EXPERIMENTAL GAME THEORY

Werner Güth
Max Planck Institute of Economics, Jena, Germany

Keywords: common knowledge, repeated play, ultimatum game, adaptation dynamics, strategic bargaining, characteristic function experiments, random price mechanism

Contents

Summary

Whereas orthodox game theory relies on the unrealistic assumption of (commonly known) perfect rationality, the participants in game-playing experiments are, at best, rational only within limits. This makes it necessary to supplement orthodox game theory with a behavioral theory of game playing. This contribution first points out that this applies also to (one person-) decision theory. After reviewing influential experiments based on repeated games and the ultimatum game, typical reactions to the striking experimental results are categorized. Further sections are devoted to alternating offer bargaining and to characteristic function experiments.

1. Introduction

Orthodox game theory relies on what is commonly understood as "perfect decision rationality," or unlimited cognitive and information processing capabilities on the part of the players. Even for finite games of perfect information like chess, however, it is obvious that these requirements lie far beyond what human decision makers can accomplish.

Another problem in applying orthodox game theory is that it assumes the existence of individual cardinal utilities and subjective beliefs that can hardly ever be observed clearly, assuming that they exist at all. Of course, one may specify utilities in terms of material payoffs such as profits (which can often be seen and measured), and beliefs using objective probability whenever possible, but then the predictions of game theory are often not confirmed by experimental observations.

At the beginning of the twenty-first century we can look back at half a century of experimental game theory. We have tried to implement game theoretical models as (laboratory) experiments, to test orthodox game theory (assuming its applicability, for example, by specifying utilities as material payoffs and beliefs by appropriately designed chance moves), and to supplement orthodox game theory using behavioral concepts, since narrowly defined orthodox game theory often produces misleading results.

In what follows we begin by discussing decision-theoretical experiments. Regarding games involving interpersonal strategic interaction, we reverse the natural chronological order somewhat by first reporting on experiments based on non-cooperative games. Experimental game theory, similar to orthodox game theory, was initially dominated by cooperative game experiments (see *TU Games*).

2. One-Person Decision Making

Testing rationality experimentally in one-person games mainly involves testing (the axioms of) utility theory. There is probably no need to prove that human players will be unable to solve optimization tasks involving complex combinatory factors unaided. While people clearly differ in their capabilities, it is a fact of human existence that even the most capable among us may encounter optimization problems which they cannot solve when faced with finite sets of alternative choices. Let us therefore discuss three choice problems whose degree of difficulty differs greatly: dynamic optimization, risky choices, and dominance solvability in one-person games.

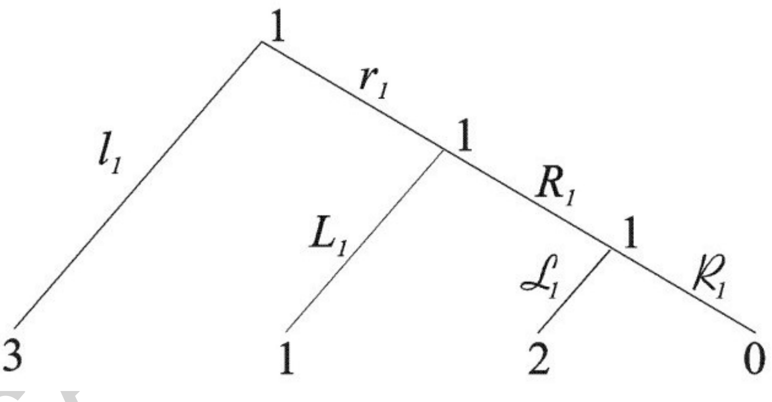

Figure 1. A simple dynamic one-person game

The simple dynamic one-person game in Figure 1 has an obvious solution (l_1, R_1, $\mathcal{L}_1$). It shows that any discussion of whether "rationality" can be assumed at all decision nodes cannot be restricted to interpersonal strategic interaction. If player 1 has to choose between L_1 and R_1, an optimal choice R_1 anticipates his/her own future rationality by preferring $\mathcal{L}_1$ over $\mathcal{R}_1$. However, the fact that one must choose between L_1 and R_1 seems in itself to cast doubt on the player's rationality. A rational player 1 would choose l_1 (yielding the payoff of 3), and thus would never actually face the choice between L_1 and R_1.

In more complex dynamic games, initial suboptimal choices are the rule rather than the exception. Such problems are more thoroughly studied in experimental (and cognitive) psychology. In experimental game theory (and economics) one tests the quantitative, or at least the qualitative, aspects of rational behavior, using models of inter-temporal allocation behavior such as models of rational addiction or the so-called "life-cycle-saving" models. Even the data generated by experienced participants clearly reveals that players, if they behave at all systematically, rely on heuristics rather than backward induction (dynamic programming).

Most decision theory experiments by experimental game theorists focus on (axioms of) cardinal utilities where the experimental procedures vary widely: for example, from pure questionnaires without monetary incentives to those where non-optimality leads to substantial losses. To some extent, it may be argued that deviations from optimal behavior should only be taken seriously when they imply substantial losses (saliency). Although the theory of rational decision making does not offer any guidance here, the saliency requirement can be justified by the (uncontrolled and small) costs of optimizing (for example) the utility loss of deriving an optimal alternative. In most cases, a participant is asked repeatedly to choose between two simple lotteries of the form $L = \left(\underline{P}\middle|w, \overline{P}\middle|1-w\right)$ with $0 \le \underline{P} < \overline{P}$ and $0 < w < 1$ where sometimes the monetary prizes $\underline{P}$ and $\overline{P}$ resulting with probability w, respectively $1-w$, are substituted by lotteries. Comparing all these choices usually reveals that certain axioms of expected utility maximization are violated.

Explaining some apparent paradoxes with reference to individual attitudes to risk can be excluded experimentally by applying the binary lottery technique. (Describing experimental results as "paradoxical" only shows how naive one's expectations have been!) Using this method, the payoff of a participant is the probability $1-w$ of winning times the utility $u\left(\overline{P}\right)$ of the high prize $\overline{P}$ plus w times $u\left(\underline{P}\right)$, the utility of the low prize $\underline{P}$ resulting with complementary probability w. By setting $u\left(\underline{P}\right)=0$ and $u\left(\overline{P}\right)=1$ the utility $u\left(L\right)=1-w$ results: in other words, utility depends linearly on the experimental payoff variable $1-w$ (implying risk neutrality). Thus specifying game payoffs by $1-w$ values makes every player risk-neutral. To justify this, all players need only prefer more $\left(\overline{P}\right)$ over less $\left(\underline{P}\right)$ money, with all obeying the laws of probability calculus (in the event of multiple chance moves).

When trying to observe experimentally how a lottery L is evaluated, one may rely on mechanisms rendering the truthful revelation of preferences as optimal: for example, in the sense that truthful revelation is the only undominated value statement. Let $\left[a,b\right] \subset \mathbb{R}$ be an interval with $a < b$ and $\varphi\left(\cdot\right)$ a density over $\mathbb{R}$ with $\varphi\left(p\right)=0$ for all $p \notin \left[a,b\right]$ and $\infty > \varphi\left(p\right) > 0$ for all $p \in \left[a,b\right]$. According to the random price mechanism the price *p*, which one can receive or must pay, is randomly determined according to $\varphi\left(\cdot\right)$.

For a potential seller the expected profit is $\int_{l}^{b}(p-v)\,d\varphi(p)$ and for a potential buyer $\int_{a}^{l}(v-p)\,d\varphi(p)$, where v with $a<v<b$ is the value for the commodity under consideration.

The only decision variable affecting a potential seller (whose willingness to accept one wishes to respect) or buyer (in whose willingness to pay one is interested) is thus the price limit l, meaning that one only sells at prices $p \geq l$ and buys at prices $p \leq l$ respectively. Clearly, $l = v$ is the only undominated price limit. Specifically, the optimal decision $l = v$ does not depend on *a*, *b*, and $\varphi(\cdot)$ as long as $a<v<b$ and the qualitative requirements for $\varphi(\cdot)$ are satisfied. Nevertheless, experimentally observed choices l react to changes of *a*, *b*, and $\varphi(\cdot)$. Since dominant choices do not depend on risk attitudes, given true values v seems more a normative concept than a fact of life. Human decision makers do not exercise fully-informed preferences. Instead they must generate their preferences by cognitive appraisal of their decision environment, imagining how choices may affect their basic concerns, and so on. In the context of such a dynamic process, aspects which are strategically irrelevant may nevertheless become influential.

The consequences of all this are that the normative concept of incentive compatibility may have little behavioral relevance or reliability. More generally, optimal mechanisms may perform relatively poorly. An institution that works best when all parties act rationally can itself induce non-rational behavior, and bad results then follow. One may wish to compare alternative mechanisms after replacing rational agents with more realistic ones, whose motivations may be context-dependent. This illustrates why orthodox (game) theory has to be supplemented by a behavioral theory of decision making, whose formalization could be based on the (stylized) results of decision making experiments (see *Mechanism Theory*).

-
-
-

Bibliography

Allais M. (1953). Fondements d'une théorie positive des choix comportant un risque et critique des postulats et axiomes de L'Ecole Americaine, *Econométrie* **40**, 257–332. [An influential article, based on questionnaire results, challenging the validity of the theory of expected utility.]

Anderhub V. and Güth W. (1999). On intertemporal allocation behavior: a selective survey of saving experiments. *Ifo-Studien* **3**, 303–333. [Reviews the few experimental studies of intertemporal allocation, a problem typically discussed as saving behavior.]

Anderhub V., Engelmann D., and Güth W. (2002). An experimental study of the repeated trust game with incomplete information. *Journal of Economic Behavior and Organization* ***48***, 197-216. [Reputation equilibria are tested by experimentally controlling incomplete information; allows for mixed strategies so that theory can also be tested at the level of an individual.]

Anderhub V., Güth W., Kamecke U., and Normann H.-T. (2003). Capacity choices and price competition in experimental markets, *Experimental Economics*,6, 27-52 [After experiencing price competition for given capacities, participants repeatedly choose capacities which remain constant for ten market periods.]

Andreoni J. (1988). Privately provided public goods in a large economy: the limits of altruism, *Journal of Public Economics* **35**(1), 57–73. [Discusses altruism as an explanation of behavior in public goods games.]

Aumann R. (1985). Repeated games. *Issues in Contemporary Microeconomics and Welfare* (ed. G. R Feiwel), pp. 209–242. Albany, NY: State University of New York Press. [An influential discussion of what are usually discussed as folk theorems, showing that in infinite horizon games many forms of behavior—both cooperative and non-cooperative—are possible.]

Aumann R. (1995). Backward induction and common knowledge of rationality. *Games and Economic Behavior* **8**, 6–19. [Argues that common knowledge of rationality is not self-contradictory if it is properly interpreted.]

Aumann R.J. and Maschler M. (1964). The bargaining set for cooperative games. *Advances in Game Theory* (eds. M. Dresher, L.S. Shapley and A.W. Tucker). Princeton, NJ: Princeton University Press, 443-476 [This cooperative solution concept avoids an empty core by allowing for counter objections to objections: in other words, not every dominance relation between payoff vectors is accepted.]

Axelrod R. (1984). *The Evolution of Cooperation*. New York: Basic Books. 241 pages. [Influential work leading to the literature on tournaments, where all strategies are matched and can be ranked according to their success.]

Becker G.S., de Groot M.H., and Marshak J. (1963). An experimental study of some stochastic models for wagers. *Behavioral Science* **8**, 199–202. [Introduces the random price mechanism, according to which it is the only dominant strategy to reveal one's value.]

Becker G.S. and Murphy K.M. (1988). A theory of rational addiction. *Journal of Political Economy* **96**, 675–700. [Drug consumption is determined by intertemporal optimization. assuming that all future consequences can be foreseen. (This article is not a joke!).]

Bicchieri C. (1989). Self-refuting theories of strategic interaction: a paradox of common knowledge. *Erkenntnis* **30**, 69–85. [Attempts to show that common knowledge of rationality is self-contradictory.]

Binmore K., Shaked A., and Sutton J. (1985). Testing noncooperative bargaining theory: a preliminary study. *American Economic Review* **75**, 1178–1180. [This experimental study claims that fairness matters more for inexperienced than for experienced participants.]

Bohm P., Lindén J., and Sonnegard J. (1997). Eliciting reservation prices: Becker-De Groot-Marschak mechanisms vs. markets. *Economic Journal* **107**(443), 1079–1089. [This experimental study questions whether random price mechanisms actually lead to truthful bids.]

Bolton G. (1991). A comparative model of bargaining: theory and evidence. *American Economic Review* **81**, 1096–1136. [An influential early study incorporating an emphasis on fairness when modeling the preferences of bargainers.]

Bolton, G. and Ockenfels A. (2000). ERC: a theory of equity, reciprocity and competition. *American Economic Review* **90**(1), 166–193. [By including inequality aversion, many experimental results can be explained even when rationality is maintained.]

Bush E. and Mosteller F. (1955). *Stochastic Models for Learning*. New York: Wiley. 365 pages. [Influential book introducing reinforcement learning, also referred to as stimulus-response learning.]

Camerer C. (1995). Individual decision making. *Handbook of Experimental Economics* (ed. J.H. Kagel and A.E. Roth), 587–703. Princeton, NJ: Princeton University Press. [Surveys experimental studies of individual decision making under conditions of risk.]

Cournot A.A. (1838). *Recherches sur les Principes Mathématiques de la Théorie des Richesses*, Paris: Hachette 198 pages. [English translation: *Researches into the Mathematical Principles of the Theory of Wealth*. New York: Macmillan, 1897.] [Very influential study in oligopoly theory, whose solution concept later led to the concept of strategy equilibria, and whose dynamics later became known as best-reply dynamics.]

Chamberlin E.H. (1948). An experimental imperfect market. *Journal of Political Economy* **56**, 95–108. [Seen as the first study in experimental economics to test the competitive (market) equilibrium.]

Davis D.D. and Holt C.A. (1993). *Experimental Economics*. Princeton, NJ: Princeton University Press. 572 pages. [Introduction to experimental economics, providing examples and discussing experimental results.]

Edgeworth F.Y. (1881). *Mathematical Psychics: An Essay on the Application of Mathematics to the Moral Sciences*. London: Kegan. 150 pages.[An impressive book which became famous for its sophisticated analysis of (replica) exchange economies. It already used the concept of a core, and proved an early limit theorem stating that the core shrinks to the set of competitive equilibria when the number of traders goes to infinity.]

Fehr E. and Schmidt K.M. (1999). A theory of fairness, competition and cooperation. *Quarterly Journal of Economics* **114**, 817–868. [By including inequality aversion, many experimental results can be explained even when rationality is maintained.]

Festinger L. (1957). *A Theory of Cognitive Dissonance*. Stanford: Stanford University Press. 291 pages. [This book introduces an influential psychological concept claiming that one avoids cognitive dissonance often by reevaluating concerns and evidence or by biased information acquisition.]

Fischbacher U. (1999). Z-Tree: Zurich toolbox for readymade economic experiments, *Working paper* No. 21, Institute for Empirical Research in Economics, University of Zurich. [Provides easily applied software for programming software for experiments with strategic interaction.]

Fouraker L.E. and Siegel S. (1963). *Bargaining Behavior*. New York: McGraw-Hill. 309 pages.[An early and influential book on experimental studies of bargaining behavior, including market behavior.]

Friedman D. and Sunder S. (1994). *Experimental Methods: A Primer for Economists*. Cambridge, UK: Cambridge University Press. 229 pages. [Introduction to experimental economics.]

Gale J.K., Binmore G. and Samuelson L. (1995). Learning to be imperfect: the ultimatum game. *Games and Economic Behavior* **8**(1), 56–90. [This study tries to justify the typical experimental findings of ultimatum experiments as stable results of adaptive processes.]

Geanakoplos J., Pearce D., and Stacchetti E. (1989). Psychological games and sequential rationality. *Games and Economic Behavior* **1**(1), 60–79. [The so-called “psychological idea” is that players do not want to disappoint the expectations of others, which must be consistent with actual behavior; devoid of (social) psychology.]

Güth W., Ivanova-Stenzel R., Königstein M., and Strobel M. (2003). Learning to Bid – An Experimental Study of Bid Functions in Auctions and Fair Division Games. *The Economic Journal,*3(4),477-494. [Participants play four different games repeatedly: 1st- and 2nd-price auctions and fair division games. The resulting data reveal anticipation and deliberation as well as path dependence.]

Güth W., Ockenfels P., and Wendel M. (1993). Efficiency by trust in fairness? Multiperiod ultimatum bargaining experiments with an increasing cake. *International Journal of Game Theory* **22**, 51–73. [In this experimental study of alternating offer bargaining, the “pie“ increases over time; proposers always command ultimatum power, which, however, is often not used in early periods.]

Güth W., Schmittberger R., and Schwarze B. (1982). An experimental analysis of ultimatum bargaining. *Journal of Economic Behavior and Organization* **3**(4), 367–388. [Introduces what was later termed the ultimatum game (experiment); led to many subsequent studies, all essentially confirming the first basic results.]

Hammerstein P. and Selten R. (1994). Game theory and evolutionary biology. *Handbook of Game Theory, Vol. 2* (eds. R.J. Aumann and S. Hart), 928–993. Amsterdam, Netherlands: Elsevier. [Surveys the concepts of evolutionary stability in biology and game theory.]

Harrison G.W. (1994). Expected utility theory and the experimentalists. *Empirical Economics* **19**, 223–253. [Claims that most deviations from expected utility maximization are non-salient, i.e. based on insufficient monetary incentives.]

Henning-Schmidt H. (1999). *Bargaining in a Video Experiment: Determinants of Boundedly Rational Behavior*. Lecture Notes in Economics and Mathematical Systems 467. Berlin, Heidelberg, New York: Springer. 221 pages. [Reports on videotaped bargaining experiments.]

Hoggatt A.C. (1959). An experimental business game. *Behavioral Science* **4**, 192–203. [An early study in experimental economics.]

Hey J.D. (1991). *Experiments in Economics*. Oxford, MA: Blackwell. 242 pages. [Introduction to experimental economics.]

Huck S., Normann H.-T., and Oechssler J. (1999). Learning in Cournot oligopoly: an experiment, *Economic Journal* **109**, C80–C95. [An experimental study of oligopoly markets, supported by varying degrees of information.]

Huck S. and Oechssler J. (1999). The indirect evolutionary approach to explaining fair allocations. *Games and Economic Behavior* **28**, 13–24. [This study tries to explain the typical experimental findings of ultimatum experiments as stable results of adaptive processes.]

Kagel J.H. and Roth A.E. (1995). *Handbook of Experimental Economics*, Princeton, NJ: Princeton University Press. 721 pages. [Contains many survey articles on various topics in experimental economics, as well as a historic account of how experimental economics developed.]

Kahneman D. and Tversky A. (1986). Rational choice and the framing of decisions. *Journal of Business* **59**(4), Part 2, 251–278. [Framing refers to different presentations of a decision model, which, according to rational choice theory, should not be critical. Framing still matters, however, especially when representation affects what are perceived as gains and losses.]

Kahneman D. and Tversky A. (1992). Advances in prospect theory: cumulative representation of uncertainty. *Journal of Risk and Uncertainty* **5**(4), 297–323. [A decision's yield is compared to a reference point, so that one may speak of the gains and losses which a decision implies. It is assumed that one is risk-averse in the "gain" region and more accepting of risk in the "loss" region.]

Kalai E. and Smordinski M. (1975). Other solutions to Nash's bargaining problem. *Econometrica* **43**, 513–518. [An axiomatic bargaining theory, based on an intuitive monotonicity axiom rather than on independence of irrelevant alternatives, allowing for a simple geometric derivation.]

Kalish G., Milnor J.W., Nash J.F., and Nering E.D. (1954). Some experimental n-person games. *Decision Processes* (eds. R.M. Thrall, C.H. Coombs and R.L. Davis), pp. 301–328. New York: Wiley. [An early experimental study of game-playing behavior.]

Kirchsteiger G. (1994). The role of envy in ultimatum games. *Journal of Economic Behavior and Organization* **25**(3), 373–389. [Explains ultimatum bargaining results in terms of envy.]

Komorita S.S. (1974). A bargaining theory of coalition formation. *Psychological Review* **80**, 149–162. [An experimental study of weighted majority games.]

Kreps D., Milgrom P., Roberts J., and Wilson R. (1982). Rational cooperation in the finitely repeated prisoners' dilemma. *Journal of Economic Theory* **27**, 245–252. [Introduces the reputation equilibrium by claiming incomplete information even where it is not experimentally induced and controlled.]

Maynard Smith J. and Price G.R. (1973). The logic of animal conflict. *Nature* **246**, 15–18. [Influential article showing the similarity between evolutionary stability and the (symmetrical) equilibrium concept in game theory.]

McKelvey R.D. and Palfrey T. (1992). An experimental study of the centipede game. *Econometrica* **60**, 803–836. [Experiment featuring the centipede game: explains initial cooperation (i.e. not terminating the game) in terms of reputation formation.]

Modigliani F. and Brumberg R. (1954). Utility analysis and the consumption function: An interpretation of cross-section data. *Post-Keynsian Economics* (ed. K.K. Kurihara). New Brunswick, NJ: Rudgers University, 388-436 [Related to intertemporal allocation and the life-cycle hypothesis.]

Nash J.F. (1953). Two-person cooperative games. *Econometrica* **21**, 128–140. [Presents the equilibrium concept and proves its existence.]

Nydegger R.V. and Owen G. (1975). Two person bargaining: an experimental test of the Nash axioms. *International Journal of Game Theory* **3**, 239–349. [In this experiment, two players can bargain how to allocate two stacks of chips, with different colors and different values for each; all pairs are distributed such that both receive the same monetary payoff.]

Peleg B. and Tijs S. (1996). The consistency principle for games in strategic forms. *International Journal of Game Theory* **25**(1), 13–34. [Provides a new axiomatic justification of the equilibrium by (converse) consistency and optimality.]

Pruitt D.G. 1967. Reward structure and cooperation: the decomposed prisoner's dilemma game. *Journal of Personality and Social Psychology* **7**, 21–27. [The experimental treatments are partly decompositions of the same prisoners' dilemma game which, however, yield widely differing degrees of cooperation.]

Rabin M. (1993). Incorporating fairness into game theory and economics. *American Economic Review* **83**(5), 1281–1302. [Applies psychological game theory to explain experimental results.]

Rapoport A. and Chammah A.M. (1965). *Prisoner's Dilemma: A Study in Conflict and Cooperation*. Ann Arbor, MI: University of Michigan Press. 258 pages. [An influential book leading to many subsequent studies of prisoners' dilemma games.]

Roth A.E. (1995a). Introduction to experimental economics. *Handbook of Experimental Economics* (eds. J.H. Kagel and A.E. Roth), pp. 3–109. Princeton, NJ: Princeton University Press. [Reviews the early development of experimental economics.]

Roth A.E. (1995b). Bargaining experiments. *Handbook of Experimental Economics* (eds. J.H. Kagel and A.E. Roth), pp. 253–348. Princeton, NJ: Princeton University Press. [Reviews bargaining experiments.]

Roth A.E. and Malouf M.W.K. (1979). Game theoretic models and the role of information in bargaining. *Psychological Review* **86**, 574–594. [In this experiment two parties bargain how the unit probability of receiving a high versus a low premium should be allocated among them, varies information about what one knows about others' low and high monetary payoff: an early application of the binary lottery technique.]

Rubinstein A. (1982). Perfect equilibrium in a bargaining model. *Econometrica* **50**, 97–110. [An elegant alternating-offer bargaining model for a shrinking "pie," which avoids multiple (perfect) equilibria.]

Rubinstein A. (1991). Comments on the interpretation of game theory. *Econometrica* **59**, 909–924. [A claim that game theory's assumptions and implications can be interpreted rather too freely.]

Sauermann H. (1978a). *Bargaining Behavior, Contributions to Experimental Economics, Vol. 7*. Tübingen, Germany: Mohr. 383 pages. [A collection of experimental studies of bargaining.]

Sauermann, H. (1978b). *Coalition-Former Behavior, Contributions to Experimental Economics, Vol. 8*. Tübingen, Germany: Mohr. 375 pages. [A collection of experimental studies of bargaining and coalition formation.]

Sauermann H. and Selten R. (1959). Ein Oligopolexperiment. *Zeitschrift für die gesamte Staatswissenschaft* **155**, 427–471. [English translation: An experiment in oligopoly. *General Systems Yearbook of the Society for General Systems Research* 5 (eds. L. von Bartalanffy and A. Rapoport.), pp. 85–114. Michigan 1960. [An early study in experimental economics.]

Schmeidler D. (1969). The nucleolus of a characteristic function game. *SIAM Journal of Applied Mathematics* **17**, 1163–1170. [Introduces the nucleolus and proves its uniqueness.]

Selten R. and Stöcker R. (1986). End behavior in sequences of finite prisoner's dilemma supergames: a learning theory approach. *Journal of Economic Behavior and Organization* **7**(1), 47–70. [An experimental study of repeating repeated games.]

Selten R. and Uhlich G.R. (1988). Order of strength and exhaustivity as additional hypotheses in theories for three-person characteristic function games. In: Bounded rational behavior in experimental games and markets: Proceedings of the Fourth Conference on Experimental Economics (Bielefeld, West Germany, September 21–25 1986), R. Tietz, W. Albers, R. Selten (eds.), *Lecture Notes in Economics and Mathematical Systems* **314**, 235–250. Berlin: Springer. [A behavioral theory for characteristic function experiments explaining many results.]

Shapiro E.G. (1975). Effects of future interaction in reward allocation in dyads: equity or equality. *Journal of Personality and Social Psychology* **31**, 873–880. [Participants first work and obtain a joint reward which is distributed by a dictator; varies the expectation of future interaction.]

Shapley L.S. (1953). A value for n-person games. *Contributions to the theory of games II. Annals of Mathematical Studies Series* **28** (eds. H.W. Kuhn and A.W. Tucker), pp. 307–317. Princeton, N.J.: Princeton University Press. [Introduces the Shapley value using an axiomatic characterization and an algorithmic procedure for forming the grand coalition.]

Taylor P. and Jonker L. (1978). Evolutionary stable strategies and game dynamics. *Mathematical Biosciences* **40**, 145–156. [Studies adaptive dynamics of the type known as replicator dynamics.]

Tirole J. (1988). *The Theory of Industrial Organization*. Cambridge, MA: MIT Press. 479 pages. [An introduction to what has been called oligopoly theory, and is now named industrial economics.]

von Neumann J. and Morgenstern O. (1944). *Theory of Games and Economic Behavior*. Princeton, NJ: Princeton University Press. 625 pages. [The book that established game theory as a field of active research.]

Weg E, Rapoport A., and Felsenthal D.S. (1990). Two-person bargaining behavior in fixed discounting factors games with infinite horizon. *Games and Economic Behavior* **2**, 76–95. [An experimental study of alternating-offer bargaining, with a decreasing "pie" and no definite time horizon.]

Weibull J.W. (1995). *Evolutionary Game Theory*. Cambridge, MA, London: MIT Press. 265 pages. [Surveys the theoretical results for various static and dynamic concepts of evolutionary stability.]

Biographical Sketch

Werner Güth has studied economics at the University of Münster where he also received his doctoral degree (1972) and habilitation (1976). He was professor for economic theory of the University of Cologne (1977 – 1986), the University of Frankfurt (Main) (1986 – 1994) and Humboldt-University of Berlin (1994 – 2001) before becoming the director of the Strategic Interaction Group of the Max Planck Institute of Economics in Jena in 2001. Since 2002 he is honorary professor of economics of Schiller University in Jena and a member of the Berlin-Brandenburg Academy of Sciences. His research topics are game theory, experimental and micro-economics with strong leanings towards (social) psychology, philosophy, (evolutionary) biology and the political sciences.