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Abstract

The assumption of rationality is both one of the most important and most controversial assumptions of modern economics. This article discusses what current experimental economic as well as neuroscience research tells us about the relationship between rationality and the mechanisms of human decision-making. The article explores the meaning of rationality, with a discussion of the distinction between traditional constructivist rationality and more ecological concepts of rationality. The article argues that ecological notions of rationality more accurately describe both human neural mechanisms as well as a wider variety of human behavior than do constructivist notions of rationality.

NEUROECONOMICS AND RATIONALITY

TERRENCE CHORVAT* & KEVIN MCCABE**

The assumption of rationality is both one of the most important and most controversial assumptions of modern economics. This article discusses what current experimental economic as well as neuroscience research tells us about the relationship between rationality and the mechanisms of human decision-making. The article explores the meaning of rationality, with a discussion of the distinction between traditional constructivist rationality and more ecological concepts of rationality. The article argues that ecological notions of rationality more accurately describe both human neural mechanisms as well as a wider variety of human behavior than do constructivist notions of rationality.

INTRODUCTION

A greater understanding of human thought processes can aid us the study of law in at least two ways. First, it can help us to better predict what will be the effect of a particular legal regime on behavior, which is of primary importance in deciding on the proper structure of a legal regime. Second, it can also help us to understand what it means improve the welfare of the members of society. Just as all human decision-making involves making estimates concerning optimality, so it must be for the government and its decision-making, and neuroscience can and should inform these decisions.

In recent years, we have learned a great deal about human decision making. Not only has there been an enormous amount of behavioral research but there has also been a large and increasing amount of research on the neural mechanisms involved in human decision-making. It is difficult to overstate the importance of this research to our understanding of human decision-making. Although Milton Friedman once suggested that, as we formulate models, the truth of the assumptions does not matter if the

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model can predict behavior reasonably correctly,[1] butas Herbert Simon pointed out that would only be this is a good way of thinking if we don't have microscopes.[2] Effectively, we do now have microscopes which we can use to examine the mechanisms of human decision making.

I. HUMAN DECISION-MAKING AND RATIONALITY

One of the key problems for both economics and for the application of economics to legal scholarship is the extent and the nature of rationality exhibited by economic actors. This is one of the largest areas of disagreement between adherents of traditional law and economics and the proponents of what is often referred to as behavioral law and economics,[3] This article discusses what some of the most recent research in experimental economics, as well as research in neurology and the relatively new discipline of neuroeconomics, can tell us about rationality and the importance of rationality for legal scholarship.

The notion of rationality creates many problems for economics and legal scholarship. First, it is not immediately obvious what it means to be rational.[4] A reasonable definition would be a decision process that results in the selection of the "best" method of accomplishing a goal. Alternatively, almost any decision process which is rule-based can be argued to be rational.[5] In addition, rationality can be applied to many aspects of decision-making. For example, rationality can be applied to belief, which forms a key part of choice behavior. If a decision maker ignores some pertinent evidence in forming the relevant beliefs, then one might term these beliefs irrational. On the other hand, one could argue that an action could be rational given the beliefs of the individual, although the model building process is faulty.

The notion of rational belief is important to understanding of legal issues in part because reasoning about social problems generally must be highly opportunistic. We rarely have direct answers to those questions which we would most like to be answered. We can only imperfectly understand human behavior and the range of potential responses to

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1. MILTON FRIEDMAN, ESSAYS IN POSITIVE ECONOMICS(1953).

2. Herbert Simon, *Discussion: Problems of Methodology* 53 AM. ECON. REV. 229, 230 (1962)

3. Colin Camerer, and George Lowenstein *Behvaioral Economics: Past , Present and Future* in ADVANCES IN BEHAVIORAL ECONOMICS (2003), 3-4.

4. One might view rationality to include the selection of the optimal neural mechanism, which is discussed *infra* at section II.c

5. Such a process can be said to maximize conformity with the rules on which it is based. GARY S. BECKER, THE ECONOMIC APPROACH TO HUMAN BEHAVIOR (1976).

particular legal regimes. Therefore, we can only make probabilistic predictions about that behavior which will result under differing combinations of legal rules.[6] At best, we can claim that the process by which those predictions are made may be more or less rational.

Another inherent problem that rationality poses for legal scholarship is how should we address the fact that the degree of rationality found in the population is heterogeneous? Should we treat all individuals as equally rational? If most but not all individuals are rational generally rational, what does this mean in terms of what presumptions policymakers and judges should make? No agent, either individual or institutional, possesses all the relevant information for making decisions.[7] Therefore, decisions must be made in the absence of perfect information. To what extent should we treat such agents as rational if the level of information varies, and consequently the decision-making processes vary?

Modeling Rationality

Those models relevant to law will generally have as their inputs environmental variables, and have as their outputs the behavior of individuals, groups of individuals, or institutions. Therefore, one might argue that research into neurobiology and neuroeconomics will only give us information that in some sense we could have learned from psychological or standard economic research. This argument, however, reflects a faulty understanding of the model-creating process. It is very likely that by understanding the neural mechanisms of decision-making we will be able to create better models of the interaction between the environment and human behavior. Proceeding without the insights of neurobiology and neuroeconomics would be rather like attempting to model the behavior of a car without understanding the intricacies of the internal combustion engine. As an understanding the oxygen requirements of the combustion process will serve to explain why cars do not perform as well at high altitude, or on cold days, research in neurobiology and neuroeconomics will help us resolve many conflicts over the nature of human behavior, such as the extent to which, as well as the ways in which,

6. A good example of this is the development of the hub and spoke system as a result of the deregulation of airlines in the 1970s, because the airport operators did not charge as higher fee for increased airport congestion. *See* Vernon Smith, *Constructivist and Ecological Rationality in Economics: Nobel Prize Lecture* 2002, 93 AM. ECON. REV. 465 (2003).

7. We do not know if the sun will explode tomorrow, or if the earth's magnetic field will dissipate more quickly than anticipated. Both of these events would have a dramatic effect on our future plans.

humans are rational (which might change from individual to individual as well as society to society).

One can argue that law and economics is in fact a form of applied psychology in that it seeks to apply a particular model of human behavior i.e., choiceto solve problems. The methodology of law and economics has been able to help us to answer a number of important questions because it is able to from precise models that create falsifiable predictions. The results from testing earlier predictions are then used to alter the models to cause them to come into greater conformity with observed behavior, both by revealing the likely result of particular policy prescriptions and also by modifying our understanding of what an optimal society might be. Here, the new relatively new discipline of hedonic psychology can play an important role.[8]

While the premises behind its normative conclusions can of course be questioned, it is difficult to question the usefulness of economic analysis in the discussion of any number of diverse issues such as optimal tax policy, the drug legalization debate, "three strikes" laws, or any form of economic regulation such as anti-trust and securities laws. It is difficult to argue that there is no correlation between behavior and well-being. Some of the utility of economic analysis derives from the fact that for many purposes, it does appear that for many purposes individuals can be considered rational.[9] Recall that rationality can be defined as selecting the best method of accomplishing a specified goal. Clearly, from an evolutionary perspective, pleasure and pain exist to motivate human behavior but, as research in cognitive neuroscience has shown, these are not the only systems which influence behavior and therefore it should not be surprising to us that some behavior appears irrational.[10] One of the hallmarks of rational decision-making is the notion that preferences, whatever they may be, are stable.[11] If choices are random, it may difficult to refer to these choices as guided by preferences.[12]

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8. See generally WELL-BEING: THE FOUNDATIONS OF HEDONIC PSYCHOLOGY (Daniel Kahneman et al. eds., 1999).

9. Alvin Roth, *Adaptive Behaviour and Strategic Rationality: Evidence from the Laboratory and the Field* in THE RATIONAL FOUNDATIONS OF ECONOMIC BEHAVIOUR (Kenneth Aroow et al. eds, 1996)

10. Bartley G. Hoebel, *Neural Systems for Reinforcement and Inhibition of Behvaior: relevance to Eatring, Addiction and Depression in* WELL-BEING: THE FOUNDATIONS OF HEDONIC PSYCHOLOGY (Daniel Kahneman et al. eds., 1999), 558.

11. ADREU MAS-COLELL ET AL., MICROECONOMIC THEORY (1995).

12. *See* Gary S. Becker, *Irrational Behavior and Economic Theory* , 70 J. Pol. Econ. 1 (1962).

A common defense of the rationality assumption has been that a wide variety of behavior can be explained by models based on this assumption. However, many academic commentators have discussed how predictions of the standard economic model do not seem to be borne out in either experiments with individuals or in the econometric data.[13] A number of academics have argued that, in fact, individuals *systematically* deviate from standard notions of rationality.[14] This work is sometimes referred to as behavioral economics, but is more accurately thought of as economics with an empirical focus. Note that many of these examples cited in this literature are not merely violations of expected utility in a manner similar to the Allais paradox or the Ellsberg paradox, which can be rationalized through the use of complex risk preferences,[15] but rather violate notions of rationality altogether. In the face of such evidence, psychologists such as Amos Tversky have questioned why economists have such reluctance to give up the rationality hypothesis in the face of such strong evidence.[16]

Many economists argue that we can gain some level of confidence for the view that the realism of the assumptions does not matter from the fact that often other disciplines such as physics make unrealistic assumptions.[17] Indeed, if this is the case, reference to other disciplines might indicate how these models might be useful in a variety of ways. Other disciplines often use mathematical forms of optimization even where almost no one is hypothesizing that some actual choice process is occurring. physicists often use optimization methods in studying physical systems yet, except for a very small fringe group, physicists do not assume that the physical systems at issue are in any real sense part of a decision-making process.[18] Economists have long acknowledged that rational models are not the only ways in which individuals exhibit choice behavior. In essence, many macroeconomic models actually assume certain levels of irrationality.[19]

Economists have also argued that the rationality assumption is reasonable even though it cannot explain all human behavior, because it

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13. See Camerer and Lowenstein, supra note

14. For an early example of this work, see K.O. May *Intransitivity, Utility and the Aggregation of Preference Patterns* 22 ECONOMETRICA 1 (1954).

15. See description in Terrence Chorvat, *Taxing Utility*, forthcoming in the Journal of SOCIOECONOMICS (2005).

16. Amos Tversky, *Rational and Constructive Choice in* THE RATIONAL FOUNDATIONS OF ECONOMIC BEHAVIOUR (Kenneth Arrow et al. eds, 1996).

17. FRIEDMAN, *supra* note 1, at __.

18. *See* PAUL A. SAMUELSON, FOUNDATIONS OF ECONOMIC ANALYSIS (2nd ed., 1983). *See* RICHARD P. FEYNMAN, 1 THE FEYNMAN LECTURES ON PHYSICS, 26-3(1970).for a description of the least time principle.

19. Kenneth Arrow, *Rationality of Self and Others*_-J. OF BUS.__ (1986).

can be used to predict much of human behavior. This was form of Alvin Roth's response to Amos Tversky's argument against the rationality hypothesis. Roth argues that the applicability of rational models depends on the level of analysis required for the problem.[20] Roth divided the levels of analysis into standard economic models (further subdivided into risk-neutral models and expected utility models), psychological models, and neurobiological models. One could further divide neurobiological models into those models that address the interactions between larger neural mechanism (– for example, certain models address how the dorsolateral prefrontal cortex appears to process data in a manner different than the insula cortex)[21] – versus biochemical models (for example, certain models address how higher levels of serotonin lead to less impulsive behavior because of the lower levels of activation in various cortical neural circuits).[22] Research on these two types sis isof a different sort and, while clearly connected, they yields different types of results. The raityassumption would seem to be more to the models which involve larger scale process (e.g., the agent as a whole) than to those models which address the electrochemical changes is the cells that make up the brain

1. The Risk Neutral Model

Using Roth's terminology, the first category of models of economic behavior are the risk neutral models. Rs of their wealthThis may be viewed as the very first model for utility theory, as it was designed to explain the value of various gambles and why individuals are likely to take certain gambles and not take other gambles. The risk neutral model posited that individuals act so as to maximize their expected value. This theory was formulated by Fermat and Pascal in the late 1600's. Soon after its formation, problems with the model were discovered.[23] The most famous of these problems is known as the St. Petersburg Paradox, which was "solved" by Daniel Bernoulli through the creation of an antecedent of expected utility theory.[24]

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20. Alvin Roth, *Adaptive Behaviour and Strategic Rationality: Evidence from the Laboratory and the Field* in THE RATIONAL FOUNDATIONS OF ECONOMIC BEHAVIOUR (Kenneth Arrow et al. eds, 1996)

21. *See* Alan G. Sanfey et al., *The Neural Basis of Economic Decision-Making in the Ultimatum Game*, 300 *SCI*. 1755, 1755-58 (2003).

22. JOSEPH LEDOUX, THE SYNAPTIC SELF (2002) 286-8.

23. *See* Terrence R. Chorvat, *Ambiguity and Income Taxation,* 23 CARDOZO L. REV. 617, 620-22 (2003).

24. Daniel Bernoulli, *Specimen Theoriae Novae de Mensura Sortis,* 5 COMMENTARII ACADEMIAE SCIENTIARUM IMPERIALIS PETROPOLITANAE 175 (1738), *translated in Exposition of a New Theory on the Measurement of Risk*, 22 ECONOMETRICA 23 (1952). The St. Petersburg paradox involves a gamble

2. Expected Utility Models

As a result of further developments of Bernoulli's ideas, a new model of human behavior – the expected utility model – became the standard model for economic analysis. This second family of models has more explanatory power regarding behavior than the first, including why individuals purchase insurance, why stocks have a higher return than bonds, *et cetera*.[25] Models based on the assumptions of expected utility theory have also been used to explain the pricing of assets, both real and financial. These models form the backbone of what can be referred to as both neoclassical economics and traditional law and economics. These theories form the basis for game theory, price theory, and the rational expectations models of macroeconomics.[26] Interestingly, while the more recent expected utility models are able to explain a greater variety of behavior, there still remain many applications of risk neutral models in economics. For example, many argue that corporate managers should be essentially risk-neutral in their decision-making, because shareholders can diversify away most of the idiosyncratic risk of any corporation.[27] Furthermore some economists have argued that the government should essentially act in risk-neutral manner.[28]

3. "Almost Rational" Models

Another type of model which has developed more recently can be described as "almost rational" models.[29] These models resemble expected utility models in many respects, but add the assumptions that individuals may have more complicated risk preferences, and may not ignore sunk costsIn many versions of these models, the reference points of the agents significantly affect the predicted behavior. One can still call such persons

with an infinite expected value for which individuals are only willing to pay a modest amount. For a description of the St. Petersburg paradox see Chorvat, *supra* note 23, at 620-22.

25. Alvin Roth, *Adaptive Behaviour and Strategic Rationality: Evidence from the Laboratory and the Field* in THE RATIONAL FOUNDATIONS OF ECONOMIC BEHAVIOUR (Kenneth Arrow et al. eds, 1996)

26. ROBERT E. LUCAS, JR. MODELS OF BUSINESS CYCLES (1987).

27. Alvin Haim Levy and Marshall Sarnat, *Diversification, Portfolio Analysis and the Uneasy Case for Conglomerate Mergers*, 27 J. FIN. 795 (1970)*Adaptive Behaviour and Strategic Rationality: Evidence from the Laboratory and the Field* in THE RATIONAL FOUNDATIONS OF ECONOMIC BEHAVIOUR (Kenneth Arrow et al. eds, 1996)

28. Kenneth J. Arrow & Robert C. Lind, *Uncertainty and the Evaluation of Public Investment Decisions*, 60 AM. ECON. REV. 364 (1970).

29. Alvin E Roth, *Bargaining Experiments, in* T OF EXPERIMENTAL ECONOMICS349 (John H. Kagel & Alvin E. Roth eds., 1995).

rational although they may have seemingly complicated views of risk.[30] These models include a variety of non-expected utility theories.[31]

4. Psychological Models

Another family of behavioral models might be described as psychological models. These models do not posit stable preferences functions, but rather a set of psychological processes which interact with the environment to create behavior.[32] One could argue that in some sense that even these models are constitute examples of economic models as well. The actors in these models are various psychological needs, instead of individuals of standard economic models, and how the action of the individual is decided upon depends on the internal dynamic between these psychological needs. One can analogize these models to economic theories of group interactions. These models allow for preference reversals, just as social choice theory shows that group decision making will not always lead to consistent choices.[33] Even these psychological models essentially assume some rationality principle, in that there is some choice process behind the various psychological processes and, to the extent that this is rule based, it too can be rationalized.

5. Neurobiological Models

The final type of model for human behavior which we should consider are the neurobiological model. These models are based not on preferences or psychological processes, but rather on the physical processes of decision-making. In some sense, these represent the height of rationalizable models, because physical processes follow deterministic rules until on arrives at the quantum level.[34] There are a variety of these types of models. Two prominent types of these models are first models which address the interactions between different brain regions, and second the models which address the underlying neurochemistry of decisions. Much of the research in this field is conducted on particular areas of brain activation during decision-making, as well as research on a more microscopic level.

30. Matthew Rabin & Richard Thaler, *Risk Aversion* 15 J. ECON. PERSPECTIVES 219, 221 (2001).

31. For a description of these models see Colin Camerer, *Individual Decision-Making* in THE HANDBOOK OF EXPERIMENTAL ECONOMICS 626-651 (John H. Kagel & Alvin E. Roth eds., 1995).

32. Alvin Roth, *Adaptive Behaviour and Strategic Rationality: Evidence from the Laboratory and the Field* in THE RATIONAL FOUNDATIONS OF ECONOMIC BEHAVIOUR (Kenneth Arrow et al. eds, 1996)

33. DAVID KREPS, A COURSE IN MICROECONOMIC THEORY 174-81(1990)

34. For a discussion of the impact of quantum mechanics of the determinism of the classical Newtonian physics, see RICHARD P. FEYNMAN, 1 THE FEYNMAN LECTURES ON PHYSICS, 37-11 (1970).

revealing the changes to neurons and glial cells that occur as the result of certain events in the brain. Carried to their logical extreme, for example, these models might reveal that the reason a particular decision was made was a change in the membrane permeability in certain neuronal and glial cells.

At the current time, it seems rather far-fetched for economists to calculate the effects of a 20% versus 25% income tax rate on neuronal membrane permeability in various regions of the brain. While such models might eventually attain this level of accuracy, nonetheless, at least currently, these results would essentially be impractical and would include too many degrees of freedom to yield helpful predictions.

It is indeed important to understand that level of rationality appropriate to explain the particular behavior at issue. One of the keys of science is the creation of falsifiable hypotheses. If a model can always accommodate all factual evidence, then it is non-falsifiable and therefore non-scientific.[35] Because there are so many differing models for human behavior, a key problem arises in that one can always *ex post* choose the model to best fit the data rather than *ex ante* predicting what the data should be. For example, if individuals behave rationally, we might use rational models; if they don't, we use psychological or neurobiological models. Picking and choosing of models *ex post* in this fashion is unsatisfactory. We should rather develop a *meta* model for deciding when to use rational models, psychological models, or whatever models we eventually develop. This is particularly true given that, in some sense, psychological and neurobiological models are more in the nature of catalogues of decision-processes rather than over-arching models of decision-making. Future models which incorporate neurobiological research must be able to predict the behaviors that are more likely to be better approximated by rational models and those that are more likely to be better approximated by non-rational models. The models should both explain the diversity of human behavior and yet predict what will commonly happen.

II. ECOLOGICAL VERSUS CONSTRUCTIVIST RATIONALITY

Another of the problems with the argument against using rational models as predictive of human behavior is that it is assumes only one type of rationality, commonly referred to as constructivist rationality.

35. KARL R. POPPER, THE LOGIC OF SCIENTIFIC DISCOVERY (1934).

Constructivist rationality is based on the rationality utilized by Descartes in trying to deduce morality and rules of decision-making from a small set of first principles.[36] One can see this type of rationality played out to a great extent in modern game theory, which assumes a relatively small set of axioms about the utility of the players and deduces an enormous number of findings of great complexity.[37]

But this is not the only form of rationality. It is important to distinguish constructivist rationality from ecological rationality. Ecological rationality is not rational in the sense that it concerns a set of decision rules that are able to predict what should happen in each situation, or that it will *necessarily* give the optimal path to the solution that we can see would have been optimal *ex post*.[38] Rather ecological rationality results in optimal decision rules given the costs of making the decision and the neurological mechanisms available to the decision-maker. This is related to constrained optimization, under which the cost of obtaining new information is included in the decision constraints. As with bounded rationality, the decision rules created by ecological rationality may not be rational for all possible states of the world, but they might be rational in states of the world that are likely to occur. This view is more likely to reflect neurological reality than are constructivist notions of rationality.

Not only is individual decision-making more likely of an ecological nature, but one can argue that governmental decision-making should be of this variety as well. Just as individuals who are able to learn about their environment are more likely to survive, institutions which are able to adapt and change are more likely to survive, and therefore over time are more likely to comprise a higher proportion of the institutions we see.[39] Even though no one person may understand why an institution has survived, it will have survived because it was better able to adapt to situations than other institutions, just as crocodiles do not understand why their kind has survived since before the time of the dinosaurs.

36. See generally, RENE DESCARTES, DISCOURS DE LA METHODE POUR BIEN CONDUIRE SA RAISON, & CHERCHER LA VERITÉ DANS LES SCIENCES. PLUS LA DIOPTRIQUE, LES METEORES, LA MECHANIQUE, ET LA MUSIQUE, QUI SONT DES ESSAIS DE CETTE METHODE (*1668)*

37. ROGER B. MYERSON, GAME THEORY: ANALYSIS OF CONFLICT (1997).

38. Vernon Smith, *Constructivist and Ecological Rationality in Economics*, 93 AM. ECON. REV. 465 (2003).

39. Armen A. Alchian, *Uncertainty, Evolution and Economic Theory*,58 J. POL. ECON. 211 (1950).

A. Game Theory and Constructivist Rationality

Decision theory is the study of how individuals make decisions.[40] When these decisions are strategic – that is, where the behavior of each agent affects decisions made by the others – this study is called game theory.[41] In classical game theory, games are employed as a metaphor for strategic decision-making by economic actors in situations where choices by each affect decisions by the others. One can argue that mathematical decision theory and mathematical game theory give the normatively "correct" answers to problems. However, in real world situations the "right" answers might depend on the actual actions of others who may not be game theorists, and so therefore it is important also to understand the decisions humans actually make, not just those they "should" make.

Very commonly individuals do not behave as predicted by game theory.[42] This may be for reasons of cognitive limitations, or it may be because of other reasons which are more difficult to describe but involve social cognition and group dynamics.

B. Adaptive Learning

One of the most common tests of rationality is the ability to avoid what is referred to as a "Dutch book." A "Dutch book" is a mechanism by which a series of bargains are placed before a subject, and while each of the bargains is favorable to the subject yet, at the end of the series, the subject has no money and nothing to show for it.[43] Because we do not observe many Dutch books in the real world, nor does it seem that rational persons would permit a Dutch book to operate against them, this has become one of the standard tests of rationality. It can be demonstrated that, were a robot endowed with many of the standard utility functions of human beings, they would be subject to the Dutch book argument.[44] Why then don't we see Dutch books in the real world?

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40. Peter Gärdenfors and Nils-Eric Sahlin, *Introduction: Bayesian Decision Theory: Foundations and Problems* in DECISION, PROBABILITY AND UTILITY: SELECTED READING, 3-4 (Peter Gärdenfors and Nils-Eric Sahlin, eds, 1988)

41. KREPS, supra note _. At 355

42. See generally, COLIN CAMERER, BEHAVIORAL GAME THEORY (2003)

43. See Menahem E. Yaari, *The Role of Dutch Books in the Theory of Choice* in FRONTIERS OF RESEARCH IN ECONOMIC THEORY: THE NANCY L SCHWARTZ MEMORIAL LECTURES 1983-1997(Donald Jacobs et al. eds, 1998).

44. Rabin, and Thaler

Dutch books do not work because people learn not to let others take advantage of them.[45] One can see how learning based models may be both better predictors of behavior, and in some sense are to be preferred over the strict expected utility models. For example, it may be optimal for a group of individuals to allow each member to experiment individually and then after some period of time the members of the group could begin to imitate others who have succeeded.[46] From an evolutionary perspective, one can see how agents who adopt the imitation of the success of others as a basic strategy might succeed in wide variety of environments. This concept is connected with the notion that we do not need to understand every aspect of a principle in order to understand how it can be used.[47]

Therefore, the experiments discussed as disproving rationality might be better thought of as disproving constructivist rationality.[48] With some introspection, we should not be surprised that individuals who are not trained as statisticians will make significant mistakes in their decisions. This does not mean that individual cannot make correct decisions about questions that involve statistical inference, but rather the method by which these decisions are made may not reach the normatively correct answer in all cases.

Both behavioral and neurological research indicates that learning occurs in very complex frameworks, not merely simple Hebbian association or "selectionist" models.[49] Explanations of human decision-making based on evolutionary psychology *et cetera* are fascinating and helpful but, ultimately, scientific knowledge and models must flow from experimental or other empirical evidence, rather than introspection alone.

Focusing on ecological rationality as opposed to constructivist rationality may cause us to realize that there is no real substitute for the careful study of natural environments. Were economists to attempt to understand market behavior without studying real behavior (for example, in the case of the St. Petersberg paradox[50] and insurance), we might not have been inspired to create the expected utility models in place of the expected value models. Economic models generally assume tastes are both

45. Rabin and Thaler, supra note x At.

46. Roth, supra note x at.

47. FEYNMAN, *supra* note 23, at 4-1.

48. For example, the experiments conducted by May, *supra* note 14, do not necessarily disprove some type of ecological rationality

49. For a discussion of Hebbian models, See LEDOUX, *supra* note _ at 80-81.

50. Daniel Bernoulli, *Specimen Theoriae Novae de Mensura Sortis*, 5 COMENTARII ACADEMIAE SCIENTIARUM IMPERIALIS PETROPOLINTANAE 175 (1738), *translated in Exposition of a New Theory on the Measurement of Risk*, 22 ECONOMETRICA 23 (1952).

exogenous and stable.[51] We assume that when choices are made which are different than previous choices, rationality has been violated. It is of course always possible that preferences have changed. If we were to allow preference changes to commonly enter into our explanations, we would almost never be able to falsify a theory, thus removing it from a Popperian notion of science.[52] Without a good theory of how tastes change, we cannot allow these consideration to enter the models.

Where psychological models and neurobiological models might be particularly helpful is in enabling us to elucidate how tastes are formed. This may help to explain paradoxes such as Tversky's Williams-Sonoma catalog example (the existence of a third alternative will cause more purchases of the one of two previous available alternatives, *et cetera*).[53] Research in both psychology and neurology with likely be very helpful in explaining the effectiveness of advertising, as well as phenomena such as the degree of trust and trustworthiness of members of different societies. One reasonable hypothesis about the behavior of subjects in experiments in different societies is that we are seeing artifacts of their behavior in the world. This notion is buoyed up by recent research which seems to indicate that members of different societies often adopt different strategies in simple experimental situations.[54] However, one must consider that one of the possible effects of the double blind study might be to make clear to the subjects that the standard rules of society do not apply.

Many researchers in human behavior and biology have adopted an approach, referred to as cognitive neuroscience, which integrates psychology, biochemistry, neurology, evolutionary biology and related sciences in order to further our understanding of human behavior.[55] One problem with such interdisciplinary efforts is coordinating the different methods of inquiry. Grossly oversimplifying, biological sciences follow more of a cataloguing approach (e.g., this behavior is correlated with this neural mechanisms), whereas economics attempts to create models which predict a wide variety of behavior with very simple models.

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51. We say this noting the exception of models such as Becker'(see Gary Becker et al., *Rational Addiction and the Effect of Price on Consumption* 81 AM. ECON. REV. 237 (1991))and derivatives of it.

52. POPPER, *supra* note 24

53. Amos Tversky, *Rational and Constructive Choice in* THE RATIONAL FOUNDATIONS OF ECONOMIC BEHAVIOUR (Kenneth Arrow et al. eds, 1996)

54. Joseph Henrich et al., *In Search of Homo Economicus: Behavioral Experiments in 15 Small-Scale Societies* 91 AM. ECON. REV. 73 (2001)

55. MICHAEL GAZZINGA, RICHARD IVRY, & GEORGE MAGNUN, COGNITIVE NEUROSCIENCE (2nd, ed. 2002)

One of the problems with the cataloging method, which has been the dominant paradigm in the neurological research, is that it fails to predict new behavior. The opposite problem can be argued applies to economics with its assumption of rationality. The rationality hypothesis is quite resilient when there is only a finite amount of data (as long as it complies with the weak axiom of revealed preference).[56] One can analogize some of the results of economic analysis to the famous experiments in which split-brain patients were able to rationalize what they did not understand, even while it was clear that the rationalization was incorrect.[57]

It has long been hypothesized that biological mechanisms can have direct control of our behavior in particular areas.[58] Merely understanding that there may be genetic influences on behavior does not tell us how this behavior is created, nor how the mechanism utilized for one problem may influence other types of behavior. Cognitive neuroscience can help us to resolve these questions by directly examining the neural mechanisms involved. As pointed out by Joseph LeDoux, the link between the brain and behavior is much, much stronger than the link between genetics and behavior.[59]

C. Ecological Rationality and Neurological Mechanisms

For a variety of reasons, including those discussed above, constructivist rationality seems unlikely as a paradigm of behavior, particularly given what we know about neurological mechanisms. Constructivist rationality seems rather based on forethought about future states with precise payoffs. Neurological research shows us that there are many different regions of the brain which process information differently. This section will discuss some areas of research which explore how this compartmentalization occurs. In particular, it will examine research which examines differences between conscious and unconscious process, differences between personal and impersonal decision and finally some interesting work on the ultimatum game.

1. The Cost of Conscious Awareness

Neurological research indicates that cognition is a costly resource. Because brains are finite, and because there is a payoff to increasing our

56. MAS COLELL ET AL., *supra* note_ at 12.
57. GAZZANIGA, ET AL., SUPRA NOTE_, AT 436-37.
58. *Id. at 62-95.*
59. LEDOUX, *supra* note 16, at 3-5.

understanding of the world, the constraints on the capabilities of our brains can seriously affect the manner in which functions are performed.[60] Most of the brain does not seem to be directly involved in conscious processes.[61] Two key questions are, then, how does the brain decide which problems it will address and, once this selection has been made, what neural mechanisms are used to solve the problem? It appears that the answers are governed by rules similar to those which economists and operations research specialists use in their optimization calculations. In particular, it appears that the brain consists of modules which solve particular kinds of problems.[62] There are clear evolutionary advantages to this. Individuals are confronted with a finite, although very large, set of problems. Solving the specific problems presented and having tissues structured for solving those problems would be more efficient than having general purpose tissues which would likely be more costly and not as well adapted.[63]

Because there are a nearly infinite number of stimuli in the world at any given time, in order to focus on any object, we must decide to ignore some stimuli and focus on others. Even after we are aware of a "problem," we have many potential mechanisms to use to address the issues raised. For example, we may react impulsively or we may calculate the optimal decision. Research in cognitive neuroscience suggests that different methods of problem solving are located in different parts of the brain. An example of this can be found in the fact that, patients with damage to the ventromedial prefrontal cortex (PFC) are unlikely to exhibit emotional responses to stimuli, whereas those patients with dorsolateral PFC damage appear to have problems in cognitive processing of tasks that do not seem to evoke emotional processing (for example, the Wisconsin Card Sorting tasks).[64] Interestingly, both types of reasoning seem to be necessary for optimal problem solving. Because of cognitive limitations, it is not the case that one should always use either cognitive processing (or more

60. Herbert Simon, *Bounded Rationality*, *in* THE NEW PALGRAVE 266-286 (J. Eatwell et al. eds., 1987).

61. GAZZANIGA, ET AL., SUPRA NOTE_, AT 660-68.

62. J. N. Wood & Jordan Grafman, *Human Prefrontal Cortex: Processing and Representational Perspectives*, 4 NATURE REVIEWS NEUROSCIENCE 139-147 (2003).

63. P. E. Roland and K. Zilles, *Structural Division and Functional Fields in the Human Cerebral Cortex* 26 BRAIN RESEARCH REVIEWS 87-105 (1998).

64. MICHAEL S. GAZZANIGA, RICHARD IVRY, & GEORGE R. MANGUN, COGNITIVE NEUROSCIENCE: THE BIOLOGY OF THE MIND (2nd ed., 2002); The Wisconsin Card Sorting Task involves sorting cards which have objects on them which vary along three dimensions: shape, color, and number. The cards are to be sorted according to a method determined by the experimenter, but not explicitly told to the subjects. The subjects learn the rule by trial an error, via feedback from the experimenter as to whether a particularly sorting is in accord with the rule or if it violates it.

colloquially "logic") or affective processing (more colloquially "emotion") which has been conditioned by evolutionary pressures to punish or reward behavior. Because of these conflicts, and the lack of inherent superiority of one mechanism over the other, there needs to be some mechanism to resolve these conflicts. A significant amount of research now focuses on how this resolution occurs. The goal of this research is to discover how we maintain cognitive control over our state of mind as well as our actions.[65]

One region of the brain which is clearly involved in cognitive conflict resolution is the anterior cingulate cortex (ACC). This area is currently thought to be involved in registering a conflict between regions. Some researchers argue that after a conflict is recognized, various areas of the PFC included the ACC also become active and the choice of regions activated depends on the cognitive requirements of the problem presented.[66] In addition, the context in which the problem is presented may have a significant impact on the mechanism used to address the problem.[67]

Some economists have argued that even self-destructive behaviors can best be modeled as conscious rational choices.[68] Others, generally psychologists, argue that these behaviors are the result of lack of control, these individuals did not set out to become criminals or addicts, but the behaviors are the results of cognitive or emotional deficits. Both sides have significant evidence for their arguments. To the extent these discoveries are conscious, it is clear that the law can affect them. However, to the extent that they are unconscious, the ability of law to alter them is less clear.

The extent to which processes are conscious or unconscious may have a significant effect on legal questions. For example, to what extent should law attempt to alter unconscious processing in addition to conscious processes? To what extent can it affect these processes? This is a question that future research will have to answer.

2. The Effects of Personal Interaction

There has been a fair amount of research which analyzes the different brain regions activated by personal as opposed to impersonal interactions. One example of this is research on the neural mechanisms involved in the

65. James Riling et al., *A Neural Basis for Social Cooperation* 35 NEURON 395-405 (2002).

66. J.B. Ponchon, R. Levy, P. Rossati, S. Leherily, J.B. Poline, B. Pillon, D. Le Bihan and B. du Bois, *The Neural System that Bridges Reward Cognition in Humans: An fMRI study.* 99 PRO. NAT. ACADEMY SCI. 5669 (2002).

67. J. Metcalfe & W. Mischel, *A Hot/Cool-Systems Analysis of Delay of Gratification: Dynamics of Willpower*, 106 PSYCH. REV. 3-19 (1999).

68. Gary Becker et al., *Rational Addiction and the Effect of Price on Consumption* 81 AM. ECON. REV. 237 (1991).

reactions of subjects to standard hypothetical moral dilemmas that involve personal and impersonal decision-making.[69] While using fMRI technology to image the brains of the subjects, they asked a number of questions, including a thought experiment regarding how the subjects would respond if faced with a moral dilemma with the following facts. Subjects are told that a train is coming down a track and, if they do nothing, the train will hit a car on the track and five people will be killed but, alternatively, if they press a button, the train will be diverted to a side track and only one person will be killed.[70] As has been known for many years, most people report that they would choose to press the button.[71] Interestingly, the response is quite different if a similar, but slightly different, situation is presented. In this second moral dilemma, the subjects would have to push the person next to them onto the track, killing them.[72] Here, most people answer they would not do that. The study shows that the parts of the brain that are actively involved in the decision to push the person are similar to those involved in fear and grief.[73] The decision to flip the switch, which would also result in killing a human, involved far fewer emotional reactions. In particular, the areas more likely to be active in personal moral dilemmas – such as pushing the person on to the tracks – were areas of the medial frontal gyrus, the posterior cingulate gyrus, and the bilateral superior temporal sulcus (STS). These areas are normally involved in social-emotional processing.[74] The non-moral or impersonal dilemmas (e.g., switching the train track) tend to activate areas in the dorsolateral PFC and the parietal cortex (normally involved in calculation) and executive function.[76] For those subjects who did decide to push the person next to them, one might argue that "logic" or cognitive processes prevailed over "emotion". Interestingly, those who did decide to push the other person took significantly longer in making this decision than those who chose not to push the other person (a difference of 5 seconds for those who would not push the person versus 6.75 for those who would). There was very little difference between the

69. *See* Joshua Greene et al., *An fMRI Investigation of Emotional Engagement in Moral Judgment*, 293 SCI. 2105 (2001).

70. *Id*.

71. *Id*.

72. *Id*.

73. *Id*.

74. Joshua Greene and Jonathon Haidt, *How and Where Does Moral Judgment Work,* 6 TRENDS IN COGNITIVE NEUROSCIENCE 517 (2002).

76. Stanislas Dehaene, *The Organization of Brain Activations in Number Comparison*, 8. J. COG. NEUROSCIENCE 47 (1996).

brain activation or decision time between impersonal moral dilemmas and non-moral dilemmas (less than ½ of second). This would tend to indicate that the more impersonal the decision becomes, the more we can be "rational" or rather adopt what one might argue are socially optimal decision making mechanisms. This suggests that certain types of moral decision making involves a fair amount of social thinking and invokes notions of positive and negative reciprocity, and personalization. Other more recent experiments confirm that the regions of the brain involved in moral processing are also the same regions used in social cognition.[77] One recent study by Moll *et al.* attempted to separate out the regions involved in moral judgments as opposed to those involved in emotional processing. They found that moral situations differentially activated the STS and the OFC.[78] One key distinction between this experiment and the Greene experiment is that the subjects were merely reacting to stimuli rather than making decisions about how to behave.

Consistent with these experiments as well as many others, it appears that the method of reasoning changes depending on the nature of the problem presented. This may have many applications for our understanding of law and the legal system. For example, in attempting to understand how juries reach the decisions they do, we can see that individuals may make socially-optimal choices more when they keep the subject of the decision at a distance. If the decision is personalized in some way, this can in and of itself alter the decision. Of course, more work needs to be done to fully understand what kinds of situations result in personalization and the precise way in which reasoning processes differ between personal and impersonal situations. To the extent that the conclusions from these experiments bear up in further experiments, society may have an interest in depersonalizing problems that are presented to decision-makers. In addition, objectivity may require more than simply not being related or having a direct stake in the outcome. These and other experiments suggest that even having to face someone is enough to invoke personal and social triggers.[80] This research may also indicate that society needs to frame interactions so that the "personalization" will result in actions that are in accord with what is

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77. Jorge Moll *et al.*, *The Neural Correlates of Moral Sensitivity: A Functional Magnetic Resonance Imaging Investigation of Basic and Moral Emotions* 22 J. OF NEUROSCIENCE 2730 (2002).

78. Jorge Moll *et al.*, *Functional Networks in Emotional Moral and Nonmoral Social Judgments* 16 NEUROIMAGE 696 (2002).

80. John Ledyard, *Public Goods in* THE HANDBOOK OF EXPERIMENTAL ECONOMICS (John Kagel and Alvin Roth eds., 1995).

socially optimal, rather than being in conflict with it (e.g., attempt to utilize personalization to obtain optimal cooperation). One hopes that further research in this area will examine how individuals personalize problems when the stakes to personalization are high.

It appears that moral reasoning is spread across many neural mechanisms[81] and how any particular problem is resolved appears to depend on the interaction of these mechanisms. It appears that any moral problem may be approached in a very different manner than another that may appear to be similar to our conscious minds. Therefore, an important line of future research is the attempt to understand the mechanisms by which problems are interpreted. In particular, how problems become perceived as social and how at other times problems can be interpreted as "simply" cognitive problems is one of the key questions for understanding the impact of law on behavior.

3. The Ultimatum Game

Many of the mechanisms used by the brain to deal with situations of cognitive conflict are illustrated in the ultimatum game. The neurological studies of how players in this game make decisions illustrate the mechanisms the brain uses to resolve the conflict between deciding whether to accept money (something generally desired) but, at the same time, also accepting what individuals are likely to view as an unfair bargain, or choosing to reject the money and enforce fairness. Similar mechanisms appear to be invoked whenever actions against the subject's immediate self-interest are chosen.

The ultimatum game is a two-player game in which the first player is given a stake and is told to divide it between the two players. After the first player has decided, the second player can then choose to accept the division, or to reject the division. If the second player rejects the division, both player get nothing. It is fairly common for the proposed division to be a 50/50 split. However, many time the first player will propose an unfair split (e.g., a 90/10 split). These latter splits are commonly rejected by the second player.[82]

One experiment on the neural mechanisms involve in the decision of the second players found that those players who rejected "unfair" offers

81. William Casebeer & Patricia Churchland, *The Neural Mechanisms of Moral Cognition: A mulitple- Aspect Approach to Moral Judgment and Decision-Making* 18 BIOLOGY AND PHILOSOPHY 169-194 (2003).

82. See CAMERER, *supra* note 42 at 8-12.

had much higher activation in the insula cortex, than those who accepted these offers. On the other hand, those who accepted these offers had higher activations in the dorsolateral prefrontal cortex. In both types of subjects the ACC was also significantly active.[83]

As the Sanfey et al. experiment shows, different brain regions (such as the insula and the dorsolateral prefrontal cortex) seem to embody different thought processes.[84] To some extent the ACC seems to moderate between these different regions depending on the situation. The neurological mechanism would appear to be more consistent with an ecological approach to be more consistent with an ecological approach to rationality. That is, individuals have a variety of mechanisms which adopt different approaches to problems. These approaches are then mediated by neural mechanisms, which are likely based on reward signaling. Therefore it should not come as surprise that individuals adopt seemingly "irrational" strategies to problems.

4. Ecological Rationality and Economics

Neurological research seems to indicate that the brain has different decision-making mechanisms which often lead to different decisions. This would not seem to be in accord with constructivist notions of rationality, which imply only one type of decision-making mechanism. Far from being problematic, this actually allows for a more ecological approach to decision-making, where different approaches are considered before the best solution is selected. This kind of decision-making works best when not every decision concerns life or death, but rather merely increases or decreases the likelihood of survival in some understandable way. If it is not possible to guess ahead of time what mode will necessarily yield the correct decision, it may be more productive to be able to generate a variety of different strategies and later determine which might work best.

In addition, ecological rationality is not necessarily antithetical to many of the prediction of traditional economics. A large portion of standard economic results are of type referred to as comparative static results, i.e. what will occur at equilibrium. Ecological rationality models indicate that the comparative statics of boundedly rational actors will often result in efficient outcomes, in fact possibly more efficient than standard economic theory predicts. It might very well be the case that these models

83. *See generally* Alan G. Sanfey et al., *The Neural Basis of Economic Decision-Making in the Ultimatum Game*, 300 SCI. 1755, 1755-57 (2003) (explaining the neural mechanisms involved with regard to inequality aversion).

84. *Id.*

depart from the predictions of constructivist rationality more in the dynamics of how the predicted equilibria arise, rather than in the characteristics of these equilbria.

When problems are particularly hard for individuals to solve, we often create institutions to deal with these problems. Consider for example the institutional forms of corporations or governments. These do not really exist as physical entities but are merely mechanisms which we have adopted in order to more easily account for certain actions given our cognitive mechanisms. These are examples of institutions that were developed by a relatively small number of individuals, but have now been adopted world-wide.

CONCLUSION

Current empirical research on decision-making indicates that there are important ways in which individuals do not conform to standard economic models. However, it would be a mistake to conclude from this that individuals should be labeled irrational. In fact, the research indicates that individuals who are behaving irrationally under constructivist notions of rationality are often behaving consistently with ecological notions of rationality. However, much more work needs to be done to understand the precise nature of human decision-making. This research need to consider context, both environmental and neurological, in which these decision are made.