Artículos

NEW DIRECTIONS IN ECONOMIC THEORY-BOUNDED RATIONALITY

Ariel Rubinstein (*)
Department of Economics Tel Aviv University

Resumen Este trabajo presenta varios modelos que destacan el contraste entre las teorías de la decisión y de los juegos, por una parte, y la intuición y los datos empíricos y experimentales, por otra. Estos ejemplos estimulan la adopción del punto de vista de la racionalidad limitada por parte de las teorías económica y de los juegos. A la luz de dichos ejemplos, se analizan varias direcciones en las que se está desarrollando (o es probable que se desarrolle en el futuro) la teoría económica.

Abstract The paper presents several models in which there is a strong contrasts between the theories of decision making and games, on the one hand, and intuition as well as empirical and experimental facts on the other hand. These examples act as spring boards for the bounded rationality approach in economic and game theory. The paper discusses the directions in which economic theory is developing (or is likely to develop in the future) in light of these examples.

INTRODUCTION

Economic theory and game theory are commonly defined as dealing with the interaction between *rational* individuals (economic agents or players). The rationality of an agent has several implications. For example, we assume that the rational man has a perfect ability to make inferences. If the price of a good car is 50 while the price of a lemon is 5 then the rational man will deduce that the quality of a car priced 5 is necessarily inferior. The rational man has perfect recall; he does not hold a bond after its expiration date. Most importantly, the rational man acts only in accordance with the following procedure:

a) The assessment of feasible alternatives.

b) Predictions regarding the possible consequences of his actions.

c) The definition of a preference over the set of consequences.

d) The choice of action from the feasible set which leads to the preferred consequence.

(*) A Lecture presented in the XIV Simposio De Análisis Económico, Barcelona, 20.12.1989. Some of the material in this lecture is based on lecture notes given to my students during courses I delivered at the London School of Economics and the University of Pennsylvania. I would like to thank those institutions for their wonderful hospitality.

Thus, for example, the rational consumer chooses the best bundle from among the budget set. Economists have always felt uneasy with the assumption that economic agents use this procedure and they tend to emphasize that for Microeconomic analysis we do not need to assume such a strong assumption and it is enough to assume that the economic agents behave *as if* they follow this procedure. The concept of revealed preference was invented, at least partially, as a response to this criticism.

There are two major arguments against the assumption of rationality even in its weak form. One argument is that very often we find (both from personal experience and from results of experiments conducted by psychologists and economists) significant behavioral patterns that are not explained by the rational man paradigm. The second argument is that there are economic phenomena which are rooted in precisely those factors which are ignored when we assume that all consumers, firms, players and even governments behave rationally. Among those phenomena are: advertising, consulting, the organization of the firm, incomplete contracts and speculative trade.

The observation that behavior is not rational in the traditional sense does not imply, however, that it is completely chaotic. As we shall see, various experiments suggest some interesting alternative procedures to rational decision making. Following Herbert Simon, let us distinguish between substantive rationality and procedural rationality. Substantive rationality refers to behavior which "is appropriate to the achievement of given goals within the limits imposed by given conditions and constraints". On the other hand, "behavior is procedurally rational when it is the outcome of appropriate deliberation", i.e., procedurally rational behavior is the outcome of some procedure of reasoning. In contrast, irrational behavior represents impulsive responses without an adequate intervention of thought. We will depart from substantive rationality but retain procedural rationality. In particular, we are interested in seeing the influence of decision making procedures not consistent with the "rational" man assumptions on orthodox theory. "Bounded Rationality" is the area which tries to integrate the procedural aspects of economic agents' decision making into economic theory.

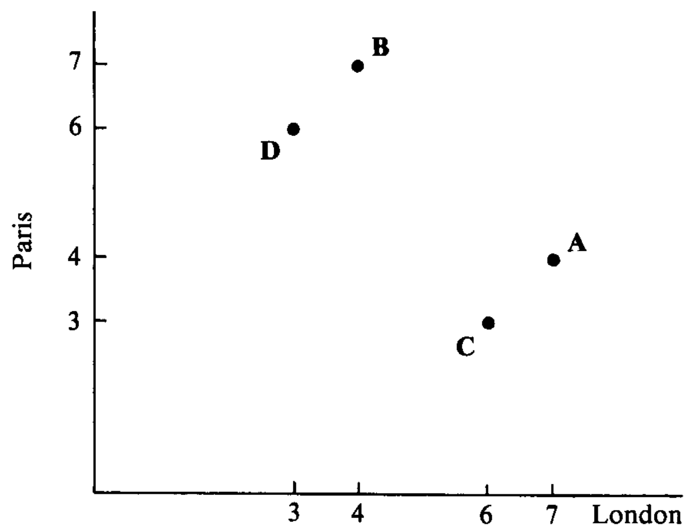
The beginnings of "Bounded Rationality" ideas in economics are found in the work of Herbert Simon who claimed already in 1955 that: "Recent developments in economics... have raised great doubts as to whether this schematized model of economic man provides a suitable foundation on which to erect a theory-whether it is to be a theory of how firms do behave or of how they 'should' rationally behave". Simon also showed himself to pioneer the following call: "There is an urgent need to expand the established body of economic analysis... to encompass the procedural aspects of decision-making". For a collection of Simon's work on the subject see Simon (1982).

This lecture will present several models in which there is a strong contrast between the theories of decision making and games, on the one hand, and intuition as well as empirical and experimental facts on the other hand. These examples act as spring boards for the bounded rationality approach in economic and game theory. I will touch on the directions in which economic theory is developing (or is likely to develop in the future) in light of these examples.

1. CHOOSSING FROM AMONG BUNDLES

Psychologists, (in particular Amos Tversky and Daniel Kahneman) have in the last two decades supplied a stream of colorful and outstanding examples that demonstrate the failure of the rationality assumption as a behavioral description of human beings [see for example, Tversky and Kahneman (1986)]. Let us consider one example taken from Sattath (1989) (see also Huber, Payne and Puto (1982) and Tversky (1988)): the four vectors A = (7,4); B = (4,7); C = (6,3) and D = (3,6) are holiday packages in Paris and London. A vector indicates the number of days in each city. All subjects agree that a day in London and a day in Paris are desirable goods.

DIAGRAM 1



Some of the subjects were requested to choose between the three objects A, B and C; others had to choose between the objects A, B and D. The subjects exhibited a clear tendency to choose A out of the set (A, B, C) and to choose B out of the set (A, B, D). Obviously, this behavior is not consistent with the behavior of "rational man". Given the universal preference of A over C and B over D, the preferred element out of (A, B) should be chosen from both (A, B, C) and form (A, B, D).

Here we have a robust example which is reflected in our own thought experiments. The beauty of this example lies not only in its contradiction of the rational man paradigm. It also indicates the existence of a systematic decision procedure for choices among vectors. Decision makers, (namely ourselves) look for reasons to prefer A over B and included in the list of reasons is the property of "dominating a third alternative".

The response of economic theory to these results is to construct new reasoning frameworks, models, in which the consumer is presented as operating procedures rather than as maximizing utility and which include the elements that Sattath and Tversky draw our attention to. The industrial organization theorists will surely use these models to explain the phenomenon of firms offering inferior commodities which are seldom purchased. The existence of the bundle C, suggested by the producer of A, is not necessarily a mistake but may be a part of his war against B's producer and an expression of a good understanding of the psychology of the consumer's decision process.

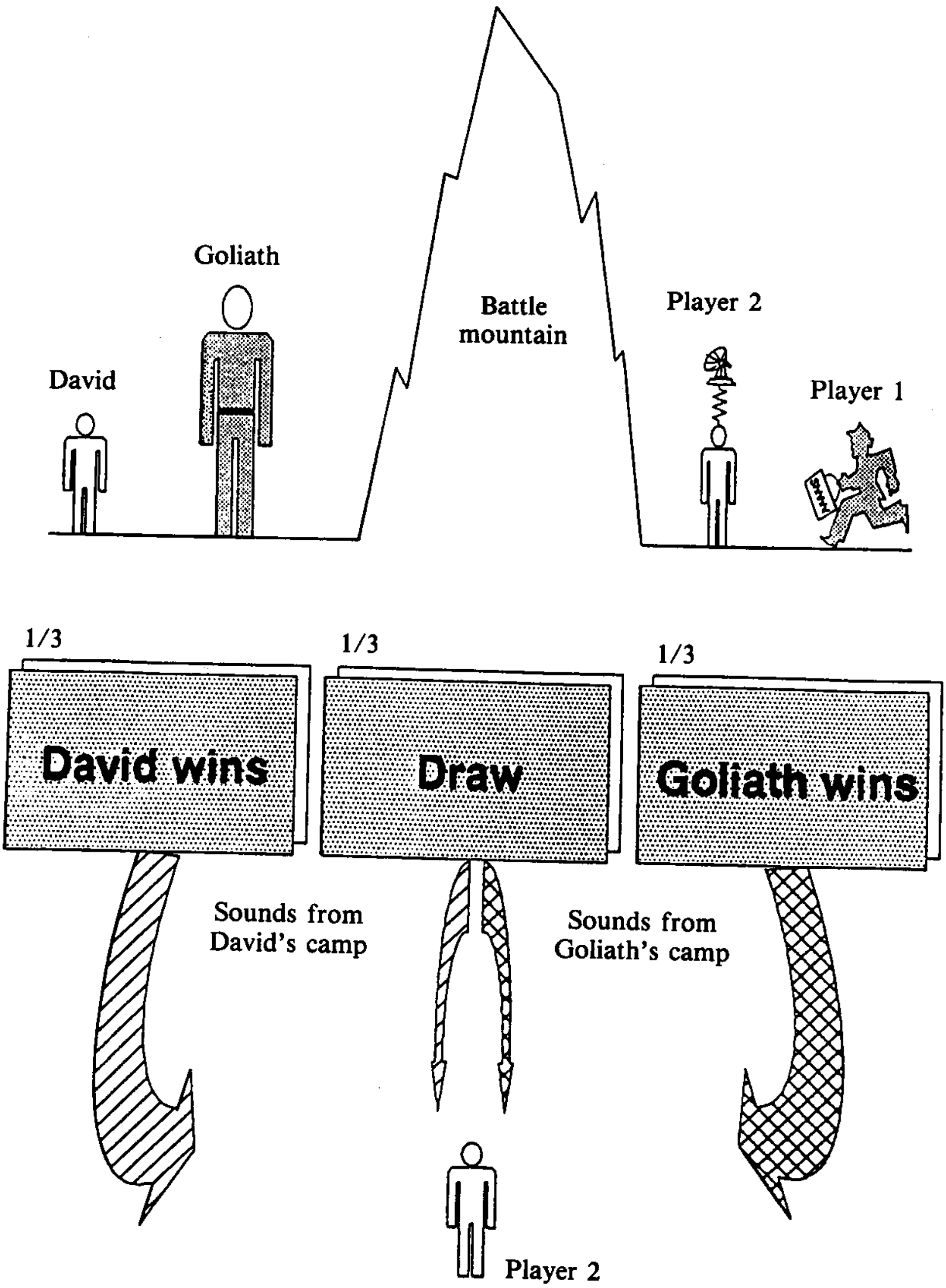
2. SPECULATIVE TRADE

Let us consider two biblical arms dealers trading secret military equipment whose value depends on the outcome of a duel between David and Goliath. The outcome of the duel may be a victory for David, a victory for Goliath or a draw. A priori, the two dealers believe that all three outcomes are equally likely. In the event of a victory by one of the two opponents the value of the equipment will be 0 while in the event of a tie, war will break out between the two camps and the value of the equipment will be 1,000 camels. Initially, the equipment is held by the dealer called "Player 1". Player 1 is far away from the battle field and does not receive any information on the battle's outcome. The second dealer, Player 2, remains behind the battle hill and listens to the cries of the mob watching the battle. If Goliath wins, Player 2 hears cheering from Goliath supporters while if David wins he hears the cheers of David's camp. In the case of a tie, Player 2 will hear the cheers of both camps each claiming a victory. If Player 1 is rational he will be able to infer the precise outcome of the battle from the signals he receives. Lack of cheering from a particular camp means that its representative has lost. Cheering from both camps means that the outcome is a tie.

In the evening, the two dealers meet far away from the battle field. Would it be possible that Player 1 (the non-informed dealer) will sell the equipment to Player 2, (the information holder)? Player 2's willingness to trade will be interpreted by Player 1 (if he is rational and if he assumes that his opponent is rational) as evidence that the outcome of the battle was a tie. In such a case, player 1 will not be willing to sell the equipment for less than 1,000 camels, a price player 2 is not ready to pay. Thus, a speculative trade is impossible under those circumstances (for a full discussion see Milgrom and Stokey [1986]).

Following Geanakopolos (forthcoming), assume now that Player 2 is not a perfect rational player and has difficulties interpreting the information he receives. When he hears the cheers of Goliath fans he concludes that David has not won the fight. If Goliath is the winner, Player 2 assigns probability 1/2 to each of the events "Goliath won" and "Tie". He evaluates the expected value of the equipment as 500 and he is ready to pay a price of, let us say 400 camels. In fact, he would also be willing

DIAGRAM 2


Goliath
David
Battle
mountain
Player 2
Player 1
1/3
David wins
1/3
Draw
1/3
Goliath wins
Sounds from
David's camp
Sounds from
Goliath's camp
Player 2

to pay this price in the event of the other two outcomes. Thus, the willingness to pay 400 camels does not reveal to Player 1 any new information and he still evaluates the expected value of the equipment as only 333 and is happy to sell the equipment for 400. Thus, speculative trade is possible when one of the players does not make all possible inferences from the information he holds; in this case he is receptive to cheers but ignores silence.

We see that the phenomenon of speculative trade, which is difficult to explain in a world of rational individuals, can be explained in a world with imperfect knowledge. By "imperfect knowledge" I refer to knowledge which does not satisfy the frequently used axiom that "I do not know X" implies "I know that I do not know X". In our example, Player 1 is assumed not to infer from the fact that he does not know that there has been a draw, that one of the parties has won. Economic theorists react to the example by applying tools, borrowed from epistemology, to represent patterns of knowlegde which are systematically imperfect and to see how a change in the knowledge assumptions affects conventional economic conclusions.

3. WHAT DO YOU MEAN BY SAYING "GOOD"?

The next example is related to a well known philosophical question: why is it that the class of office furniture is divided into the set of chairs and the set of desks and not into another partition in which some of the chairs and some of the tables are classified together as "chables" and the others as "tairs"? Explaining classification systems requires a discussion of the role of words in everyday life. "Internally", words are a part of our reasoning process and our memory. ("I will replace one desk with two chairs"). "Externally", words are used as part of our communication system ("Be careful, the bomb is under the desk!"). It would be interesting to develop a theory in which economic methods are used to explain human perception.

Returning to economics, let us consider the following problem taken from Meyer (1989): an employer is interested in hiring workers for a one-time task. The employer has unlimited capacity to employ workers and will hire any worker expected to produce non-negative profits. The profits are drawn randomly from the set (2, 1, -1, -2). The candidates belong to two groups of equal size. Each type is characterized by a random profits variable which receives values according to the following table:

	Profits			
Type	2	1	-1	-2
Positive	0.4	0.2	0.2	0.2
Negative	0.2	0.2	0.2	0.4

The employer tests the candidates by having them perform a task similar to the task they will perform in their job. Since the information is random he tests each candidate once a day for two days. At the end of the two days the employer announces his decision as to which candidates will be hired.

There are numerous candidates and the employer is not able to record all the details of the tests' results. He is holding a worksheet on which he marks "+" or "—" beside the name of each candidate. Perhaps, he does not even write the results down but merely records a mental impression about each candidate's performance. As employers often do, he is using only two categories to describe the candidates, "Good" or "Bad". Here we have the element of bounded rationality on which we focus our attention. The decision maker is either unable to remember or uninterested in the exact test-performance of each candidate. The number of categories he can use to classify a candidate is limited due to either limitations, learning problems or difficulties in further utilizing the information in the decision process.

The meaning of the "+" or "—" signs and of "good" or "bad" impressions determine the decision maker's choice. Different meanings lead to different decisions. Those meanings are not necessarily exogenous. The decision maker may determine the terms he uses according to the functions they fulfill. It is natural to include in the "+" category, the positive profits and, in the "—" category, the negative profits. However, given this definition of the categories "+" and "—", the second test is redundant. If the impression which remains from the first period is positive (or negative) the outcome on the second day will never affect the final decision. No matter what the second period impression, the expected value of the worker is non-negative (non-positive). Given this classification, it is optimal to accept those workers who received + on the first test, which results in the employer hiring 60% of the good candidates and 40% of the bad candidates.

The employer can achieve better results by using the terms "Good" and "Bad" dynamically. Assume that the employer's second impression is prejudiced and the term "good" is kept unless his second day test is very poor (—2) and similarly, a first day bad impression is reversed only by a +2 performance on the second day. In this case, the employer hires 64% of the good workers ($0.6 \times 0.8 + 0.4 \times 0.4$) and only 36% of the bad workers.

This example demonstrates the rationale of the dynamic meaning of positive and negative impressions. As such, it is the beginning of an exciting area of research in economic theory, which will attempt to explain the functional rationale of terms used in our reasoning.

4. CHESS

Our discussion of Bounded Rationality in Game theory begins with Chess. Chess is a microcosm which is frequently used to demonstrate the limitations of rational decision making in a game.

Several properties of Chess are worth noting:

1. Chess is a game with perfect information. When making a decision a player knows the preceding sequence of moves.
2. It is a game with diametric conflict of interests (a zero sum game). Each game has three possible outcomes: "W" (player 1 wins), "B" (player 2 wins) and

"D" (a draw). Player 1 prefers W on D on B and Player 2 prefers B on D on W.

3. The game is finite. The finiteness of Chess follows from the fact that the number of positions on the Chess board is finite and from the rule that if the same position is repeated 3 times in the course of one game the outcome is declared a draw.

In 1912, Zermelo proved that for rational players Chess is a trivial game. Every game which satisfies the above three properties has a value, i.e. the game has a consequence such that each of the players has a strategy which assures that whatever his opponent does, the outcome of the game is at least as good for him as the value. In other words, one of the following is true of Chess: either the White player has a strategy which assures that whatever Black does he wins, or Black has such a strategy, or each player has a strategy which guarantees that whatever the opponent does the players achieve at least a draw.

If we knew the value of Chess and the corresponding (maxmin) strategy, as we do in the case of Tic-Tac-Toe, then Chess would become an uninteresting game. If the maxmin strategies were simple and average human beings could implement them, we would not expect expensive prizes to be given to winners in Chess competitions, in the same way that the title Master is not awarded to a player of Tic-Tac-Toe.

Furthermore, Zermelo suggested an algorithm for calculating the value of Chess and the maxmin strategies as part of his proof. The principle of the algorithm is simple. Chess is described by a finite tree. At the origin of the tree one of the players has to move, i.e. to select one of the edges (corresponding to actions) starting from that node. At each of the subsequent nodes the other player has to make a move and so on. Some of the nodes of the tree are terminal, i.e. there are no further branches originating from those nodes. Inductively from the end of the game, the algorithm assigns a value to each of the nodes by the principle that it is the best (according to the preference of the player who has to move at that node) value from among the subgames which follow the player's node of decision. The algorithm ends after a finite number of steps. The assigned value to the origin is the value of the game.

This is a simple algorithm which is taught in the first lecture of courses in game theory. However, even though we know the algorithm, we are unable to execute it. The Chess tree is so large that no computer is able to execute the algorithm. In contrast, the rational man in game theory has that capability. He is able to make unbounded calculations including those involved in solving Chess. Any differences in talents, memory, IQ or other characteristics which make one player better than another are excluded from the analysis.

5. THE "REPEAT THE NUMBER" GAME

The following two-stage game demonstrates the bounded rationality elements ignored in game theory: first, Player 1 announces a sequence of words of length L. Player 2 is then asked to announce a sequence of words of the same length. If player

2 repeats Player 1's sequence exactly, then Player 2 gets a dollar; otherwise, Player 1 gets the dollar.

This game shares with Chess the above mentioned three properties. In contrast to Chess, the game has a computable value. Player 2 has a maxmin strategy which assures that he will win the game: respond to $(a_1, \ldots a_L)$ by $(a_1, \ldots a_L)$... Indeed, the fact that this value is known makes the game with L = 1, 2 or even 5 uninteresting. However, for L = 17, for example, I would prefer to play the game as Player 1 than as Player 2. In fact, research has shown that most human beings can memorize strings only of 7 or 8 items. Thus, there is a serious problem in implementing the optimal strategy for player 2 even though it is well known and can be stated very simply. The inclusion of the "physical" human bounds in the description of a game is currently one of the principal goals in game theory.

6. REPEATED GAMES

One area of game theory in which Bounded Rationality ideas have already been applied and achieved results is the theory of repeated games. In this section I will deal mainly with ideas taken from Rubinstein (1986) and Abreu and Rubinstein (1986). To introduce the topic let me focus on a very simple example: two countries using a common source of water. At the beginning of the game, each country has a narrow tunnel which they use for transferring water. Each of the countries can widen the tunnel and increase the amount of water it draws. However the act is irreversible, i.e. the width of the tunnel cannot be reduced later on. Each of the countries' first preference is for its tunnel to be wide and its opponent's tunnel to be narrow. The worst possibility is to have a narrow tunnel while the other country has a wide tunnel. Of the other two possibilities, both countries prefer the possibility that both tunnels are narrow over the possibility that both tunnels are wide. If the water conflict lasts for only one season, then the game is equivalent to the Prisoner's dilemma: a player prefers to build a wide tunnel independently of the other player's action. However, if the conflict is ongoing and if widening the tunnel is an operation which may only be done at the beginning of every summer, then we have a model similar to the infinitely repeated prisoner's dilemma with the difference that once a player plays "Wide" he is not able to play "Narrow" again. Let us review some of the strategies available to the players in the repeated game:

1. *The honest strategy:* Whatever happens, don't widen the tunnel. This is a simple strategy which does not require having the (physical or psychological) means for widening the tunnel. The strategy does not require monitoring the opposing party since knowing his past actions does not make any practical difference.
2. *"Never rely on the Enemy":* Expand the tunnel right away. This is another simple strategy which does not require adjustment to two different modes and does not require monitoring of the opponent.

DIAGRAM 3

		Player 2: Narrow	Player 2: Wide
Player 1	Wide	3, 3	0, 4
	Narrow	4, 0	1, 1

Strategy	*Description*
"Honest"	Do not expand the tunnel
"Never rely on the enemy"	Expand the tunnel immediately
"We shall determine the time and the place"	Expand the tunnel at time T
"Deterrence"	Expand the tunnel immediately after finding out that your rival has expanded his tunnel

3. *"We will determine the expansion timing":* Expand the tunnel at time T. This strategy requires holding two modes of water utilization, one for the narrow tunnel and one for the wide tunnel. It also requires the operation of counting up to T and remembering that at the T'th season, the expansion is to take place. If the players do not have calenders, then they count by etching on the tunnel walls. The larger T is, the more complex this operation. I would like to suggest to the skeptic in the audience to consider the following example. Suppose you weve in need of a hotel late at night in a foreign city and received the following instructions: "You can find a hotel within a 5 minute drive from here by driving straight and turning right at the seventh intersection. Alternatively, a right turn will get you to the hotel within 10 minutes".
4. *The Deterrence Strategy:* Expand the tunnel immediately after your opponent does so. This strategy does not require counting but does require monitoring of the opponent and having the capacity to expand the tunnel.

The four possibilities illustrate the complexities associated with implementation of strategies in the repeated game:

[1] Being ready to operate the tunnel in several (one or two) modes.

[2] Making calculations (in this case counting).

[3] Monitoring the opponent.

A discussion of the above requires a precise definition of complexity and the tradeoff between it and the repeated game payoff. In order to accomplish this, several papers have presented a strategy as a machine (an automaton).

A *machine* has four components:

1. A set of *states*. The set may be any set. The names of the states are meaningless and the content of a state is determined by the machine.
2. An *initial state*. A specified element from among the set of states. The machine starts to operate from the initial state.
3. An *output function* which specifies an action for every state. The output function determines the one-shot action to be taken corresponding to the present state.
4. A *transition function* which spells out how the machine moves from one state to another. At each period the machine receives input and may move into a new state. The new state depends on the current state and the input received.

One can interpret the machine as a mechanical tool for carrying out a strategy. In essence, one can think of the machine as an abstraction of the process by which the repeated game rule of behavior is implemented.

The main problem is to determine the input which the machine receives. We assume that the machine receives as input the action that the other player chose. This assumption fits the description of a "rule of behavior" or a "strategy" as a plan of how to behave in all possible circumstances which are consistent with the player's plans. [Notice that the traditional definition of a strategy requires that it specifies an action for histories which are inconsistent with the player's own strategy. This is essential for the existence of subgame perfect equilibrium. Subgame perfect equilibrium requires specification of the change in the state of the machine as a response to a player's deviation from his own plans].

In the literature the number of states is taken as the measure of complexity. This means that the "honest" and "don't trust" strategies have complexity 1, the deterrence strategy has complexity 2 and the "expand at T" strategy has complexity T. This measure is sensitive to the number of modes of behavior and the complexity of the operation of counting; however monitoring is complexity-free according to this measure.

In the repeated game without complexity considerations, the players weigh the short run (one season) gain versus the loss in the future. If the one period gain is offset by the future loss then the pair of deterrence strategies is a Nash equilibrium. In the game in which players attempt to minimize complexity as long as it does not reduce the repeated game payoff, we get different results. If Player 2 uses the deterrence strategy, Player 1 does not need the extra threat state (few countries hold armies against invisible enemies). Replacing the threat strategy by the honest strategy does not reduce the repeated game payoff and does save the extra state used for threatening the opponent. Actually, the only equilibrium in the game with the complexity consideration is the pair of strategies "never trust the opponent".

For the case in which narrowing the tunnel is possible the machine game has more interesting equilibria. Consider the strategy "war now peace later": Start playing with a wide tunnel. Use a wide tunnel in the first P periods. After P periods narrow the tunnel if and only if your opponent has used a wide tunnel during the last P periods. After you have narrowed your tunnel, respond to your opponent's expansion of his tunnel by starting your strategy from its initial state. This strategy is implemented with a P + 1 state machine.

If both players adopt this strategy with the same number P, then the play of the game starts with P periods of "war". This hell is the ticket to heaven. The peace is built on the threat to punish a deviator for P periods (P is selected as long enough to offset the short run gain). Notice that here a player cannot reduce complexity without affecting his repeated game payoff. Each player must hold the capacity to punish the opponent for P periods; otherwise he will not get into the peace era.

Finally, consider the case in which the water source will dry up after T periods. If the complexity of strategy is not taken into account by a player, then there is a single Nash equilibrium in which the players use the "don't trust" strategy. In contrast, the pair of honest strategies is a Nash equilibrium if counting up to T is more "costly" than the one period gain achieved by a sudden widening of the tunnel.

7. CONCLUSION

In this lecture I have discussed some of the recent developments in economic and game theory in the direction of Bounded Rationality. I should say that the papers I based my lecture on are quite formal and the understanding of the formal models is necessary to fully appreciate the ideas. Some people claim that Bounded Rationality is the perpetual "next hot topic" of economic theory. Even so, I think we have recently observed a shift of interest towards expanding economic theory to include bounded rationality elements.

Much has to be done before the questions I have discussed in this lecture lead to any practical applications in understanding inflation, growth or unemployment. My interest in these topics, however, does not stem from practical applications but from the interest in the questions themselves. In this line of research I feel we are taking part in a universal human effort to understand the logic of social interaction. The exciting thing about this exploration is that it is done in our own minds and each of us is a laboratory for examining these issues.

REFERENCES

ABREU, D. and A. RUBINSTEIN (1988), "The Structure of Nash Equilibrium in Repeated Games with Finite Automata", *Econometrica* 56 (1988), 1259-1282.

GEANAKOPOLOS, J., "Common Knowledge, Bayesian Learning and Market Speculation with Bounded Rationality", *Journal of Economic Perspectives* (forthcoming).

HUBER, J., J. W. PAYNE and C. PUTO (1982), "Adding Asymmetrically Dominated Alternatives: Violations of Regularity and the Similarity Hypothesis", *Journal of Consumer Research,* 9, 90-98.

MEYER, M. (1989), "Learning from Coarse Information: Biased Contests and Career Profiles", Mimeo, Nuffield College, Oxford.

MILGROM, P. and STOKEY, N. (1986), "Information, Trade and Common Knowledge", *Journal of Economic Theory,* 26, 17-27.

RUBINSTEIN, A. (1986), "Finite Automata Play the Repeated Prisoner's Dilemma", *Journal of Economic Theory,* 39, 83-96.

SATTATH, S. (1989), "The Maximization Principle and Constructive Decision Theory", unpublished dissertation, Department of Psychology, The Hebrew University.

SIMON, H.A. (1982), *Models of Bounded Rationality,* The MIT Press.

TVERSKY, A. (1988), "Context Effects and Argument Based Choice", paper presented at the Association for Consumer Research Conference, Maui, Hawaii.

TVERSKY, A. and KAHNEMAN, D. (1986), "Rational Choice and the Framing of Decisions", in *Rational Choice,* edited By R. HOGARTH and M. REDER, The University of Chicago Press.