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Mixture models of choice under risk

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ABSTRACT

This paper is concerned with estimating preference functionals for choice under risk from the choice behaviour of individuals. We note that there is heterogeneity in behaviour between individuals and within individuals. By ‘heterogeneity between individuals’ we mean that people are different, in terms of both their preference functionals and their parameters for these functionals. By ‘heterogeneity within individuals’ we mean that the behaviour may be different even by the same individual for the same choice problem. We propose methods of taking into account all forms of heterogeneity, concentrating particularly on using a Mixture Model to capture the heterogeneity of preference functionals.
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1. Introduction

As is clear from Starmer (2000), the past five decades have witnessed intensive theoretical and empirical research into finding a good descriptive theory of behaviour under risk. Since the general acceptance of the criticisms of Expected Utility made by Allais (for example, in Allais, 1953) and others, theorists have been active in developing new theories to explain the deficiencies of Expected Utility theory. Hey (1997) provides a list[1] of the major theories at that time: Allais’ 1952 theory, Anticipated Utility theory, Cumulative Prospect theory, Disappointment theory, Disappointment Aversion theory, Implicit Expected (or linear) Utility theory, Implicit Rank Linear Utility theory, Implicit Weighed Utility theory, Lottery Dependent Expected Utility theory, Machina’s Generalised Expected Utility theory, Perspective theory, Prospect theory, Prospective Reference theory, Quadratic Utility theory, Rank Dependent Expected (or Linear) Utility theory, Regret theory, SSB theory, Weighted Expected Utility theory, and Yaari’s Dual theory. All these theories were motivated by the inability of Expected Utility theory to explain all observed behaviour. This burst of theoretical activity took place in the last thirty years or so of the 20th century. Since then, activity has been concentrated more on discovering which of these theories are empirically most plausible and robust; see, for example, Hey and Orme (1994). This period of empirical work revealed clearly that there is considerable heterogeneity of behaviour both between individuals and within individuals. By ‘heterogeneity between individuals’ we mean that people are different, not only in terms of which type of preference functional that they have, but also in terms of their parameters for these functionals. By ‘heterogeneity within individuals’ we mean that the behaviour may be different even for the same choice problem. Econometric investigation has to take these heterogeneities into account.

Some of the empirical literature adopted the strategy of trying to find the best preference functional individual by individual; see, for example, Hey and Orme (1994) and Gonzales and Wu (1999). Another part of the literature attempted to find the best preference functional across a group of individuals, by, in some way, pooling or aggregating the data; see, for example, Harless and Camerer (1994). In fitting data subject by subject, the problem of heterogeneity *within* subjects becomes immediately apparent in two different ways. First, when confronted with the same decision problem on different occasions, people respond differently. Second, and perhaps more importantly, it was soon realised that *none* of the long list of preference functionals listed above fitted any (non-trivial) data exactly. Economists responded

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[1] Full references can be found in Hey (1997).

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in their usual fashion — by declaring that individuals were *noisy* in their behaviour, or that they made errors of some kind when taking decisions. At this point, interest centred on ways of describing such noise and incorporating it into the econometric investigation. A number of solutions were proposed: the constant-probability-of-making-a-mistake model of Harless and Camerer (1994), the Fechner-error model adopted by Hey and Orme (1994), and the random-preference model of Loomes and Sugden (1998), implemented econometrically by Loomes et al. (2002). In the first of these, subjects in experiments are thought of as implementing their choices with a constant error; in the second, subjects were perceived as measuring the value of each option with some error; in the third, subjects were thought of as not having precisely defined preferences, but preferences drawn randomly from some probability distribution. The tremble model, analysed in Moffatt and Peters (2001), can be considered like the constant-probability model but perhaps appended to one of the other two types. A useful discussion of the relative merits of these different models can be found in Ballinger and Wilcox (1997), which concludes that the constant-probability model on its own is dominated by the other two approaches. Further results can be found in Buschena and Zilberman (2000).

Those economists who followed the measurement error story soon realised that the error might not be homoscedastic and could well depend on the nature of the choice problem (see, for example Hey, 1995). Indeed, Blavatskyy (2007) argues that, with the appropriate heteroscedastic error specification, Expected Utility theory can explain the data at least as well as any of the generalisations (after allowing for degrees of freedom). Not all would go as far as this, but the incorporation of some kind of error story has led to the demise of many of the theories noted in the list above. Two remain pre-eminent: Expected Utility – henceforth EU – theory; and Rank Dependent Expected Utility – henceforth RDEU – theory (Quiggin, 1982). Machina (1994) comments that the Rank Dependent model is "the most natural and useful modification of the classical expected utility formula". In certain contexts, for example the Cumulative Prospect theory of Tversky and Kahneman (1992), the theory is enriched with a context dependent reference point. Nevertheless, the consensus seems to be that EU theory and RDEU theory remain the leading contenders for the description of behaviour under risk.

As we have already remarked, some of the investigations of the appropriate preference functional have taken each individual separately and have carried out econometric work individual by individual. There are problems here with degrees of freedom and with possible over-fitting. Other investigations have proceeded with pooled data — from a set of individuals. The problem with this latter approach, even though it saves on degrees of freedom, is that individuals are clearly different. They are different, not only in terms of which type of preference functional that they have, but also in terms of their parameters for these functionals. The latter can be taken care of by assuming a *distribution* of the relevant parameters over the individuals concerned and in estimating the parameters of this distribution. This *heterogeneity* may depend on observable and observed (demographic) characteristics of the individuals or it may just be unobserved heterogeneity. In either case, estimating the parameters of the distribution saves on degrees of freedom compared with estimating the underlying economic parameters for each individual. Moreover, the resulting estimates may be preferred if they are going to be used for predicting the behaviour of the same, or a similar, group of individuals. Some economists are now taking into account such heterogeneity. The dangers of not so doing are well illustrated by Wilcox (2006), who shows that serious distortions in the econometric results may well be the consequence. Similarly, the paper by Myung et al. (2000) shows clearly the problems with fitting a single agent model to a heterogeneous population.

Taking into account the fact that different individuals may have different preference functionals is more difficult. In this paper we adopt a solution: that of using a *Mixture Model*; see McLachlan and Peel (2000). We emphasise that we are by no means the first to use such a solution in such a context: a very useful reference is Harrison and Rutstrom (2009), which includes a discussion of the previous use of mixture models in economics.[2]

We restrict our attention to EU theory and RDEU theory, and we proceed by assuming that a proportion $(1-p)$ of the population from which the sample is drawn have EU preference functionals, and the remaining proportion have RDEU preference functionals. The parameter p is known as the *mixing proportion*, and it is estimated along with the other parameters of the model. Obviously the method can be extended to more than two functionals, but the purpose of this paper is to illustrate the power of the approach. Moreover, within each model we shall assume heterogeneity of parameters. Thus we take into account both types of heterogeneity *between* individuals, without sacrificing degrees of freedom, and without getting distorted results. Finally, to take into account heterogeneity *within* subjects we shall incorporate both a Fechner-type error and a tremble.

We illustrate the approach with data from an experiment reported in Hey (2001). The next section describes the experiment. Section 3 details the specification of EU theory and RDEU theory, while Section 4 discusses the econometric detail, including the application of the Mixture Model (with unobserved heterogeneity) in this context. Section 5 discusses the results and Section 6 concludes.

2. The experiment and the data

The data used in this study, previously analysed by Hey (2001) and more recently by Moffatt (2005), was obtained from 53 subjects, drawn from the student population of the University of York. Each subject faced a set of 100 pairwise-choice problems between two different lotteries, repeated on five different days over a two-week period, so that the total number of problems faced by each subject is 500. The ordering of the problems changed between days and also between subjects. The probabilities defining the 100 problems are listed in Table A.1 in the Appendix A. All 100 problems involved three of the four outcomes £0, £50, £100 and £150. The random lottery incentive system was applied: at the end of the final session, one of the subject's 500 chosen lotteries was selected at random and played for real. For each subject and for each pairwise-choice problem we know the lottery chosen by the subject. The resulting matrix, of size 500 by 53, is our data.

3. The preference functionals under consideration[3]

We denote the four outcomes in the experiment by x_i ($i = 1, 2, 3, 4$).[4] In both the EU formulation and the RDEU formulation, there is a utility function, and we denote the corresponding utility values by u_i ($i = 1, 2, 3, 4$). We normalise[5] so that $u_1 = 0$ and $u_4 = 1$. Each choice problem involves two lotteries: the **p**-lottery and the **q**-lottery. We denote the probabilities of the four outcomes in these two lotteries in pairwise-choice problem t ($t = 1, \ldots, 500$) by $p_{1t}, p_{2t}, p_{3t}, p_{4t}$ and $q_{1t}, q_{2t}, q_{3t}, q_{4t}$ respectively.

The EU specification envisages subjects evaluating the expected utilities $EU(\mathbf{p}_t)$ and $EU(\mathbf{q}_t)$ of the two lotteries in pairwise-choice

2 We note that, while this paper and that of Harrison and Rutstrom (2009), are similar in many respects, there are differences, in particular that we include unobserved heterogeneity of parameter values across individuals. They, however, include demographic effects, which we do not.

3 A glossary of notation can be found in Table A.2.

4 Respectively £0, £50, £100 and £150.

5 The utility function in both specifications is unique only up to a linear transformation.

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