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Behavioral Game Theory

Simon Gächter

Introduction

Game theory is a mathematical tool to describe and analyze situations of conflict, cooperation, and coordination. In rational player models it is typically assumed that players are highly rational beings who completely understand the strategic situation and who always maximize their consistent preferences given their rationally formed beliefs about the behavior of their opponents. At the opposite extreme, in evolutionary models, players have no cognition and therefore "no choice" but are "programmed strategies" that survive or go extinct in an evolutionary contest.

By contrast, the approach of behavioral game theory (BGT) is to seek empirical information about how *human* beings – as opposed to highly rational beings or programmed strategies – behave in strategic situations. Thus, BGT takes the middle ground between these two extremes but builds on the great advances of formal game theory, without which BGT would not exist. BGT aims to answer the following research questions:

- To what extent is standard game theory a useful approximation to the strategic behavior of real people?
- If we observe deviations from what standard theory predicts, can we disentangle the reasons for the discrepancies?
- What are the players' preferences and their strategic reasoning processes?
- How do people learn in games?

In the long run, the goal of BGT is to discover theories that rest on plausible psychological foundations. BGT has this approach in common with the field of behavioral finance (see Chapter 26, this volume). Thus, BGT is not about "disproving" game theory but rather about making it a more powerful tool for the analysis of strategic situations. The most important research tool of BGT is incorporating insights from psychology and conducting controlled laboratory experiments.

In this chapter I will discuss some seminal experiments and recent developments in BGT. Lack of space makes my approach selective. This chapter is structured as follows. In the next section, I will discuss the most important concepts of standard game theory, as they are relevant for understanding the goals of BGT. I then review some classic findings on classic games. This sets the stage for the following section, which concentrates on three building blocks of modern game theory – preferences, strategic reasoning, and equilibration. The final section provides my concluding remarks.

For those who want to dig deeper, Camerer (2003) provides the most comprehensive overview available of the field of BGT. Crawford (1997) is a very useful shorter survey. Kagel and Roth (1995) provide an extensive overview of research in experimental economics. Selten (1998) offers a bounded rationality perspective on BGT.

What is (Behavioral) Game Theory?

Game theory is a branch of applied mathematics that provides a framework for modeling and predicting behavior in social situations of cooperation, coordination, and conflict. The famous book by John von Neumann and Oskar Morgenstern (1944), *Theory of Games and Economic Behavior*, founded the field of game theory. While in the first two decades after the publication of von Neumann and Morgenstern's book game-theoretical research was mainly confined to small mathematical communities, it entered the intellectual discourse in the social and biological sciences in the 1960s and 1970s. Two decision theorists, Duncan Luce and Howard Raiffa wrote one of the first textbooks in game theory (Luce and Raiffa, 1957). In his classic book, *The Strategy of Conflict*, Thomas Schelling introduced game-theoretic arguments to political science (Schelling, 1960). Game-theoretic reasoning also has had a great impact on evolutionary theories in the biological sciences. There are also applications of game theory in anthropology and sociology. In economics, game theory is a cornerstone in all curricula, and an essential element of modern economic theory.

Before I discuss the goals of BGT in more depth, it is useful to introduce some important game-theoretical concepts. I will confine myself to rational player models and to concepts that are relevant for our discussion of BGT. A full account of modern game theory can be found in Colman (1995), or Gintis (2000) who both frequently refer to experimental findings on the various games they discuss. The latter book also covers recent evolutionary models.

There are two ways of describing strategic situations – the normal form and the extensive form. I will start with the normal form and introduce the extensive form later. The *normal form* of a game consists of a specification of (1) a set of n players, (2) their actions or strategies, and (3) their payoffs. Examples may help to fix ideas. To keep things simple, I will concentrate on two-person games where each player has just two strategies. Of course, everything can be extended to n-player games with m actions.

		Mary C	Mary D
John	C	2, 2	0, 3
John	D	3, 0	1, 1

(a) Prisoners' dilemma

	Mary C	Mary D
C	2, 2	0, 1
D	1, 0	1, 1

(b) "Stag hunt"/"Weak link"

	Mary C	Mary D
C	3, –3	–1, 1
D	–9, 9	3, –3

(c) Zero-sum game

Figure 24.1 Classic games of (a) cooperation, (b) coordination, and (c) conflict in normal form

Figure 24.1 depicts three classic games in normal form. These games describe generic social situations of cooperation, coordination and conflict. The chosen games are also interesting for the solution concepts needed to solve them.

In all games of Figure 24.1, there are two players, Mary and John. Both of them have two actions they can choose, C and D. It is assumed that John and Mary choose simultaneously, i.e., without knowing about their opponent's choice. In all games, there are four strategy combinations: (C, C); (D, C); (C, D); and (D, D). The numbers in each matrix refer to the payoffs each player receives as a result of the possible strategy combinations. The first number in each cell refers to John and the second to Mary. For example, if in game (a) John plays D and Mary plays C, then John's payoff will be 3 and Mary will get 0. Payoffs are numerical representations (called "utilities") of players' preference orderings over possible outcomes. For instance, game (a) is a situation where John prefers the outcome (D, C) over (C, C), over (D, D), over (C, D). The utilities reflect this preference ordering.

Solution concepts predict how people will play the game. As in other domains of rational decision making (compare Chapters 2 and 20, this volume) the behavioral assumption about rational play in games is that players maximize their expected utilities. The most basic solution concept is *dominance*, i.e., the assumption that rational players will not play strategies that are dominated by other strategies that a player has at his or her disposal. Look at game (a). In this game, both John and Mary are better off by choosing D than C regardless of what the opponent chooses, i.e., C is a dominated strategy for both players. Thus, dominance as a solution concept predicts outcome (D, D). This game is the famous prisoners' dilemma, the prototype game to study issues of *cooperation*.

Not all games are dominance-solvable. In games (b) and (c) no solution in dominant strategies exists. An appropriate solution concept for these games is the *Nash equilibrium*. A Nash equilibrium prevails if players choose mutually best responses, i.e., each player chooses the strategy that maximizes his or her utility given the strategies played by the opponents. In other words, in a Nash equilibrium, no player has an incentive to choose another strategy than the one he or she is currently playing. If we apply this reasoning to game (a) then we find that only (D, D) is a Nash equilibrium. Game (b) has two Nash equilibria (in so-called "pure strategies"): (C, C) and (D, D). Game (b) is a so-called coordination game, because the fact that it has multiple equilibria requires *coordination* on one of the equilibria.

If we apply the solution concept of Nash equilibrium to game (c), we find that no solution in pure strategies exists. Yet, in a seminal paper John Nash (1950) proved that any game with finite player and strategy sets has an equilibrium at least in mixed strategies. A mixed strategy is a probability distribution over pure strategies. *A mixed-strategy Nash equilibrium* requires that the mixed strategies are mutual best responses. In the unique mixed-strategy Nash equilibrium of game (c) both John and Mary will play C with probability $^3/_4$. Game (c) is a prototypical example of pure *conflict*, because it is a zero-sum game: John's gains are Mary's losses, and vice versa.

We are now in a position to take a first look at three issues of BGT that are closely linked to conceptual building blocks of modern game theory that I will discuss more thoroughly in the fourth part of this chapter. One important recent issue concerns the players' preferences. In theory, payoffs are utilities and just represent the players' preferences. These utilities can accommodate almost every taste, as long as some basic consistency axioms are met. Yet, in (economic) applications of game theory it is often presumed that the utilities represent material payoffs. For instance, firms maximize profits and employees their income. In experiments, participants earn money. Players are then viewed as selfish maximizers, who only care for their own payoff. Yet, as we will see below, this assumption is frequently at odds with the facts. A second task of BGT is to understand human strategic reasoning. Many models assume that players possess infinite reasoning powers and form rational beliefs about how their opponents will behave and thereby take into account the belief formation of their opponent players, including beliefs about beliefs . . . ad infinitum. In an equilibrium these beliefs will be mutually consistent. Equilibrium play may look like an innocuous assumption, in particular if each player has a dominant strategy, like in the prisoners' dilemma game. Yet, in games where a number of iterations are necessary to eliminate dominated strategies (see section on "Measuring and modeling cognitions"), or in games with multiple equilibria such an assumption is far less innocuous. With multiple equilibria, it is an empirical question which equilibrium is played. A third issue of BGT therefore is to investigate how players learn in games and how an equilibrium might emerge. I will set the stage for a discussion of these issues by first looking at some classic results in classic games.

Classic Games of Cooperation, Coordination, and Conflict

Laboratory experiments are the best-suited tool to study behavior in games. A game with its decision rules can be directly implemented in the lab. The most difficult part is "controlling" the preferences. When behavioral game theorists run experiments, participants are paid according to their decisions. Practices in psychology often differ here (see Hertwig and Ortmann, 2001). An important argument in favor of paying is that it is safe to assume that all people, regardless of their preferences, are non-satiated in money. Thus, paying subjects for their decisions ensures that at least the subjects' monetary preferences are controlled. Decisions will have true opportunity costs and are not just hypothetical statements.

Games of cooperation

In a sense, BGT started right after game theory was invented. The prisoners' dilemma, for instance, was conceived in 1950. At about this time the first experiments on the prisoners' dilemma were conducted. Rapoport and Chammah (1965) report one of the first series of systematic experiments on the prisoners' dilemma. Several hundred studies followed. The striking result is that people cooperate much more than is compatible with a simple dominance argument that underlies the prediction in the prisoners' dilemma (if we assume that players maximize only their monetary payoffs). This result also holds for "social dilemma games" and "public goods games", which are both generalized *n*-person prisoners' dilemmas (see, e.g., Dawes, 1980; and Ledyard, 1995).

Coordination games

Many situations in social life require the coordination of activities. Examples abound. Language is an obvious case. A further prominent example of a solved coordination game is on which side of the road to drive. At an abstract level, any game with multiple equilibria is a coordination game. Which equilibrium, if any, will people play? This is fundamentally an empirical question and an important task of BGT to understand how people actually solve coordination problems. Important issues concern the role of "saliency" (e.g., Mehta, Starmer, & Sugden, 1994) or communication (e.g., Cooper, DeJong, Forsythe, & Ross, 1990) as coordination devices. The literature is large and I therefore concentrate on one class of coordination games, namely "stag-hunt" games. See Camerer (2003) for a more complete discussion.

Stag-hunt games are interesting because the equilibria in these games differ according to their "riskiness" and efficiency. Game (b) in Figure 24.1 illustrates this nicely. Think of John and Mary who can cooperate in hunting big game or defect and hunt a rabbit. If they both go for the stag they earn two payoff units; if John defects and goes for the rabbit, he catches a rabbit, worth one payoff unit, but Mary will be unable to catch a stag, and earn nothing. If both defect and go for the rabbit they both will catch a rabbit and get a payoff of 1. This game has three equilibria: the pure strategy equilibria (C, C), (D, D), and an equilibrium in mixed strategies. The stag-hunt game captures a situation where cooperation pays but is risky. Choosing D is safe because it yields a secure payoff of 1. In the language of game theory, the (C, C) equilibrium is "payoff-dominant," but (D, D) is "risk-dominant." Experiments by Cooper et al. (1990) and Van Huyck, Battalio, & Beil (1990) show that, after some initial miscoordination, play converges to an equilibrium. Yet, unless the players can communicate, they almost invariably end up playing the risk-dominant instead of the payoff-dominant equilibrium.

Games of conflict

Zero-sum games, for which game (c) in Figure 24.1 is an example, are interesting because of their purely competitive nature that implies the absence of pure strategy equilibria.

Players want to be "unpredictable" (for instance, a tennis player doesn't want to be predictable about whether she serves the ball left or right). Being unpredictable requires playing a mixed strategy.

In any mixed-strategy equilibrium players will choose probability distributions such that their opponent will be indifferent in choosing his or her pure strategies. For instance, in the mixed-strategy equilibrium of game (c), John will play C with probability $^3/_4$ and D with probability $^1/_4$.

Yet, behaviorally, there are at least three problems. First, in equilibrium, players have to accurately guess the exact probabilities with which the opponents will play their mixed strategies. Second, players should really randomize their choices. However, it is well known from psychological research that people are not very good in producing random sequences (Rapoport and Budescu, 1997). Third, learning is difficult, because in equilibrium people are indifferent between their choices. This implies that there are no positive incentives for playing a particular strategy. Yet, the degree to which human players display behavior that is consistent with the mixed-equilibrium prediction is an empirical question and an important task for BGT.

Malcolm and Lieberman (1965) report one of the first tests of game (c). The mixed-strategy equilibrium prediction is that C will be played with frequency 0.75. Yet, the actual frequency of plays of C of pairs of subjects who repeated this game 200 times, is only 0.57. Results from other studies are ambiguous. Maybe for this discouraging reason, research on mixed-strategy play stalled for many years. It was rejuvenated by a paper by O'Neill (1987), who reported more favorable results in an improved design. New experiments with further improved designs and data analysis by Binmore, Swierzbinski, & Proulx (2001) and Shachat (2002) report results that are favorable for mixed-strategy equilibrium in the sense that the observed frequencies are close to the theoretical frequencies. These results are quite surprising and good news for the mixed-equilibrium prediction, given that there are sound psychological reasons to assume that the concept is behaviorally rather demanding.

Preferences, Strategic Thinking, and Learning

The results from the previous section provide the backdrop for my discussion of recent advances in BGT. The topics I will touch concern three conceptual building blocks of modern game theory, the players' preferences, their strategic reasoning, and the process of learning.

Measuring and modeling motivations – social preferences

To appreciate the recent advances in BGT research on preferences, remember that payoffs in games are utilities that reflect the players' preferences over the outcome profiles. In theory, provided they are consistent, preferences can encompass any motivation. Yet, most applications of game theory make the assumption that the players are purely selfish.

An important contribution of BGT in recent years concerns our understanding of human players' actual social preferences, i.e., to what extent people take the well-being of other players into account in their preferences. The results from the cooperation games suggest that many players are not purely selfish. Yet, simultaneous-move games of cooperation are rather blunt tools to measure social preferences because it is very hard to distinguish altruism, reciprocity, and selfishness. Therefore, games in so-called "extensive form," where players move sequentially, are more apt to measure social preferences than simultaneous-move games. Before I discuss social preferences, I introduce the extensive form as a tool to describe situations that require sequential decisions, and the most important solution concept, the subgame-perfect equilibrium.

A digression: Extensive form and subgame-perfect equilibrium

The *extensive form* depicts the sequence of moves, the information and actions players have when it is their turn to make a move, and the final payoffs as a function of the moves of all players in the game. Figure 24.2 is a very simple example. It shows the extensive form of a simplified ultimatum game, called the "mini-ultimatum game." Next to the prisoners' dilemma, the ultimatum game, invented by Güth, Schmittberger, & Schwarze (1982), is probably the most researched game in BGT. As I will show below, this game is ideally suited to measure reciprocal preferences.

In this simple game John moves first. He has the choice between two allocations of \$10, offer A or B. After John has made his offer, Mary is informed about it. She has two actions: she can either accept or reject the proposed allocation. If Mary accepts offer A, for instance, then John will receive \$8 and Mary will get \$2. If she turns it down, both receive nothing. This simple game is called the "ultimatum game" because Mary gets only one offer that she can either take or leave. It is a "mini-ultimatum game" because its "big brother" is a game where John can split \$10 as he likes.

To find the solution, we will apply the principle of backward induction, i.e., we will start at the second stage first. Surely, Mary will accept any offer because in either case she ends up with more than 0. Since John anticipates this, he will propose A and Mary will

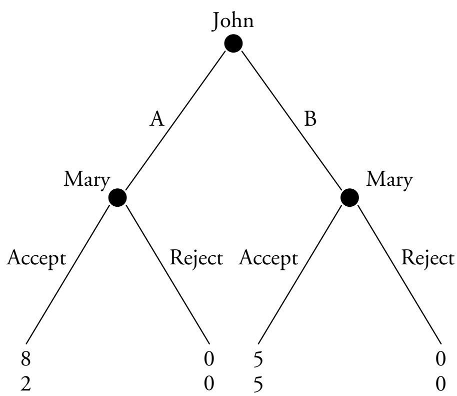

Figure 24.2 The extensive form of the mini-ultimatum game

accept. Yet, it is easy to verify that there is another Nash equilibrium, where John offers B and Mary accepts B, but threatens to reject offer A. While this is a Nash equilibrium, it does not satisfy sequential rationality. In the subgame after offer A, Mary would reject an offer that gives her more than 0, which is an incredible threat and hence not "subgame perfect" (Selten, 1975). Thus, a subgame-perfect equilibrium is a Nash equilibrium that is also sequentially rational. Next to the concept of Nash equilibrium, the subgame-perfect Nash equilibrium is a cornerstone of game theory.

Measuring social preferences with simple games

I now discuss the most important social preferences as they have been investigated in hundreds of experiments. The games are deliberately simple to avoid cognitive complexities that might interfere with the measurement of social preferences. Likewise, most games are one-shot, in the sense that the experimental subjects play only once against a particular opponent. This excludes strategic incentives that come from repeated interactions with the same opponents. Moreover, all games contain induced monetary incentives that allow a straightforward prediction if people are solely motivated by monetary returns. Deviations from this prediction can be interpreted as a willingness to pay (a "revealed social preference") for implementing the preferred action.

Negative reciprocity

Because the subgame-perfect equilibrium concept looks so compelling in simple games like the ultimatum game, the results of the first experiments by Güth et al. (1982) came as a shock and surprise to many economists and game theorists. Güth et al.'s (1982) version of the game is the same as in Figure 24.2, except that John can split $10 in any way he wants. Under the assumption that both players only care about their own monetary payoffs, subgame perfection predicts that John will offer the smallest money unit, say 1 cent, and pocket $9.99. Mary will accept the cent.

This is not what happened in Güth et al.'s (1982) experiment. The average offer was roughly 35 percent and offers below 50 percent were increasingly likely to be rejected. This result has been replicated dozens of times under various conditions, including "high stakes." One very remarkable study is by a group of anthropologists who ran experiments in 15 remote small-scale societies (see Henrich, Boyd, Bowles, Camerer, Fehr, & McElreath, 2001). They showed that unfair offers are likely to be rejected almost everywhere.

Most researchers today agree that rejecting a positive offer in the ultimatum game indicates negative reciprocity. A person has negatively reciprocal preferences, if she is willing to pay some price to punish an opponent for behavior that is deemed unfair or inappropriate. The observation of negative reciprocity is not confined to ultimatum games. It has also been observed in social dilemma and public goods games where players had the opportunity to punish their opponents. Many cooperators were willing to incur costs to punish the defectors, even in one-shot games without any future interaction (e.g., Fehr and Gächter, 2002). Rejecting a positive offer in a one-shot ultimatum game or punishing defectors means to forgo money without any material benefit. Many people have a willingness to punish even in the absence of any present or future rewards. This kind of behavior is fundamentally different from punishment strategies in repeated games (like "tit-for-tat" – see e.g., Axelrod, 1984), where punishment can be motivated by future returns.

Positive reciprocity

The friendly version of reciprocity is called positive reciprocity. Positive reciprocity means that people are prepared to pay a price to reward a friendly or a generous action by an opponent player. They are willing to pay this price even in the absence of any present and future material benefits. Thus, a purely self-interested individual would never exhibit positive reciprocity. And yet, positive reciprocity is quite common. One of the first demonstrations of positive reciprocity in an experimental game is from Fehr, Kirchsteiger, & Riedl (1993) in the so-called "gift-exchange game." This game mimics a labor relation where an employer pays a wage to an employee, who then chooses his or her effort level. In the game, incentives are set such that the employee always has a strict incentive to provide the lowest effort level, because effort is increasingly costly. The results are not consistent with this clear-cut prediction. Most employees respond with a high effort level if their employer pays them a generous wage. This result has been replicated under various institutional conditions (see Fehr and Gächter, 2000, for an overview). Positive reciprocity has also been demonstrated in a game related to the gift-exchange game, the so-called trust game (Berg, Dickhaut, & McCabe, 1995).

Altruism

There is a lot of evidence that many people are prepared to make anonymous donations to charities or to spontaneously help others who are in need. A person has altruistic preferences if her utility increases with the well-being of others. The experimental tool to study this is the "dictator game" (Kahneman, Knetsch, & Thaler, 1986). A player (the "dictator") is endowed with some money, say $10, and can then decide how much to pocket, and how much to pass on to a passive recipient, who cannot veto the offer. Of course, under standard assumptions, the dictator will keep everything. Under double-blind conditions, roughly two-thirds of the people give nothing and one third gives amounts between 10 and 50 percent of the pie. Offers are significantly lower than in the ultimatum game, because the dictators do not have to fear rejections (see, e.g., Forsythe, Horowitz, Savin, & Sefton, 1994). The significance of the results from the dictator games is that many people, even under complete anonymity, are willing to share their wealth with others.

Attributions

The implicit assumption made in almost all of rational choice analysis and regardless whether people are selfish or other-regarding is that decision makers only care about outcomes. Yet, casual evidence and daily experience suggest that not only outcomes but also the "intentions" (the attribution of motivations) behind a decision matter for our evaluation of outcomes. To fix ideas, look again at Figure 24.2. In this game, John can choose between offer A, which, if Mary accepts it, gives John $8 and Mary $2. Offer B gives both players $5. Now imagine another game where the rejection payoffs and offer A stay the same, but offer B gives John $2 and Mary $8, instead of ($5, $5). If Mary just cares about final payoffs, the rejection probability of *offer A* should not be influenced by the unchosen offer B. Yet, experimental evidence shows that unchosen alternatives matter a lot for the rejection probability of offer A. For instance, Falk, Fischbacher, & Fehr (2003) who implemented this game, found that the rejection probability of offer A, when the alternative offer B is (5,5) is 44.4 percent, and only 26.7 percent if offer B amounts to (2,8). An explanation is that in case (5,5) is available, to offer A signals a greedy intention, whereas this is not the case if offer B is (2,8) and therefore as unequal as offer A. Rejections are also lower if a computer, which has no intentions, generates the unfair offers (e.g., Sanfey, Rilling, Aronson, Nystrom, & Cohen, 2003).

Modeling social preferences

How can we theoretically account for the empirical results? My interpretation of the results is that they show us people's apparent willingness to pay to achieve fairness or to punish unfair behavior. In other words, their behavior reveals a preference. Yet, many social scientists, most fervent the economists, traditionally have been very hostile against using preference explanations to rationalize social phenomena, because almost every result can be "explained" this way. This is a very strong argument if preferences are unobservable. However, the simple experiments and the more refined tools of neuroscientific research (see, e.g., Sanfey et al., 2003) are instruments to gather the necessary empirical evidence. Thus, the challenge now is to find a utility function that is psychologically plausible, can explain a wide variety of games and can be subjected to further experimental tests. Meanwhile a large literature has developed that has made a start on this issue. Camerer (2003) provides a comprehensive overview. In the following I will focus on models of inequity aversion (Fehr and Schmidt, 1999; Bolton and Ockenfels, 2000) because they are now used in applied work.

The idea of these models is to assume that individuals have a higher utility the more material resources they possess but, in addition to this self-centered motivation, people also care for the fairness of the allocation, i.e., they are inequity averse. To make this precise, let us assume (following Fehr and Schmidt, 1999) that Mary has the utility function U_M, which depends on the allocation of material resources to her and John:

$$U_M(x_M,x_J) = x_M - \alpha_M \max[x_J - x_M,0] - \beta_M \max[x_M - x_J,0]. \qquad (24.1)$$

Mary's utility increases with her own resources x_M, and decreases with the inequity of the allocation. If John gets more than Mary ($x_J - x_M > 0$), Mary experiences a disutility because of unfavorable inequity, provided $\alpha_M > 0$. If Mary also dislikes inequity that favors her ($x_M - x_J > 0$), β_M is positive as well. A typical assumption is that $\alpha_M > \beta_M$, i.e., Mary's disutility is larger in case of unfavorable than favorable inequity. This utility function also contains selfish preferences (that characterize a significant group of subjects in almost all experiments) as a special case. If Mary is selfish, she only cares for x_M and not about the inequity of the allocation, i.e., $\alpha_M = \beta_M = 0$. Various combinations of α and β allow us to model the observations that people are heterogeneous with respect to their social preferences.

How can inequity aversion explain, for instance, rejections in the mini-ultimatum game depicted in Figure 24.2? Assume John proposes allocation A, which gives him \$8 and leaves \$2 for Mary. If Mary does not care about the inequity of this offer, she will surely accept, because \$2 > \$0. If, however, Mary is sufficiently inequity-averse, she will reject the offer and thereby restore equity. A similar logic holds in the public goods game with punishment, because a free rider has a payoff advantage that can be reduced by punishment. Aversion against favorable inequity ($\beta > 0$) can also explain why some people reject offers that give them more than the opponent player. This approach that is only sketched here can also explain the results from dictator games, public goods games, and a variety of market games.

A drawback of models like this is that they cannot explain that often the set of alternatives and the intentions behind a choice, and not just final outcomes, matter for decision makers. For instance, when people reject offers in the ultimatum game or punish defectors in the public goods game, they often do this not only because they are inequity averse, but they also want to punish the greedy intention.

Models that incorporate intentions by modeling them as beliefs that are part of the utility function (so-called "psychological games" – see Geneakoplos, Pearce, & Stacchetti, 1989) do a better job here. A seminal model is Rabin (1993) who shows how the perceived "kindness" of a choice can, e.g., explain why cooperation in the prisoners' dilemma can be a "fairness equilibrium." Dufwenberg and Kirchsteiger (2004) and Falk and Fischbacher (1999) generalize Rabin's (1993) approach from normal form games to extensive form games. Falk and Fischbacher (1999) and Charness and Rabin (2002) merge inequity aversion and intention-based reciprocity.

Except for changing the utility function the models retain all assumptions about rationality and optimal strategic play that characterize solution concepts in rational choice game theory. This assumption might be approximately correct for describing very simple games, but in more complex games it is certainly doubtful to assume away cognitive costs and bounded rationality. In the next section I will therefore look at the insights gained on people's cognitions, when they play (strategically complex) games.

Measuring and modeling cognitions – strategic thinking

Backward induction

Backward induction is an important rationality principle because it ensures sequential rationality. To put backward induction to a test requires separating it from social preferences. The observation that people deviate from subgame-perfect play can have two reasons – people have social preferences and/or they do not behave sequentially rationally. The fact that recent theories of social preferences can rationalize observed play in deliberately simple games where backward induction is probably not an important issue does not mean that people really obey the principle of backward induction. While backward induction surely is a very convincing principle of rational behavior, it is psychologically demanding and may be deemed unnatural, at least by untrained subjects. Backward induction requires looking forward to the end of the game tree and thinking about subgames that are possibly never reached in the game.

Johnson, Camerer, Sen, & Rymon (2002) conducted a psychologically rich experiment on backward induction that controls for social preferences. The experimental subjects play a three-stage alternating bargaining game (where John makes the first proposal how to split that is followed by Mary's counteroffer if Mary rejects John's first offer and where John can make a final offer if he rejects Mary's offer). After each rejection the pie shrinks. There are two novel features in Johnson et al.'s (2002) experiments. First, to control for social preferences, participants in one treatment know that they play against a payoff-maximizing computer, which excludes payoff comparisons to another human being. In another treatment, the opponent is another human player. Second, in both treatments Johnson et al. (2002) apply a so-called "Mouselab" procedure used in decision research, to infer thinking processes from observed information acquisition. Specifically, subjects see on a computer screen the covered boxes of the pie sizes in each of the three rounds. They also see the covered boxes that contain the information of the role of a subject in a given round. By moving the cursor to a box the box automatically uncovers and reveals the corresponding information (moving away the cursor re-covers the box). The software records the time the subject spends looking at a specific box, how often this box is visited and how a subject switches back and forth between the boxes. If people backward induct, they should start by looking at the third-round boxes.

There are two main results. First, offers were closer to the standard equilibrium predictions when subjects played against the computer, which suggests that payoff comparisons to other human players matter. Second, most subjects spent most of their time looking at the first-round boxes instead of the third-round boxes, as required by backward induction reasoning. There are a number of subjects who never looked at the third-round boxes. When subjects were told about backward induction, their information acquisition became more rational. The significance of these results is twofold: First, they nicely demonstrate that both social preferences and limited cognitions determine bargaining behavior. Second, the patterns of information acquisition tell us something about principles of strategic reasoning of people who are less than fully rational. In the following section I will return to normal form games and take another look at principles of strategic thinking.

Strategic sophistication

Strategic thinking in games requires players to form beliefs about what opponents will do. The issues that are involved can most easily be demonstrated with the concept of *dominance,* which is a very basic rationality principle. For instance, if in game (a) of Figure 24.1 numbers reflect the player's real utilities, then strategy D dominates C for both players. This game is the simplest example of a dominance-solvable game. Yet, most games that are dominance-solvable require the *iterated* elimination of dominated strategies. If this process allows the elimination of all but one strategy combination the game is dominance-solvable. In rational game theory the iterated elimination of dominated strategies is a mental exercise that rational players will entertain under the assumption of common knowledge of rationality. Yet, empirically, it might be that a particular player avoids playing a dominated strategy but is not sure that other players are doing the same.

The following game, known as the "beauty contest game" nicely illustrates the issues that are involved in strategic reasoning. All players in a group of n players simultaneously write down a real number between 0 and 100. The average of these numbers is multiplied by a factor $p < 1$. The player whose stated number is closest to this statistic is the winner and gets the prize. The others receive nothing. In case of ties the prize is randomly given to one of the tied winners. Assume, for instance, that $p = 0.7$. Applying iterated elimination of dominated strategies immediately eliminates all numbers larger than 70, because they can never be winning numbers. Given that all numbers above 70 are eliminated, the winning number cannot be larger than $70 \times 0.7 = 49$, and so on. The only number that survives the iterated elimination of weakly dominated strategies is 0. Yet, even if players understand this logic, zero is most likely not the winning number (at least not when this game is played for the first time). Nagel (1995) was the first study on this game. In her experiments with $p = 2/3$, the average number was 35 in the first round and quickly converged to zero after a few further plays of the game. The game has been replicated many times (see Nagel 1999).

The beauty of this simple game is that it can be used to measure depths of strategic reasoning, which might differ between people. For instance, all studies report that some subjects choose their number more or less randomly. Following Stahl and Wilson (1995) these people might be called "level-0 players," because they do not think strategically. Level-1 players make one step of iterated reasoning. They believe that others are level-0 types who choose randomly (with an average of 50). Level-1 types best-respond by picking 35. Level-2 players anticipate that there are level-1 players around and choose a number in the vicinity of 25. Thus, a level-*k* player assumes that all others are one level below him or her, and best responds to this belief by choosing a number $50p^k$. Only a level $k = \infty$ would choose zero. Yet, choosing zero is "too smart" a choice. Estimations from first-round data of various experiments show that most people are level-3 or lower-level types, i.e., they use up to three steps of iterated reasoning. The trick is to be one step ahead of the opponents, but not further.

One drawback of the beauty contest games to measure levels of strategic thinking is that just one single choice is observed and the player is then classified on the basis of this choice. To circumvent this problem, Costa-Gomes, Crawford, & Broseta (2001) designed a series of normal form games and also used the "Mouselab" technique to see how players use payoff information. They confirm that most players are level-2 or level-1 types (see also Stahl and Wilson, 1995). These results are important information for any theory of boundedly rational strategic play. In the following section I will briefly discuss two models that aim at explaining people's behavior in one-shot games.

Models of strategic play

I concentrate on two aspects: First, when people play games, they make errors. Second, people differ in their levels of iterated reasoning.

A sensible assumption is that the likelihood of playing a particular strategy is a function of the strategy's expected payoff, but people make mistakes. A desirable property of a choice rule is that the probability of choosing a particular strategy increases with the expected payoff of the strategy and decreases with the errors people make. The logit function is a frequently used rule that has these desirable properties. Assume that we want to explain the choices in the games of Figure 24.1. The probability $p_M(\mathrm{C})$ that Mary plays her strategy C, given Mary's expected utility of playing C, $EU_M(\mathrm{C})$, is:

$$p_M(C) = \frac{e^{EU_M(C)/\mu}}{e^{EU_M(C)/\mu} + e^{EU_M(D)/\mu}}. \tag{24.2}$$

The parameter μ is an error rate. If $\mu \rightarrow 0$, the strategy with the higher expected payoff is played with probability 1. If $\mu \rightarrow \infty$, then Mary chooses randomly between her strategies (i.e., in the games of Figure 24.1 the probability of choosing C approaches 0.5). Thus, this logit choice rule has the desired properties. Imposing the assumption that in equilibrium the choice probabilities have to be consistent, leads to the solution concept of the "Quantal Response Equilibrium" (QRE, see McKelvey and Palfrey, 1995), which generalizes the concept of a Nash equilibrium by allowing for errors. QRE does a surprisingly good job in explaining both small and large deviations from the Nash equilibrium in a variety of one-shot games (Goeree and Holt, 1999). QRE can also be adopted to incorporate iterated reasoning with errors ("noisy introspection" – see Goeree and Holt, 1999).

The "cognitive hierarchy" model (Camerer, Ho, & Chong, 2003) assumes that level-*k* players believe that all other players are level-*k*-1 players and that for reasons of memory constraints more thinking steps are increasingly rare. Camerer et al. (2003) show that the frequency distribution of level-*k* types follows a Poisson distribution with mean and variance τ, where τ is the number of thinking steps. They fit a great many games and find that the average τ is 1.5. Data from the "beauty contest" experiments with various student and non-student subjects pools show that τ varies from 3.8 (computer scientists and game theorists) to 0 (some college students).

The noisy introspection model and the cognitive hierarchy model have primarily been developed to explain strategic thinking in games that people play only once, i.e., where there are no learning opportunities. These models can explain how people start playing a game. Learning models, to which I turn next, explain how people change their strategies as a function of their experience in playing the game and give us a hint how equilibration may come about empirically.

Learning

How does an equilibrium arise in a game? One theoretical interpretation is that players reason their way to an equilibrium, as, for example, in dominance-solvable games. Yet, in all but the simplest games this is psychologically not very plausible. Instead, people will play an equilibrium only after some process of trial-and-error, i.e., after some learning. Thus, a psychologically convincing interpretation is to see an equilibrium as the possible limit point of a learning process.

Learning models aim to explain the learning process, i.e., to understand how people change their strategies with experience. There exist plenty of learning models. For lack of space I will concentrate in this section on three frequently used models. See Camerer (2003) for an extensive overview of the experimental literature and Fudenberg and Levine (1998) for a theoretical account of learning in games.

Reinforcement learning

The learning models I look at typically assume that a particular strategy has a certain propensity, or initial attraction with which this strategy will be played. This attraction may come from the experiences of having played a similar game in the past, strategic considerations like the ones discussed in the previous section, or some other analysis. Learning rules then model how these attractions get updated as a function of experience. One simple rule, rooted in behaviorist psychology, is "choice reinforcement," which says that the attraction of a strategy is increased by its previous payoff. The attraction of a strategy that has not been played stays the same. The attractions then determine via a probabilistic choice rule how likely a particular strategy will be played. The more successful a strategy the more frequently it will be chosen (which is also known as the "law of effect"). Erev and Roth (1998) looked at normal form games with mixed-strategy equilibria and Roth and Erev (1995) applied this model to explain behavior in ultimatum games and two further games with similar subgame perfect equilibria. The simulations showed that the reinforcement-learning rule tracks the observed choices.

Belief learning

A cognitively more demanding approach, traditionally mostly used by game theorists, is belief learning. The most frequently used model is "fictitious play." It assumes that players play best responses given the beliefs they have about their opponents' strategies. Players are assumed to have a good memory – beliefs are formed by observing the whole history of strategy choices. Players play a best response to the relative frequency with which their opponents have played their strategies in the past. A special case of "fictitious play" is Cournot learning, where players best respond just to the most recent strategy choice of their opponents. Cheung and Friedman (1997) provide a general framework, called "weighted fictitious play" that contains both fictitious play and Cournot learning as special cases. Specifically, the main idea is that beliefs are formed by weighting past choices of opponent players by a discount factor γ, such that the most recent choices get more weight than historical choices. If $0 < \gamma < 1$, then people learn adaptively. If $\gamma = 1$, then all past choices are equally weighted – this is the case of fictitious play. If $\gamma = 0$, only the most recent choice is considered, i.e., we have Cournot learning. Cheung and Friedman (1997) test their model on 2×2 normal form games. The estimated median γs do not strongly differ between games and are closer to 0 than to 1, i.e., people are closer to Cournot learning than to fictitious play.

Experienced-weighted attraction learning (EWA)

The final model I look at is EWA, invented by Camerer and Ho (1999). EWA is a hybrid model that combines belief and reinforcement learning and contains their pure forms as special cases. Camerer and Ho (1999) show that belief learning and reinforcement models are closely related, despite their very different appearances. The crucial feature of all learning models is how the attractions get updated. In EWA both actually chosen and unchosen strategies are reinforced. The chosen strategies are reinforced by the payoff they actually yield. For instance, if both Mary and John in game (b) of Figure 24.1 choose C, then Mary's strategy C is reinforced by the payoff $\pi_M(C,C) = 2$. The unchosen strategies are reinforced by the payoff they could have yielded, weighted by a so-called "imagination factor" δ. In the example, Mary's unchosen strategy D is reinforced by $\delta\pi_M(D,C) = \delta$. If the imagination factor $\delta = 0$, forgone payoffs are ignored and only the actually chosen strategy is reinforced; if $\delta = 1$, actual and forgone payoffs equally determine the attractions. The experience-weighted attractions then determine via a probabilistic choice rule the actual choice probabilities.

The ambition of EWA is that all important parameters have a natural psychological interpretation and can be measured empirically. The interpretation of the most important parameter, the imagination factor δ, is that it captures two important aspects of human learning, which Camerer and Ho (1999) aptly call the "law of actual effect" and the "law of simulated effect," respectively.

Camerer and Ho (1999) evaluate their model econometrically and compare it to reinforcement and belief learning with data from constant sum games with unique mixed-strategy equilibria, dominance-solvable beauty contest games, and a coordination game with Pareto-rankable pure-strategy Nash equilibria. Estimations show that EWA outperforms reinforcement learning in all three games and is better than belief learning in most cases. On average, across all the data sets that Camerer and Ho (1999) study, the imagination factor $\delta = 0.50$, which says that people weigh forgone payoffs about half as much as actual payoffs. People not only learn from their successful strategies (as in reinforcement learning) but also from simulating what they could have earned had they chosen another strategy.

Concluding Remarks

What will the future of BGT be? The ultimate goal of BGT should be to predict behavior not only in lab experiments but in real-world strategic situations. A couple of steps are probably necessary to get there. One direction is to study more systematically how the results from individual judgment and decision research, and bounded rationality apply in games (compare Hastie and Dawes, 2001; and Chapters 4, 5, and 20, this volume). Knowing how groups, compared to individuals, behave in strategic decisions certainly would be fruitful for many practical purposes (see also Chapter 23, this volume). One important observation from many experiments is that people are heterogeneous both with respect to their social preferences and their strategic sophistication. A better understanding of motivational and cognitive heterogeneity, and their interplay, is surely necessary. One of the biggest payoffs for all these questions may come from paying more attention to the "mental models" people apply, how people reason in games, what determines players' social preferences, and the role of emotions in strategic reasoning and behavior (see also Chapter 22, this volume). "Mouselab" and neuroscientific techniques have already been successfully employed. These instruments, along with standard experiments and belief elicitation, certainly are very apt tools for further increasing our understanding of strategic thinking and behavior.

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