QUANTIFYING LONG RUN AGRICULTURAL RISKS AND EVALUATING FARMER RESPONSES TO RISK

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A BEHAVIORAL APPROACH TO DECISION MAKING UNDER UNCERTAINTY: IMPLICATIONS AND LESSONS FOR EXPECTED UTILITY THEORY

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Abstract

Experimental investigations by psychologists have uncovered many instances where decision makers consistently and persistently violate the postulates of classical expected utility theory. Modification and weakening of the expected utility assumptions/axioms have resulted in the development of a class of non-expected utility models which can account for some but not all observed violations. Introduction of psychological decision dimensions has resulted in theories of choice designed to describe observed behavior (e.g., regret theory and portfolio theory) and in models that formalize such psychological variables as perceived riskiness or ambiguity. Finally, at a meta-theoretical level, realization of the nature and extent of human cognitive processing and memory limitations has resulted in a reevaluation of rationality or optimality criteria ("bounded rationality"), in process-model modifications of expected utility models (i.e., prospect theory), and in the study of cost-benefit tradeoffs of task-contingent judgment and decision strategies. This paper reviews recent work in these areas with an emphasis on implications for prescriptive theories for risky decision making.

Introduction

Some 35 years ago, psychologists started to discover that newly developed or formalized normative theories of judgment and choice (e.g., expected utility theory or Bayesian probability revision) often failed to describe human performance in risky choice situations (Edwards, 1954). The ensuing behavioral and cognitive study of human decision processes developed at least partially as a dialectic between behavioral data and normative theories. This approach of measuring observed performance against prescriptive models has been deplored by some (Lopes, 1986) but accepted as fruitful and productive by most (March, 1978). In this paper, three different approaches or solutions to the observed discrepancy between behavior and normative theory will be examined. It is argued that these approaches have different implications for prescriptive recommendations or decision aiding.

Development of Non-Expected Utility Models

Whereas the normative/prescriptive status of expected utility models has been firmly established since von Neumann and Morgenstern's (1947) classical axiomatization and subsequent axiomatic developments (e.g., Savage, 1954), the status of (S)EU theories as descriptive models has always been more controversial. Early conterexamples (Allais, 1953; Ellsberg, 1961) and more recent data (Keller, 1985) have largely questioned the empirical validity of the substitution principle of EU theory (alternatively known as either independence axiom or monotonicity assumption). Several good reviews of this literature exist and need not be repeated here. (See Machina, 1987; Sarin, 1989; M. Weber & Camerer, 1987).

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The response of economists and mathemeticians to this discrepancy between axioms and behavior has been to successively modify or weaken the axioms of EU theory (especially the substitution principle) until the resultant model described the observed behavior. The resulting models (e.g., Becker & Sarin, 1987; Chew, 1983; Fishburn, 1983; Karmarkar, 1978; Machina, 1982; Yaari, 1987) all relax the expectation principle of EU theory but differ in the constraining assumptions about the effects of probability on overall utility suggested in its stead. Luce and Narens (1985) and Luce (1989) take a slightly different approach (measurement theoretical rather than axiomatic) and explain both violations of the expectation principle as well as ambiguity effects with a theory that models uncertainty not in terms of risk, i.e., probabilities, but in terms of subjective decision weights that are not constrained by the laws of the probability calculus. Their dual-bilinear model is the most general type of interval-scaled utility model of which (S)EU theory and prospect theory are special, more restricted, cases.

While mathematically elegant, the theoretical and practical implications of these generalized utility models are somewhat unclear. Most of their originators are either silent or undecided on the prescriptive status of their models. If we assume that these models are intended to be purely descriptive, then they offer little assistance in decision aiding. That is, these models are silent on the question why and through what processes people's decision differ from those of EU theory and thus offer no guidance as to how to modify or correct people's perceptions or decision processes to bring them in line with the prescriptive model(s) of choice. If, on the other hand, these models are intended as prescriptive models (currently a minority opinion, but see, e.g., Machina, 1988), then the present generation of decision-analytic technology will have to undergo complicating modifications of several orders of magnitude.

Psychological Models of Risky Decision Making

Psychologists reacted differently to the observation of discrepancies between the prescriptions of EU theory and people's observed behavior when making risky decisions. Their approach to reconciliation has been to search for variables in addition to utility that influence people's preferences. The resulting models -- theories which incorporate anticipated regret or disappointment; portfolio theory which incorporates perceived risk and an ideal risk point; and prospect theory which incorporates a simplifying editing phase -- were designed to describe people's preferences as observed. In addition, by providing insight into people's actual behavior and the variables and processes governing it, these models give useful guidance for prescriptive decision analysis.

Regret Theory. Regret theory, independently developed by Bell (1982, 1983) and Loomes and Sugden (1982) incorporates the psychological variable of decision regret into the decision. It assumes that people maximize utility using a two-attribute utility function $u(x,y)$ over the attributes final assets, X, and foregone final assets, Y. This second attribute involves an intra-dimensional comparison of outcomes for every possible state of the world. In other words, $u(x,y)$ is defined as $u(x,y) = v(x) + f[v(x) - v(y)]$, where $v(x)$ reflects the value of the final assets, $v(x) - v(y)$ the level of decision regret (foregone assets), and f the tradeoff between the two (Bell, 1982).

Regret theory predicts many of the empirical choice phenomena described by Kahnemann and Tversky (1979) by making assumptions about the functional form of f. However, computation of the utility of alternatives according to regret theory quickly becomes complex when alternatives with several outcomes are involved and alternatives are independently realized. Thus regret theory has seen few empirical tests or applications but has had some conceptual impact with its assumption that decision makers will and maybe should incorporate possible post-decision regret into their original decisions. A key prediction of regret theory, not shared by any of its competitors, is that it should matter to a decision maker whether the result that a foregone choice alternative would have had is revealed or not (Bell, 1983).

Disappointment Theory. Similar to regret theory, disappointment theory (Bell, 1985) assumes that decision makers may be willing to trade off a certain measure economic payoff for psychological satisfaction. In regret theory, psychological satisfaction is operationalized as minimizing regret, i.e., the psychological reaction of having made a "wrong" decision in the sense that the outcome obtained under the chosen alternative is less desirable than that which would have been obtained if a different alternative had been chosen. In disappointment theory, psychological satisfaction comes from minimizing disappointment, i.e., the psychological reaction of obtaining an outcome that is less desirable than the outcome the decision maker was expecting to obtain given his or her choice.

Portfolio Theory. In the theories of risky choice discussed up to this point, the perceived riskiness of alternatives did not enter into decision making as an explicit variable. In expected utility theories and their extensions, risk is treated as epiphenomenal. Risk attitudes are merely descriptive labels for the shape of utility functions (risk aversion for concave functions, and risk seeking for convex functions). An early critic of this was Allais (1953) who argued that, even with the introduction of nonlinear utility functions, the expectation principle alone was insufficient to explain risky choice.

Coombs' (1975) portfolio theory postulates an explicit relationship between perceived riskiness, risk preference, and risky choice. Preference is a joint function of the expected value of choice alternatives and their perceived riskiness in relation to some ideal risk point (an individual difference variable). For each level of expected value, an optimal level of risk is assumed to exist. Choice among risky options is a compromise between maximizing expected value and optimizing level of risk. Portfolio theory thus accounts for qualitative characteristics of risky choice which cannot be explained by (S)EU theory (e.g., violations of the betweenness property, Coombs & Huang, (1976)).

Models of Perceived Risk. As all mean-risk models, applications of portfolio theory require an operational definition or measure of risk, and in this case, perceived riskiness. Psychological studies of perceived risk in the early 1970s demonstrated the inadequacy of common economic measures of risk, such as the variance of outcomes, in capturing people's intuition about risk. The development of a descriptively more appropriate measure of risk which captures both commonalities as well as individual differences in people's risk perceptions is reviewed in Luce and Weber (1986) and Weber (1988). Weber and Bottom (1989a,b) provide additional evidence for the good qualitative and quantitative fit of the conjoint expected risk model suggested by Luce and Weber (1986).

An additional benefit of considering perceived riskiness as an explicit variable in choice, is the opportunity it offers to unconfound the role of risk perception and of risk attitudes in determining risky decisions. In situations where losses or failures lead people to opt for objectively riskier choice alternatives (e.g., more bets on long-shots at the end of a racing day, McGlothlin (1956)), it is not clear what mediates such changes in behavior. On the one hand, previous failure or losses may affect people's risk attitudes, making them more willing to assume risk. On the other hand, such failures or losses may affect their perception of the relative riskiness of choice alternatives, so that their choices may change while their risk attitudes remain constant. For purposes of decision aiding (i.e., preventing people from such risk escalation) it is, of course, crucial to know whether changes in risk attitudes or changes in the perception or definition of risk mediate such changes in behavior.

Effects of Human Cognitive Processing and Memory Limitations

There are many ways in which to classify the large body of empirical results in the field of behavioral decision making (see reviews by Edwards, 1954, 1961; Rapoport & Wallsten, 1972; Slovic, Fischhoff, & Lichtenstein, 1977; Einhorn & Hogarth, 1981; Pitz & Sachs, 1984). The following discussion will focus on four topics: (i) Cognitive limitations of human information processing; (ii) Restructuring of the problem representation by the decision maker; (iii) Use of heuristics or simplifying processing algorithms; and (iv) Instability of preference structures.

Cognitive Limitations of Human Information Processing. Several limitation on human information processing capacity can be distinguished (Hogarth, 1987). Because humans cannot process the multitude of incoming information, perception of information is selective. Processing usually occurs in a sequential manner or using simple procedures designed to reduce mental effort which may not always produce optimal results. The final limitation is on memory capacity. Unlike computers which can access all stored information in its original form, much of human memory works by a (less reliable) process of reconstruction. The realization of human information acquisition and processing costs and constraints underlies Simon's advocacy of "bounded rationality" (March, 1978; Simon, 1955). The next two phenomena to be reviewed, namely restructuring of the problem space and the use of heuristics, can be seen as procedures people develop over time and with experience to deal with their cognitive limitations. While adaptive and "boundedly rational" in the context of intuitive judgments, these processing styles can become so habitual or automatic that they will be applied even in important and formal decision situations where they can lead to serious biases.

Restructuring of Problem Representation. One of the basic assumptions of the classical economic model of rational choice (e.g., expected utility theory) is the requirement that choice alternatives be evaluated in terms of their effects on final assets. That is, the outcomes of choice alternatives should be combined with current assets and that alternative should be selected which provides the most desirable final asset position. Continuously updating current asset levels and integrating those with the outcomes of every new choice set requires a significant amount of cognitive effort. Therefore it is perhaps not surprising that people do not encode outcome information in this way, but instead in terms of gains or losses from the status quo or some other reference point. This is one of the central assumptions of Kahneman and Tversky's (1979) prospect theory which (in conjunction with a value function that is concave for gains, convex for losses, and steeper for losses than for gains) accounts for a wide variety of decision behavior that no version of expected utility theory can explain. The reference point used to encode a particular outcome as a gain or a loss can be manipulated by normatively irrelevant changes in context or wording, often leading to reversals of preference between two choice alternatives. These "framing effects" are striking and robust, occur in natural environments, and for experts as well as naive decision makers (McNeil, Pauker, Sox, & Tversky, 1982; Tversky & Kahneman, 1981).

Use of Heuristics. The use of heuristics (i.e., simplified processing rules that provide the correct answer most but not all of the time) has been found extensively in people's judgments of the likelihood of uncertain events (Tversky & Kahneman, 1974). In making such judgments, people over time and experience learn certain regularities in their environment. One such regularity is the fact that similarity is an index of class membership. Estimating the probability that object A belongs to class B on the basis of A's similarity to B is an application of the representative heuristic. Another regularity is the fact that more probable events occur more frequently and thus produce more memories. Estimating the probability of an event by the ease with which instances or

occurrences can be brought to mind is an example of the availability heuristic. These heuristics often lead to biased probability judgments because representativeness and availability are diagnostic but not exclusive determinants of probability. Use of the representative heuristic, for example, can lead to the neglect of baserates or prior probabilities. Use of the availability heuristic can lead to overestimation of easily imagined events and to the perception of illusory correlations.
Just as for framing effects, demonstrations of availability or representativeness biases have been reported both in the lab and in natural environments (e.g., Dube-Rioux and Russo, 1989).

Instability of Preference Structures. Another assumption of the classical economic model of rational choice is that of procedure invariance, especially with respect to the elicitation of a decision maker's preference space. That is, his or her preference order for a set of outcomes or alternatives should not depend on the particular method by which it is assessed. However, empirical evidence is beginning to accumulate which suggests that people often do not have stable and well-defined preferences (Fischhoff, Slovic, & Lichtenstein, 1980; Grether & Plott, 1979; Shafer & Tversky, 1985). In such situations, judged or revealed preference is not a reflection of the "true" internal preference structure, but is actually constructed during the elicitation process. Different elicitation procedures highlight different aspects of decision alternatives and may suggest different heuristics or different decision frames, thus giving rise to inconsistent responses (Tversky, Sattath, & Slovic, 1988).

Prescriptive Models and Techniques -- Decision Aiding

Prescriptive techniques (e.g., decision trees or linear programming) employed in decision aiding are based on normative theories of decision making. Psychological research has raised profound questions about the validity of these normative theories, hence calling "... the foundations of choice theory and decision analysis into question" (Tversky, Sattath, & Slovic, 1988). In particular, a decision aid is developed based on three normative assumptions: Given a decision problem, the decision maker should (a) be able to articulate his preference structure in order to evaluate relative merits of alternative solutions or choice alternatives, (b) be able to assess the probabilities of uncertain events using his or her problem domain knowledge, and (c) select the choice alternative that maximizes (subjective) expected utility. The bad news is that, as reviewed in the previous section, empirical studies of decision making have uncovered human heuristics, biases, and limitation that violate every one of these normative assumption.

Experimental results demonstrating systematic and persistent deviations of human behavior from normative standards have created much controversy (Schoemaker, 1982). From the prescriptive perspective the results are, at one extreme, sharply rejected as "... unwarranted generalizations from unrepresentative experiments" (Phillips, 1983, p. 537), and, at the other extreme, simply ignored (Keeney, 1982). For practioners developing decision aids, there seem to be two relevant points of view. One is that human cognitive limitations and biases, even if they exist outside of the laboratory, do not have any significant effect on the quality of decisions (Christensen-Szalanski, 1986). Yet, there seems to be little empirical evidence for this position, and the instances cited seem to refer to circumstances with a flat criterion maximum.

In contrast, the other viewpoint acknowledges potential errors and inconsistencies in decision makers and advises the analyst to deal with them prudently (von Winterfeldt & Edwards, 1986; Watson & Buede, 1987). For example, von Winterfeldt and Edwards view the decision maker's errors and inconsistencies as "... an asset rather than a liability [which] forces both the analyst and the client to think hard and provides them with an opportunity to gain insights into the decision problem" (1986, p. 385). Furthermore, they perceive some non-normative behavior as "creative stress" between the demands of a decision model and human intuition.

This viewpoint seems overly idealistic. It is neither fair nor realistic to expect an analyst to have the expertise and experience that Edwards and von Winterfeldt have in dealing with such conflicting situations without the support of some operational rules from a sound theory. Indeed, decision analysts in practice may be tempted to perform blatantly erroneous analyses in order to release the "creative stress" through oversimplistic approaches rather than "thinking hard." After all, practioners, despite their professional training and ethics, operate under their own limitations, biases, and utilities. It has been suggested that decision analysis is a clinical skill even under normal circumstances and one that should only be practiced after an internship with an expert (Brown, Kahr, & Peterson, 1974). Moreover, even if decision makers and analysts judiciously and prudently think hard, how can they detect the violation of, for example, the independence axiom of EU? If they do, how should they proceed? These, and a host of other questions necessitate the development of sound theoretical principles and methodological tools.

Implications of non-normative behavior

What then is the impact of non-normative behavior of a decision maker on decision aiding tools? A prescriptive approach to decision aiding goes through four principal stages: (i) problem formulation, (ii) solution, (iii) post-solution analysis (e.g., sensitivity analysis, reiteration, etc.), and (iv) implementation (i.e., actual execution of the solution). The formulation stage takes into consideration the nature of the problem and may lead to a representation of the problem in form of a decision tree or a linear program. Formulation can further be subdivided into the following three components: identifying the variables, options, parameters, and objectives; establishing the relationships between them (e.g., constraints in a linear program, consequences of options and their probabilities in a decision tree); and determining the preference (value) structure of the decision maker (i.e., the objective function, composed of a multiattribute utility function, to be maximized). Potentially, all of these steps in the prescriptive procedure can be affected by non-normative behavior. Elicitation of probabilities and utility assessment can, for example, be affected by certainty and framing effects. The certainty effect, in turn, violates the independence principle and hence the solution procedure of folding back the decision tree. This suggests two, complementary, approaches to solving the problem: the first one is to change the non-normative behavior and the second to modify the decision tools.

Rectifying non-normative behavior

The key factors in rectifying any non-normative behavior are (a) to anticipate the occurrence of such behavior, (b) to detect it, and (c) to make it explicit to the decision maker and others concerned. In order to appreciate the need for such procedures, one should recognize that an individual operating within an organizational setting cannot knowingly violate rules that are normative from the organizational perspective. For example (adapted from Tversky & Kahneman, 1981), a public health official may choose an immunization program that guarantees to save a particular number of lives in a population at risk over another program that offers some less than certain chance at saving an even larger number of lives in this population when the effects of the two immunization programs are presented in terms of lives saved, but may reverse his or her preference when the identical programs are described in terms of lives lost. From a public policy perspective, such inconsistency is unacceptable, and the only criterion to decide between the two immunization programs (all other things being equal) probably should be the expected number of lifes saved (i.e., the final asset position) which is identical under the two formulations. In their personal choices, decision makers may or may not want to represent alternatives in terms of their final asset position. However, in dealing with an organization's assets, decision makers probably should not have this latitude. In such situations, decision makers need to be reminded and encouraged to use a final results perspective. (Machiavellian decision analysts, aware of the power and mechanisms of "framing effects," can of course also employ decision frames in such a way that the public official or employee will make decisions in line with the policies of his or her organization.)

Cases where a decision maker insists on violating a normative principle knowingly raise the question of whether some important factor has been overlooked in the formulation of the problem. For example, a quality control engineer may find a particular part out of tolerance after the machining operation. The part may not necessarily be defective, but its defectiveness will be revealed only in the actual assembly process. Should the engineer accept the part and send it to the assembly line, taking the risk of an expensive revelation of the defect should one exist, or should she scrap the part? The normative answer would, of course, depend on the probability that a part registering out of tolerance is actually defective as well as on the cost of revealing the defect on the assembly line. However, the quality control engineer will most likely insist on scrapping the part even in situations where this decision has smaller expected utility than the other alternative. Situations where a retained part turns out to be defective are not only costly, but also constitute an identifiable and visible error on her part. Regret theory or some other multi-attribute representation that incorporates the cost of making a wrong decision or accountability could perhaps explain the decision of the quality control engineer. However, the goal may not be to predict or justify her decision by some formal model, but to guide the decisions towards some organizationally acceptable standards. Hence, a decision tool should, in addition to traditionally desired qualities, be able to remove any contextual biasing effects or to make them explicitly known to all concerned if the decision maker insists on his or her non-normative behavior. The latter case may, in fact, reveal a factor not considered in the original problem formulation which is of sufficient normative appeal to be included in future versions of the prescriptive model.

Similar arguments can be made for decision tools designed to elicit probability judgments. Awareness, understanding, and anticipation of the heuristics used to make such judgments and the conditions under which these heuristics will lead to biases, can actually help prevent their occurrence by suggesting effective countermeasures. Thus it has been shown, for example, that base rate neglect as a function of use of the representative heuristic can be significantly reduced by explicitly emphasizing the causal connections between events (Bar-Hillel, 1980).

Summary and Conclusions

The first purpose of this article was to provide a representative if not exhaustive list of risky choice behaviors that do not conform to the prescription of traditional (S)EU theory. Secondly, it provided an overview and classification of different descriptive models that have been developed to account for such deviations from normative behavior.

Relaxing the violated axioms of utility theory with less restricting conditions, i.e., the class of non-expected utility models, may be of great measurement-theoretical interest, but needs to establish a more widely accepted rationale for use as prescriptive tools. Furthermore, these theories provide no account of how violations of rationality conditions come about and hence no advice about how to avoid them.

The second group of models, multiattribute choice theories which incorporate such psychological variables as expected regret or disappointment or perceived riskiness into the optimization function, and thus represent a broadening of the problem frame which allows one to account descriptively for a wider variety of choice phenomena. Prescriptively, such models that trade off psychological comfort for economic payoffs may be appropriate for decisions whose outcomes affect solely the decision maker. In cases where the decision maker acts as an agent for the interests of other individuals or groups, the prescriptive validity of trading the economic payoffs of other people for the decision makers personal psychological comfort with the decision becomes questionable.

Finally, the last class of models surveyed, namely cognitive and behavioral information processing models, seem best able to offer practical guidelines for prescriptive decision aiding. As process models about the origins and mechanisms of cognitive biases and suboptimal decision rules, these theories also provide suggestions on how such behavior can be avoided or corrected.

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