# Estimating conditional certainty equivalents using choice-experiment data

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## ABSTRACT

Expected-utility theory is embraced by some researchers because of its theoretical and empirical tractability, although empirical testing has exposed systematic behavioral inconsistencies that violate the axiom of independence in the theory. In particular, empirical evidence suggests that people making choices under uncertainty do not have a unique certainty equivalent when single-stage games are turned into multistage games, even if the likelihood of outcomes remains unchanged. We show analytically why a violation of the independence axiom is not inconsistent with random-utility models and data obtained from discrete-choice experiments. Results from a health care application are used to demonstrate the feasibility of estimating certainty-equivalent functions that can be used to test the validity of the independence axiom by modeling data from choice-experiment surveys. Further, we show how estimating certainty-equivalent functions with a simple survival model can also help us understand choice-experiment respondents' implicit perceptions of the likelihood of future outcomes. This information is particularly valuable when only part of the risk details in a multistage game can be provided to respondents who complete a discrete-choice experiment either because the actual risk levels are unknown or because risk levels vary significantly from person to person, neither one of which is uncommon in health applications.

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## 1. Introduction

For many years economists have used expected-utility theory (EUT) (Van Neumann and Morgenstern, 1947) as the normative framework linking choice and preferences for uncertain outcomes. Although EUT is still embraced by some researchers because of its simple and tractable structure, empirical testing of EUT has documented systematic behavioral inconsistencies that violate the axioms of this framework (Allais, 1953; Machina, 1982, 1989; Van Houtven et al., 2011). Most, although not all, such violations relate to the condition of independence that stems from the linearity assumption in EUT (Krantz et al., 1971).

The condition of independence or "sure-thing principle" (Savage, 1954) requires that the choice of one uncertain outcome over another is not affected by the timing of uncertainty or the sequence in which multiple uncertainties unravel, but by the overall level of uncertainty associated with an outcome. This is reflected in the fact that, under EUT, the joint likelihood of uncertain outcomes in multiple periods can be characterized simply as the product of their individual probabilities

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without affecting people's decisions.

The assumption of independence in EUT is what makes possible predicting choice in multistage games by back-solving the decision calculus. The ability to evaluate decisions independently from what occurs before or after a specific point in time is at the core of elicitation methods in health that rely on EUT. Such methods assume that values attached to chronic and non-chronic health states are independent of preceding and following health states (Bleichrodt and Quiggin, 1997).

Evidence against the independence axiom in choices among multistage games indicates that people's financial certainty equivalents for an outcome vary with the likelihood of outcomes of prior lotteries (Machina, 1982; Kahneman and Tversky, 1979; McCrimmon and Larsson, 1979). Although this evidence pertains to financial decisions, we extend the evaluation of independence in choices under uncertainty that involve interventions that affect health outcomes.

Behavioral inconsistencies with EUT identified in both the economics and psychology literature (Machina, 1982; Starmer, 2000; Lichtenstein and Slovic, 1971; Lindman, 1971) motivated the development non-expected-utility frameworks (NEUF). These frameworks relax the additively-linear structure in EUT associated with independence (Starmer, 2000). The most notable NEUF are rank-dependent utility (Quiggin, 1982), prospect theory, (Kanneman and Tversky, 1979) and more recently cumulative prospect theory (Tversky and Kahneman, 1992). All of these frameworks use decision weights to modify the effect of objective probabilities on the value function underlying choice, while maintaining desirable properties of EUT. NEUF have allowed the evaluation of responses to uncertainty in transportation (Koster and Verhoef, 2012), health (Bleichrodt et al., 2007; Van Houtven, et al., 2011) and environmental economics (Shaw and Woodward, 2008), among other areas.

Recently, Van Houtven, et al. (2011) proposed using random-utility models (RUMs) and choice experiments as a way to estimate linear and non-linear decision weights for the objective probabilities of uncertain health outcomes. They showed analytically and empirically how discrete-choice experiments can be used to obtain nonlinear decision weights that are consistent with NEUF.

In this study we look at yet another way RUMs and choice-experiment data can help identify behavioral inconsistencies with EUT, and directly test for the suitability of the independence assumption in multistage games. We show analytically why violations of independence are not inconsistent with RUMs, and use choice-experiment data to estimate a certainty-equivalent function to test the validity of independence in a health application.

Certainty-equivalent functions estimate the effect of outcome uncertainty on utility through changes in the acceptable certain or near-certain substitutes for the uncertain outcome. We evaluate medical interventions that extend life expectancy by protecting respondents from a specific ailment, but that also may truncate life expectancy by imposing an increased risk of a potentially fatal adverse event. Furthermore, we combine the estimated certainty-equivalent information with basic survival models to identify choice-experiment respondents' implicit risk perceptions. This information is particularly valuable when only part of the risk details in a multistage lottery can be provided to respondents who complete a discrete-choice experiment either because the actual risk levels are unknown or because risk levels vary significantly from person to person. These situations are not uncommon in the evaluation of new health technology for which clinical trial evidence is limited. In that context, certainty-equivalence information can be used to inform respondents' expectations of the ultimate benefits of treatments based on the information currently available to them.

## 2. Multistage games and (conditional) certainty equivalents

In economics, uncertain outcomes commonly are conceptualized as the end result of lotteries. The paths available to reach an outcome are defined as games. In multistage games a person chooses a path with multiple lotteries that can yield multiple outcomes at different points in time. Decision makers may act at certain points or passively allow nature to define the path through consecutive lotteries in the game. The former is a dynamic and the latter is a static multistage game. We are particularly concerned with the axiom of independence in EUT as it relates to static multistage games. Fig. 1 shows a standard decision-tree diagram for a static multistage game. See Fig. 1.
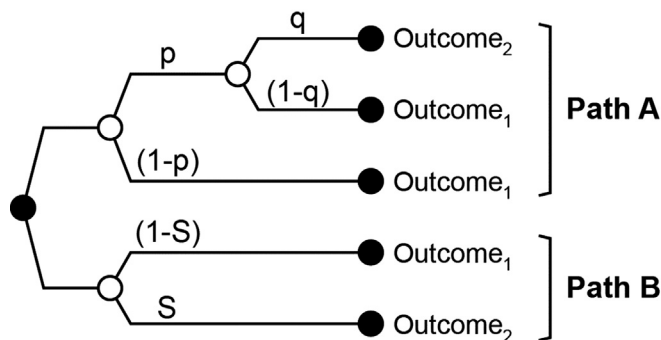


**Fig. 1.** Standard decision-tree diagram for a static multi-stage game.