Universität Bielefeld/IMW

Working Papers
Institute of Mathematical Economics

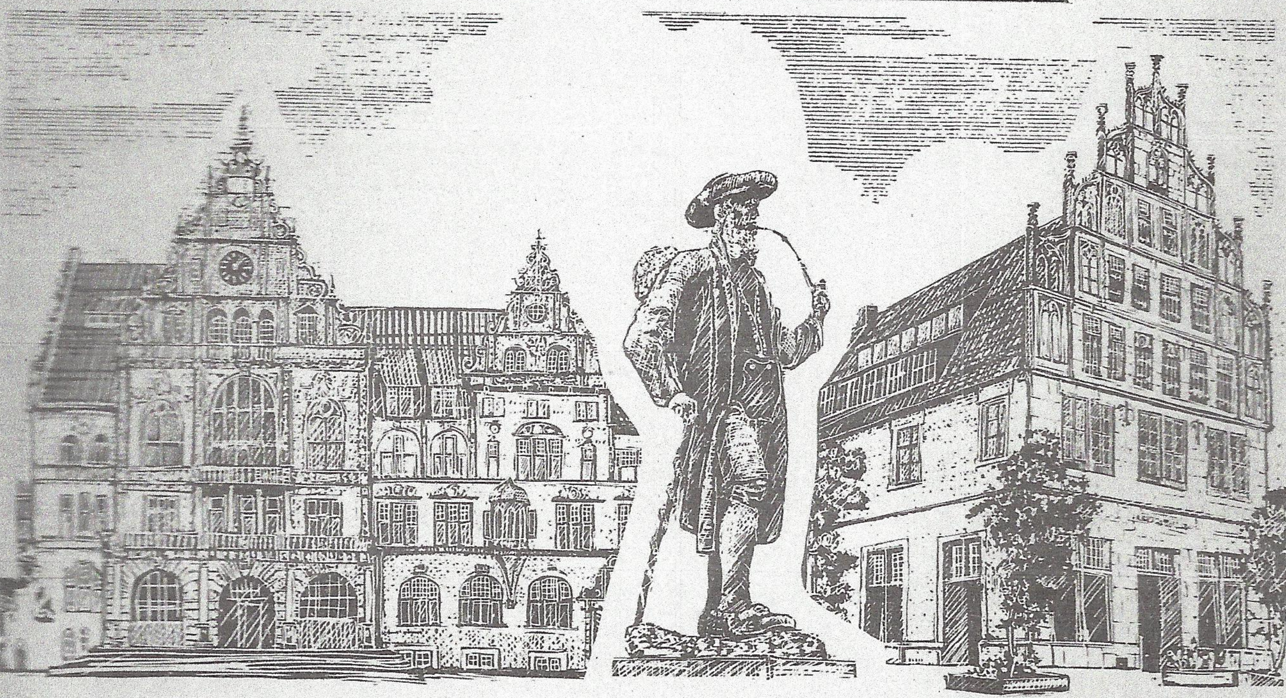
Arbeiten aus dem
Institut für Mathematische Wirtschaftsforschung

Nr. 39

A. Hoggatt, R. Selten
and
D.Crockett, S.Gill, J.Moore

Bargaining Experiments with Incomplete Information

November 1975



H. G. Bergenthal

Institut für Mathematische Wirtschaftsforschung
an der
Universität Bielefeld
Adresse/Address:
Universitätsstraße
4800 Bielefeld 1
Bundesrepublik Deutschland
Federal Republic of Germany

Bargaining Experiments with Incomplete Information

Austin Curwood Hoggatt
Professor of Business Administration
University of California, Berkeley

Reinhard Selten
Professor of Economics
University of Bielefeld
Federal Republic of Germany

David Crockett
Shlomo Gill, Jeff Moore
Research Assistants
Center for Research in Management Science
University of California, Berkeley

Bargaining Experiments with Incomplete Information *

In this paper we present bargaining experiments in a laboratory situation which was guided by a theory of bargaining under incomplete information. First we shall describe the experiment then we present a sketch of the theory and list predictions which stem from it. After discussing the results and the areas of agreement or lack of agreement between theory and experiment we then employ the data from the laboratory to construct a behavioral robot which summarizes our behavioral results and which provides insights into the structure of these bargaining games.

---

* The idea for these experiments was jointly developed by the two senior authors during 1968 when Selten was a Visiting Professor in the School of Business Administration at Berkeley. The theory had already been under development by John Harsanyi and Reinhard Selten. Hoggatt proposed the general format of the bargaining sessions and the use of separate risk-taking experiments prior to bargaining. The first laboratory control program was written by Jeff Moore and it was later extended by David Crockett. Crockett recruited subjects and supervised the 12 sessions in 1969. He also wrote several of the data reduction and analysis programs. These analysis programs were later extended by Gill. The two senior authors shared in the analysis and in the drafting of this paper in Schloss Rheda during June and July 1973 for which period Hoggatt was Visiting Professor of Economics, University of Bielefeld.

1. Description of the Experimental Sessions

All the sessions in the experiment were held in the Laboratory for Research in Management Science. This facility, which has been described in detail elsewhere,[1] has been designed so as to permit the precise control over group interaction of the kind we wished to investigate. It is ideal for the study of non-cooperative games in as much as the space configuration provides for adequate isolation and there is complete control over information exchange which is accomplished via a time-shared computer which has been developed for this purpose by the research group of the Center for Research in Management Science.

In each session six persons were seated in the central section of the laboratory and they were told that they would take part in bargaining games. Then they were each taken to separate cubicles each with its own television monitor and teletype. They were given a brief period to adjust to their environment, an assistant handed them instructions as shown in Figure 1 and then they were left alone to watch a TV tape of Reinhard Selten who gave the instructions verbally to them and illustrated them with examples. Our purpose in using TV-taped briefing was to standardize instructions and to permit each subject to be briefed in isolation.
As it turned out even though they were given opportunity to discuss the procedures with assistants they seldom availed themselves of this privilege. The main experimental purpose of this first half of the session was to obtain data on risk-taking propensity of each subject in simple situations. The sums of money involved in these gambles were selected to be relevant to the amounts which would later arise in the bargaining games which are

---

1) Hoggatt, Austin C., Joseph Esherich and John T. Wheeler "A Laboratory to Facilitate Computer-Controlled Behavioral Experiments, <u>Administrative Science Quarterly</u>, Vol. 14, No.2, June 1969.

our major interest. These measures of bahavior in simple risk-taking situations may then be employed as explanatory variables in the analysis of bargaining. The reader may refer to Figure 1 for a complete description of the situation. The notes which are appended to the text are for purposes of description here and they were not given to subjects.

Figure 1 First Written Instructions

Instructions for Participants in a Bargaining Game

Throughout this experiment you will earn "money units." 1)
These are equivalent to 10¢, and they will be paid in chips and converted to cash after this experiment. In Addition,there will be a bonus of 20% of your earnings 2)
which will be held back according to our agreement.

Before we enter the main part of the experiment, we want to determine your preferences in some risk-taking situations. On the next page is a list of 10 choice-situations to which you will respond on the teletype. You may choose alternative A or alternative B by typing A or B. After each response, the assistant will come to your booth and perform the necessary random experiments. You will then be paid according to your choice of A or B and the outcome of the random experiment. For example, on situation 1, someone who chose "A" with "L" the result of the random experiment would get 0, whereas if "H" had come up, he would have received 50¢. Under alternative "B", no random experiment is needed, and he would receive 10¢ with certainty.

3)

After each situation is resolved, the assistant will enter the payoff on the teletype and signal that the next situation may begin.

4)

The teletype is now asking for your name. Please type 5)
your name followed by the symbol "↑." The teletype will request your ID number which is on the card you received when you entered in the Laboratory. Type your 6)
number followed by "↑." Then you may type your response for the first choice situation. This will continue until all choices have been completed. If you mistype on any situation the question will be repeated until you respond with A or B.

7)

Figure 1 (continued)

Choice Situations

Note: In all choice situations involving random events you will draw a ball from a cloth bag. There will be two balls in the bag on labeled "H" the other "L."

Situation	Money Units : Alternative A	Money Units : Alternative B
1	0 If "L" is drawn 5 If "H" is drawn	1 with certainty
2	0 If "L" is drawn 4 If "H" is drawn	1 with certainty
3	0 If "L" is drawn 3 If "H" is drawn	1 with certainty
4	0 If "L" is drawn 2 If "H" is drawn	1 with certainty
5	0 If "L" is drawn 13 If "H" is drawn	7 If "L" is drawn 10 If "H" is drawn
6	0 If "L" is drawn 14 If "H" is drawn	6 If "L" is drawn 10 If "H" is drawn
7	0 If "L" is drawn 15 If "H" is drawn	5 If "L" is drawn 10 If "H" is drawn
8	0 If "L" is drawn 16 If "H" is drawn	4 If "L" is drawn 10 If "H" is drawn
9	0 If "L" is drawn 17 If "H" is drawn	3 If "L" is drawn 10 If "H" is drawn
10	0 If "L" is drawn 18 If "H" is drawn	2 If "L" is drawn 10 If "H" is drawn

Notes to Figure 1

1) The experiment is parameterized on money units. In this paper all data were collected in situations in which one money unit was 10 ¢.

2) These subjects were also participants in other experiments and the bonus was employed to assure participation in these other, unrelated activities.

3) These activities also acquaint the subjects with the teletype and some procedures which are later encountered in the bargaining sessions.

4) It is important that assistants are in contact with subjects frequently during the first exposure to this kind of task. The subjects are imbedded in a "mechanical" environment and are being paced by a machine. The frequent appearance of the assistant softens the impact of all this on sensitive subjects.

5) Subject names are kept confidential.

6) These ID numbers are unique to each subject and this situation. All data from the experiment are recorded on magnetic tape and become part of the data archive on the CRMS Laboratory.

7) The terminator " ↑ " is employed so that the subject may recover from a typing error. Striking "rubout" caused the input to be ignored.

After the risk-taking decisions were completed each subject received the written instructions of Figure 2 and a briefing tape was played in which Professor Selten presented the instructions of the Bargaining Experiment verbally and illustrated the concepts with numerical examples.

Figure 2 Second Written Instructions

Bargaining Experiment

There are six persons participating in this session and you will play the same bargaining game once against each of the others. In any game two players may divide 20 money units between themselves if they reach agreement. If they reach conflict neither receives any money units. At the beginning of a bargaining game it is decided by a separate random experiment for each player by drawing an "H" or "L" from the bag whether he has high or low cost. High cost = 9 money units, and low cost = 0 money units. These costs are deducted from the payments in the event that agreement is reached. If no agreement is reached then the net payoffs to both players are zero regardless of whether they are high or low cost players.

7)

8)

You will not know the cost of the other player but you will know your own cost and you also know that the cost of the other player was chosen high or low with equal probability independently from the selection of your costs. In any one game you will not know against which of the other participants you are playing. The other player will find himself in exactly the same general situation. 9)

The bargaining is done via teletype and proceeds in discrete stages. At the first stage the teletype will accept your demand for a share which must be an integer no lower than your cost and not higher than 20. In succeeding stages your demand must not be higher than the demand in the previous stage and no lower than your cost. The demand payment will be reported as soon as both bargainers have made demands. If a player's move is not completed within the decision time for a stage the computer will take the demand of that player in the previous stage. The decision time for both bargainers is limited to at most 2 minutes for each stage.

10)

Conflict occurs at any stage for which neither player makes a concession, i.e. both demands remain at the levels set in the previous stage. Therefore if you decide not to make a concession you take the risk of conflict since the other player also might not make a concession. In case of conflict (see above) both players have a net payoff of zero.

Agreement is reached should a stage occur in which the sum of both demands is at most 20 money units. If your demand in the agreement stage is D_1 and the other player's demand is D_2 then your gross agreement payoff is:

$$D_1 + \frac{1}{2}\left[20 - (D_1 + D_2)\right].$$

This means that each player gets his demand and then the amount by which the sum of demands falls short of 20 is split evenly.

If an agreement is reached your net payoff is your gross payoff minus your cost. You will receive this net amount in money units at the end of each play.

At the end of each stage, after the demand of the other is reported to you, you will be required to make a guess about the cost of the other player. If you think he is high cost type "H" and if you think he is low cost type "L". The teletype will not accept your new demand be- 11)
fore you have made this guess.

Examples of how the teletype printout will look are given below:

Example 1

YOUR COST IS: L

STAGE	DEMAND		GUESS	
	YOUR	HIS		
1	19 ↑	17	L	
2	18 ↑	17	L	
3	17 ↑	16	H	
4	17 ↑	16	H	CONFLICT: YOUR NET PAYOFF IS ZERO.

Note: You must type an "↑" after each integer you input. To recover from a typing error type "rubout key." Once you input the "↑" you cannot change your demand. For illegal inputs the message INPUT ERROR will be typed out and the line will be repeated.

Example 2

YOUR COST IS: H

STAGE	DEMAND		GUESS	
	YOUR	HIS		
1	17 ↑	12	L	
2	17 ↑	11	L	
3	16 ↑	8	L	
4	16 ↑	4	L	AGREEMENT: YOUR NET PAYOFF IS 7

We expect you to be motivated by profit and it should be your goal to play in such a way as to earn as much money as you can.

12)

Notes to Figure 2

7) The money unit was previously defined in the risk-taking experiment as 10 ¢. See note 1) to Figure 1.

8) The same device (a bag with 2 balls one labelled "L" the other "H") as employed in risk-taking was used here. This was done with the intent to convince the subject that he was not being manipulated with false information about these random results.

9) This introduces a condition of incomplete information. From the information provided the subject ought to infer that his opponent has equal probability of having high or low cost.

10) The default condition occurred infrequently. This is discussed below.

11) With the guess as an instrumental variable we shall inquire into the state of mind of the player at each stage of the game when he must make a demand.

12) We tell the player we are interested in his behavior when it is motivated by money reward. Payoff on each risk situation and each round was immediately given to the subjects in the form of chips which were calibrated in money units and later were exchanged for cash. No experimental data have been collected by us in which there is an attempt to orient subjects towards cooperation. Suitable modification of the text at this point would make such study possible with little other change in the experimental controls.

In parallel with these subject reports a detailed report is generated for the experiments on a teletype which is located in the main room. It is used to inform assistants when they should go to a cubicle and to assure the experimentators that the process is proceeding correctly. Since this has no bearing on the analysis we do not report on the details here.[2)]

---

2) For details of this control program see CRMS Laboratory Research Report No. 17, Hoggatt, Austin; Selten, Reinhard; Moore, Jeff; Crockett, David : "A Program to Control Bargaining Games under Uncertainty with Regard to State of Opponent."

Subject Selection

Subjects were recruited from the undergraduate population of the University of California at Berkeley. Four sessions were all male, four sessions were all female and four sessions were mixed with (1 male, 5 female), (2 male, 4 female), (2 male, 4 female) and (3 male, 3 female), respectively. Thus 32 males and 40 females took part in the controlled part of the experiment. These 12 sessions were run during fall of 1969. We have data on three more sessions which were less controlled. One was a group of 13 year old junior high school students (girls, boys) who were close friends. This was the pilot session, it was run with a variant of the risk-taking experiments in which a random draw determined for which of the 10 experiments in Figure 1 the subjects would be paid. Difficulties in explaining this idea to the subjects led us to pay off on all 10 risk-taking situations. These data were collected in 1968. The other two sessions were with 12 internationally known game theorists. They participated in the risk-taking experiments but were not paid (and they knew that they would not be paid before-hand). They were paid for the bargaining experiments from a bank which was underwritten by two interested parties. These latter data were collected in summer 1970.

2. Theory of the Game

The game played by the subjects in this experiment can be described as a two person bargaining game with incomplete information. In a game of incomplete information each of the players has certain pieces of information about the nature of the game not known to the other players. In our case this is the knowledge whether his cost is low or high. This information is like a secret personal trait not known to other people. In the theory of games of incomplete information the different states that a player may be in are often referred to as types of that player. Thus in our case each player has two types, L and H where L stands for low cost and H stands for high cost.

For some purposes it is convenient to regard the different types of one player as different players. In this connection we also use the term "subplayer". Consider for example a player in the game of this paper and suppose that he is of type L. He does not know whether the other player is of type L or Type H. In a sense he is up against two opponents, the two subplayers L and H of the other player. The interests of these two opponents are different from each other. In the same way the other player is up against two subplayers of the first player. Altogether there are four subplayers in the game. The strategic situation of the game is that of a four person game between these four subplayers.
A theory for two-person bargaining games with incomplete information has been developed in a paper by John C. Harsanyi and Reinhard Selten.[3)] According to this theory the solution of an incomplete information bargaining game is determined by the maximization of a generalized Nash product which can be written as follows:

$$\pi = \prod_{i=1}^{n} (x_i - w_i)^{p_i}$$

Here the index i refers to the subplayers in the game, numbered

3) John C. Harsanyi and Reinhard Selten, A Generalized Nash Solution for Two-Person Bargaining Games with Incomplete Information, Management Science, Vo.18, No.5, January, Part 2, 1972.

from 1 to n (in our case from 1 to 4). The expected payoff of subplayer i is denoted by x_i and his conflict payoff is denoted by w_i. The conflict payoff w_i is that payoff which subplayer i receives if not agreement is reached. p_i is the probability with which subplayer i occurs in the game.

In our case x_i is the expected net payoff (gross payoff minus cost) and w_i is the conflict net payoff which is zero for all subplayers. p_i is equal to 1/2 for $i = 1,...,n$.

Actually one should make a distinction between the money payoffs and the von Neumann-Morgenstern utilities of the money payoffs. As a theoretical point of departure for the analysis of the game at hand we neglect this distinction and assume that the players' von Neumann-Morgenstern utilities are linear in money.

The region X over which the generalized Nash product π is maximized is not the region of all feasible expected payoff vectors $(x_1,...,x_n)$ but the convex hull of all expected payoff vector connected to strict equilibrium points. A strict equilibrium point is characterized by the property that the expected net payoffs of all subplayers remain unchanged if one of the subplayers uses an alternative best reply.

The game played by the subjects in this experiment is essentially the same game as the numerical example for the general theory which has been described and analysed in detail in a recent paper by one of the authors.[4)] It is not difficult to transfer the results obtained there to the situation examined here.

The numerical example is based on the bargaining model introduced in the above-mentioned paper by Harsanyi and Selten. The experiment reported here uses a simplified

---

[4)] Reinhard Selten, Bargaining under Incomplete Information - A Numerical Example, in: Otwin Becker and Rudolf Richter (eds.), Dynamische Wirtschaftsanalyse ,J.C.B. Mohr (Siebeck), Tübingen 1975, pp. 203-232.

version of the same model. Contrary to the model of the general theory the subjects were not permitted to increase their demands or to demand less than their costs. Moreover in the experiment the case where both demands add up to less than 20 automatically leads to agreement, whereas the general theory handles the same situation in a more complicated way. We shall not describe in detail how the examination of the numerical example needs to be adapted to these simplifications.

In the following we shall exhibit an approximate solution of the game played in the experiment. It can be shown that in terms of the generalized Nash product the approximate solution is near to the true solution.[5)] Moreover the approximate solution permits a relatively simple kind of behavior.

In the general theory proposed by John Harsanyi and Reinhard Selten the solution is not an equilibrium point but rather an equilibrium payoff vector; equilibrium points with the same payoff vector are regarded as equivalent. A whole class of strict equilibrium points can be found which yield the approximate solution as expected payoff vector. The members of this class are called representations of the approximate solution.

One of the representations of the approximate solution deserves our special attention. It seems to be simpler than other representations and more economical in terms of the number of stages needed until the end of a play. We call this equilibrium point the main representation of the approximate solution. In view of its simplicity it seems to be justified to single out the main representation as a theoretical prediction which permits a meaningful comparison with the results of the experiment.

---

5) The exact sense in which one can speak of an approximate solution is explained in R. Selten, Bargaining ..., op.cit., p. 221 and p. 229.

The essence of the main representation can be seen most easily in Figure 3 which shows theoretical demands for both types.[6)] A type H subplayer always demands 14 and a type L subplayer

type	stage 1	stage 2	stage 3
H	14	14	14
L	14	10	6

Figure 3: Theoretical Demands for Types H and L.

first asks for 14 then for 10 and finally for 6. More than 3 stages cannot occur. If both players are of type H then the game ends in conflict. Both players repeat their demands 14 in the second stage. If both players are of type L then agreement is reached at the second stage. Both players receive 10. If an H player meets an L player then agreement is reached at stage 3. The H player receives 14 which corresponds to a net payoff of 5 and the L player receives 6. The net payoffs resulting from the 4 type combinations are shown in Figure 4.

---

6) In the numerical example of R. Selten, Bargaining under Incomplete Information, op.cit., the sum to be split is 100 and the smallest money unit is ε. Here the sum to be split is 20 and the smallest money unit is 1. The main representation described in the above-mentioned paper must be adapted to this. Thus for example in the experiment reported here the demand 14 corresponds to the demand $75-\varepsilon$ there.

	H	L
H	0, 0	5, 6
L	6, 5	10, 10

Figure 4: Theoretical Net Payoffs.
The number in the upper left corner is the net payoff of the player whose type is indicated in the row, the lower right corner gives the net payoff of the player whose type is indicated in the column.

Since each of the both types occurs with probability 1/2 the expected net payoffs are as follows:

	expected net payoffs
type H:	$.5 \cdot 0 + .5 \cdot 5 = 2.5$
type L:	$.5 \cdot 6 + .5 \cdot 10 = 8.0$

The demands in figure 3 do not give a full description of the equilibrium strategies of both types. Figure 3 contains the theoretical demands of the equilibrium plays which may result if both players stick to their equilibrium strategies, but it does not tell us what a player is supposed to do, once he has observed something which should not have happened according to figure 3. A full description of the equilibrium strategies must cover all possible situations including those which cannot arise if the equilibrium strategies are played. A lot of detail has to be supplied which is of little interest with respect to the purposes of this paper. Therefore we shall not engage in the tedious task of giving a full description of the main representation.[7)]

The equilibrium character of the main representation is not obvious. In order to prove that a strategy combination is an equilibrium point, one has to look at all possible deviations. This shall not be done here. We shall discuss only one possible deviation which is of special theoretical importance: a type L subplayer behaves as if he were a type H subplayer. In the following this kind of behavior will be called "bluffing".

If the subplayers of the other player behave as prescribed by the main representation of the approximate solution, then bluffing does not pay. Bluffing yields 14 against a type L player and 0 against a type H player. The expected payoff is $.5 \cdot 14 + .5 \cdot 0 = 7$ which is less than the expected payoff of 8.0.

In order to understand the nature of the main representation it is useful to compare it with other strategy combinations of the same general structure. Suppose that in figure 3 the numbers 14 and 6 are substituted by m and 20-m, respectively, wherever they occur; here m is an integer not below 10 and not above 20. In this way we can construct modifications of the main representation which we shall call m-modifications.

The only case of an m-modification where no conflict is reached between two H players is the case m=10. Here agreement is always reached at gross payoffs of 10 for both players, independent of the type combination. For $m > 10$ the

---

7) The main representation is fully explained in R. Selten, Bargaining ..., op.cit.. Of course, the equilibrium strategies described there must be adapted to the simplified bargaining rules underlying the experiment reported here.

situation is similar to that of the main representation; conflict is reached between two H players and agreements are reached for all other type combinations.

We shall now explain why m=14 is theoretically superior to all m-modifications with m=14.

EXPECTED NET PAYOFFS

m	type H	type L follow-ind the rules	type L bluffing	generalized Nash product
10	1.0	10.0	10.0	10.0
11	1.0	9.5	5.5	9.5
12	1.5	9.0	6.0	13.5
13	2.0	8.5	6.5	17.0
14	2.5	8.0	7.0	20.0
15	3.0	7.5	7.5	22.5
16	3.5	7.0	8.0	24.5
17	4.0	6.5	8.5	26.0
18	4.5	6.0	9.0	27.0
19	5.0	5.5	9.5	27.5
20	5.5	5.0	10.0	27.5

Figure 5: m-Modifications of the Main Representation

As we can see from Figure 5 from m=16 on upwards it is advantageous for a type L player to bluff. This means that for m=16,...,20 the m-modifications of the main representation fail to be equilibrium points. For m=15 we receive an equilibrium point but it fails to be a strict one. This is due to the fact that here bluffing is an alternative best reply for a type L player. If this alternative best reply is used by the type L subplayer of one player, then the type H subplayer of the other player will receive a net payoff of O. A strict equilibrium point is characterized by the property that the expected payoffs remain unchanged if one of the subplayers uses an alternative best reply. Obviously this is not the case here.

Among the remaining cases m=10,...,14 the case m=14 is that with the highest generalized Nash product. As m is increased the relative increase of the expected payoffs of the type H subplayers outweighs the relative decrease of the payoff of the type L subplayers.

3. Predictions Derived from Theoretical Considerations

The theory of the main representation of the approximate solution yields several predictions which can be compared with the data. To some extent these predictions do not depend on the fact that we have singled out the main representation. Thus the prediction about conflict is true for all possible representations of the approximate solution.[8)]

Prediction about conflicts: Whenever two players of type H play against each other, conflict will result. In all other cases agreement is reached.

Without knowledge of the theory this prediction may seem to be counterintuitive. One might think that two players of type H should always reach an agreement at gross payoffs of 10 for each of them since this is advantageous for both of them.

Prediction about agreement payoffs: If a player of type H reaches an agreement with a player of type L, then the player of type H will get a gross payoff of 14 and the player of type L will get a gross payoff of 6. Two players of type L will reach an agreement where each of them gets a gross payoff of 10.

Prediction about first stage behavior: The first stage behavior of a type L player is the same as the first stage behavior of a type H subplayer.

---

8) See R. Selten, Bargaining ..., op.cit. p. 230.

The fact that at stage 1 both types behave in the same way is not an arbitrary feature of the main representation.[9] A type L player does not prematurely reveal the weakness of his bargaining position. Thereby he deters the type L subplayer of the other subplayer from bluffing. The type H subplayer on the other side has to demonstrate his strength by taking the risk of conflict.

One may imagine other representations of the approximate solution where the first stage demands of both types are equal to each other but different from 14. Thus for example both types might begin to demand 19 and then go down step by step until they reach 14, from where on they might behave analogously to Figure 3.

Prediction about the knowledge of the other player's type: After the game is over each of both players knows the type of the other player.

In a sense this prediction can be regarded as a conclusion from the predictions about conflicts and agreement payoffs. If the players expect conflicts and agreement payoffs to occur in this way, they will be able to deduct the other player's type after the game is over.

4. Structure of the Data Base

At the conclusion of an experimental session the experimenter has a file of records on magnetic tape which unambigously specify each demand for each of 6 subjects in the 5 games that each played and the ten risk-taking choices which he made together with the outcome of each random experiment. The computer also has a real time clock so that in addition to each demand and guess it is possible to record response latency for each (in tenths of seconds). Thus we have available an additional physio-psychological variable which

---

9) See R. Selten, Bargaining ..., op.cit.,pp 218-219.

may be of use in studying the behavior of subjects in these situations. There are 11899 pieces of information in our main experimental data base. These were collected in approximately 18 hours of laboratory time. Once the date were collected in this form on the lab-computer they were transferred to file sets at the Campus Computer Center and all of the facilities of a large data processing center became available for analysis. Since Time Sharing is not available at the Berkeley Computer Center it was found that hand computation of many of the tests was superior to programming these tests for the large processor hence many of the results reported below were computed by hand.

5. Comparison of the Theory with the Data

In the following we shall compare the theoretical considerations of section 3 with the experimental results.

Conflict frequencies: Figure 6 shows the theoretical and the actual conflict frequencies for the four type combinations.

	H	L
H	1.00	.00
L	.00	.00

theoretical conflict frequencies

	H	L
H	.729	.471
L	.471	.097

observed conflict frequencies

Figure 6: Theoretical and Observed Conflict Frequencies.[10)]

The observed conflict frequencies show a weak tendency in the direction of the theory. Where the theory predicts that conflict occurs with probability 1, the observed conflict frequency is

---

10) The table is slightly redundant since the mixed case with one type L and one type H player appears twice.

high. Where the theory predicts 0 conflict probabilities the observed conflict frequencies are low (in the case of two type L players) or at least lower than .5 (in the case of one type L and one type H player). This weak tendency in the direction of the theory is not trivial, since a superficial analysis of the game may easily come to the conclusion that there should be no conflict at all, since mutually profitable agreements are possible for each of the type combinations.

Agreement payoffs: The theory presented in the last section yields some predictions about the agreement payoffs in situations with at least one L player. The observed distributions are shown in Figure 7.

LL-agreements		LH-agreements	
Lower payoff	number of cases	payoff of the L player	number of cases
3.0	2		
3.5			
4.0		4.0	4
4.5	1	4.5	1
5.0	3	5.0	3
5.5	1	5.5	2
6.0	6	6.0	2
6.5	1	6.5	
7.0	7	7.0	3
7.5	4	7.5	2
8.0	4	8.0	
8.5	1	8.5	1
9.0	7	9.0	4
9.5	5	10.0	8
10.0	14	10.5	
		11.0	3
	56		33

mean: 7.83

Figure 7: Observed Agreement Payoffs for LL-Agreements and LH-Agreements.

Here and in the following the letter combinations LL, LH and HH refer to the type combinations with two type L players (LL), with one type L and one type H player (LH) and two type H players (HH).

For the sake of completeness it should be mentioned that there were altogether 13 HH-agreements, 12 of which had gross payoffs of 10 for both players; the remaining one had gross payoffs of 9.5 and 10.5.

The distributions of the observed LL-agreements and LH-agreements do not support the theoretical prediction that in LL-agreements both players receive payoffs of 10 and that in an LH-agreement the type L player receives 6.

The two distributions are quite similar to each other. The Kolmogoroff-Smirnov Test does not show a significant difference between them. In both distributions about one quarter of all cases are equal divisions of the total gross payoff.

It is interesting to look at the reasons for the occurrence of so many cases of LL-agreements where one player received more than the other. One may be tempted to think that the player with the higher payoff achieves this result by some kind of bluffing behavior which involves repetitions of demand in order to convey the impression that he is a type H player. Actually in 25 of the 42 cases of LL-agreements with unequal payoffs the player with the higher agreement payoff did not repeat his demand even once. Obviously in these cases the other player either had a lower initial demand or he lowered his demand more quickly. The player with the higher agreement payoff did not have to do anything special in order to get the higher payoff. If just happened to him that the other behaved in a "soft" way.

<u>First demands</u>: The theory predicts that in the first stage a type L player makes the same demand as a type H player.

This prediction is not confirmed by the results of the experiments. The first demand of a type H player tends to be higher than that of a type L player. This is true for all 5 rounds. (See Figure 8).

Round	Situation H	Situation L	Difference	Unweighted Average of values for situations H and L
1	18.13	15.70	2.43	16.92
2	17.53	16.99	.54	17.26
3	18.05	16.99	1.06	17.76
4	18.43	17.59	.86	18.01
5	18.48	17.91	.57	18.20

Figure 8: Average First Demands (Unweighted Averages of Game Averages).

After observing the first demand of his opponent, a player has to make a first guess on his type. This first guess is influenced by the expectation that first demands of type L players tend to be lower than those of type H players. As we have seen the observed behavior justifies this expactation. Figure 9 shows the frequencies of first guesses H and L in dependence of the opponent's first demand.

Opponent's first de-demand	number of cases with first guess H	number of cases with first guess L	relative frequency of first guess H
9	-	5	.00
10	1	9	.10
11	-	4	.00
12	2	4	.33
13	1	4	.20
14	2	3	.40
15	10	24	.29
16	6	12	.33
17	18	17	.51
18	51	19	.73
19	100	21	.83
20	44	3	.94

Figure 9: Frequencies of First Guesses: Dependece on the Opponent's first Demand.

The Spearman rank correlation coefficient between the opponent's first demand and the relative frequency of first guess H is equal to .926 ($p < 0.01$). The table suggests that the first guess tends to be L for opponent's demands up to 16 and H for higher demands.

Last guess: The theory predicts that after the end of the play both players will know the other player's type. Since the last guess is made after the end of the play this prediction can be compared with the data. 64% of all last guesses were correct. This shows that at the end of the play the knowledge of the other player's type is better than before the beginning of the play , but not much better. Figure 10 shows the relative frequencies of correct first guesses among all first guesses, of correct guesses among all guesses and of correct next last guesses among all next last guesses. The next last guess is that guess which was made just before the stage which ended the play.

	relative frequency
correct first guesses	.52
correct guesses in all stages	.55
correct next last guesses	.59
correct last guesses	.64

Figure 10: Relative Frequencies of Correct Guesses.

Note that the percentage of correct guesses increases during the course of the game. Obviously the bargaining process reduces the incompleteness of the information as one would expect from theoretical considerations but this reduction is much smaller than the theory suggests.

Bluffing and Weakness: As we have seen in the previous section according to the theory it cannot be advantageous for a type L player to behave as if he were a type H player. Such behavior is called bluffing. We may ask whether bluffing occurred in the experiment. Since we have no data on the intentions of the players we need some operational definition of bluffing which allows us to investigate this question. We shall approach this problem by identifying bluffing with a mode of behavior which strongly indicates that a type L player tries to get a greater gross agreement payoff than his opponent and also is willing to take the risk of conflict in order to achieve this. We say that bluffing occurs if a type L player whose last previous demand was greater than that of his opponent repeats his demand in the current period. Figure 11 shows that in this situation the relative frequency of the bluffing response is 13%. This means that bluffing does occur but we also know that bluffing is not the main causal factor leading to unequal agreement payoff divisions between two type L players, since as we have seen already in 25 out of 42 such cases the player with the higher agreement payoff did not repeat his demand even once.

My gross demand greater than his

type	yield 0	yield 1	yield > 1	number of cases
L	.13	.71	.17	417
H	.36	.54	.10	511

My gross demand equal to his

type	yield 0	yield 1	yield > 1	
L	.18	.66	.16	170
H	.23	.63	.14	192

My gross demand less than his

type	yield 0	yield 1	yield > 1	
L	.28	.54	.18	536
H	.50	.41	.09	392

Figure 11: Yielding Behavior for Different Gross Demand Conditions and Types.

"My gross demand greater than his" means that in the previous stage the player had a greater gross demand than his opponent. The yield is the amount by which the player's new demand is lower than his last previous one. It often happens that a type H player does not repeat his demand in spite of the fact that in the last previous stage his gross demand was already lower than that of his opponent. This kind of behavior may be called weakness. As we can see from the table the relative frequency of weakness is 50% which is much higher than the relative frequency of bluffing.

Measurement of risk-taking behavior: In the risk-taking experiment the alternative A was always the more risky one. Therefore the number of A responses is a measure of the subjects willingness to take risks. This variable ranged from 4 to 10.
Figure 12 shows how the subjects responded.

choice situation	relative frequency of A response
1	.99
2	.92
3	.83
4	.47
5	.08
6	.22
7	.36
8	.83
9	.89
10	.96

Figure 12: Relative Frequencies of A Responses to the Choice Situations in the Risk-Taking Experiment.

29 subjects made choices which in all cases were in harmony with the expected money value maximization hypothesis. Among the remaining 43 subjects there were 23 whose choices were in-

consistent in the sense that they cannot be reconciled with the hypothesis that the choices are guided by a monotonically increasing utility function for money payoffs which is the same for all 10 choice situations. These inconsistencies are of very simple nature: a subject was counted as inconsistent if either in choice situations 1 to 4 a choice B was followed by a choice A or in choice situations 5 to 10 a choice B was followed by a choice A. Since in both sequences the difference between the utility of choices A and B is increasing for any monotonically increasing von Neumann-Morgenstern utility function for money payoffs, a subject with a reasonably stable utility function for money payoffs should not show such behavior. One might argue that a rational subject has a utility function for his asset position rather than a utility function for money payoffs but since the money amounts are small, comparisons between additional utilities for money should not change much in the course of the experiment. Therefore we are inclined to think that the observed inconsistencies are real behavioral inconsistencies and not an artifact caused by a misspecification of the utility function. The fact that about 32% of the subjects made inconsistent choices in the risk-taking experiment, throws serious doubts on the applicability of arguments about subject behavior which are based on utility theory.

6. Measures of Risk-Taking Propensity, Choice Inconsistency and Dropping

From the unlimited number of measures which may be defined on the sequences of ten choices which are made in the risk-taking experiment we shall consider only two. First, as we have already discussed, we have Subject Risk-Taking Propensity $\equiv$ number of A's chosen. In each situation alternative A has a larger variance than alternative B, so to choose A is to undertake risk and to choose B is to avoid risk. Thus the count of the number of A choices is a measure of the risk-taking propensity of the subject.

A natural measure of inconsistency would be the count of the minimal number of reversals of A and B which are required to produce a consistent sequence of choices under the definition of section 5. So we have

> Subject Inconsistency in Risk-Taking ≡ minimal number of reversals of A and B alternatives in the sequence of risk-taking choices which are required to produce a consistent sequence of choices under the hypothesis of a monotonically increasing utility for money.

Defining 0 on this index to be associated with consistent behavior and values greater than 0 to be associated with inconsistent behavior we saw in the previous section that 23 of our subjects were inconsistent in their risk-taking behavior. One would expect this to be associated with other measures of behavior but to our surprise no significant correlations were found.[11)]

Another opportunity to display inconsistent behavior occurs during play of the game when a guess of H could occur at a stage when opponent's demand was below 9 (recall that a high cost player cannot demand less than 9). Only two subjects actually made this error in guessing, so there was no possibility of relating this behavior to other kinds of behavior.

Dropping: The final category of behavior which we consider in this section is one we have termed "dropping." During play of the game this involves yielding more than would be called for under any possible construction of the strategic situation. In this category we include all yields of two or greater which take the demand from above 10 to 10 or lower, together with initial demands of 10 or less. In view of our experimental results we feel that dropping is disadvantageous since it yields bargaining room in situations where it is not necessary. Note that this is

---

11) In section 8 we report on sex dependence of inconsistent behavior.

not necessarily non-rational since the game theoretic analysis of the game produces an equilibrium strategy which specifies dropping in the condition where a low player faces a high player. Each of our 72 subjects had 5 opportunities to exhibit dropping behavior,so there were 360 opportunities. In all there were 104 drops so that the relative frequency of drops is .289. We may test for subject independence of this behavior by counting the number of drops which occurred for each subject and computing the expected number of drops from the overall probability under the assumption of independence. This table is shown in Figure 13. Clearly we may reject the hypothesis that dropping is subject independent.

	Number of Subjects with 0 drops	Number of Subjects with 1 drop	Number of Subjects with 2 drops	* Number of Subjects with > 2 drops
Observed Number	23	21	12	16
Expected Number	13.1	26.6	21.6	10.7

$\chi^2 = 15.56$ (two degrees of freedom) $p < .001$

Figure 13: Test for Hypothesis that Dropping is Subject Independent.

*cells with 3, 4 and 5 drops collapsed to provide for conservative use of χ^2-test. The value of these cells is:

Number of Drops	0	1	2	3	4	5
Number of Subjects	23	21	12	9	3	4

7. Determinants of Global Performance

In this section we examine relationships which may exist among our several measures of behavior with particular emphasis on net payoffs which we take as our global measure of performance. We cannot simply average the values of our several variables with regard to each subject. While all start each session with equal strategic opportunities the random selection of costs produces differential strategic situations. In each round there are four possible strategic situations in which a subject may find himself. These correspond to the four possible combinations of own cost and opponents cost. Thus we will find it necessary to normalize our variables by measuring them from the mean values which obtain for each of these four strategic situations. These average values for normalization are given in Figure 14.

We note that the probability of first guess H is .65 which is much greater than .5. This tendency toward guessing high we have termed H-bias.

Our method is as follows. For each subject and each round we determine the strategic situation and then subtract the appropriate mean value to normalize that observation. On completing this step we have 360 normalized observations on each of the global variables. Within each of the 12 sessions these observations are averaged by round and subject to produce average values for each session. Rank correlations on these 12 observations are then computed between all pairs of these global variables. The variable names and definitions together with the rank correlation coefficients are given in Figure 15. It should be pointed out that statistical analysis at this level has a high level of integrity. Sessions are statistically independent. With each session mean based on a large number of cases we are in an ideal situation with regard to the power of our statistical tests. In order to facilitate the discussion we repeat here the definitions of these several variables.

Strategic Condition own cost	opponent's cost	Conflict Probability	Net-Payoff	Drops	Repeating Frequency
L	L	.097	9.03	.403	.2248
L	H	.471	4.14	.329	.2410
H	L	.471	1.67	.186	.3491
H	H	.729	.27	.188	.3801

Figure 14: Average Values for Normalization of Global Variables.

Number of A's	≡	Count of the number of A alternatives in the risk-taking experiment
Average First Demand	≡	Unweighted average of all first demands in a session
H-bias	≡	Relative frequency of all first guess H in a session
Normalized number of drops	≡	for each subject round count drops = 1 and no drop = 0, then subtract the overall relative frequency of drops for the appropriate strategic condition - average these over the session
Normalized conflict frequency	≡	for each subject round count conflict= 1 and agreement = 0, subtract the overall relative frequency of conflict for the appropriate strategic condition - average these over the session
Normalized repeating frequency	≡	number of yields of 0 minus corrected number of stages where, yields of 0 were not counted if they were made by an H player with demand of 9 or 10 and where, corrected number of stages is the number of stages up to a demand of 9 or 10 by an H player
Normalized net payoff	≡	for each subject round subtract from net payoff the average net payoff for the appropriate strategic situation - sum these over the session.

Coefficients (All cases were averaged across rounds and subjects to yield one independent observation per session).

	Average First Demand	H-bias	Normalized Number of Drops	Normalized Conflict Frequency	Normalized Net Payoff
No. of A's	+.397	+.374	-.197	+.567	-.744
Average First Demand		+.670	-.241	+.420	-.368
H-bias			-.529	+.588	-.306
Normalized Number of Drops				-.832	+.594
Normalized Conflict Frequency					+.762

Figure 15: Global Variables and their Pairwise Rank Correlation.

Note: Correlations with single underline are significant at .05 level and correlations with double underline are significant at .01 level. Normalized repeating frequency failed to show a significant correlation with any other global variable so it has been deleted from this table.

This matrix begins to reveal a structure of global relationship holding for sessions. It is surprising that normalized number of repeated demands has no significant correlation with other global variables. In as much as the action of repeating a demand is the strongest signal of "toughness" which can be sent to an opponent our prior expectation was for strong relationships for this variable. The other variables, however, do seem to be related to each other in an interesting way. In Figure 16 we have imposed one possible

pattern of causality on the relationships. This is , of course, subjective but it represents our best estimate of the structure which we can derive from theory, experimental observation, analysis at lower levels of aggregation and intuition.
In our diagram we show number of A's, normalized number of drops and average first demands as primary variables. Since risk-taking occurs prior to play it is natural that causality should obey temporal order for this variable. First demands occur early during play so it is also natural to make other measures dependent on them. Dropping has been shown to be subject dependent and as such it is natural to make game outcomes depend on this behavioral trait. Normalized conflict frequency and H-bias are shown as intervening variables.

The causal relationships are shown by connecting lines; the direction of causality is indicated by arrows. The causal nature of the connection between H-bias and normalized conflict frequency is unclear; therefore no arrow is attached to this line. The broken line between normalized number of drops and normalized net payoff indicates that we interpret this correlation as the result of the stronger connection of both variables to the intervening variable normalized conflict frequency.

High numbers of A's are connected with high normalized conflict frequencies and with low normalized net payoffs. As one would expect risk-taking leads to conflict and conflict reduces net payoffs but note that the rank correlation between the number of A's and normalized net payoffs (-.744)is stronger than the rank correlation between number of A's and conflict frequency (+.567). This shows that the influence of risk-taking on the frequency of conflict does not fully explain the influence of risk-taking on normalized net payoffs. It is not only important how often conflicts occur but also where they occur. Conflicts which involve L players are more costly in terms of total net payoffs than conflicts in the HH-condition. As we shall see in section 8 higher levels of risk-taking are associated with less conflicts in the HH-condition and with more conflicts in

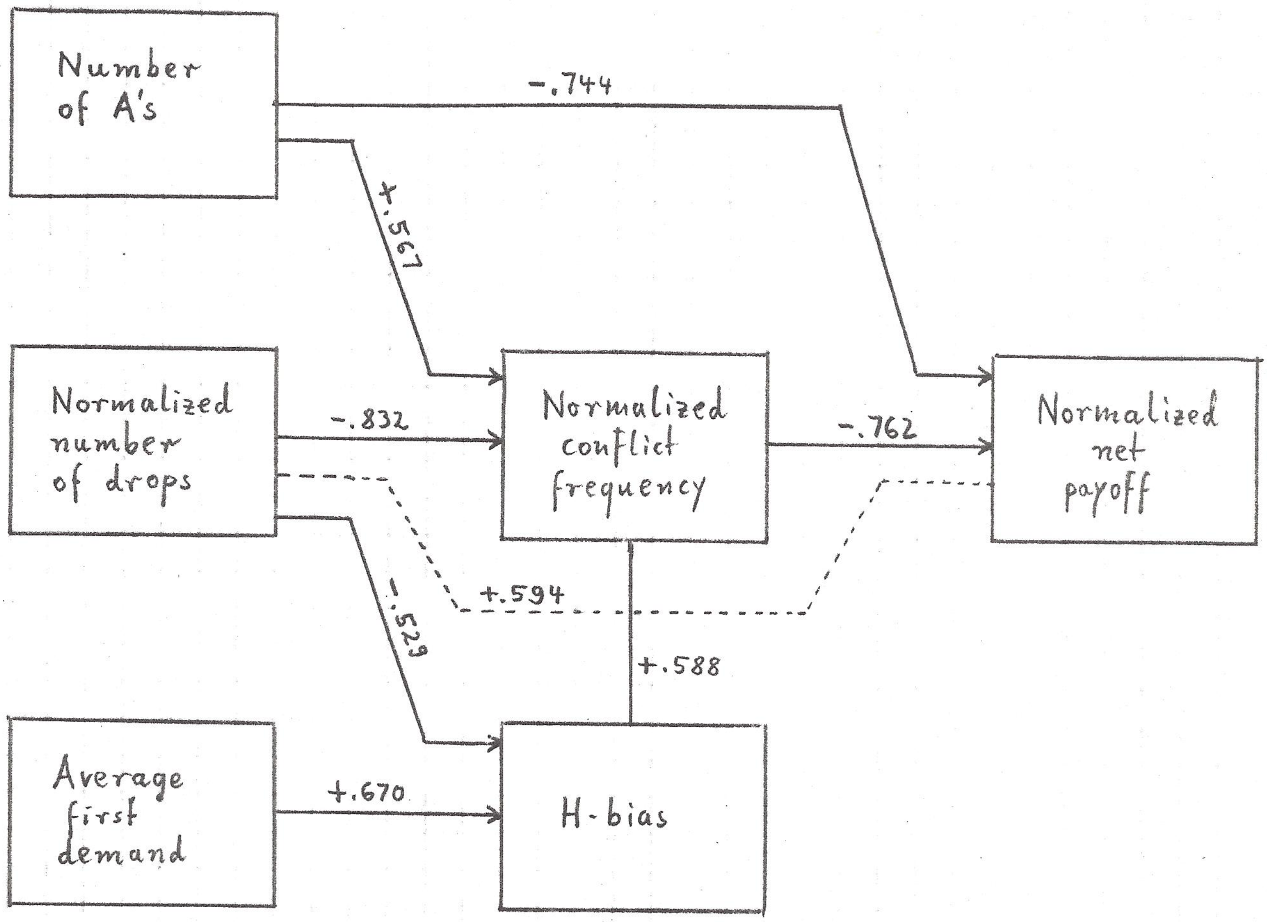


Figure 16: A Plausible Causal Structure at the Global Level.

the other conditions. Higher levels of risk-taking do not only produce more conflict but also more costly conflict. This explains why the number of A's is more strongly connected to normalized net payoffs than to normalized conflict frequencies.

Droppers tend to avoid conflict and hence this trait is positively associated with net payoff (albeit that of the other player). High first demands tend to be associated with H-bias which is positively associated with normalized conflict frequency. Having thus established a structural relationship between risk-taking and performance we will examine this relationship in greater detail in the following section.

8. Risk-Taking Behavior, Consistency and Play Performance

In section 6 we developed measures of risk-taking and consistency. We have systematically investigated the relationship of these variables and other subject attributes. Only the count of the number of inconsistencies in choices has displayed a relationship with the sex of our subjects. The contingency table of consistent-inconsistent risk-taking vs. sex is shown in Figure 17. This table shows an association which is significant at the .05 level, we may conclude that females tend to be inconsistent in risk-taking. However, this trait is not correlated with other measures in this experiment.

	Male	Female	
Consistent Choices	27	22	49
Inconsistent Choices	6	17	23
	33	39	72

$\chi^2 = 4.204 \qquad p < .05$

Figure 17: Consistency of Risk-Taking and Sex of Subject.

Propensity to Take Risks and its Relation to Conflict Frequency

We may inquire into the relationship between propensity to take risks and frequency of conflict by examining individual pairings of subjects. We take the number of As of both subjcts in a round, note whether they ended in conflict or agreement and average the sums of As by strategic situation and Agreement-conflict. These results are displayed in Figure 18.

Strategic Situation	Outcome Agreement	 Conflict	U-Test (one tailed)
LL	13.161	14.333	p < .00003
LH-HL	12.838	13.333	p = .00003
HH	13.462	12.714	p = .12 reversed
L in LH-HL(double)	12.594	13.212	p = .15
H in LH-HL(double)	13.081	13.455	p = .04

Figure 18: Average Number of A's for Pairs of Subjects by Strategic Situation and Agreement or Conflict.

These means are not sharply divergent. That we have a strong result is due to the large number of cases. The results for LL and LH-HL situations are in the intuitive direction - higher number of A's for a pair is associated with an increased frequency of conflict. However, when we examine situation HH, we find that a high number of A's for a pair of bargainers tends to be associated with agreement. This reversal bears further study. To do this, we examine average repeating frequency for players in LL and HH condition and examine its dependence on the number of As.
These data are presented in Figure 19.

Number of A's	LL Average Repeating Frequency	HH Average Repeating Frequency
4	.197	.528
5	.144	.394
6	.177	.399
7	.175	.420
8	.303	.228
9	.390	.262
10	.623	.385
	$r_s = .750$	$r_s = -.714$
	($p < 0.05$)	($p < 0.05$)

Figure 19 : Average Repeating Frequency* for LL and HH Strategic Situations by Number of As for each Player.

* player averaged. The same subject is counted as many times as it occurred in LL plays. The other averages computed in the same way.

With this result we can now understand the reversal in Figure 18. Risk-takers are attracted by large payoffs and they are more likely to repeat a demand if there is a possibility of a large net payoff. A small additional net payoff does not induce them in the same way to take the risk of loosing a small net payoff.

This result illustrates the value of sequential analysis on a large data base. Given the anomoly in Figure 18, we were led to search for an explanation by making a finer breakdown of the data - because we have a large data base, this was successful in the present instance.

9. Learning and Asymptotic Behavior

9.1 Latency of Decision Making

Learning has to do with change in behavior over time in response to experience. The game theoretic approach does not lead to predictions with regard to this aspect of behavior. Rather we fall back on general experience and bring to the analysis an expectation that subjects will learn during the play of these games in extensive form and we expect to find evidence of this in the data. Each subject plays 5 rounds of bargaining one with each of the other 5 subjects in his session. As these rounds occur sequentially in our design[12] we may aggregate behavior by rounds and look for systematic variation by rounds.

Latency is measured at two points in each stage of the bargaining. Referring to the teletype output format as shown in Figure 2 we see that the teletype prints the stage number then spaces and waits for input of a demand. Demand latency for each subject stage is the time recorded in 10th of seconds from the time the computer entered the wait on subject response until the " ↑ " was typed after a legitimate demand. Correction by subject or rejection by computer leads to larger than normal values for demand latency **and failing to strike " ↑ " leads to a default after** 120.0 seconds without completion of legitimate input. This default procedure is necessary. Otherwise a subject may place the entire experimental process in a state of indefinite delay. As the latency in such a case is 2 orders of magnitude larger than the mean latency, we have suppressed these cases in taking averages. (There were 9 such cases in the 12 main sessions, 8 of which occurred in round 1. They may have been generated by curiosity about what would happen but were most likely related to forgetting that the terminator was required).

---

12) With our method of computer control it is not necessary for rounds to be sequential. For an example of a game which rounds were in parallel see, Hoggatt, Austin, "Response of Paid Subjects to Differential Behavior of Robots in Bifurcated Duopoly Games" ; Review of Economic Studies, Vol. XXXVI, Oct. 1969, pp. 417-432.

Guess latency is defined as the time in 10th of seconds that the computer waits from the point at which the carriage spaces to the "GUESS" column. In this case we decided to prompt the subject after an 30 sec. wait and we programmed the machine to type a message "GUESS HIS COST". This prompting was rarely required. Since this is a single character response no terminator is required. The absence of delay at this stage reinforces our belief that nonresponse at the demand input was related to forgetting to press the "↑".

Average latency by rounds is reported in Figure 20. The first thing we notice is that there are small numbers. Overall these decisions are being made very quickly. Secondly, latencies are diminishing uniformly over rounds with 5th round values less than half that of first round. There is a sharp learning effect which was still going on in the 5th round.

Round	Average Latency of First Demand	Average Latency of First Guess	Average Latency of Demand for all Stages
1	23.5	9.28	26.66
2	14.5	6.38	16.43
3	12.5	5.07	15.74
4	11.7	4.72	15.71
5	11.6	4.60	10.81

Figure 20: Average Demand and Guess Latency by Rounds.

A careful examination of latencies over all conditions of cost and past history of the demands in the game was made and, in general, average latencies are independent of all conditions averaging about 10 sec. for demands and 5 sec. for guesses when first stage is excluded. We did find one set of systematic differences which is shown in Figure 21. Low cost players have lower demand latencies than do high cost players but the difference are very small in the last two rounds.

We, in company with most other students of decision making, relate response latency to task difficulty. The processes by which decisions are recorded are repetitive and similar (except that demands below 10 require one less stroke on the keyboard all decision inputs are identical in effort required). We may assume that the major determinant of the delay is the account of thought and information processing which the subject is giving to his decision. We are thus led to the following conclusion:

Learning reduced the information processing time required for decision making uniformly across the 5 bargaining rounds of this experiment. Choices were made in short periods of time. The information processing effort employed by subjects did not depend in an important way on the strategic situation in which individual demands or guesses were made.

Round	Low Cost	High Cost	All
1	25.64	27.86	26.66
2	13.51	21.93	16.43
3	15.01	16.33	15.74
4	15.63	15.77	15.71
5	10.68	10.98	10.81

Figure 21: Average Demand Latency by Costs and Round (excluding stage 1).

9.2 <u>Guess Switching:</u> At each stage after the first there is a probability that the guess of opponent's cost will be switched from the guess of the previous stage. Over all rounds and stages this switching probability is .104 so the inertia of guessing is seen to be high. There is a strong round effect as seen in Figure 22. There we see that the switching probability drops regularly across rounds from .159 in round 1 to .083 in round 5. Since the number of stages is increasing it is not remarkable that this probability falls over rounds. However, if we examine the number of switches each subject makes one sees a different pattern. (See Figure 23). There the number of cases of subjects with no switches drops uniformly by rounds from 42 in round 1 to 26 in round 5. Even though the probability of switching at each stage is lower the increased number of chances to switch is offsetting this so that the likelihood that a subject will switch at least once is increasing.

	Round 1	Round 2	Round 3	Round 4	Round 5	All
Number of Switches	48	51	42	43	46	230
Number of Stages-1	302	397	448	513	554	2214
Relative Freq. of Switch	.159	.128	.094	.084	.083	.104

Figure 22: Relative Frequency of Guess Switching by Rounds.

Number of Switches	Round 1	Round 2	Round 3	Round 4	Round 5	All
0	42	37	30	29	26	164
1	17	24	19	19	15	94
2	9	7	7	6	9	38
3	3	3	3	4	3	16
4	1	1	0	0	1	3

Figure 23: Distribution of Numbers of Guess Switches of each Subject by Rounds.

9.3 Initial Demands and Yielding Behavior

We have characterized certain behavior as "weak" and players who employ them are said to be weak players. In Figure 24 we show the frequency of initial demands below 15. These moves often place a player in a weak strategic position. As play proceeds across rounds these moves are being extinguished and mean demands increase uniformly over rounds. Subjects learn to avoid weak initial position.

Yields greater than one (My demand at stage t-1 less my demand at stage t is two or more) are also weak in that they give away more than is necessary to insure that conflict will be avoided. Relative frequency of yields of 0,1, and $\geqq 2$ are shown in Figure 25. Yields $\geqq 2$ are being extinguished while "strong" moves of yield 0 do not show a tendency to be extinguished. Again we see that subjects learn to avoid weak moves.

As a consequence of these shifts in relative frequency of moves and the stability of median first demands over rounds (see section 11) and the extinguishing of low first demands we would expect number of stages to increase by rounds. They do as is shown in Figure 26.

Round	Frequency of Initial Demands below 15	Mean of First Demand
1	10	16.9
2	9	17.0
3	6	17.5
4	5	17.9
5	4	18.1
All		17.5

Figure 24: Initial Demands below 15 by Rounds.

Rounds	Yield=0	Yield=1	Yield≥2
1	.333	.414	.253
2	.261	.556	.183
3	.340	.529	.132
4	.296	.593	.111
5	.271	.653	.076
ALL	.296	.565	.138

Figure 25: Relative Frequency of Yields of 0,1 and ≥2 by Rounds.

Round	Average Number of Stages*
1	4.974
2	6.682
3	7.222
4	8.039
5	8.812

* unweighted LL, LH, HL, HH

Figure 26: Number of Stages by Rounds.

Many variables which we might have expected to show a round effect did not do so. In Figure 27 we show just two important response variables, normalized net payoff and conflict frequencies which do not show round effects. Some important responses are not modified by learning.

Round	Normalized Net* Payoff	Unweighted LL, HL, LH, HH conflict frequency
1	-.871	.690
2	+1.056	.366
3	-.265	.506
4	-.145	.417
5	+.237	.437

* per player and play

Figure 27: Normalized Net Payoff and Unweighted LL, LH, HL, HH Conflict Freqency by Rounds.

10. Subect Differences

We have not made systematic attempts to study behavior of different classes of subjects.[13] Our Berkeley undergraduates are a relatively homogenous group by virtue of the fact that they pass through rigerous screening for admission to the university. The only major difference in attributes among these subjects was male-female. We attempted to find systematic variation with regard to this variable. The only one we found (see Figure 17) shows that females have a significantly higher number of inconsistencies in risk-taking behavior but this is uncorrelated with any other response variables in the experiment. For these 72 subjects and this bargaining situation we conclude that university undergraduates are a homogenous population with regard to attributes brought into the experiment.

---

[13] This has been done systematically for Siegel-Fouracker situations, see Harnett, Donald L. and Barry L. Commings, "Bilateral Monopoly Bargaining: An International Study" Contributions to Experimental Economics, Vol. 3, Heinz Sauermann, ed, Mohr (Siebeck), Tübingen 1972, pp. 100-129.

Using the normalizing coefficients of the 12 sessions with undergraduates we also normalized the two sessions with game theorists and the one session with junior high school students giving us 15 sessions for which we have values for response **variables.**Game theorists had the two highest normalized conflict frequencies and the lowest and third lowest normalized net payoffs. Whereas the junior high school students had the highest (rank 15) normalized net payoff and were third lowest (rank 3) in normalized conflict frequency. In the post session debriefing the high-school students expressed great interest about which opponent they had played in which game and were generally interested in the small rewards. Some game theorists in the debriefing sessions seemed to be interested in differences in total payoff. It seems that youth may loose its innocence (increasing attention to differential payoff with age) and theoretical knowledge does not necessarily lead to higher net payoff in non-zero sum games.

11. Robot Players Based on Modal Subject Response

Robots have been developed from theoretical models and used by experimenters as instruments with which to study human response[14]. Robots of this kind for the two subplayer types H and L of our bargaining situation developed naturally out of the theoretical discussions of the game. These particular robots lack behavioral plausibility. Another way to develop robots is to observe subject behavior as they play against each other and then seek to build robots which imitate this behavior. The goal in this endeavor is to capture essential human behavioral characteristics in the robot. The test is Turing's test. A successful robot has been constructed when the frequency of detection by another robot or human player is no greater than chance. We return to this point

---

14) See for example Hoggatt op. cit.

in our closing remarks. In this section our remaining task is to build a behavioral robot from observations on our 72 subjects. With this robot we are able to produce a complete behavioral representation of modal behavior for the game we have been studying.

<u>11.1 Latency of Robot Response</u>: Subject responses were found to be essentially independent of strategic conditions and average latency for H players approaches that of L players by round 5. We decided to use the overall modes of 10 seconds for demand latency and 5 seconds for guess latency. Where one concerned about transparency of the robot then a simple disturbance with mean zero and range (-k,+k) would adequately mask regularity in this variable.

<u>11.2 First Demand of Robot :</u> As the subject decides his first demand he knows only his own costs. A complete enumeration of first demands by rounds and cost is given in Figure 28. In all cases except round 1 with high cost the mode is 19. There 19 is the second mode. Overall the mode is 19 and the medians tend over rounds to 19. Thus we set the robot first demand at 19 and it is thus independent of cost.

<u>11.3 First Guess of Robot</u>: After the first demands are made each subject has the report of the others first demand and his first guess of the others cost may be conditional on it. In order to determine the modal decision we tabulate in Figure 29 the frequencies of first guesses of all subject with initial demands of 19 by cost and opponent's demand. In this condition the modal response for a low cost player is to GUESS high if his demand $\geq$19 otherwise to guess low. For the high cost player the modal response is GUESS high if his demand $\geq$18 if his demand is 17 guess either higher or low and if < 17 guess low.

First Demand	Low Cost						High Cost						
	Round 1	Round 2	Round 3	Round 4	Round 5	ALL	Round 1	Round 2	Round 3	Round 4	Round 5	ALL	Total
20	4	0	2	8	5	19	5	2	6	5	8	26	45
19	9	13	9	11	16	58	8	8	16	17	15	64	122
18	6	13	7	2	8	36	10	5	7	8	5	35	71
17	4	7	5	6	2	24	3	4	4	2	0	13	37
16	3	2	2	2	1	10	2	0	1	2	2	7	17
15	6	6	5	4	6	27	2	3	2	0	0	7	34
14	0	1	0	0	0	1	0	1	1	0	1	3	4
13	2	0	0	1	0	3	0	2	0	0	0	2	5
12	1	2	2	1	1	7	0	0	0	0	0	0	7
11	0	0	2	0	0	2	0	0	0	0	0	0	2
10	6	2	0	1	0	9	0	0	1	1	1	3	12
9	1	1	0	1	1	4	0	0	0	0	0	0	4
Total	42	47	34	37	40	200	30	25	38	35	32	160	360

Note: In each column the median is underlined.

Figure 28: First Demands by Round and Cost for 72 Subjects.

Opponent's First Demand	Low Cost Guess low	Low Cost Guess high	High Cost Guess low	High Cost Guess high	All Guess low	All Guess high
20	0	6	0	8	0	14
19	1	12	3	13	4	25
18	6	4	3	11	9	15
17	5	1	4	4	9	5
16	3	0	6	0	9	0
15	9	0	5	0	14	0
14	8	0	7	0	15	0
ALL	32	23	28	36	60	69

Figure 29: First Guess for all Subject Rounds with Initial Demand of 19 by Cost and Opponent's First Demand .

<u>11.4 First Yield of Robot</u>: After the first guess is made the subject in determining his second demand also determines, by definition, his first yield. Following down the tree one step further we may examine the frequency of yields in that part of the tree corresponding to the modal response up through first guess. This is shown in Figure 30. We see that the first yield is 1 independent of cost or guess. Here we must stop following down the tree for at each branch we would find fewer observations and even at this branch our data is getting thin. From here on we shall find it necessary to aggregate across conditions and determine modal responses with less than complete detail.

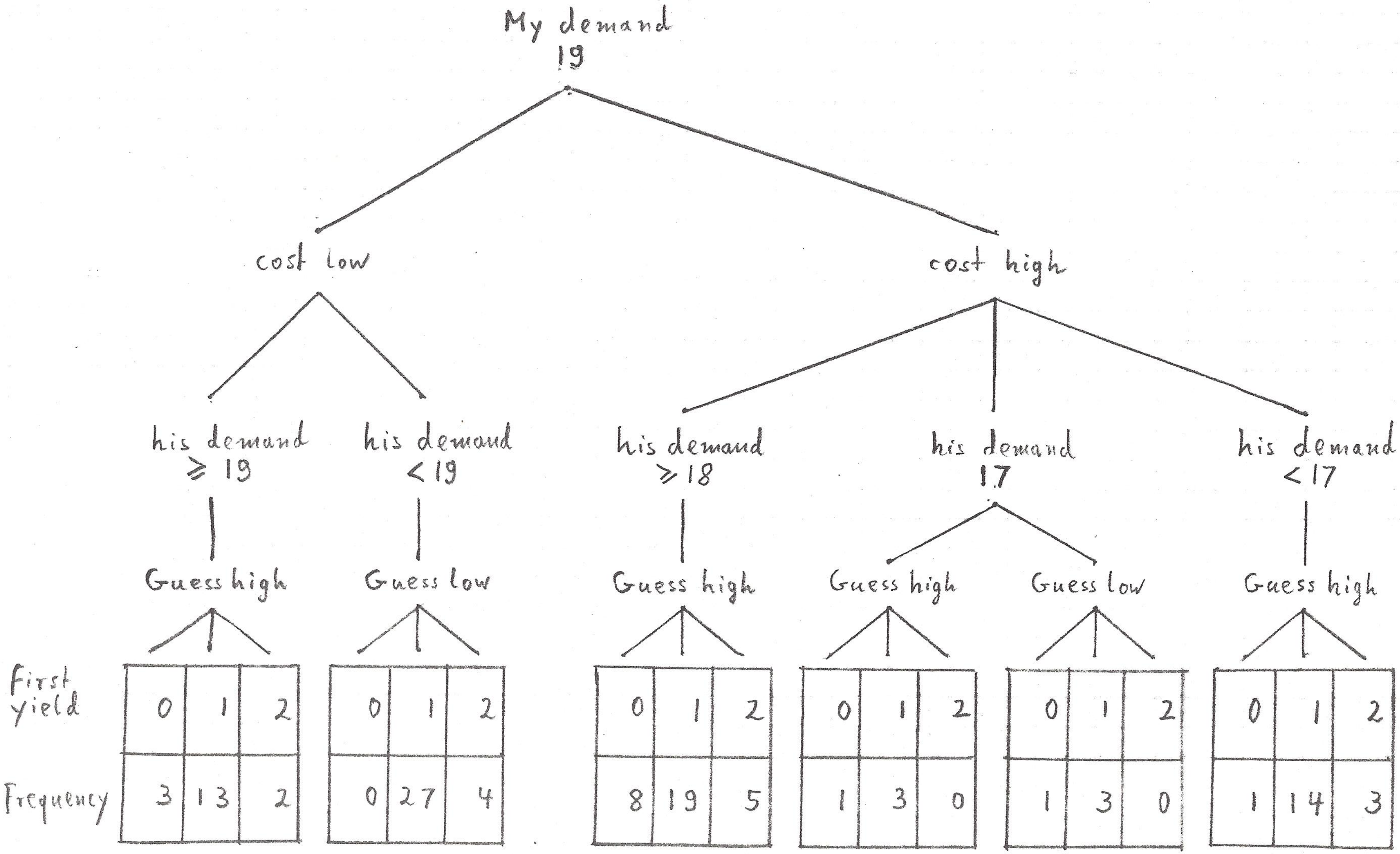


Figure 30: First Yields by Cost and Opponent's Demand for Subjects who also made Modal First Guesses.

11.5 Methods of Aggregation for Determining Robot next Guess and next Yield: In attempting to find useful ways of aggregation we may take some helpful hints from theoretical considerations. For example a player whose current demand is below 10 must be low cost so all uncertainty is removed about which subplayer he is. If current demands are equal then players are in symmetric positions whereas if demands are unequal then one may be said to have a stronger position than the other. From these simple considerations we are led to define 5 current demand conditions CT1,...,CT5, explained below. In these conditions the words "my demand" and "his demand" refer to the demands of the preceding stage.

CT1 ≡ My demand is greater than his demand and his demand is at least 10

CT2 ≡ My demand is greater than his demand and his demand is smaller than 10

CT3 ≡ My demand is equal to his demand

CT4 ≡ My demand is smaller than his demand and my demand is at least 10

CT5 ≡ My demand is smaller than his demand and my demand is smaller than 10.

There are good reasons why behavior should be dependent on these five conditions and we will proceed to aggregate on this basis. Additionally my cost clearly alters my strategic situation and we will continue to use this condition. My current guess of his cost has subjective value in determining my behavior so we shall also continue to employ it. Finally we wish some information about the path by which we arrived at the current pair of demands. We have already reduced yields to three classes, viz.

0 = yield zero
1 = yield 1
2 = yield greater than 1

Knowledge of my yield category and his yield category at the preceding stage provides much qualitative information about the paths yet it greatly reduces the number of past path categories from 10.000 to a manageable 9. We decided to employ this method of collapsing the path for reasons of necessity. Our data base is too small to sustain more detail. In particular lags of greater depth have not been considered. With these decisions in hand a program was written to tabulate and compute relative frequencies for each cell in this classification and for 6 responses corresponding to the product of the two possible guesses and three possible yield categories. The lag structure is such that all of these conditions do not exist for stages 1 and 2. However, we have already determined responses in stages 1 and 2 on the basis of a full examination of the tree. To complete our behavioral robot it remains to examine the relative frequencies which result from this method of collapsing the data.

In the following lower indices t or t-1 behind the name of a variable will be used in order to indicate the current or the previous stage resp.. Thus guess_{t-1} denotes the guess of the preceding stage.

11.6 Switching Probabilities for Next Guess of Robot: The reader is referred to the previous section (11.5) for the categories by which we shall proceed to collapse our data. We have already seen in section 9.2 that guessing inertia is high so we may expect the switching probabilities to be low in most decision situations. We wish to discover whether or not the observed switching probabilities are dependent on the categories which we have specified.
In Figure 31 we report the absolute frequencies of cases tabulated by previous guess, own cost and opponents pre-

vious yield. We have already collapsed this data so that it does not reflect my yield on the previous move. Since my opponent did not know this at the time his demand was made it would violate time preceedence were we to make the estimate of his state dependent on my yield.

	$Gues_{t-1}$ low						$Guess_{t-1}$ high					
	My cost low			My cost high			My cost low			My cost high		
Condition	his yield 0	his yield 1	his yield 2	his yield 0	his yield 1	his yield 2	his yield 0	his yield 1	his yield 2	his yield 0	his yield 1	his yield 2
CT1	54	103	50	158	48	256	19	69	13	31	87	22
CT2	4	16	16	2	30	11	0	1	0	0	0	0
CT3	10	30	6	5	21	4	21	56	12	26	90	9
CT4	26	52	7	7	25	2	80	195	14	85	187	25
CT5	4	2	0	0	0	0	29	32	9	2	2	0

Figure 31: Frequency of Guessing Situations Categorized by Previous Guess, My cost, His Yield and Conditions CT1,...,CT5.

Even at this level of aggregation we have cells with small absolute frequencies, so we find that we must proceed with our aggregation even further if we are to avoid the caprice of small samples. Our primary rule will be to collapse categories whenever possible until remaining cells contain at least 30 observations (the traditional division point between small and large samples.) Now we specify the program which we will follow:

1. Do not merge across $guess_{t-1}$ low and $guess_{t-1}$ high: in as much as we are trying to study switching from one guess to the other collapsing here would not be sensible.

2. Merge his yield 1 and his yield 2 and if all cells then exceed 30 stop.

Else, merge high and low cost.
Since dependence of his cost on my cost is subjective we may give this up first. Should this produce all cells with frequency over 30 stop.

3. Else, merge his yield 0, his yield 1 and his yield 2. Stop.

This program was followed for guess switching and resulted in the collapsed decision trees of figures 32 and 33. In every case the modal response is to repeat the previous guess. Thus we had to resort to probabilities of switching else there would never occur a change of guess. In the figure we have tabulated the probability at each mode that the guess would be switched. Much of the behavior which is summarized by this figure is plausible. We consider first the tree for previous guess low. When demands are above 10 and he is below me and if he yielded 0,I am more likely to switch my guess to high than if he yielded 1 or 2. Also if I am high cost I am more likely to switch to guess high than if I am low cost. If he is below 10 the error of guessing high is seldom made! Under equal demands I am more likely to switch from guess low to guess high than from guess high to guess low - this is clearly related to the H-bias which was noted in an earlier section. In condition 5 (my demand below 10) we have few observations. Our subjects avoid going below 10 when they think they face a low cost player - a not unreasonable behavior.

Turning to the tree for previous guess high all of the switching probabilities have reasonable levels and relationships except for the branch CT4 (my demand above 9 and below his demand) and my cost low. Here, if he yields 0,I am more likely to switch and guess him low than if he yields 1 or more. A χ^2-test for the two way contingency on yield 0, yield > 0 and guess low, guess high is significant at the .05 level. This behavior which is counter intuitive should

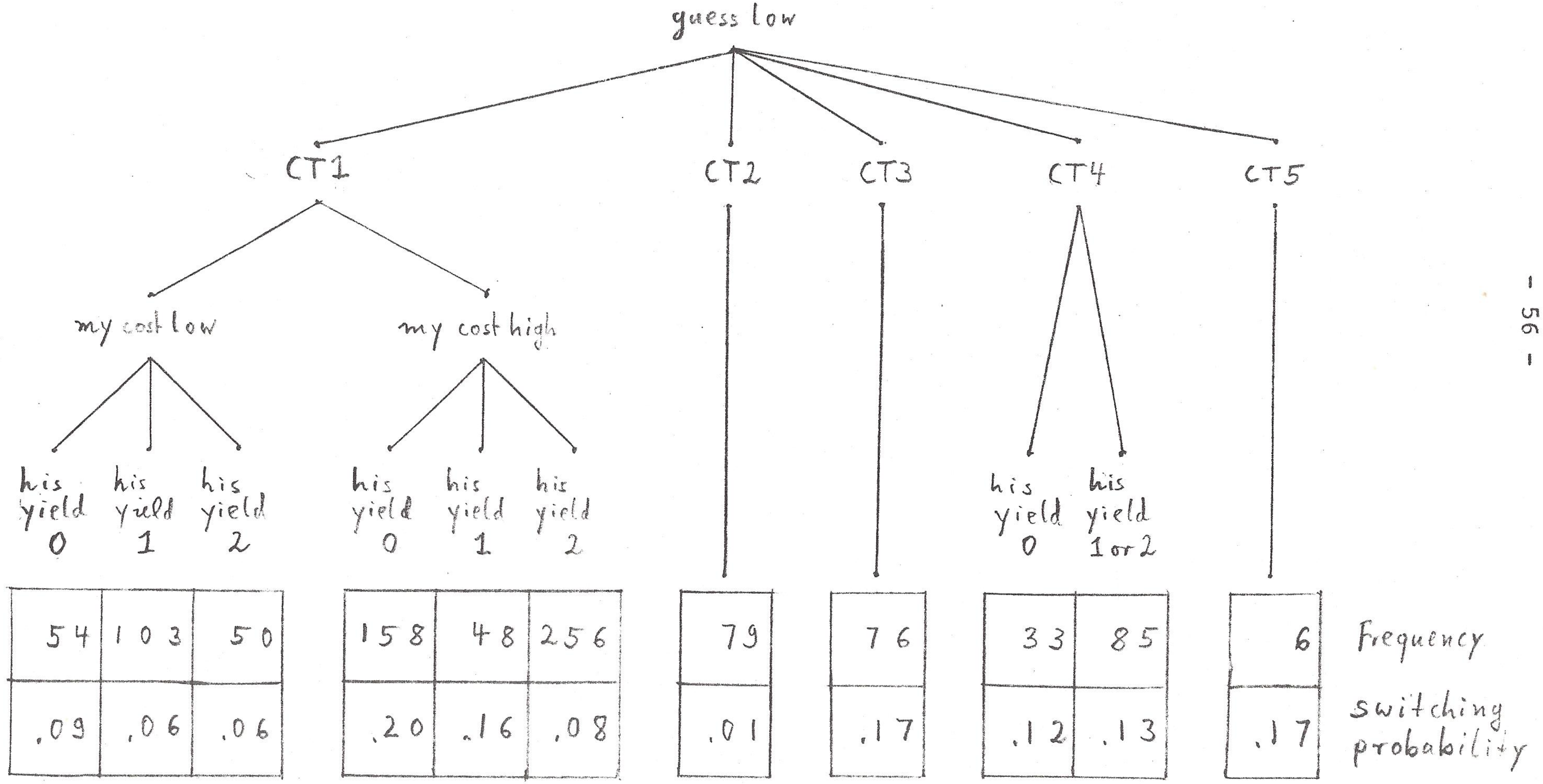


Figure 32: Guess Switching Probabilities and Absolute Frequency for Collapsed Categories: Guess low, Conditions CT1,...,CT5, my Cost and his Yield.

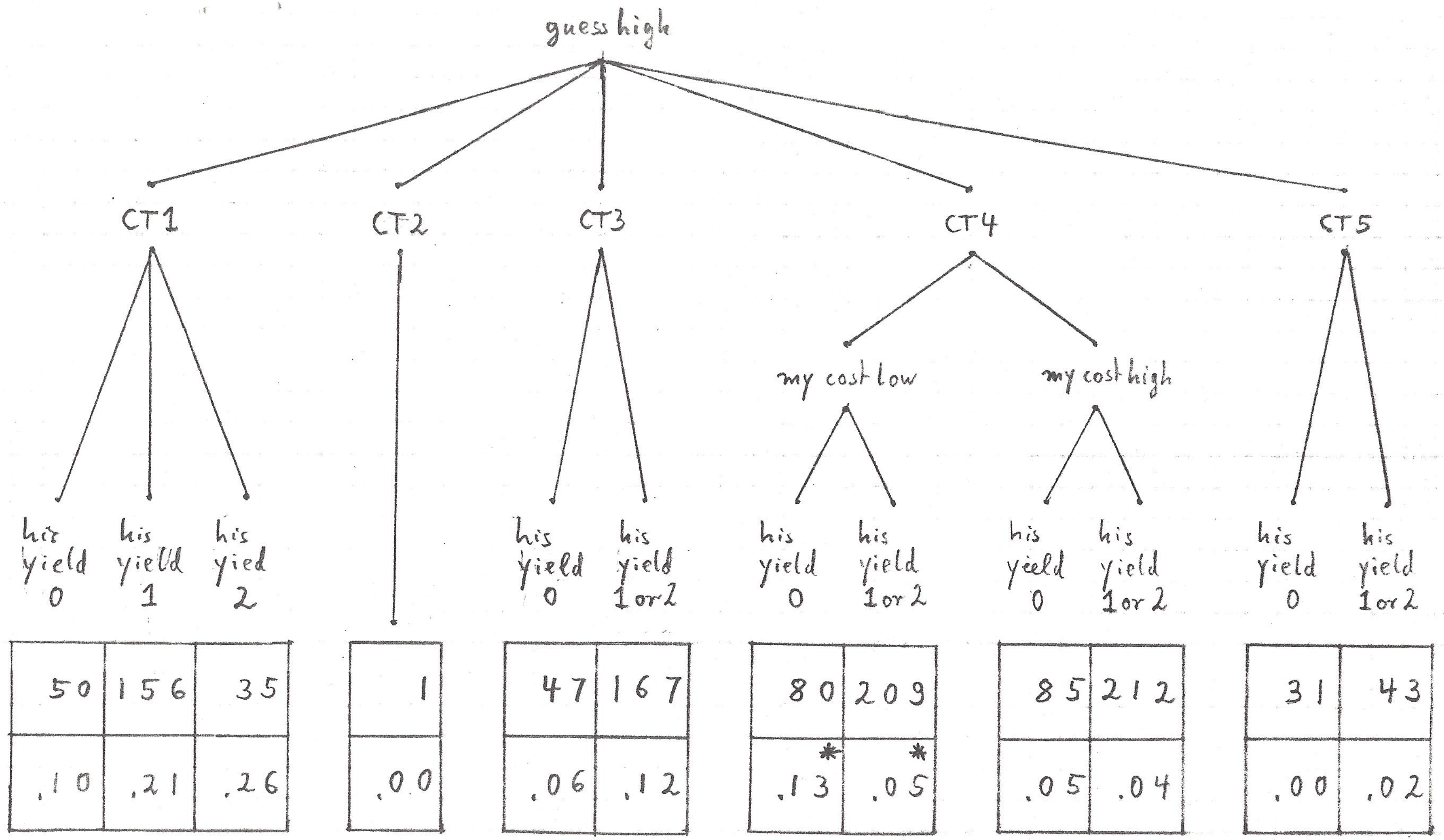


Figure 33: Guess Switching Probabilities and Absolute Frequency for Collapsed Categories: Guess high, Conditions CT1,...CT5, my Cost and his Yield.

* Note: χ^2 test for significance of difference in these two proportions yields $\chi^2 = 4.26$ which is significant at the .05-level. Since these data are not independent (subjects may be on both sides of this branch) too much reliance should not be put on this test.

CT1: In the previous stage my demand was greater than his demand and his demand was at least 10.

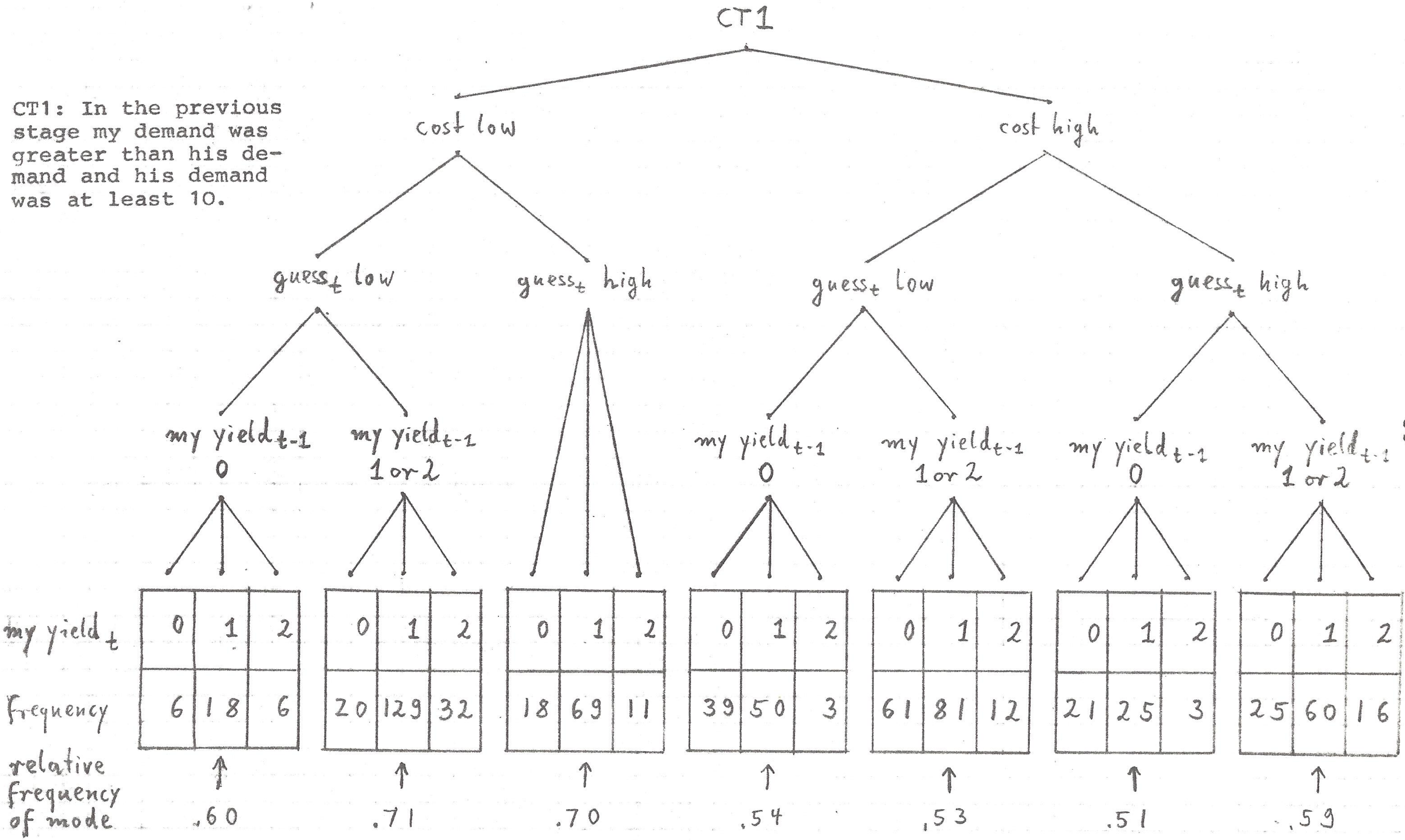


Figure 34: Modal Yielding Behavior for Demand Conditions CT1. Categories Collapsed until Terminal Frequencies 30 or Greater.

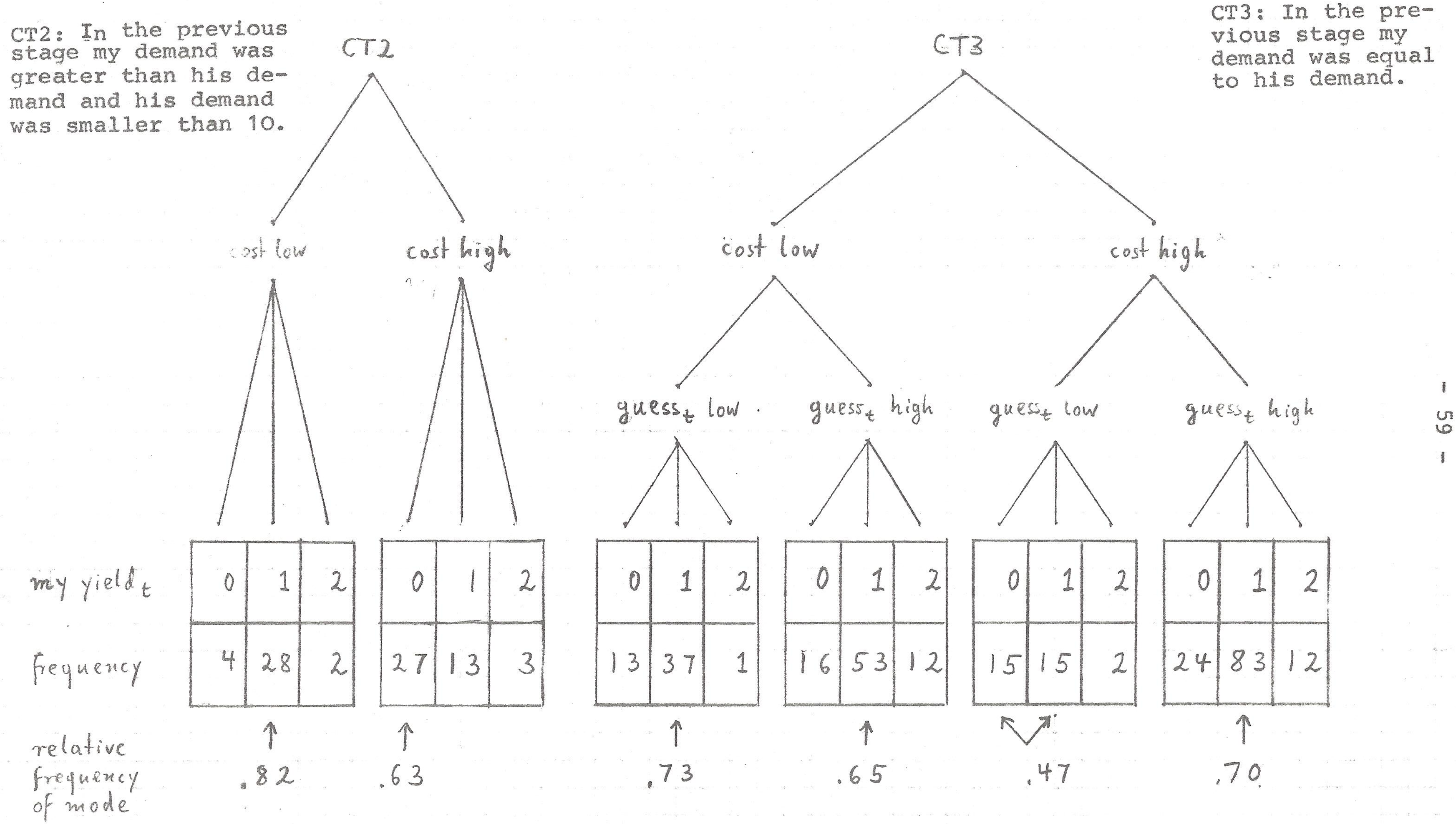
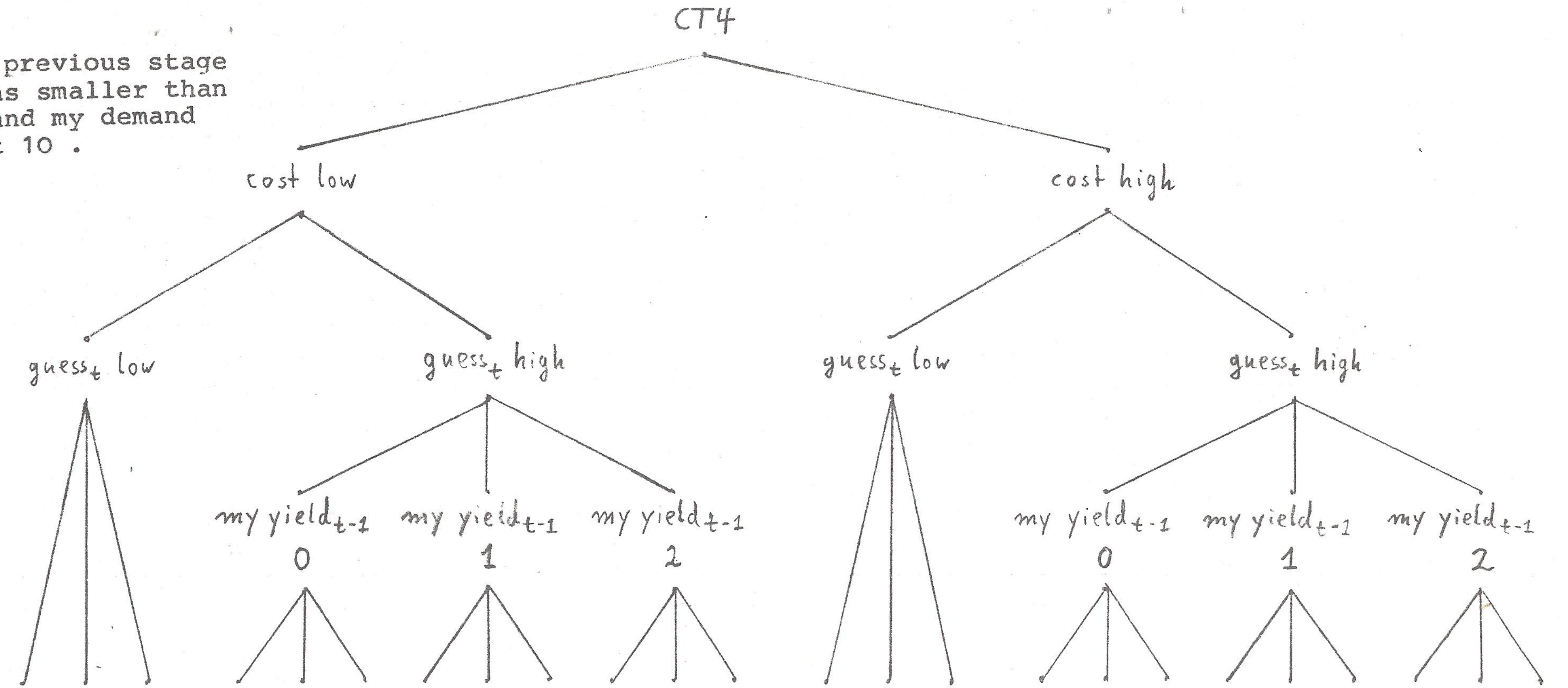


Figure 35: Modal Yielding Behavior for Demand Conditions CT2 and CT3. Categories Collapsed until Terminal Frequencies 30 or Greater.

CT4: In the previous stage my demand was smaller than his demand and my demand was at least 10 .



my yield$_t$	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2
frequency	32	52	10	22	19	4	38	125	15	12	24	20	27	13	1	45	21	6	66	90	5	27	16	14
relative frequency of mode		.55		.49				.70				.43	.66			.62				.56		.47		

Figure 36: Modal Yielding Behavior for Demand Condition CT4. Categories Collapsed until Terminal Frequencies 30 or Greater.

CT5: In the previous stage my demand was smaller than his demand and smaller than 10.

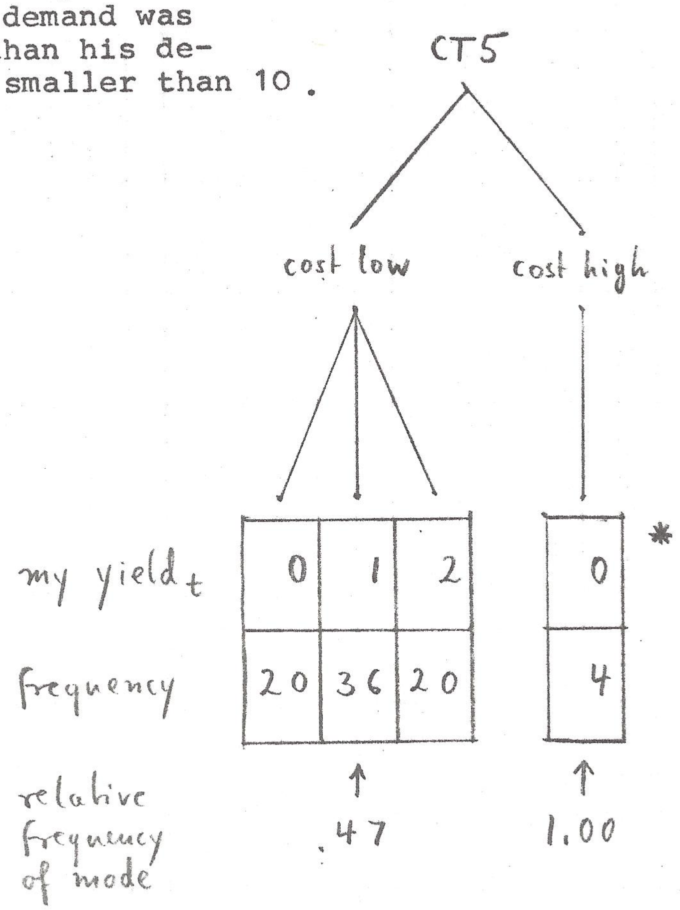


Figure 37: Modal Yielding Behavior for Demand Condition CT5. Categories Collapsed until Terminal Frequencies 30 or Greater.

* The rules do not permit a high cost player in demand condition CT5 to lower his demand, since he must demand at least 9.

be examined in greater detail. Our current data base does not permit this.

Figures 32 and 33 summarize our observations of guess switching behavior and represents our modal robot's guess switching rules. We had hoped to find modal responses in some categories with probabilities greater than 1/2 so that a deterministic robot could have been attempted - this did not occur and so we are left with more complexity than we had expected.
We are also left with a bit of a behavioral puzzle which will have to be resolved by further experimentation.

<u>11.7 Robot Behavior with regard to next Yield:</u> We will collapse our data according to the same general procedures we used in the study of guess switching. However, in this case - since we have guess of his cost at the time of the determination of yield it is reasonable to collapse the previous guess. Demand conditions, cost and guess of his cost at time t are all important factors in yielding behavior. However, when we look at the path by which we arrived at current demand condition we find nine categories (my yield_{t-1} vs his yield_{t-1}). This is too fine for our data base. We conjecture that similar to the guessing situation we also have a phenomenon of yielding inertia, that there is a tendency to repeat yields. So we arbitrarily collpase across his previous yield. Even yet we have some terminal nodes with fewer than 30 observations so we employ the following rule:

1. Collapse my $\text{yield}_{t-1}=1$ and my $\text{yield}_{t-1}=2$ if this produces cells with 30 or more observations stop,
2. else, collapse my yield_{t-1} if this is adequate stop,
3. else, collapse guess at t. Stop.

This procedure failed to produce 30 or more observations in each category only under condition CT5 and high cost. We leave that branch stand, since here the rules permit only one response.

We now show in figures 34 to 37 an empirical decision tree in which the modes are strong. In 19 out of 23 cases the weight of the mode exceeds 50% of the terminal frequency. Under these conditions a simple deterministic rule may be constructed by instructing the robot - select the mode: in a bimodal situation (which occurs for CT3, cost high, $guess_t$ low) select either 0 or alternative with equal probability.

The behavior as summarized by this tree appears plausible. There is a clear rationale for each response. Further the response varies with conditions. Under suitable situations the robot will not yield and thus risks conflict. Fortunately for the rationality of this robot the response of yielding 2 or more has been swamped and does not occur anywhere as the modal response.

Now we have completed the construction of the modal robot player. Specifications are complete through initial demand, first guess, first yield, probability and switching guess and modal yield for any point in the state space of the game. We have not modeled the <u>last</u> guess separately from the rest since this would not alter the playing behavior of our robot.

<u>11.8 Pitting the Robot against itself</u>: We may obtain an understanding of the robot personality by pitting it against a copy of itself under the three conditions: each is high cost, each is low cost and one is low while the other is high. To begin with we suppress guess switching and allow the robot to be modal in all aspects (the modal guessing response is to continue last guess). In this case the path is always started at 19,19, then each player yields 1 at each stage until

agreement is reached at (10,10). Since the robots never venture into that part of the space where yields of zero are forthcoming we have very quiet games. Play with guess switching requires a computer and at this time these programs have not been written.

11.9 Taking Advantage of the Robot: One may enquire as to whether or not the robot strategy with guess switching suppressed is an equilibrium strategy. It is easy to see that a deviator may take maximal advantage of the robot by setting initial demand 2o and not yielding until the robot is at 10. Then the deviator yields 1. If the robot is low cost it will next demand 9 and then the deviator may obtain a gross payoff of 19 by not yielding as the robot continues down to 1. If the robot is high cost then it will stick at 10 and the deviator obtains a gross payoff of 10 by dropping to 10. This shows that the modal robot does not behave according to an equilibrium strategy. The possibility of not yielding at each stage is essential for good play. It seems that good performance cannot be obtained from deterministic robots which are based on imitating the local behavior of human players.

12. A Program for further Work

Our work will proceed in two parts. First we will simulate the robot with probability of guess switching and examine its play under the three cost conditions. Then we will examine ways to adjust the parameters to approach equlibrium strategies. Assuming that this is possible we plan a follow-on series of experiments of the following general format:

1, A robot will be employed in the play and subjects will be informed that they will meet robots during some rounds of the session.

2. The number of players in a session will be 9. This is the current capacity for simultaneous inputs by subjects; with 1 robot there will be 10 players.

3. Each subject will play each other subject and the robot twice. This will provide 18 rounds of data and

should be sufficient for learning to be damped out. The rapid rate of play of the sessions with 6 players indicates that this design is possible.

4. The design will be balanced by assigning costs so that each player will be high cost in one half of his games and his opponents cost will be set so that the frequency of the conditions HL, HH, LH will be equal. Players will be told that they may inspcet the console printouts of other players after the session is over and that they will be rewarded if they find that the design was not balanced. This should convince them that probability of opponents cost is truly 1/2. With a balanced design analysis will be facilitated, for example normalization would not be necessary. This will also speed play since draws of H or L will not be required.

5. At the end of the session players will be asked to indicate in which 2 of the 18 rounds they faced a robot and will be paid a reward for correct guesses. This enables us to perform Turing's text for the assertion that the robot successfully apes the human players.

6. A more extensive set of risk-taking experiments will be performed in order to get more precise information about risk-taking propensity for each subject.

A major advantage of this design is that the power of statistical tests will be greatly increased.[15)] The greatly increased data base will also facilitate investigations of global anomolies by study of the details of behavior in finer branches of the tree than is possible with the current design.

---

15) For example with 18 rounds the order statistics are robust notice that with 5 rounds any reversal results in rejection of the hypothesis.