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> *Hamlet: "What a piece of work is a man! how noble in reason! how infinite in faculties!"*
> *Hamlet,* II.2.319.
>
> *Puck: "Lord, what fools these mortals be!"*
> *Midsummer Night's Dream,* III.3.116.

NEARLY EVERYONE would see the truth as between Hamlet and Puck. Including Hamlet and Puck. Hamlet is feigning madness, and Puck is just being, well, puckish. Model-writing economists, however, tend not to the middle but to the "infinite in faculties" extreme. Although the postulate of unbounded rationality has dominated economic modeling for several decades, the dominance is relaxing. Is this encouraging? Why bounded rationality?

In this survey, four reasons are given for incorporating bounded rationality in economic models. First, there is abundant empirical evidence that it is important. Second, models of bounded rationality have proved themselves in a wide range of impressive work. Third, the standard justifications for assuming unbounded rationality are unconvincing; their logic cuts both ways. Fourth, deliberation about an economic decision is a costly activity, and good economics requires that we entertain all costs. These four reasons, or categories of reasons, are developed in the following four sections. Deliberation cost will be a recurring theme. Most references are to the last 15 years, though many earlier works are also cited. A longer version of the survey, including many more references, is available from the author on request.

I. *Spoiling a Good Story: Evidence of Bounds on Rationality*

> *Should the facts be allowed to spoil a good story?*
> Michael Lovell (1986, p. 120)

Lovell asked this question about unbounded rationality in forecasting (about rational expectations). We can ask it about unbounded rationality in general. We know there are critical physiological limits on human cognition (Herbert Simon 1990, p. 7), but are the limits important to economics? Do they spoil any of the good story told by the standard theory of optimizing behavior? To be clear, the question is not whether bounds on rationality are always important. They are not; there are many contexts in which the hypothesis of unbounded rationality surely works well. Rather the questions are whether bounds on rationality are often enough important to include in economic analysis and, if so, when.

The evidence sketched in this section will be put in two categories, direct evidence and confounded evidence, though the dividing line is vague. The "direct" category will concern studies, mostly experimental, which test economic rationality more or less directly by testing the cognitive abilities relevant to economic decisions. The "confounded" category will concern tests in which rationality hypotheses are entertained jointly with other hypotheses in economic settings.

A. *Direct Evidence—Rationality Tests on Single Individuals*

There are many studies in which single individuals are faced with decisions which have objectively correct answers and which test the kinds of reasoning frequently ascribed to agents in economic theory. Do subjects do well in such tests? Often not.

Hundreds of studies of this type have been done, mostly by psychologists but more recently by experimental economists also. There is a mountain of experiments in which people: display intransitivity; misunderstand statistical independence; mistake random data for patterned data and vice versa; fail to appreciate law of large number effects; fail to recognize statistical dominance; make errors in updating probabilities on the basis of new information; understate the significance of given sample sizes; fail to understand covariation for even the simplest 2X2 contingency tables; make false inferences about causality; ignore relevant information; use irrelevant information (as in sunk cost fallacies); exaggerate the importance of vivid over pallid evidence; exaggerate the importance of fallible predictors; exaggerate the ex ante probability of a random event which has already occurred; display overconfidence in judgment relative to evidence; exaggerate confirming over disconfirming evidence relative to initial beliefs; give answers that are highly sensitive to logically irrelevant changes in questions; do redundant and ambiguous tests to confirm an hypothesis at the expense of decisive tests to disconfirm; make frequent errors in deductive reasoning tasks such as syllogisms; place higher value on an opportunity if an experimenter rigs it to be the "status quo" opportunity; fail to discount the future consistently; fail to adjust repeated choices to accommodate intertemporal connections; and more.

In such experiments, the mental tasks put to people are often simple, at least relative to many economic decisions; whereas their responses are frequently way off. Most important, reasoning errors are typically systematic. Psychologists hypothesize that subjects make systematic errors by using decision "heuristics," or rules of thumb, which fail to accommodate the full logic of a decision, as when a person makes systematic forecast errors by using adaptive rather than rational expectations. The systematic errors are often referred to as "biases," and the general topic often carries the label "heuristics and biases."

The sheer number of experiments reporting biases is so great that a sizable number of books and long survey papers have been written just to review the evidence. For example, see the books by Hal Arkes and Kenneth Hammond (1986), Robin Hogarth (1980), Daniel Kahneman, Paul Slovic, and Amos Tversky (1982), and Richard Nisbett and Lee Ross (1980); and see the survey papers by John Payne, James Bettman, and Eric Johnson (1992), Gordon Pitz and Natalie Sachs (1984), and Slovic, Sarah Lichtenstein, and Baruch Fischhoff (1988). For mini-surveys aimed at economists, see George Loewenstein and Richard Thaler (1989), Tversky and Thaler (1990), and Kahneman, Jack Knetsch, and Thaler

(1991). For examples of bias experiments by economists, see David Grether and Charles Plott (1979) on preference reversals, Grether (1992) on Bayes rule tests, and John Sterman (1989) and Richard Herrnstein and Drazen Prelec (1991) on suboptimal decisions in the face of dynamic complications.

At the same time that psychologists view heuristics as a source of bias, they also view heuristics as critical to problem solving (Rudolf Groner, Marina Groner, and Walter Bischof 1983; Allan Newell and Simon 1990, section II; and Payne, Johnson, and Bettman 1993). At first glance, this seems puzzling. Why not condemn problem solving which leads to systematic error? The answer is simple. Deliberation cost. For a boundedly rational individual, heuristics often provide an adequate solution cheaply whereas more elaborate approaches would be unduly expensive. As Pitz and Sachs (1984, p. 152) put it, "a tradeoff exists between cognitive effort and judgmental accuracy." It is ironic that this economic tradeoff should be better recognized in psychology than in economics. Experimental and selected other economists recognize the tradeoff, but it tends to be pushed out of sight in economics by the emphasis on unbounded rationality.

This summary obviously stresses negative evidence. There are also many experiments in which subjects reason accurately, especially after practice. In principle, we expect that virtually any clear cut reasoning error can be made to disappear through an experiment which provides adequate incentive and which cleverly enough exposes or punishes the error. Ultimately, we would like to know when and why people get it right or wrong. Psychologists have addressed this question through "debiasing" tests—tests of whether biases will diminish or disappear when experiments are designed to give subjects stronger incentives, greater initial expertise, better opportunities to learn, and the like. Although such design conditions do attenuate biases, the attenuation is typically limited. The prevailing overall impression is that biases are not fragile effects which easily disappear, but rather substantial and important behavioral regularities. On debiasing, see the discussions in Raymond Battalio, John Kagel, and Komain Jiranyakul (1990, p. 28), Berndt Brehmer (1980), Grether (1992), Hogarth (1980, ch. 5), Fischhoff (1982), Nisbett and Ross (1980, pp. 251–54), Payne, Bettman, and Johnson (1992, pp. 106, 114–16), Robert Slonim (1994), and Slovic, Lichtenstein, and Fischhoff (1988, pp. 683–85, 688–89).

As Vernon Smith (1989, 1991) and Smith and James Walker (1993) emphasize, market discipline, through repeated transactions with significant stakes, can be potent in attenuating discrepancies between optimizing and observed behavior; whereas psychological studies of debiasing typically do not include such market forces. However, Smith and Walker also emphasize that attenuation is a matter of degree. They take a deliberation cost view, arguing that decision makers try "to achieve a balance between the benefits of better decision making and the effort cost of decision" (1993, p. 260) and that "there are both low stake and high stake economic decisions in life, and all are of interest" (p. 249). Experiments described in Smith and Walker and in Mark Pingle (1992) verify the importance of deliberation cost. See also Day and Pingle (forthcoming) and Bruno Frey and Reiner Eichenberger (1994).

There is one other source of (more or less) experimental evidence, vast in quantity and intimately familiar to academic economists. Course exams. We carefully administer mental tests of economic reasoning to many thousands of student subjects; and we provide sizable incentives for getting the right answers (namely grades, later redeemable for scholarships, higher starting salaries, and other large economic rewards). Though we teach that agents act as if unboundedly rational, we use gallons of red ink to inform students that they do not.

In summary, the bias evidence suggests that people are capable of a wide variety of substantial and systematic reasoning errors relevant to economic decisions. Further, the evidence suggests that the magnitude and nature of the errors are themselves systematically related to economic conditions such as deliberation cost, incentives, and experience. In this sense, investigaton of bounded rationality is not a departure from economic reasoning, but a needed extension of it.

B. *Confounded Evidence—Testing Economic Rationality Jointly with Other Hypotheses*

Turn next to tests of predictions based on both unbounded rationality and other hypotheses. If the predictions fail, explanations are confounded. We can't be sure which hypothesis is at fault. What follows are examples, or "anomalies," for which a case can be made (i) that conventional economic theory is at odds with the evidence, (ii) that bounded rationality provides a possible reconciliation, and (iii) that economists have not agreed on a better reconciliation. The examples are merely cited, not argued; the citations develop the arguments and give many further references. Richard Thaler is probably the leading anomaly hunter among economists. A number of the citations are to Thaler's anomaly columns in the *The Journal of Economic Perspectives*. Many of the columns are collected in Thaler (1992).

Consumer behavior. Household consumption data are often at odds with standard life cycle theory. Relative to the theory, with or without liquidity constraints, people seem to be inefficient in smoothing consumption over the life cycle. Various studies report that the young and the old consume too little, that consumption is unduly sensitive to short run income fluctuations, that consumption is not sensitive enough to expected future changes in income, and that consumption is improperly sensitive to the composition of wealth and income (Thaler 1990; Christopher Carroll 1994; John Shea 1995; and references there). Aggregate consumption data also display excess sensitivity of consumption to income (Marjorie Flavin 1981, 1993); and tests of representative agent models of consumption, output, and asset prices are routinely rejected (Kenneth Singleton 1990). Angus Deaton (1992) discusses some of these anomalies in his survey of consumption behavior.

In purchasing large appliances, consumers tend to buy models with low price and high energy use even though, at plausible discount rates, the initial price saving does not compensate for the later energy dissaving, as if consumers were myopic (Jerry Hausman 1979; Dermot Gately 1980; Loewenstein and Thaler 1989, pp. 182–83). In purchasing flood and earthquake insurance, consumers also appear to make inefficient choices; see the large study by Howard Kunreuther et al. (1978). In the foreword, Kenneth Arrow describes the results as "certainly disconcerting from the point of view of generally accepted theory" (p. vii). Appliances and insurance are purchases for which consumers may have little experience or training, and for which the deliberation and other costs of expertise may be large relative to potential benefits.

Expectations. Survey data on expectations of inflation and other variables commonly reject the unbiasedness and efficiency predictions of rational expectations (John Cragg and Burton Malkiel 1982; K. Holden, D. A. Peel, and J. L. Thompson 1985, ch. 3; Lovell 1986; Jeffrey Frankel and Kenneth Froot 1987; Werner De Bondt and Thaler 1990; Takatoshi Ito 1990). Rational expectations can also be tested, jointly with other hypotheses, in experiments. The classic probability matching experiments in psychology rejected rational expectations as early as the 1950s (Sidney Winter 1982). Data from recent experimental asset markets favor adaptive over rational expectations (Smith, Gerry Suchanek, and Arlington Williams 1988; Plott and Shyam Sunder 1988; Ramon Marimon and Sunder 1993; Steven Peterson 1993; John Hey 1994); although the experimenters note that experienced subjects move toward rational expectations. The evidence suggests that expectations may or may not be rational, depending on experience, difficulty of the forecasting task, and other conditions.

Asset prices. Despite the presence of highly experienced and motivated traders, financial markets generate numerous anomalies. According to the efficient markets hypothesis, arbitrage should force predictability out of stock price changes. Yet stock prices display: slow mean reversion (De Bondt and Thaler 1985; Eugene Fama and Kenneth French 1988); predictable end-of-week, end-of-year, seasonal, and holiday effects (Thaler 1987; Josef Lakonishok and Seymour Smidt 1988); excess fluctuation in prices relative to fluctuation in fundamentals (Stephen LeRoy 1989; Robert Shiller 1989); dramatic bubbles unexplained by changes in fundamental values (Colin Camerer 1989; and Smith, Suchanek, and Williams 1988); excess risk premia relative to bonds (Rajnish Mehra and Edward Prescott 1985); systematic deviation of mutual fund prices from the values of the component securities (Charles Lee, Andrei Shleifer, and Thaler 1991); excess trading volume on shares that have risen in price relative to volume on shares that have fallen in price (Hersh Shefrin and Meir Statman 1985); predictability from lagged insider trading data (Nejat Seyhun 1992); and more (see the De Bondt and Thaler 1994 survey). On the significance of anomalies for market-beating portfolios, see Hashem Pesaran and Allan Timmermann (1995). Various related anomalies are found in foreign exchange rate markets; see the surveys by Froot and Thaler (1990), Karen Lewis (1994), and Frankel and Andrew Rose (forthcoming).

David Cutler, James Poterba, and Lawrence Summers (1991, p. 529) suggest four stylized facts as giving overall pattern to the anomalous price behavior of stocks, bonds, foreign exchange, and some real assets (housing, collectibles, and precious metals):

> First, returns tend to be positively serially correlated at high frequency. Second, they are weakly negatively serially correlated over long horizons. Third, deviations of asset values from proxies for fundamental value have predictive power for returns. Fourth, short term interest rates are negatively correlated with excess returns on other assets.

Decision experiments. The "asset integration" hypothesis—that an agent's objective function is defined on total wealth rather than on changes in wealth—has the status of a rationality postulate in the sense that total wealth, not change in wealth, is what dictates the agent's opportunity set for consumption, the ultimate conveyor of utility. There is substantial evidence from decision experiments that asset integration often fails (Camerer 1992; Battalio, Kagel, and Jitanyakul 1990; Robert Gertner 1993). The issue is greatly complicated by the fact that the relevant wealth concept is lifetime wealth, implying that asset integration effects are confounded with intertemporal choice effects.

Individuals often express a substantially lower willingness to pay than willingness to accept for a marginal unit of a commodity. Although there is controversy over magnitudes, and although effects diminish with practice (as in repeat-trial experiments), the body of results is hard to reconcile with standard models of economic rationality. Tversky and Kahneman (1991, p. 1054) and Raymond Hartman, Michael Doane, and Chi-Keung Woo (1991) emphasize the magnitude of the anomaly. Jason Shogren et al. (1994) and Robert Franciosi et al. (1995) emphasize the mitigating effects of experience. As a related anomaly, individuals seem to place higher value on an opportunity if it is associated with the status quo; see William Samuelson and Richard Zeckhauser (1988). For example, Knetsch (1989) finds that most students first given a fancy mug then refuse to trade it for a large chocolate bar, whereas most students first given a large chocolate bar then refuse to trade it for a fancy mug.

Experimental auctions and games. In experiments on common value auctions, there is evidence of systematic overbidding relative to theoretical predictions. This "winner's curse" is also found in some real auctions (Alvin Roth 1988, section III; Thaler 1988; Orley Ashenfelter and David Genesove 1992). However, Susan Garvin and Kagel (1994) find that the winner's curse disappears in experiments when subjects gain substantial experience through repeated auctions with the same design settings; and James Cox, Samuel Dinken, and Smith (1995) find a stronger disappearance effect when subjects are allowed to withdraw from bidding to an alternative activity yielding a positive safe payoff.

Related experiments suggest overbidding in private-value auctions. See Smith (1989, p. 158) on first price auctions and Kagel, Ronald Harstad, and Dan Levin (1987) on second-price auctions. For first price auctions, Smith emphasizes that the suggestion of overbidding is relative to risk neutrality and that the bidding pattern, over wide variation in experimental stakes, can be interpreted coherently as a risk aversion effect. This interpretation, however, strains other dimensions of standard theory. The stakes in the auctions, though varying widely, are still small relative to subjects' base wealth, whereas risk aversion is a second order effect. Thus, substantial risk aversion effects require that we either give up asset integration or give up declining absolute risk aversion. Further, there is the conflict that, in other small-stake experiments, risk-seeking, risk-neutrality, and risk-aversion are all found, both over losses and over gains (Battalio, Kagel, and Jiranyakul 1990, section 3.2; references in Conlisk 1993a, p. 259).

Many experiments test whether subjects will contribute to public goods or will free ride (John Ledyard 1995; Robyn Dawes and Thaler 1988). The optimal selfish strategy is free riding, whereas the experiments show substantial contributions. Although most experiments cannot distinguish whether departures from selfish optimality are due to decision error or to altruism, Thomas Palfrey and Jeffrey Prisbrey (1993) design an ingenious experiment which allows the distinction. They find substantial decision error and little altruism.

In the large experimental literature on game theory, predictions based on the usual strong rationality postulates are often violated (and often not). See Anatol Rapoport, Melvin Guyer, and David Gordon (1976), Roth (1988), Camerer (1990), Camerer et al. (1993), Dale Stahl and Paul Wilson (1994), and references there.

What are we to make of such anomalies? Some may yield to further optimizing theory. Others, however, seem to achieve anomalous status only because economists push optimizing theory too far. For example, there seems little doubt that consumption-smoothing behavior is observed and that competition is a powerful force in squeezing predictability out of stock price changes. However, as theories of these successful ideas push to finer and finer margins of optimality, predictions begin to defy the data, as if rationality, a matter of degree, is being pushed too hard. Arrow (1986) discusses how much the computational power attributed to agents has increased as economic theory has evolved. Anomalies are not surprising relative to theories which neglect deliberation cost, experience, and other conditions bearing on how close to unbounded rationality it is possible or sensible to be. Fortunately, the anomalies suggest not just shortcomings of standard theory but also directions for improved theory. Many of the models surveyed in the next section are motivated by anomalies.

II. *Bounded Rationality in Economic Models: A Sampler*

Though a small fraction of the total literature on economic theory, there are many models which allow for bounded rationality. This section is a sampler. The models spread in all directions, making them hard to categorize. The categories used, though each has its own logic, overlap in various ways.

Firms, organizations, and institutions. Ronald Coase (1937, 1992), Alfred Chandler (1962), Richard Cyert and James March (1963), March and Simon (1968), Oliver Williamson (1985, 1986), and Jacob Marschak and Roy Radner (1972) are pioneers in analyzing the nature of firms, organizations, and economic institutions. A central insight is that the existence, size, structure, and workings of organizations are critically shaped by a need to economize on various transaction costs. Williamson (1986, p. 110) traces transaction costs to agents' limited cognitive abilities: "Economizing on transaction costs essentially reduces to economizing on bounded rationality . . ." Williamson's work has had huge impact on the literature of industrial organization (Richard Schmalensee and Robert Willig 1989) and organizational design (Radner 1992). Although many organizational theorists avoid mention of bounded rationality, preferring imperfect information hypotheses to imperfect rationality hypotheses, some do not. For example, Raaj Kumar Sah and Joseph Stiglitz (1988) and Joel Sobel (1992) analyze organizational designs to protect against the mistakes of fallible workers and decision makers.

X-Inefficiency. An organization can be inefficient because its outputs lie at the wrong point on an efficiency frontier or because its outputs lie inside the efficiency frontier. The latter was dubbed "*X*-inefficiency" by Harvey Leibenstein (1966), who pioneered in its study. There is now a sizable body of theoretical and empirical work on *X*-inefficiency, much of it rooted in notions of bounded rationality. See Leibenstein (1987), Leibenstein and Shlomo Maital (1994), Roger Frantz (1992), and references there.

Boundedly rational choice—early models. In standard optimizing theory, agents act as if they perform exhaustive searches over all possible decisions and then pick the best. Simon (1955, 1987) hypothesizes that agents instead perform limited searches, accepting the first satisfactory decision. This "satisficing" hypothesis is the direct inspiration for a number of the models cited below (including Day and Herbert Tinney 1968; Winter 1971; and Radner and Rothschild 1975), and the spirit of the idea is pervasive.

A related idea is suboptimization. A decision maker who finds optimization impossible or unduly costly may instead solve a simpler, approximate optimization problem. Because errors due to suboptimization in one period may call for adjustments the next, it is natural to embed suboptimization in a dynamic context which generates feedback. Although suboptimization with feedback has a long history (for example, dynamic Cournot models), Day and colleagues were the first to develop the idea into a broad and coherent approach, calling it "recursive programming." Such models generate rich dynamics, foreshadowing the recent interest in complex economic dynamics. For theory and numerous empirical applications, see Day (1963), Day and Alessandro Cigno (1978), and references there. Hierarchical decision models (Ermini 1987, 1991) also have a recursive programming form.

Markup pricing, adaptive expectations, partial adjustment, imitation, and stochastic choice are examples of more passive decision making. In the John Cross (1973, 1983) and Susan Himmelweit (1976) models of stochastic choice, for example, an agent chooses at random among a list of possible actions, where the choice probabilities evolve according to the historical performances of the various possibilities. Cross and Himmelweit apply the theory to store choice, lottery choice, advertising, supply decisions, and other issues. Rajiv Sarin (1994) applies the theory to evolutionary game theory. The approach has precedents in psychological learning theory and is a rough precedent for the economic classifier models discussed below.

Boundedly rational choice—heuristics, norms, and other imports from sister disciplines. Psychologists and cognitive scientists study heuristics (rules of thumb) by which people deal with their cognitive limitations. For example, in Tversky's (1972) theory of "elimination by aspects," an individual chooses among alternatives, not by comparing alternatives in all their aspects at once, but rather by the heuristic of comparing alternatives one randomly chosen aspect at a time, eliminating alternatives along the way. Heuristics are rational in the sense that they appeal to intuition and avoid deliberation cost, but boundedly rational in the sense that they often lead to biased choices. Sociologists and anthropologists also study behavioral rules relevant to economics, often in the form of social norms and conventions (Jon Elster 1989). Biases, heuristics, and norms have been used in various economic models to explain otherwise puzzling behavior.

Winter (1982) uses learning heuristics to explain experimental results on "probability matching" violations of rational expectations. George Akerlof and William Dickens (1982) and Matthew Rabin (1994) use cognitive dissonance (the bias of fitting beliefs to convenience) to model worker safety, innovations, advertising, social security, crime, and morally dubious behavior. Akerlof (1991) uses salience (the bias of attaching undue weight to recent or vivid events) to explain why people may procrastinate or show excessive obedience to authorities, and he shows how small effects of this sort may cumulate into inadequate saving, organizational failure, addiction, and crime. Akerlof and Janet Yellen (1987) use biases to sketch microfoundations for traditional Keynesian analysis. Tversky and Kahneman (1991) use loss aversion (greater marginal sensitivity to losses than to gains) to explain various behavioral puzzles representable as deformations of an indifference map in the neighborhood of a current consumption point. Shlomo Benartzi and Thaler (1995) add myopia to loss aversion to propose a resolution of the equity premium puzzle. Brian Arthur (1994) considers a model in which individuals shift among a menu of possible heuristics as experience dictates. Leibenstein and Maital (1994) use defensive bias (rationalization of error) in a game theoretic model of X-inefficiency.

Time inconsistency can be viewed as multiple selves bounding each other's rational choices; the Doer Self wants dessert whereas the Planner Self wants to stick to the diet (terminology from Thaler and Shefrin 1981). Many behavioral rules (for example, don't keep dessert in the house) arise as responses to such conflicts (Thomas Schelling 1984). Negative time preference is a major source of time inconsistency. Loewenstein and Prelec (1992) use loss aversion to explain time inconsistency flowing from negative time preference. To explain consumption anomalies, Shefrin and Thaler (1988) and Thaler (1990) hypothesize budgeting heuristics; income is allocated to different accounts, such as a current spending account and a retirement account, with transfers across accounts not allowed.

Some economists argue that inherited emotions and social norms (anger, embarrassment, sensitivity to relative position, loyalty, altruism) can improve economic performance in ways outside the scope of standard theory. For example, loyal individuals cooperate better, and a person who involuntary blushes at a lie is better able to win trust. Amartya Sen (1977) refers to the selfishly rational agents of economic theory as "rational fools" because they lack these advantages of emotions and norms. For models of the advantages, see Akerlof (1984) on loyalty and on gift exchanges, Jack Hirshleifer (1987) on emotions as guarantors of threats and promises, Robert Frank (1985, 1988) on emotions and on sensitivity to relative position, and Schelling (1978) and Simon (1993) on the fitness of altruism. The emotions and norms in question might be inherited either biologically or culturally; see the dual inheritance models of Robert Boyd and Peter Richerson (1985). Norms might be the cause of bounds on individualistic rationality. Or norms might be the effect of bounded rationality; Simon (1993) argues that docility to social norms improves economic fitness by inducing people to augment their limited rationality with the collective wisdom of their social group.

Ronald Heiner (1983, 1989) develops the stimulating hypothesis that economic behavior is predictable in large part because bounded rationality leads people to adopt rules of thumb which display greater regularity than does optimization. Thus, Heiner argues, standard economics is subject to an ironic misspecification problem: "the observed regularities that economics has tried to explain on the basis of optimization would disappear if agents could actually maximize" (1983, pp. 586–96).

Evolutionary economics. Many of the models cited above and below are evolutionary models—dynamic models in which more successful agents and activites gradually increase their share of the economy at the expense of less successful agents and activities. The evolutionary approach to economics has a long history, is currently experiencing an upswing of interest, and might be the longer run mainstream to which economists return, encompassing optimization models as a special case. Core ideas of the evolutionary approach have been surveyed recently by Richard Nelson (1995) in this *Journal.* The approach is especially well suited, for example, to analyzing growth and technical change. Because the rate of technical change is limited in large part by agents' bounded ability to perceive and exploit opportunities for improving production processes, technical change relates more naturally to bounded than to unbounded rationality, and more naturally to evolutionary than to equilibrium approaches. The pioneering work is Nelson and Winter (1982); more recent models include Silverberg, Giovanni Dosi, and Luigi Orsenigo (1988), Conlisk (1989), Eliasson (1991), and various other models cited in Nelson (1995, section IV).

Bounded rationality and market outcomes. The effect of bounded rationality on market outcomes is a central question. Does it make a difference, or are outcomes the same as if all agents optimized? What are the differences and when do they occur? The issues are explored in many models. Some are evolutionary models with full dynamics; others investigate only equilibria.

In a classic early paper, Winter (1971) shows how, under strong conditions, market competition may select for survival only those firms which display "as if" optimization. However, Ulrich Witt (1986) addresses the same issue and finds convergence to optimization under some circumstances and not under others. Conlisk (1983) shows how a broad array of firm reaction functions may lead a market to approximate perfect competition; and Dhananjay Gode and Sunder (1993) give examples of double auction markets in which "zero-intelligence" traders (computers which bid randomly subject only to budget constraints) may achieve near perfect market efficiency. However, Thomas Russell and Thaler (1985) show that a small reasoning error by a fraction of the consumers in a market may alter market equilibrium; and John Haltiwanger and Michael Waldman (1985, 1991) show how a small proportion of boundedly rational agents in a market may have more than proportionate influence on market equilibrium due to congestion effects (or less than proportionate effect under opposite conditions). Conlisk (forthcoming) relates the severity of fluctuations in a market directly to the deliberation cost of individual firms; depending on conditions, fluctuations may increase or decrease when deliberation cost increases.

Stimulated by empirical anomalies, a number of authors investigate the effect of boundedly rational traders in asset markets. Bradford De Long et al. (1990) show how boundedly rational traders, by accepting "too much" risk and thus earning higher returns than unboundedly rational traders, may come to dominate an asset market. Shefrin and Statman (1994) develop a "behavioral capital asset pricing model" in which some traders display reasoning errors suggested by the bias literature from psychology. The model provides a broad theory which covers return anomalies and the survival of boundedly rational agents, along with the usual asset pricing issues. Timothy Cason (1992) shows how learning may lead to market efficiency, whereas Timmermann (1995) shows how learning may itself be the mechanism leading to various anomalies.

In an old and very simple model, James Meade (1964, ch. V) showed that, as a result of saving and other effects, individuals with superior investment efficiency need not accumulate wealth faster than other individuals. Lawrence Blume and David Easley (1992) elaborate the logic with modern methods, finding that, in an asset market, "fit rules need not be rational, and rational rules [need] not be fit" (p. 9).

Timur Kuran (1991) explains how cognitive limitations may influence the evolution of preferences, in which case the whole notion of evolution to optimality becomes problematic.

Evolution to rational expectations in markets. Among strong rationality hypotheses, rational expectations are special, for at least three reasons. First, expectations are critical to market outcomes, for example to macroeconomic policy. Second, because departures from rational expectations can be detected without knowing utility functions, rational expectations are easier to test than most implications of unbounded rationality. Third, because an agent's rational expectation depends on knowledge of an entire market or economy, not just on knowledge of the agent's own narrow circumstances, calculation of a rational expectation may involve high deliberation cost.

There has been great interest in whether adaptation might lead agents to rational expectations. The answer depends on exact conditions—on whether the context is simple enough, on whether agents' prior beliefs are compatible with the context, on how agents process new information, and so on. Overall, authors are quite cautious about claiming support for rational expectations on adaptive grounds. See Margaret Bray (1982), Blume and Easley (1982), Bray and David Kreps (1987), Thomas Sargent (1993), Jerome Detemple and Shashidhar Murthy (1994), and George Evans and Seppo Honkapohja (1995). In an empirical extension of this work, Timmermann (1994) asks whether stock market investors in the U.K. could have learned rational expectations from the historical record. He makes a case that they could not unless they had good prior information about long-run properties of stock price series.

Near rationality, complexity, and market outcome. Akerlof and Yellen (1985) combine two insights to argue the importance of bounded rationality to market outcomes. First, because objective functions are often flat at their optima, an agent may be "near rational" in utility or profit achieved, but far from unbounded rationality in terms of action taken. See John Cochrane (1989) for a striking example on intertemporal consumption choice. Second, there may be correlation across individuals in these decision errors, due to common responses to changes in the economy. From these insights, Akerlof and Yellen demonstrate that a fraction of boundedly rational agents in an economy, though suffering utility or profit losses which are only second order small, may cause first order effects on market outcomes. They give various examples; other examples are in Stephen Jones and James Stock (1987), Howard Naish (1993), and references there.

Near rationality models suggest that the benefit of upgrading from bounded to unbounded rationality may be small. At the same time, computational complexity models suggest that the deliberation cost of upgrading may be sizable, even astronomical. For example, in many integer programming problems (such as scheduling, capital budgeting, cargo loading, and itinerary problems), computational complexity increases exponentially with problem size; see Christos Papadimitriou and Kenneth Steiglitz (1982) and Silvano Martello and Paolo Toth (1990). A classic example from game theory is chess. The optimal strategy in chess is conceptually simple, just as in tic-tac-toe, because both games involve only a finite number of possible sequences of play. However, for chess this number is "comparable to the number of molecules in the universe" (Simon and Jonathan Schaeffer 1992, p. 2). Simon (1990, p. 6) concludes, "If the game of chess, limited to its 64 squares and six kinds of pieces, is beyond exact computation, then we may expect the same of almost any real-world problem . . ."

Self-organizing markets. Suppose, in a society with no organized market for a certain good, potential buyers and sellers meet pairwise at random, agreeing to trade if their reservation prices allow, otherwise adjusting their reservation prices before the next period. Because each new period produces new pairings, there is an expanding web of effects connecting the whole population. It may occur that all reservation prices converge to an equilibrium price, in which case a market is born, despite the absence of an organizing institution. The market is self-organizing. Jacques Lesourne (1992, 1993) and colleagues have developed an enlightening series of models of self-organizing markets. The models deal with the birth of intermediaries, the emergence of speculators, the formation of opinions, the generation of sunspot equilibria, the founding of unions, changes in the structure of competition, and the effects of critical maverick agents. Such models, with their rich interactions among adaptive agents, are at an opposite pole from representative agent models, which sacrifice nearly all interactions to pursue optimization.

In summary of the last four topics, does bounded rationality alter market outcomes? The models answer with a resounding maybe. Depending on circumstances, boundedly rational agents may or may not self-organize into markets. If a market is already organized, boundedly rational agents may have no special effect at all, may affect either the level or variability of price and output, may have effects that are less or more than proportionate to their numbers, and may have second order effects on themselves but first order effects on the market (or the opposite). With experience, boundedly rational agents may or may not learn more accurate behavioral rules, may do better or worse than unboundedly rational agents in the short run, and may disappear, dominate, or coexist in the long run. Thus, bounded rationality matters, but not in a simple way.

Population distribution models. In a common type of model, a population of individuals distributes over categories of some sort, making adaptive transitions among the categories as time passes. Transitions are governed by imitation, fitness-sensitive reproduction, or other mechanisms. (Evolutionary game models often fit this description, but are discussed under separate heading below.) In Michael Farrell (1970), investors distribute over wealth states. In Winter (1971), firms distribute over profitability states. In the older diffusion models surveyed in David Bartholomew (1982), and in the newer models of Arthur (1989) and Glenn Ellison and Drew Fudenberg (1993), agents distribute over technological states, informational states, disease states, or the like. In Conlisk (1980), Waldman (1994), and John Harrington (1994), individuals distribute over decision-making rules. In Edmund Phelps and Winter (1970), Dennis Smallwood and Conlisk (1979), Mark Granovetter and Roland Soong (1986), Alan Kirman (1993), and Ellison and Fudenberg (1995), buyers distribute over sellers (among other interpretations). Although most of these models view behavior as boundedly rational, some treat agents as perfectly rational but imperfectly informed. See Abhijit Banerjee (1992, 1993), Sushil Bikhchandani, David Hirschleifer, and Ivo Welch (1992), and Welch (1992) on herding, fads, and informational cascades.

Such models are especially useful for investigating direct interactions among individuals, as opposed to indirect interactions through market prices, a distinction stressed in Kirman (1994). Among the interactions considered are imitation, word-of-mouth communication, fads and fashions, bandwagons, threshold effects, herding, increasing returns, lock-ins, and informational cascades.

Various themes emerge from this literature, but not an encompassing pattern. In a number of the models, one can ask whether the population converges to a well behaved outcome, such as a market equilibrium, highest quality brand, or best technology. The typical answer is maybe, depending on exact conditions. There may be convergence to a unique best outcome. Or there may be multiple stable equilibria such that even the worst outcome can attract the entire population when initial conditions or random events dictate. For example, increasing returns to brand popularity may lead any brand, regardless of quality, to dominate a market (as in Smallwood and Conlisk 1979); or increasing returns to usage may lead a single technology, regardless of objective efficiency, to dominate an industry (as in Arthur 1989). In some cases, more boundedly rational behavior leads to better equilibria (Smallwood and Conlisk 1979; David Lane and Roberta Vescovini 1995). Or there may be no equilibria at all, leaving the population to fluctuate forever, either periodically or chaotically. There may be quasi-equilibria in which the model rests for substantial periods of time, only to cascade off to another quasi-equilibrium on the occurrence of a small-probability event. A long-standing theme, more recently labelled "path dependence," is that initial conditions and chance events may dictate outcomes. Thus, "history matters" in determining "emergent structures" (Paul David 1985, 1986; Arthur 1989).

Games. Game theorists have recently turned to bounded rationality with enthusiasm, either to address experimental anomalies, or to provide a dynamic for selection among multiple equilibria, or perhaps simply because game theory, having pushed rationality to the furthest extreme, was ripest for a revision. In evolutionary game models, a game is played repeatedly, and players modify their strategies in light of payoff experience. The repetitions of play may involve the same pair of opponents or random rematchings from a population. Depending on conditions, models may or may not evolve to Nash equilibria. For reviews of evolutionary games, see John Creedy (1992), Daniel Friedman (1993), and Marimon and Ellen McGrattan (1995); and, for symposia, see George Mailath (1992), Crawford (1993), and Day (1993b). Especially interesting are papers which investigate evolutionary rationales for rules of thumb and conventions. For example, see the theoretical discussions of Crawford (1993, 1995), Robert Rosenthal (1993), Peyton Young (1993), Fernando Vega-Redondo (1993), and Joel Watson (1994); and see the empirical studies of John Van Huyck, Joseph Cook, and Battalio (1994).

In a different game approach, bounded rationality takes the form of restrictions on available strategies. For example, players may be restricted in the complexity of strategies they are able to implement (Dilip Abreu and Ariel Rubinstein 1988; Vega-Redondo 1994); players may be restricted to a subset of actions (Sobel 1991); or players may be restricted in the type of inference they display (Stahl 1993).

Dynamics and simulation. Bounded rationality is often modeled as some form of dynamic adaptation. Using observation and intuition, modelers endow agents with adaptive behavioral rules for interacting within some assumed environment, then set the dynamic in motion. Due to model complexity, simulation is common. Such models include the large macromodels predating the "rational expectations revolution," the tâtonement price adjustment models now out of fashion, various micro-simulation models (Guy Orcutt, Joachim Merz, and Hermann Quinke 1986; Robert Bennett and Barbara Bergmann 1986; Eliasson 1991), dynamic versions of computational general equilibrium models (surveyed in Alfredo Pereira and

John Shoven 1988), some parts of the system dynamics literature (Michael Radzicki and Sterman 1994), and the classifier models discussed under the next heading. Day (1994) relates dynamics and simulation to the mathematical field of complex dynamics.

Classifier systems. In a classifier model of bounded rationality, each agent in each period chooses one among a discrete list of actions. Choices are sensitive to the historical rewards of the actions according to primitive evolutionary rules with a genetic flavor. Classifier systems originated in the machine learning literature as models of how a machine, starting from extreme ignorance, might by trial and error come to adopt effective decision rules in performing some task (John Holland and John Miller 1991). Classifier models have been used in economics, for example, by Marimon, McGrattan, and Sargent (1990) to study the emergence of a medium of exchange, by Nicolas Vriend (1994) to study self-organized markets, and by David Midgley, Robert Marks, and Lee Cooper (1995) to study competitive strategies. A controversial issue is whether classifier models, by assuming such elementary trial-and-error learning, set the "dial of rationality" too far toward the primitive extreme. Arthur (1993) argues that the dial can be calibrated in these models to match empirically observed behavior, although his only example is a multi-arm bandit context, which by its nature virtually excludes anything but simple trial-and-error learning.

Economy of the mind—deliberation technologies and deliberation cost. If rationality is scarce, good decisions are costly. There is a tradeoff between effort devoted to deliberation and effort devoted to other activities, reflecting what Day (1993a) calls the "economy of the mind." A model of the tradeoff requires some form of "deliberation technology" by which a decision maker turns scarce cognitive and other resources into better decisions. The deliberation cost theme pervades the discussion above; yet very few explicit models of deliberation technology and deliberation cost have appeared. Day and Tinney (1968, Appendix), Marschak and Radner (1972, sections 9.6–9.7), and Reinhard Selten (1978) sketch deliberation cost models, but do not develop them.

The first full model of deliberation cost (though not presented in such terms) seems to be the model developed by Radner and Rothschild (1975), Radner (1975b), and Rothschild (1975). In their model, a decision maker, facing several planning activities, does not have enough time to optimize every activity in every period. Thus, the implicit deliberation cost in attending to any one activity is the reduced performance of other activities. Most of the few other models of deliberation cost are more recent. Conlisk (1988, forthcoming), Evans and Ramey (1992, 1994, 1995), Smith and Walker (1993), and André De Palma, Gordon Myers, and Yorgos Papageorgiou (1994) consider full deliberation technologies in which agents choose the magnitude of a costly deliberation input. A simpler approach is to suppose that agents choose among distinct behavioral rules, each carrying its own fixed deliberation cost. This approach has been used to study the fitness of cheap imitation relative to costly optimization (Conlisk 1980), the effect of bounded rationality on game equilibria (Abreu and Rubinstein 1988; and Rosenthal 1993), and aggregate technical change (Conlisk 1993b). Ermini (1991) relates deliberation cost to hierarchical decision making; and Gordon Winston (1989) discusses decision cost more broadly.

Collectively, these models show how a deliberation technology can merge standard modeling ingredients (optimization, rational expectations, market equilibrium) with boundedly rational ingredients (satisficing, learning, rules of thumb). In such a context the "degree of rationality" of a decision, relative to the decision that would prevail under unbounded rationality, is endogenously determined, along with other model outcomes, by economic forces. Section IV returns to the deliberation cost theme.

III. *Yes, But As If: Arguments for Unbounded Rationality*

The case for investigating bounded rationality has not been convincing to most economists. Arguments for optimizations-only modeling have held powerful sway, shaping the research, the teaching, and the everyday conversations of economists. The arguments are so familiar that a few code words are enough to conjure one up, as in, "Yes, but you don't understand; no one assumes that people are unboundedly rational, only that they act *as if* unboundedly rational." This section works quickly through a list of eight prominent arguments for unbounded rationality, giving a brief comment on each. The purpose is partly to review ideas which have made the literature what it is and partly to suggest more constructive versions of the arguments. A number of the arguments in effect describe conditions under which unbounded rationality seems a sensible assumption. By inspecting the conditions and their opposites, we can turn the arguments toward the more constructive question of when and why bounded rationality is likely to be important. For more extensive methodological discussions, see Milton Friedman (1953), Tjalling Koopmans (1957), Winter (1975), Gary Becker (1976, 1993), Elster (1979, 1983), Sen (1977, 1987), Ermini (1987), Robert Sugden (1991), and various papers in the journal *Economics and Philosophy*.

Argument 1. "As if" rationality. The question is not whether people are unboundedly rational; of course they are not. The question is whether they act approximately as if unboundedly rational; they do.

Comment. This hugely influential argument of Milton Friedman (1953) is a conditional argument. Do people in fact act as if unboundedly rational? According to the evidence cited in Section I, they sometimes do and sometimes do not. Under the latter condition, by the logic of the "as if" argument, we should investigate bounded rationality.

Argument 2. Learning. Though people's rationality is bounded, they learn optima through practice, in the end acting as if unboundedly rational. Economists can take a shortcut to the outcome by assuming unbounded rationality from the start.

Comment. Learning extends Argument 1 by suggesting how people come to act "as if" smarter than they are. However, the learning logic cuts both ways. Learning is promoted by favorable conditions such as rewards, repeated opportunities for practice, small deliberation cost at each repetition, good feedback, unchanging circumstances, and a simple context. Conversely, learning is hindered or blocked by the opposite conditions. That is the message of the numerous experiments cited in Section I and the numerous models cited in Section II. The learning logic makes us expect that Argument 2 will sometimes apply and sometimes not. Economic issues involving long horizons, such as life cycle decisions by individuals and technological evolution by firms, are among the most important in economics, yet are among the least likely to meet the conditions for effective learning. A young person making a life cycle plan gets no practice and therefore no feedback; the problem is enormously complex; and the environment is likely to change dramatically and unpredictably during the person's lifetime. The famous M. Friedman and Leonard Savage (1948) billiards expert plays as if a master of the laws of physics. But what of a beginner taking the first shot, in poor light, on a badly warped and randomly moving table, with assorted friends and relatives guiding the cue stick? Is a young person making life cycle decisions more like the expert player or more like the beginner?

Argument 3. Survivors and tricksters. Agents who do not optimize will not survive.

Comment. The survival argument is associated with the classic papers by Armen Alchian (1950) and M. Friedman (1953), and has been critically evaluated in general terms by many authors, notably Winter (1964, 1975) and Nelson and Winter (1982). Early on, Koopmans (1957, pp. 140–41) advised formal modeling of the hypothesis; and there are by now the numerous models cited in Section II. The models show Argument 3 to be highly conditional. Nonoptimizing firms survive under some conditions but not under others. In the presence of deliberation cost, for example, survival logic may favor a cheap rule of thumb over a costly optimization.

The survival argument carries lesser force for individuals than for firms. We commonly read in the financial pages that firms fail for lack of profits, but we seldom read in the obituary pages that people die of suboptimization. Consumers who display wasteful shopping patterns can survive at a lower standard of living, and workers who use their talents wastefully can survive at a lower wage.

There is a more subtle survival argument for individuals. Rules of thumb are typically exploitable by "tricksters," who can in principle "money pump" a person using such rules. Thus, theorists often suggest that a good theory of an individual's decisions must, as a survival condition for the individual, disallow the possibility that the individual uses pumpable rules of thumb (Mark Machina 1989, pp. 1623–24; Hirshleifer and John Riley 1992, section 1.6). However, the nonpumbability criterion is easily challenged. Although tricksters abound—at the door, on the phone, and elsewhere—people can easily protect themselves, with their pumpable rules intact, by such simple devices as slamming the door and hanging up the phone. The issue is again a matter of circumstance and degree.

Argument 4. Don't quarrel with success. Economics is built on the postulate of unbounded rationality. Utility maximization has been a powerful generator of successful hypotheses. It is foolish to quarrel with such success.

Comment. Becker, never shy about this argument, claims that "*all human behavior* can be viewed as involving participants who maximize their utility from a stable set of preferences and accumulate an optimal amount of information" (1976, p. 14, emphasis added). To accept the argument, however, we have to grant (a) that the existing success of economics should be credited to optimization hypotheses and (b) that expanded treatments of rationality would not lead to greater success. The models of the preceding section are the rebuttal to (b). Consider (a) in more detail.

Can strong rationality postulates really take major credit for the successes of economics, or do the successes originate in ideas consistent with much broader notions of rationality? Empirical practice tends to neglect this question. Instead of testing the predicted effects of optimization against the predicted effects of competing theories, we tend to test against the nonsubstantive null hypothesis of no effect. This is somewhat like arm wrestling a rag doll; it doesn't prove anything—unless the rag doll wins.

As an example of his view, Becker (1976, p. 10) credits a utility-maximization model of Michael Grossman (1975) with predicting various correlations among health and economic variables for individuals. However, Grossman himself notes (p. 148) that variants on his model "can be used to rationalize any observed correlation between two variables." Did utility maximization suggest the patterns Grossman found, or did it merely package them? Whatever the truth about the particular case, economic research often seems to work backwards from empirical findings to whatever utility maximization will work. Where the empirical arrow falls, there we paint the utility bullseye.

Putting the issue a bit differently, Arthur Goldberger (1989), Simon (1986), and Arrow (1986) note that utility maximization has little empirical content without strong auxiliary assumptions on the utility functions and other model ingredients. Because a trained economist can see through a utility maximization, stating auxiliary assumptions is often little different from stating empirical predictions outright, as, say, a sociologist might. In this sense, the utility maximization merely packages the prediction.

Argument 5. Sidewalk twenties. A model of unbounded rationality identifies an agent's best opportunity for gain. Because it is implausible for an agent to forgo opportunities for gain, unbounded rationality identifies the agent's likely action.

Comment. Forgoing an opportunity for gain, it is claimed, is like failing to pick up a $20 bill lying on the sidewalk. In the rational expectations literature, the sidewalk twenties argument appears as the claim that an agent with suboptimal expectations would be "consistently fooled" into forgoing opportunities for gain. However, suppose that the $20 is hidden in one of hundreds of cracks in the sidewalk and that, to know which crack, the walker must have reasoned through a complex pattern of logical clues. In the face of such deliberation cost, the walker may walk on by. Similarly, deliberation cost may make rational expectations cost more than they are worth. Unboundedly rational optima, by neglecting deliberation cost, may identify false opportunities for gain.

Argument 6. Discipline and "ad hocery." Without the discipline of optimizing models, economic theory would degenerate into a hodge podge of ad hoc hypotheses which cover every fact but which lack overall cohesion and scientific refutability.

Comment. Discipline comes from good scientific practice, not embrace of a particular approach. Any approach, including the optimization approach, can lead to an undisciplined proliferation of hypotheses to cover all facts. Conversely, a bounded rationality hypothesis might produce a parsimonious explanation of a variety of empirical patterns. For example, Shefrin and Statman (1994) use their behavioral capital asset pricing model to address various financial anomalies as a group. A merit of the deliberation cost idea is that it suggests a discipline for models of bounded rationality—that departures from unbounded rationality be systematically related to the deliberation cost involved.

Argument 7. Tractability and definite outcomes. The unbounded rationality postulate, because it can be formulated through well understood mathematical optimizations, confers tractable analysis and definite outcomes.

Comment. Consider tractability. Because optimizations may be arbitrarily complex, whereas bounded rationality may be represented by simple rules of thumb, optimization-based models are sometimes more and sometimes less tractable than adaptation-based models. A spectacular example of the latter is recent macrotheory. By insisting on rational expectations and intertemporal optimization, which are quite intractable in general settings, macrotheory is often reduced to considering only a single "representative" agent. We model Robinson Crusoe and pretend he's a $7 trillion economy. Arrow (1986), James Tobin (1989), Robert Solow (1989), and Kirman (1992) note the strange sacrifices required for the "ritual purity" of optimization-only models (Akerlof and Yellen's phrase, 1987, p. 137).

Consider definite outcomes. For an agent with a well behaved objective function, it is argued that an optimization gives one model and one outcome, whereas adaptation, which may take different forms, may give many models and many outcomes. The main response is that, even if we insist on looking at only one model, evidence and plausibility should be the criteria, not prior bias toward optimizations. In any case, the one optimization model may generate multiple equilibria and thus multiple outcomes, whereas the adaptive models may all converge to the same one of the multiple equilibria and thus generate a single outcome. This equilibrium-selection issue motivates a number of the adaptive models cited in Section II.

Argument 8. Definition. Economics is by definition the study of optimizing behavior; bounded rationality is the province of other disciplines.

Comment. By its most common definition, economics concerns scarcity. Because human reasoning ability is scarce, one could as well argue that economists are by definition *required* to study bounded rationality. More important, economics as a science must view every theory, including optimization theory, as open to empirical challenge. Regarding the province metaphor, scientific disciplines are in fact clusters of activity, not provinces protected by border guards. Whenever theory and evidence suggest a need to settle the sparsely populated areas between clusters, science says welcome.

In summary, the standard arguments for unbounded rationality, despite their great influence, are too extreme to be convincing. Put in more flexible form, however, the arguments contain many useful insights about conditions favoring one or another treatment of rationality. Fortunately, economists are coming to adopt more flexible interpretations. Even Becker, perhaps pushed by his long-standing interest in nonstandard costs, has recently opened the door a crack for deliberation cost. In his Nobel lecture (1993), Becker says: "Actions are constrained by income, time, *imperfect memory and calculating capacities*, and other limited resources" (p. 386, emphasis added); and he concludes, "My work may have sometimes assumed too much rationality" (p. 402).

IV. *No Free Lunch, Yes Bounded Rationality*

> *It is evident that the rational thing to do is to be irrational, where deliberation and estimation cost more than they are worth.*
>
> Frank Knight (1921, p. 67, footnote)

Human cognition is a scarce resource, implying that deliberation about economic decisions is a costly activity. To avoid a free lunch fallacy, it can be argued, we are forced to incorporate deliberation cost, and thus bounded rationality, in economic models. There are special problems.

A. *Economizing Economizing: The Regress Issue*

Unbounded rationality is typically formulated as the assumption that a decision maker optimizes an objective function subject to cost and other constraints. Because it is a routine exercise to include one more cost in an optimization model, a treatment of deliberation cost seems straightforward at first glance. Simply include that extra cost. However, we quickly collide with a perplexing obstacle.

Suppose that we first formulate a decision problem as a conventional optimization based on the assumption of unbounded rationality and thus on the assumption of zero deliberation cost. Suppose we then recognize that deliberation cost is positive; so we fold this further cost into the original problem. The difficulty is that the augmented optimization problem will itself be costly to analyze; and this new deliberation cost will be neglected. We can then formulate a third problem which includes the cost of solving the second, and then a fourth problem, and so on. We quickly find ourselves in an infinite and seemingly intractable regress. In rough notation, let P denote the initial problem, and let $F(.)$ denote the operation of folding deliberation cost into a problem. Then the regress of problems is P, $F(P)$, $F^2(P)$, . . .

There are two difficult issues here: (i) what the operator F looks like and (ii) how to deal with the regress. Start with (ii). Few authors mention the regress issue, and most mentions are little more. Examples:

> It might . . . be stimulating, and it is certainly more realistic, to think of consideration or calculation as itself an act on which the person must decide. Though I have not explored the latter possibility carefully, I suspect that any attempt to do so leads to fruitless and endless regression. (Savage 1954, p. 30).

> an optimization whose scope covers all considerations including its own costs . . . sounds like it may involve the logical difficulties of self-reference. (Winter 1975, p. 83)

> The question of how far to go . . . is in itself an optimization problem, but a peculiar one in that it can itself not be subjected to analysis . . . at least in the last instance. Should one try to analyse the question of how to strike an optimal balance , . . . then the same question could be raised in relation to this question, and so on. At some point a decision must be taken on intuitive grounds. (Leif Johansen 1977, p. 144)

Other early mentions of the regress issue are in Howard Raiffa (1968, p. 266), Radner (1968, p. 56, and 1975, p. 266), Marschak and Radner (1972, sections 9.6–9.7), and Hans Gottinger (1982). Perhaps the most succinct summary of the issue is Day and Pingle's phrase "economizing economizing" (1991, p. 509). If we can economize on economizing, then we can economize on economizing on economizing, and so on. Given the vast number of expositions of choice theory, it is remarkable how infrequently the regress issue is mentioned. I have found only three papers—Philippe Mongin and Bernard Walliser (1988), Holly Smith (1991), and Barton Lipman (1991)—which discuss the regress issue in any detail.

The regress problem seems to block any effort to maintain optimization as the ultimate logical basis for all behavioral modeling. How can we formulate an optimization problem which takes full account of the cost of its own solution? There is no reason to suppose that sequences like P, $F(P)$, $F^2(P)$, . . . will often converge (though Lipman 1991 discusses convergence of a related sequence) or, if convergence occurs, that the limit corresponds to any problem descriptive of a decision maker. We seemingly must yield to the idea that some behavioral hypothesis other than optimization, such as learning or adaptation, is needed to escape the regress. In Johansen's words, "At some point a decision must be taken on intuitive grounds."

In practical modeling, then, what

should economists do about the regress of problems P, $F(P)$, $F^2(P)$, . . . ? It seems sensible to focus on only the first two problems, P and $F(P)$. Problem P asks what the perfect decision is, and problem $F(P)$ asks in addition how much costly deliberation the decision maker should expend in approximating the perfect decision. These are sensible behavioral questions. Problem $F^2(P)$ asks in addition how much deliberation the decision maker should expend deciding how much deliberation to expend approximating a perfect decision. This problem seems overly convoluted, and $F^3(P)$, $F^4(P)$, . . . are more so. Although the regress as a whole is worthwhile to notice, because it helps to put issues in perspective, practical modeling might, at least initially, neglect all problems beyond P and $F(P)$. In any case, that is what economists have done.

B. *An Example of* P *and* F(P)

Consider a decision maker choosing a decision variable X (scalar or vector) to make a payoff function $\Pi\ (X)$ large. Let $\Pi(X)$ have unique optimizer $X*$. Suppose that the decision maker has enough information in principle to compute the value of $\Pi(X)$ for any X and thus to find $X*$. Then $X = X*$ is the unboundedly rational choice. However, suppose that $\Pi(X)$ is so complex a function that the deliberations in finding $X = X*$ would be prohibitively costly. Thus, consider a deliberation technology by which the decision maker "produces" an approximation X to the perfect decision $X*$. Let T be the costly effort devoted to approximating $X*$, where C is the cost of one unit of T. Let $X(T)$ be the actual decision resulting from this costly deliberation, and let X_0 be a rule-of-thumb decision that the agent could use for free (zero deliberation). Finally, let u be a random disturbance representing the unpredictability of deliberation (else the agent would know the answer to begin with). A deliberation technology might then be specified as a function

$$X(T) = G(T, X*, X_0, u). \tag{1}$$

It would be natural to give $G(T, X*, X_0, u)$ properties such that $X(T)$ moves stochastically from X_0 toward $X*$ as T increases from 0 to ∞. The formal assumptions might be $G(0, X*, X_0, u) = X_0$, $(\partial\ /\ \partial\ T)E[G(T, X*, X_0, u) - X*]^2 < 0$, and $G(\ \infty\ , X*, X_0, u) = X*$.

Consider the intuition of (1) under these assumptions. At one extreme, if deliberation is prohibitively costly (C very large), the decision maker is motivated to do no deliberation ($T = 0$), and (1) yields the pure rule-of-thumb decision $X = X_0$, perhaps a simple adaptive response to experience. At the opposite extreme, if deliberation is free ($C = 0$), the decision maker is motivated to do infinite deliberation ($T = \infty$), and (1) yields the unboundedly rational choice $X = X*$. In between, (1) gives a mix among rule-of-thumb behavior, deliberation, and random noise. The mix dictates the decision maker's "degree of rationality" for the problem at hand. Algebraically specific deliberation technologies of form (1) are used in Conlisk (1988, forthcoming) and Evans and Ramey (1992).

To the possible criticism that (1) doesn't look much like human cognition, we might note that a CES production function doesn't look much like a factory floor. In representing a deliberation technology as in representing a production technology, the object is not faithfulness to cognitive science or to engineering. Rather the object is a simple relationship for representing economic tradeoffs.

In this example, the original problem

P is to choose X to make $\Pi(X)$ large. Adding risk neutrality, the augmented problem $F(P)$ may be defined as the problem of choosing the deliberation effort T to make the expected net payoff $E\{\Pi[X(T)]\} - CT$ large. Summarizing:

Original problem P. Choose X to make $\Pi(X)$ large.

Augmented problem $F(P)$. Choose T to make $E\{\Pi[X(T)]\} - CT$ large.

C. *Four Rationalities*

The problems P and $F(P)$ suggest a rough way of categorizing treatments of rationality in the literature. Most models treat the original decision problem P. Only a few add a deliberation technology and treat the augmented problem $F(P)$. Among models treating P, there are two ways to close the model. Either the decision maker optimizes, or the decision maker uses some other behavioral rule, call it an adaptive rule. Among models treating $F(P)$, there are the same two ways to close the model. Either the decision maker optimizes in the sense of finding the optimal deliberation effort to devote to the choice, or the decision maker follows some adaptive rule in choosing deliberation effort. This gives four categories of models.

1. Treat problem P. Optimal closure.
2. Treat problem P. Adaptive closure.
3. Treat problem $F(P)$. Optimal closure.
4. Treat problem $F(P)$. Adaptive closure.

The categories are in decreasing order of size. Category 1 comprises models of unboundedly rational choice, the vast majority of models in the literature. Category 2 includes models of bounded rationality in which adaptive choice rules are specified outright, with no deliberation technology or explicit treatment of deliberation cost. This category includes the vast majority of models of bounded rationality surveyed in Section II. Categories 3 and 4, which require specification of a deliberation technology, contain only the very few models surveyed in the final three paragraphs of Section II.

Consider Category 3. It supposes that we have specified a deliberation technology and that the decision maker chooses the optimal amount of deliberation. In the example, the decision maker chooses the T, call it $T*$, which maximizes $E\{\Pi[X(T)]\} - CT$. Thirty years ago, William Baumol and Richard Quandt (1964, p. 23) dubbed this "optimal imperfection." In their words,

> One can easily formulate the appropriate . . . marginal conditions for what one may call an optimally imperfect decision, which requires that the marginal cost of . . . more refined calculation be equal to its marginal (expected) gross yield.

We might quarrel with the words "easily formulate," because Baumol and Quandt did not in fact present a model of optimal imperfection, nor have many authors since. In terms of the $F(P)$ example, the marginal condition referred to by Baumol and Quandt is that the marginal cost of deliberation C equal the expected marginal benefit $\partial E\{\Pi[X(T)]\}/\partial T$. If $F(P)$ is viewed as a stopping problem (when to stop deliberating and take final action), then optimal imperfection means optimal stopping. However, there is a problem. Why would a decision maker who cannot optimize relative to problem P be able to optimize relative to problem $F(P)$, which will often be more complicated? Yet, if we fold in the cost of deliberating about $F(P)$, we are off again into the regress P, $F(P)$, $F^2(P)$, . . . Optimal imperfection returns us to the regress.

Nonetheless, in the literature, the few models which treat problem $F(P)$ often do invoke optimal imperfection. What is the defense? Taking a dynamic view, we might justify optimal imperfection as an equilibrium condition. A model in Category 4 might adapt over time into a model in Category 3, just as, by more familiar adaptive logic, a model in Category 2 might adapt over time into Category 1. However, the conditions for such convergence from Category 4 to Category 3 seem delicate. We must suppose that the decision maker faces a time sequence of original problems $\{P_t\}$ sufficiently complex that deliberation cost remains important, thus leading to a sequence $\{F_t(P_t)\}$ of deliberation cost problems. We must then assume that the optimal deliberation effort is the same for each problem in the sequence $\{F_t(P_t)\}$, so that there is an invariant optimal effort T^* to which the actual efforts $\{T_t\}$ might in principle converge. Finally, we must assume that the decision maker does manage to converge.

Because these conditions are delicate, a modeler may have to justify optimal imperfection—Category 3—as nothing more profound than a compromise of expedience. Category 3, by taking direct and explicit account of deliberation cost and the tradeoffs it implies, is already a big improvement over Categories 1 and 2, which comprise most of the existing literature.

Though optimal imperfection closes a model with an optimization, it is not a retreat to some new form of unbounded rationality. An unboundedly rational decision maker optimizes every setting; whereas an optimally imperfect agent does not. In the example above, an unboundedly rational decision maker hits both settings $X = X^*$ and $T = T^* = \infty$ (where $T^* = \infty$ because deliberation is free), whereas an optimally imperfect decision maker hits only $T = T^*$. This difference is large. In the example, an optimally imperfect X mixes rule-of-thumb behavior, deliberation, and random noise.

D. *Ex Ante vs Ex Post Posts: Similarities of Deliberation Cost and Information Cost*

When I walked into a post while watching a bird, my family called it a dumb move. Among economists, however, I could have claimed that, given the spatial distribution of lamp posts, the expected utility of bird watching exceeded the expected disutility of a collision. Ex ante, the post probably was not there, and it is entirely rational to collide with an ex post post. This example illustrates the confounding of rationality issues with information issues. Am I dumb to walk into a post or merely a rational victim of imperfect information?

Expanding the deliberation technology idea, it is natural to view decisions as "produced" by a decision technology with two inputs, costly information-gathering and costly deliberation. The similarity of information-gathering and deliberation, as joint inputs in producing a decision, suggests that models of deliberation, as they evolve in economics, will inevitably have a general resemblance to existing models of information collection. For example, the illustrative deliberation technology above resembles some sampling models, with T the analog of a sample size.

It is curious that such similar economic issues, costly deliberation and costly information collection, have been treated so differently in standard economics, one avoided and the other embraced. In practice, the difference in treatment has required that anything resembling imperfect deliberation be passed off instead as imperfect information.

For example, Williamson (1985, 1986) is a towering figure in industrial organization for his insights about transactions cost. Although he sees these costs as rooted in bounded rationality, formal theories based on his ideas tend to portray the costs as information costs. Another example is the famous Gang of Four explanation of why we observe cooperation in finitely repeated prisoner's dilemma games even though the familiar unraveling argument of game theory predicts failure to cooperate. Although the observed behavior appears to be boundedly rational, Kreps et al. (1982) suggest a possible rescue of standard theory by putting the bound on information instead. They assume that, although both players really are unboundedly rational, one player thinks the other might be boundedly rational. This clever (and strained?) informational twist is enough to induce cooperation within the usual rationality assumptions. The Gang of Four approach is in sharp contrast to Selten's (1978) approach to the chain store game, another game in which the unraveling logic produces a counterintuitive prediction. Selten faces the bounded rationality issue directly and sketches a theory of bounded rationality, including a brief discussion of deliberation cost and, implicitly, of the regress issue. See also Selten and Rolf Stoecker (1986) and Selten (1991, especially p. 18) on cooperation, unravelling, and the Gang of Four.

To gain perspective, it is entertaining to imagine an accidentally different history for economic theory. Imagine that modern decision theory began, not with perfect rationality and imperfect information, but with the opposite. Observed behavior that seemed to be the result of imperfect information was instead passed off by clever economists as the result of bounded rationality. As the idea caught on, strict conventions for proper treatment of bounded rationality developed. Scholars departing from the conventions, or even worse from the perfect information postulate, were chastised as "ad hoc" and were firmly guided back to proper technique by dissertation supervisors and journal referees. No one claimed that information was literally perfect in real life, merely that agents learned their own situations well enough to act "as if" perfectly informed; after all, those who didn't would be driven out of business by those who did.

E. *Elephants in the Living Room*

Deliberation cost and bounded rationality, like elephants in a living room, are sometimes just too much to ignore. Standard economics is forced to recognize their presence, if not to refer to them by name. Consider two examples, human capital and technical change.

People spend much on human capital, in large part through schooling. The investment is partly information collection (names and dates), partly skill acquisition (typing), and partly general cognitive investment ("learning to think"). The cognitive investment must be a response to bounded rationality. Consider a deliberation cost interpretation. Deliberation cost can be specific to a particular decision, as in the $F(P)$ illustration above; or it can be the general cost of all-purpose cognitive training used in many decisions over many years. The part of schooling cost which goes into general cognitive development is general deliberation cost, and human capital theory is implicitly concerned with bounded rationality. The assumption that students invest optimally in schooling is an unusually strong example of optimal imperfection. Explicit recognition of the relation of human capital theory to bounded rationality might bring new insights to the theory.

As a second example, consider technical change. Many technological innovations result from insights that would have been made years earlier if people really could draw all possible inferences from existing information. In this sense, the rate of technical change is determined largely by bounds on rationality and by the resulting delays in exploiting economic opportunities. Yet, according to various models of research and development, decision makers engage in optimal amounts of search for the unexploited opportunities, as if unboundedly rational on that dimension. We can view the search cost as (in part) deliberation cost, and we can view the optimal search assumption as an example of optimal imperfection. If the relation of technical change to bounded rationality were recognized openly (as in the evolutionary models surveyed in Nelson 1995), standard models of technical change might be better.

V. *Final Words*

Why bounded rationality? In four words (one for each section above): evidence, success, methodology, and scarcity. In more words: Psychology and economics provide wide-ranging *evidence* that bounded rationality is important (Section I). Economists who include bounds on rationality in their models have excellent *success* in describing economic behavior beyond the coverage of standard theory (Section II). The traditional appeals to economic *methodology* cut both ways; the conditions of a particular context may favor either bounded or unbounded rationality (Section III). Models of bounded rationality adhere to a fundamental tenet of economics, respect for *scarcity*. Human cognition, as a scarce resource, should be treated as such (Section IV).

The survey stresses throughout that an appropriate rationality assumption is not something to decide once for all contexts. In principle, we might suppose there is an encompassing single theory which takes various forms of bounded and unbounded rationality as special cases. As with other model ingredients, however, we in practice want to work directly with the most convenient special case which does justice to the context. The evidence and models surveyed suggest that a sensible rationality assumption will vary by context, depending on such conditions as deliberation cost, complexity, incentives, experience, and market discipline.

Beyond the four reasons given, there is one more reason for studying bounded rationality. It is simply a fascinating thing to do. We can mix some Puck with our Hamlet.

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