

### *Alternatives to standard decision theory for decisions under ambiguity*

As an alternative to the standard approach, Ellsberg (2001, pp.190-199) suggests the use the restricted Bayes/Hurwicz criterion. Its essential features can be summarized as follows. Decisions are based on maximization over possible acts of an index containing a parameter,  $\rho$ , which varies between 0 and 1, depending upon the degree of ambiguity. If  $\rho = 1$ , the decision-maker maximizes expected utility. If  $\rho = 0$ , corresponding to the highest level of ambiguity (complete ignorance of relevant probabilities), the decision-maker acts to maximize a weighted average of the maximum and minimum expected utilities for each act. The standard Bayesian decision model assumes that *a priori* uncertainty is represented by a single probability distribution, whereas this approach allows for multiple prior probability distributions. The relative weight given to maximum versus minimum utilities is determined by a parameter  $\alpha$ , which also varies between 0 and 1. When  $\alpha = 0$  and  $\rho = 0$ , it reduces to Wald's criterion (Ellsberg 2001, p.159), also known as the minimax principle, in which the decisionmaker acts to maximize the minimum payoff – in other words, choosing the least disadvantageous of the worst case scenarios.

Gilboa and Schmeidler (1989) developed an axiomatic foundation for decision based on maxmin expected utility (MEU), encompassing application of Wald's or related criteria. This approach differs substantially from the standard approach to maximizing expected utility (e.g., von Neumann and Morgenstern 1944), which assumes an unambiguous assignment of probabilities to possible states of the world (i.e., a unique prior distribution). The MEU approach encompasses ambiguity by allowing multiple prior distributions. Gollier (2001) criticizes this approach as pathologically risk-averse, leading to the stifling of innovation. It can be viewed as an extremely pessimistic approach to ambiguity which decisions only considers the worst plausible outcomes. However, ambiguous gambles can have favorable outcomes as well, which may also influence the decision-maker (Ellsberg 2001, p.206). This can be accounted for by use of the more general  $\alpha$ -MEU decision criterion, which weighs both worst-case and best-case outcomes (Ghirardato et al. 2004, Basili and Zappia 2010).

Schmeidler (1989) developed an alternative formulation, called Choquet expected utility (CEU), in which a single prior distribution is assumed, but probabilities are treated as non-additive. In standard probability calculus, an event,  $X$ , and its complement,  $X^c$ , are assumed to be mutually exclusive and exhaustive of all possibilities, so  $p(X) + p(X^c) = 1$ . In situations characterized by ambiguity regarding the assignment of probabilities to states of the world, a decision-maker may act as if the probabilities are sub-additive,  $p(X) + p(X^c) < 1$ . Based on the CEU approach, Basilli (2006) proposed a decision rule that takes account of both familiar events (for which probabilities can be unambiguously assigned) and unfamiliar, extreme events (which are characterized by ambiguity). The decision maker is assumed to exhibit optimism with regard to

low-probability windfall gains, pessimism with respect to low-probability catastrophic losses, and to be ambiguity-neutral with respect to familiar events (Basili 2006, Basili et al. 2008).

## LITERATURE CITED

Basili, M. 2006. A rational decision rule with extreme events. *Risk Analysis* 26:1721-1728.

Basili, M., A. Chateauneuf and F. Fontini. 2008. Precautionary principle as a rule of choice with optimism on windfall gains and pessimism on catastrophic losses. *Ecological Economics* 67:485-491.

Basili, M. and C. Zappia. 2010. Ambiguity and uncertainty in Ellsberg and Shackle. *Cambridge Journal of Economics* 34:449-474.

Ellsberg, D. 2001. *Risk, Ambiguity and Decision*. Garland Publishing, New York, NY, USA.

Ghirardato, P., F. Maccheroni and M. Marinacci. 2004. Differentiating ambiguity and ambiguity attitude. *Journal of Economic Theory* 118:133-173.

Gilboa, I. and D. Schmeidler. 1989. Maxmin expected utility with non-unique prior. *Journal of Mathematical Economics* 18:141-153.

Gollier, C. 2001. Should we beware of the Precautionary Principle? *Economic Policy* 33:301-327.

Schmeidler, D. 1989. Subjective probability and expected utility without additivity. *Econometrica* 57:571-587.

von Neumann, J. and O. Morgenstern. 1944. *Theory of Games and Economic Behavior*. Princeton University Press, Princeton, NJ, USA.