Should Agricultural and Resource Economists Care that the Subjective Expected Utility Hypothesis is False?

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Abstract: This paper argues that the subjective expected utility (SEU) model has serious limitations in both positive and normative analysis. In addition to experimental evidence, I discuss examples where alternatives to the SEU provide a richer framework for the study of problems of choice under uncertainty. Opportunities for improved positive and normative analysis using non-SEU models are discussed.

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Introduction

The expected utility (EU) model of von Neumann and Morgenstern (1944) and the subjective expected utility model (SEU) of Savage (1954) have been the central frameworks for the analysis of choice under risk and uncertainty. These models have been successful not only because of their compelling axiomatic foundations and ability to describe economic choices, but also for the purely practical reason that their mathematical structure facilitates analysis.

Despite obvious strengths, however, the EU and SEU models have some serious weaknesses. Most critically, studies using both experimental and "real world" evidence have repeatedly found that individuals often do *not* behave in a manner consistent with these models. The paradoxical choices identified by Allais and Ellsberg are pervasive. If the EU models are not representative of the way that private individuals and policy makers make decisions, then it is important for economists to ask whether -- or at least in what circumstances -- our basic paradigm should be retained. The purpose of this paper will be to ask whether the failings of the EU models are relevant to applied economic analysis. I suggest that they are.

I begin by briefly presenting the EU and SEU models and discussing the systematic and overwhelming evidence of violations of the models' predictions. I then present two of the leading alternative models that are vying to replace the EU models and show that these alternatives can be fruitfully used in applied settings. I close with suggestions of how applied economic analysis, both positive and normative, should proceed in light of the evidence.

Overview of the EU and SEU models and the Allais and Ellsberg paradoxes

The EU and SEU models both hold that choices are made so as to maximize the expected value of an individual's utility, say,

$$V(\{\mathbf{x},\mathbf{p}\}) = \sum_{i=1}^{n} U(x_i)p_i \tag{1}$$

where $U(\cdot)$ is the individual's utility function, $\mathbf{x}_i$ is a vector of goods in the i^{th} state of the world and p_i is the probability that the i^{th} state of the world will actually occur. The EU formulation of von Neumann and Morgenstern (1944) assumes that the probability vector **p** is known *a priori* by the decision maker. The SEU formulation of Savage (1954) makes no assumptions about the knowledge of **p**, but instead shows that if a decision maker abides by a set of axioms she will behave *as if* she has a set of personal or subjective probabilities. While it does not follow from the axioms of either Savage or von Neumann and Morgenstern, agents are typically assumed to be risk averse, i.e., that the utility function is concave.

Violations of the EU and SEU models have been identified by many researchers including Kahneman and Tversky (1979), Loomes and Sugden (1979) and others.[2] In this paper I focus on two problems -- the Allais and Ellsberg paradoxes. I give these two problems particular attention because it is where the largest body of research has been conducted and where the possibilities for improving applied economic analysis seem to be the greatest.

Due to the independence axiom, both EU and SEU hold that an individual's wellbeing is linear in the probabilities. In effect, they assume that individuals do not have preferences over probabilities themselves, only over the outcomes that result. The limitation of this structure is explained by Yaari (1987):

> In expected utility theory, the agent's attitude towards risk and the agent's attitude towards wealth are forever bonded together. [However,] at the level of fundamental principles, risk aversion and diminishing marginal utility of wealth, which are synonymous under expected utility theory, are horses of different colors. (p. 95)

In a series of pathbreaking experiments, Allais (1953) showed that a basic axiomatic assumption of the EU models -- that utility is linear in the probabilities -- is false. Accordingly, the fact that decision makers frequently violate the independence axiom is known as Allais' (1953) paradox.

The second problem that I wish to highlight is that there is no room in the EU models for true *ambiguity*[3] or uncertainty about the probabilities in (1). The Bayesian approach implicit in the EU models assumes that any uncertainty over the probability distribution, **p**, can be expressed as second-order probability distributions which can be used to define a final probability distribution, say **p**'. Experimental evidence has found that decisions are not always made in this manner. Camerer and Weber (1992 p. 326) describe the problem here as follows: Suppose you flip a coin 1000 times and get 500 heads. Then take a second coin and flip it twice yielding one head and one tail.

> Many people … prefer to bet on the first coin, because they are more confident or certain that the first coin is fair. Ambiguity about probability creates a kind of risk in betting on the second coin – the risk of having the wrong belief. SEU effectively requires that decision makers be indifferent towards such a risk.

The fact that individuals systematically show a preference for well-defined probabilities was first shown experimentally by Ellsberg (1961) but the notion of ambiguity as distinct from risk is closely related to Knight (1921) and Shackle (1952, 1969).

Experimental evidence of violations of EU and SEU

The problems discussed above have led to an entire literature of experimental economics concerned with evaluating when and how the EU models fail and succeed. I will not attempt even a superficial review of the experimental findings as thorough reviews are available elsewhere.[4] Suffice it to say that experimental economists have shown that they are quite adept at developing situations that will cause people to violate the EU models. Experiments that follow from the work of Allais have identified a number of important tendencies. The EU model tends predict behavior quite well when the decision problem involves probabilities in the "mid-range"; however, "nonlinear weighting of small probabilities is empirically important in explaining choice behavior" (Harless and Camerer 1994, p. 1285). The EU model is also not very good at explaining choices when individuals are faced with losses as well as gains (Quiggin 1993 p. 140).

Two trends are evident in experimental work focusing on ambiguity: the distinction between ambiguity and risk and the degree of ambiguity aversion. In reviewing the literature, Camerer, Colin and Weber (1992) find no correlation between risk attitudes and ambiguity attitudes and "substantial premiums to avoid ambiguity – around 10% to 20% of expected value or expected probability" (p. 340). Ambiguity, therefore, is found to be separate from risk and economically important.

The experimental results, therefore, provide overwhelming support for the proposition that the EU models can not describe all behavior of economic agents. Where we go from here, however, is not transparent. There have been two principal responses to this experimental evidence. The first is to treat the results as "phenomena" instead of "paradoxes" (Howard 1992) which require no more of a re-evaluation of the EU models than people's confusion by optical illusions require us to invent new notions of distance (Varian 1992, p. 194). The second response has been to look for alternatives to the EU models that can explain the behavioral patterns found in the experimental work, yet retain much of the appeal of the EU models.

Alternatives to the EU models

It seems that for every pattern that has been observed in the experimental data a theoretical model has been developed that would explain the results. For many of these models axioms have been identified that, in some sense, rationalize choices that follow from the model. In this section I present two models which seem particularly promising. Both retain much of the structure of the EU framework, yet are able to explain more of the experimental evidence.[5]

The RDEU model. The rank dependent expected utility model (RDEU) was originally proposed by Quiggin (1982), has also been explored by Yaari (1984) and is closely related to the models of Schmeidler (1989) Gilboa (1987). Developed to explain the Allais paradox, the RDEU model allows probabilities to enter nonlinearly into an individual's objective function. Because it preserves first-

order stochastic dominance, Machina (1994, p. 1237) calls RDEU the first "successful" model with nonlinear probabilities.

The RDEU model (presented in depth in Quiggin 1993), is typically applied in problems with well-defined probabilities.[6] Following Quiggin (1993), the RDEU model is most easily presented in terms of a lottery in which there are n possible outcomes, x_i; i=1,…,n, which are ordered from worst (i=1) to best (i=n). Each outcome x_i has a known probability p_i and the probability of achieving an outcome of x_i or worse is written $F(x_i) = \sum_{j=1}^{i} p_j$ The RDEU functional is of the form:

$$V(\{\mathbf{x},\mathbf{p}\}) = \sum_{i=1}^{n} U(x_i) h_i(\mathbf{p}) \tag{2}$$

where,

$$h_i(\mathbf{p}) = q(F(x_i)) - q(F(x_{i-1})). \tag{3}$$

It is assumed that the function q is monotonic with $q(0)=0$ and $q(1)=1$.[7] Note that $h_i(\mathbf{p})$ is not a simple transformation of p_i, but a function of the cumulative distribution.[8] The transformation function $q(\cdot)$ is where the RDEU model generalizes EU analysis. If $q(p)=p$, then the RDEU is equivalent to EU. Quiggin (1982) proposed an *S*-shaped function that was generalized by Tversky and Kahneman (1990) to take the form $q(p) = p^g \Big/ \left(p^g (1-p)^g\right)^{1/g}$. Others (e.g., Chew, Karni and Safra (1987)) have assumed that q would be concave which is a natural extension of the notion of risk aversion to the RDEU model. While these representations add significant nonlinear complexity to the specification of an individual's preferences, they typically involve only one parameter more than the EU model.

RDEU can explain much of the evidence that has been generated in experimental studies.[9] Nonetheless, because of its close similarities to the EU model, many of the standard results can be directly applied even if decision makers are to the RDEU maximizers (e.g., Quiggin 1991).

Maxmin Expected Utility. The second model that I will highlight here is the Maxmin Expected Utility (MMEU) model due to Gilboa and Schmeidler (1989).[10] MMEU, which was developed to address the Ellsberg paradox, formalizes the criterion of Wald (1950) and is closely related to work of Arrow and Hurwicz (1972). Like the SEU model, MMEU does not make immediate assumptions of probabilities but assumes that individuals derive probabilities based on their personal experience. The MMEU differs from the SEU in the presentation of the independence axiom and through the introduction of an axiom of uncertainty aversion. As a result of these subtle differences, while the SEU finds that decision makers will act as if they possess a unique probability distribution over the set of outcomes, **p**, the MMEU model finds that individuals may make choices based on a non-unique set of probability distributions, say, **C**={**p**}. For example, in a two-outcome problem, the MMEU maximizer may believe that the probability of success is between 30 and 40 percent, but he or she is unable to place a second-order probability ranking over this range of probabilities. A decision maker following the MMEU axioms, including uncertainty aversion, would maximize the minimum expected utility. In other words, if utility is a function of choices **z** and the state *x* with the set of probabilities **C**, then **z** is preferred to **z'** if

$$\min_{\mathbf{p}\in\mathbf{C}} E_{\mathbf{p}} U(\mathbf{z}, x) \geq \min_{\mathbf{p}\in\mathbf{C}} E_{\mathbf{p}} U(\mathbf{z}', x). \tag{4}$$

where $E_{\mathbf{p}}$ is the expectation based on the probability distribution $\mathbf{p}\in\mathbf{C}$. If **C** is composed of a single distribution, then the MMEU criterion coincides with SEU theory. At the other extreme, if the decision maker is entirely ignorant of the possible probability distributions, then the criterion coincides Wald's maximin criterion.

The RDEU and MMEU models for choice under uncertainty are leading contenders in the search for improved frameworks for choice under uncertainty. Still, Harless and Camerer (1994) conclude that there are still no clear winners -- some theories explain little behavior while others cannot discriminate between behavior consistent with the model and purely random choices. While

the search for improved models will continue, non-EU models are already being found useful in applied economic analysis and applications in the area of agricultural and resource economics are abundant.

Non-experimental applications of non-EU models

While much of the impetus for non-EU models has come from the experimental work of Allais and Ellsberg, many "real-world" phenomena have also lead researchers to seek alternatives to the EU frameworks. Behavior inconsistent with the EU has been found in problems including insurance choices (Kunreuther et al.1977, Hogarth and Kunreuther 1985), tax evasion (Bernasconi 1998), criminal behavior (Neilson and Winter 1997), financial markets (Dow and Werlang 1992; Mehra and Prescott 1985), and consumer willingness to partake in precautionary saving (Leland 1968). In each instance, reasonable explanations for apparently *irrational* choices have been developed by slightly relaxing the EU axioms.

As an example, consider the problem of insurance choices in the EU framework. Quiggin (1993 pp. 80-81) shows that it would never be EU-optimal to purchase full insurance if rates are actuarially unfair and the utility function is smooth. Intuitively, this is because, in the neighborhood of certainty, the EU preferences are risk neutral so that at the limit, agents would prefer to bear some portion of the risk. While alternative explanations for observed full-insurance in the market are possible, Segal and Spivak (1990) show that RDEU preferences can explain the purchase of complete insurance. Quiggin (1993) summarizes the result: "even if first order risk aversion [curvature of the utility function] is too weak to induce the purchase of insurance, second order risk aversion [curvature of q] may lead to a preference for insurance" (p. 81). The ability to discriminate between preferences over the outcomes and preferences over the probabilities in the problem itself, therefore, can prove useful in understanding observed behavior.

While many of the inconsistencies between the EU models and observed behavior can be explained using transactions costs, imperfect information or simply errors in choice, the alternative provided by the non-EU models should be taken seriously. I turn now to explore some areas in agricultural and resource economics that might benefit from this alternative perspective.

The role for non-SEU models in agricultural and resource economics

The standard, if generally unstated, response of economists to evidence against SEU is that while violations in experimental settings might be common, EU models are satisfactory for purposes of applied analysis. In the previous section, I have mentioned a number of problems in which non-EU models have been applied; these models are beginning to find a significant niche. In this section I show that in both positive (i.e., descriptive) and normative (i.e., prescriptive) analysis, agricultural and resource economics could gain significantly from use and appreciation of non-EU frameworks.

Applications in positive economic analysis. If real preferences are not consistent with the EU models then it seems obvious that there would be some room for improving the prediction of our models of economic choice. The question is when such improvements warrant the costs.

The experimental evidence offers some guidelines as to circumstances in which non-EU models will likely be fruitful. First, when decision makers face small probabilities with large consequences, evidence suggests that they may not be EU maximizers. Problems that seem likely to benefit from non-EU analysis, therefore, include insurance and environmental safety. Second, it is clear that risk is not the same as ambiguity; when probability distributions are highly uncertain, we can expect to find significant divergences from the choices predicted by the SEU model. Choices where information is limited such as technology adoption or the valuation of environmental improvements, therefore, might also benefit from the alternative perspective.

Consider the problem of technology adoption. It seems likely that individuals choosing to whether to invest in a new technology are in a situation of ambiguity: decision makers may not be

able to formulate a precise probability distribution over the possible outcomes. Evidence of this can be found in the Saha, Love and Schwart's (1994) study of Texas dairy producers' plans to introduce bST (bovine somatotropin). Using a survey conducted in 1992, a year before it was available for commercial use, they found that, among the farmers who had heard of bST, only 52% planned to introduce the hormone. As the authors point out, increased risk aversion alone cannot explain why some farmers would implement at positive levels while others would choose not to introduce. Within the SEU framework, farmers that choose to adopt must expect higher returns. However, it can be shown that aversion to ambiguity (Dow and Werlang 1992) or uncertainty (Quiggin 1993) might lead two individuals with identical expectations to differ over their decision whether or not to adopt.

Understanding the role of ambiguity might also be important in the development of appropriate policy. Smith, Desvousges and Payne (1991) found that the framing of information about radon was a significant determinant in the choices made. Individuals that received a clear and straightforward guideline for "safety" were more likely to adopt mitigating strategies than those who received more complete information about the risks of radon. This supports the hypothesis that ambiguity is an important factor in these choices. Hence, an appreciation of the role of ambiguity might lead to more effective policies.

It seems unlikely that non-EU models will soon become the standard for positive analysis. The SEU is quite flexible and virtually all market choices can be seen as consistent with the SEU hypothesis for the appropriate utility function and subjective probabilities or by introducing other explanations such transactions costs. Non-EU models, however, offer a parsimonious structure in which to describe observed behavior. Moreover, generalizations may not be so costly. For example, the basic theory of the producer under uncertainty seems largely intact under the RDEU model (Quiggin 1993), and other comparative static results generalize immediately to the RDEU (Quiggin 1991). As we continue to study choice under uncertainty, it will be useful to recognize that EU and

SEU are special cases of more general models of choice and, to the extent possible, it should be stated where generalization is or is not possible.

Applications in normative economic analysis. The EU models are applied in many normative contexts. Whether we are referring to a farmer, a consumer or society as a whole, it is commonly held that the "optimal" policy is that which maximizes the expected net benefits.

There are two fundamental problems with this approach. First, the *true* underlying probability distributions that should be used to take the expectations are usually either unknown or unknowable (Manski 1996). As such, most, if not all, policy problems are really cases of ambiguity and should at least be interpreted within the SEU framework. However, for the analyst to arrive at a policy recommendation he or she must possess a probability distribution. This leads to the common practice of establishing a probability distribution through the use of auxiliary assumptions. The approach of Nordhaus (1994) is representative. In his analysis of global warming policies, Nordhaus makes use of a survey of experts. He then builds a probability distribution over possible outcomes "assuming that the estimates of the cost function [by the surveyed panel] represent independent draws from the true distribution" (p. 151). However, there is no empirical reason to believe that experts are random draws from a true distribution (Woodward and Bishop 1997). Making such an assumption goes beyond the analyst's role, even from the perspective of the SEU. This is particularly problematic if one accepts that society's preferences may be of the MMEU kind.

The second problem with the standard EU approach is that, given that individuals do not abide by the SEU axioms of rationality, there is some question about whether economists should be in the business of defining what is meant by rationality. Economists would be typically be quite reluctant to judge one person's utility function (i.e., the ordering of his or her choices) as wrong. However, we have been quite willing to implicitly judge that individuals are *irrational* in the sense that they do not abide by Savage's axioms.[11] For example, in evaluating the EPA's superfund

policies, Viscusi, Hamilton and Dockins (1997) state, "Conservatism in risk regulation is analogous to ambiguity aversion bias, which is one form of *irrationality* of choice under uncertainty" (p. 189, emphasis added). The rationality or irrationality of choices, however, is a function only of the axioms that one adopts. While EU and SEU preferences are reasonable, economists should be more circumspect in passing judgment over what is and what is not *rational*. This is not to say that we should withhold all judgment on policies regardless of how conservative; Viscusi and his colleagues provide objective reasons why extreme conservatism can make for bad policy (see also Viscusi 1996). Nonetheless, policies should not be deemed bad or irrational simply because policy makers seem to be acting in a manner that is inconsistent with EU models.

Summary and conclusions

There were two fundamental points in this paper. The first is to highlight the evidence that decision makers frequently violate the axioms of the expected utility and subjective expected utility hypotheses. The evidence is clear -- the SEU hypothesis is not a complete model of how choices are made by humans. This then begs the question, "Should we care?" Here consensus has not yet been reached but it appears to be growing (Fishburn 1988). For positive analysis, alternatives to the EU models are being applied to a variety of problems to explain market choices. Agricultural and resource economists should begin to pay attention to these alternative choice models and explore the extent to which they improve our analysis. Not until the frameworks are suitably tested will a winner or winners emerge from the pack of models.

In normative analysis, I believe that we have much to learn from the non-EU models. Evidence points to a role for instruction and a role for directly addressing ambiguity. For policies in the environmental arena, the problem of ambiguity is central and our normative analysis should appreciate its importance. As Faucheux and Froger (1995, p. 31) point out, "global environmental problems have no historical precedents. … This means that the information on which decisions are

made is most often a non-probabilistic kind." As economists enter into these policy debates, therefore, we should keep in mind that our recommendations are only as correct as the axiomatic foundation of the underlying decision model (Woodward and Bishop 1997).

Daniel Bernoulli's solved the St. Petersburg paradox by inventing expected utility. Today we look with puzzlement at the response of Daniel's cousin Nicholas Bernoulli who continued to look in vain for a single fair price for the game based on its expected value. After retelling this story, Harless, and Camerer (1994) ask, "Might future economists find it [equally] peculiar that twentieth century economists held firmly to EU in the face of the Allais paradox and other violations?" (p. 1284). Proven alternatives to the EU models are available. Agricultural and resource economists should begin to pay attention to these models to discover how they will improve our analysis.

Endnotes

[1] Discussions with Antony Scott and his extensive comments of and were extremely valuable in the preparation of this paper.

[2] See Anand (1993) for a review.

[3] What I am calling ambiguity here is sometimes referred to as uncertainty or Knightian Uncertainty (after Frank Knight, 1921) as opposed to risk.

[4] Anand (1993) provides a good overview of the experimental work, breaking it down significantly more than I have here. Harless and Camerer (1994) survey and synthesize the experimental evidence related to Allais-type behavior and Camerer and Weber (1992) review the studies that have addressed Ellsberg-type behavior and ambiguity.

[5] Readers are referred to Kelsey and Quiggin (1992), Camerer and Weber (1992), Quiggin (1993) and Harless and Camerer (1994) for much broader reviews of the literature and perspectives on the relative utility of different models.

[6] The RDEU model has, however, also been applied to conditions of ambiguity by Segal (1987), who uses the RDEU to apply to second-order probability distributions. Similarly, the model is quite similar to the models of Schmeidler (1989) and Gilboa (1987) that axiomatize a model that uses Choquet integration when decision makers are faced with ambiguity.

[7] The assumption that $q(1)=1$ is relaxed by Dow and Werlang (1992) to address the issue of ambiguity.

[8] This property is what guarantees that the stochastic dominance is satisfied and is roughly equivalent to Choquet integration that has been axiomatically derived by Schmeidler (1989).

[9] Harless and Camerer (1994) point out, however, that compared to other models, the RDEU framework is not very discriminating so that tests of the model have relatively low power.

[10] A similar framework has also been proposed by Kelsey (1993).

[11] The SEU model has been bolstered by de Finetti's (1974, chapter 3) result that unless an agent used SEU model, he or she could be systematically robbed of his or her money via a process known as a Dutch book. However, Machina (1989) showed that these arguments are not applicable to models that address the Allais paradox and Kelsey (1995) has questioned the practical relevance of these concerns with regard to MMEU since the developer of such a lottery would require detailed information about the decision maker.

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