, since the \$20 players (unlike the \$5 players) virtually never revealed when they knew their opponent's prize. If we suppose then that each \$5 player thought it was equally likely that his opponent did or didn't know his prize was \$5, then he faced a fifty-fifty gamble of receiving 48.8 or 42.0 if he knew the \$20 player's prize, or a fifty-fifty gamble between 42.4 or 48.2 if he didn't. Since the expected values of these two gambles do not significantly differ, the \$5 player also has no opportunity to improve his expected overall payoff by acting as he would have if his information about his opponent's prizes had been different.[14]

Thus, in the non-common knowledge conditions, the observed outcomes appear to conform to Nash equilibrium behavior.

4. CONCLUSIONS

This paper has reported the third in a series of experiments which use binary lottery games to investigate bargaining. Because agreements in a binary lottery game give each player a lottery between only two possible monetary payoffs, these games meet the conditions needed to be games of complete information, since knowing the feasible lotteries which each player can achieve is the same as knowing the set of feasible von Neumann–Morgenstern utility payoffs to the player.

Roth and Malouf **[8]** showed that information about the monetary value of the prizes (which does not alter the set of feasible utility payoffs) decisively influences the outcome of bargaining, although such information is not reflected in the classical cooperative models of games. Roth, Malouf, and Murnighan **[10]** showed that the effect of such information also could not be accounted for by theories based entirely on classical strategic (noncooperative) models of games, since strategically equivalent variations on the information available to the players were shown to have different effects. Thus, the previously observed effect is due at least in part to the "sociological" content of information about money.

The present experiment explored the component causes of this information effect, and investigated the equilibrium properties of the observed behavior.

[13] Which was often the case, since \$5 players who knew both prizes frequently mentioned the \$20 prize in their messages.

[14] Note that, although the \$5 player's choice of strategy does not influence his own expected overall payoff, the \$20 player's expected payoff is around 25 if the \$5 player acts as if he knows both prizes, and around 40 if he acts as if he doesn't.

Three principal conclusions were reached. First, the effect of information on what agreements are reached is primarily a function of whether the player with the smaller monetary prize knows both prizes. Second, whether this information is common knowledge influences the frequency with which disagreements occur. Third, in the non-common knowledge conditions, the relationship among the outcomes in the various conditions showed virtually no departures from equilibrium.

The last observation strongly suggests that the information effects observed here should properly be the concern not only of descriptive theories of bargaining, but also of prescriptive theories of bargaining among rational agents. That is, since the observed results of the non-common knowledge conditions are in equilibrium, it does not appear that a rational agent in any of these conditions could expect to receive more than the observed payoff, even if he were aware, for instance, of the results of this experiment.

Taken together, these experiments permit us to speculate fairly specifically on the cause of the observed information effects. The first experiment demonstrated an effect of information about the monetary prizes which could not be accounted for in terms of the preferences of the players over the set of consequences (lotteries). The second experiment showed that this effect could not be accounted for by the set of available actions (strategies). The third experiment showed that the effect is consistent with rational behavior. So, if we continue to hypothesize that the players are (approximately) Bayesian utility maximizers, the effect of information must be due to a change in the players' subjective beliefs. Thus, for example, information about the monetary prizes, and whether this information is common knowledge, may influence the players' subjective probabilities concerning what agreements are likely to be acceptable to their opponents. Since outcomes were observed to be at least approximately in equilibrium, it seems likely that such probability assessments are approximately correct so that the appropriate tradeoff exists between the 'toughness' of the bargaining and the frequency of disagreement.

Similar tradeoffs are observed in theories of bargaining under incomplete information (e.g., see Harsanyi and Selten [**2**], or Myerson [**5**]). It thus seems likely that analytic theories of rational behavior can be constructed to account for the phenomena observed here. Such theories will have to deal explicitly with the way in which shared information influences the subjective probabilities of the players.

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NOTE ADDED IN PROOF: In Roth and Schoumaker [**11**], an experiment is reported whose results give direct support to the hypothesis that phenomena of the kind reported here are due to changes in the players' subjective beliefs.

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