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Modelling sequential choice processes: the case of two-stop trip chaining

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Abstract. Traditional decompositional preferences and choice studies are focused on the prediction of single choices, such as choice of shopping centre or transport mode. Discrete choice experiments are used to derive choice models that predict the probability of choosing a choice alternative as a function of its attributes. In this paper these traditional models are extended by addressing the problem of sequential choice behaviour. It is demonstrated how discrete choice experiments and universal logit models may be used to predict a choice sequence. The approach is illustrated for the problem of trip chaining. The research findings support the suggested approach.

1 Introduction

Although there is an extensive literature in various disciplines on applications of decompositional preference and choice models to spatial choice problems such as shopping (for example, Louviere and Gaeth, 1987; Louviere and Meyer, 1981; Moore, 1990; Schuler and Prosperi, 1978; Timmermans, 1982; Timmermans et al, 1984; Verhallen and de Nooij, 1982), recreation (for instance, Lieber and Fesenmaier, 1984; Louviere and Timmermans, 1990b), transportation (for instance, Bates, 1983; 1988; Bates and Roberts, 1983; Hensher and Truong, 1985; Louviere et al, 1981; Wardman, 1988), and housing (Joseph et al, 1989; Knight and Menchik, 1976; Louviere, 1979; Phipps and Clark, 1988; Veldhuisen and Timmermans, 1984), no attempts have been made so far to model sequential choices. For example, consumer choice of shopping centres for clothing has been studied extensively within the decompositional choice framework, but such choice behaviour has always been viewed as a single choice; there is little understanding and modelling expertise on how such behaviour is linked to consumer choice of shopping centres for groceries, for example. This lack of attention may have some severe ramifications in the long run, as we know that increasingly more shopping trips are organized into complex activities, involving trip-chaining and multipurpose behaviour.

In the research in this paper we are taking the first step in filling this gap by developing and testing an approach that allows the estimation of models of sequential choice behaviour. The approach constitutes an extension of the decompositional choice framework. That is, individual choices are observed under experimental conditions that are varied according to the researcher's need, producing unbiased estimates of an assumed utility function and decision model as a function of the conditions varied in the experiment.

Two important components that have to be taken into account in the modelling of sequential choice behaviour are the specification of the utility function and the choice of a design strategy that allows estimation of the model of sequential choice behaviour. In this paper, we will demonstrate how principles of discrete choice experiments may be used to develop models of sequential choice behaviour.

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The paper is organized as follows. In section 2, the way the model is developed is explained. As the model draws heavily upon recent advances in decompositional choice modelling, these advances are discussed first and then we show how this approach may be extended to model sequential choice behaviour. Next, in section 3, an application of the approach to the problem of trip chaining is described. More specifically, choices of shopping centres for specialty goods, given a previous choice of shopping centres for convenience goods, are examined. Finally, the implications of the approach for future research avenues is discussed in section 4.

2 Model development

For the model developed in this section we draw heavily upon recent advances in decompositional choice modelling (Louviere, 1988a; 1988b; Louviere and Timmermans, 1990a; 1990b; Timmermans, 1984). Therefore, let us now first summarize the current state of the art in this modelling tradition. Decompositional choice models are based on the premise that individuals arrive at some choice by integrating cognitively the utilities they attach to the attribute levels representing the choice alternatives and then implementing some decision rule. In most applications, weighted additive utility functions are used, and utility-maximizing decision rules are typically used to convert utilities into choices. By assuming that individual choice behaviour under experimental conditions is functionally related to real-world choice behaviour, predictive models of choice behaviour can be developed by constructing choice designs that allow one to examine individual choice behaviour as a function of attributes, of interest to the researcher, that are systematically varied in the experiment (Louviere and Woodworth, 1983).

Traditionally, the multinomial logit (MNL) model has been used to represent observed choices. This model may be expressed as:

$$p_i = \exp(U_i) \left(\sum_j \exp U_j \right)^{-1}, \quad (1)$$

where p_i represents the probability of choosing alternative i , and U_i is the utility of alternative i . The utility function is typically assumed to be a function linear in its parameters, of the following form:

$$U_i = \sum_k \beta_k X_{ik} + \varepsilon_i, \quad (2)$$

where β_k is the importance weight of attribute k , X_{ik} is the value of alternative i with respect to attribute k , and ε_i is an error term. It should be noted that the above specification is based on actual values of choice alternatives. Often, categorical attributes are assumed, in which case some coding scheme is required to represent the categorical attributes. For example, categorical attributes may be represented by dummy or cornered-effect coding. In this case, each attribute with K levels is represented by $K-1$ indicator variables. All but one of the attribute levels are represented by a score of 1 on one specific indicator variable and a score of 0 on all other indicator variables. The remaining attribute level is coded by 0 on all indicator variables. Alternative coding schemes such as effect (centred-effect) coding or orthogonal coding may be used to represent the utility function. It should also be noted that an intercept may be added to the above specification to allow for discrimination among choice alternatives and that interaction effects among attributes may be estimated as well, provided the design allows one to do so.

In order to estimate the MNL model efficiently, one should construct an experimental design that preserves orthogonality between and within choice alternatives. Orthogonality implies that the columns of the design matrix

are uncorrelated. Consequently, the parameters of the choice models can be estimated efficiently. Orthogonality within the choice alternatives implies that attributes are independent. Orthogonality between choice alternatives implies that the effects of the attributes of competing alternatives on the utility of a particular choice alternative can be estimated efficiently. One can use either a fixed choice set or a variable choice set design. Fixed choice set designs involve a fixed set of choice alternatives. Consequently, all choice sets in the design are of the same size and composition. In contrast, variable choice set designs may or may not contain particular choice alternatives and hence involve choice sets of varying size and composition. In the case of a fixed choice set, one decides on the number of choice alternatives that one wishes to examine, and then places each profile in the choice set so as to preserve orthogonality. Thus, if one has three named alternatives, say A, B, and C, with four, three, and two three-level attributes, respectively, one can develop an orthogonal fraction of the 3^9 full factorial design to create choice sets of size 3 that vary in terms of the attribute profiles of A, B, and C. In the case of variable choice set designs, one typically uses 2^N designs, N being the total number of choice alternatives, to create choice sets of varying size and composition. Two levels are required because choice alternatives may or may not be present.

The traditional MNL model has the well-known independence of irrelevant alternatives property where the probability of choosing the i th alternative rather than the j th alternative is independent of the existence and attributes of any other alternative in the choice set. Recently, much progress has been made by estimating so-called universal or mother logit models that allow one to test for any significant deviation from this proportionality assumption and to estimate their size (Timmermans et al, 1992). This is accomplished by introducing the attribute levels of alternatives j ($j \neq i$) into the utility function of choice alternative i . Thus, it is assumed that

$$U_i = V_i + W_{ji} + \varepsilon_i, \quad (3)$$

where V_i is a vector of attributes of alternative i , and W_{ji} represents the effects of j on i . Universal or mother logit models can be estimated efficiently if the orthogonality property holds within and between choice alternatives.

Our approach to modelling sequential rather than single choice behaviour is based on similar principles. Suppose that individuals have to choose first between alternatives A and B and then, given their choice of either A or B, between alternatives C and D at a second step of the choice process. The choice of A or B, like the choice between C and D, could be modelled in the traditional way. Thus, one can develop an orthogonal, fractional, factorial design that allows the estimation of a choice model predicting the choice between A and B as a function of their attributes. Likewise, one uses an orthogonal, fractional, factorial design to model the choice between C and D. If the choice sequence were independent, one could simply multiply the choice probabilities to predict combined choices $\{A, C\}$, $\{B, C\}$, $\{A, D\}$ and $\{B, D\}$.

The research question, however, concerns whether the choice between C and D in the second step is dependent upon the choice between A and B in the first step of the choice sequence. In order to test this, one could incorporate the attribute levels of the alternative chosen in the first step of the choice sequence in the utility function of the alternative chosen in the second step. If these effects are significantly different from zero, one would conclude that the choice process is not independent but rather that subsequent choices are dependent upon the attribute levels of the alternatives chosen at the first step of the choice sequence.

In order to test for the existence of some dependence structure, one must create a design that is orthogonal within and between the successive stages of the sequential

choice process. Thus, if in our example all four choice alternatives each had three three-level attributes, one should develop an orthogonal fraction of the resulting 3^{12} full factorial design.

Given the nature of the problem, respondents should be asked first to choose between the alternatives included in the first step of the choice sequence (A or B) and then to choose between the alternatives included in the second step (C or D) *given their choice of A or B*. The frequency of the sequential choices (C|A; D|A; C|B; D|B) is then used to estimate the model through conventional methods. The specification of the utility function for C (or D) thus consists of its attribute levels and the effects depicting the influence of the attribute levels of the previous choice (A or B) on the choice of C (or D).

3 Empirical application

3.1 Objective

In this section we will describe the performance of the sequential choice model in the context of a trip-chaining problem. We were interested to see whether a consumer's choice of a shopping centre for convenience goods would affect their choice of a shopping centre for speciality goods during the same shopping trip. It should be emphasized that the objective of this application is primarily to illustrate the suggested modelling approach rather than to develop a valid model of trip-chaining behaviour.

3.2 Study area and sample

The data were collected between November 1990 and February 1991 in the city of Eindhoven, the Netherlands, by means of self-completed questionnaires. A total of 125 randomly selected respondents participated in the study. They were informed about the objectives of the study and requested to return the filled-out questionnaire to the university in the stamped return envelope that was provided.

3.3 Method

Respondents were asked to imagine that they had to choose a shopping centre to buy convenience items and, given this choice, a shopping centre to purchase speciality items during the same shopping trip. They were told that they could choose the same centre to buy both kinds of merchandise.

The first step of the modelling approach involves identifying the attributes that influence the choice behaviour under investigation. An examination of the relevant literature suggests that the choice of shopping centre for convenience goods is influenced by: (a) selection provided (in convenience goods), (b) parking facilities at a supermarket, and (c) travel time. Each of these three attributes was varied in terms of two levels. Selection could be high or low, parking facilities could be close to supermarkets or not, and travel time was varied in terms of the categories 'five' and 'ten' minutes.

Choice of shopping centre for speciality goods was also assumed to be influenced by three main attributes: (a) selection in speciality stores, (b) parking, and (c) additional travel time. Again, each of these three attributes was varied in terms of two levels. Selection in specialty stores was either high or low, parking was good or bad, and travel time was defined in terms of additional travel time from the shopping centre chosen for convenience items and varied as (1) no additional distance (same centre) and (2) an additional ten minutes.

Thus, in total, we have 4×3 (12) two-level attributes. A sixteen-choice-set orthogonal fraction of the 2^{12} full factorial design was constructed to produce choice sets (figure 1). The first six columns of this design were used to create pairs of alternatives A and B, described in terms of generic profiles. These profiles represent shopping centres providing convenience items. The remaining columns

were used to create pairs of generic profiles (C and D) representing shopping centres selling specialty items. Note that choice sets incorporating A and B are orthogonal, as is the design including C and D. Moreover, the profiles of A and B are orthogonal to the profiles describing C and D.

For each of the sixteen sets, respondents were requested to choose first between A and B or neither of these, and then, given their choice of either A or B, to choose between profiles C and D, or neither of these. Each treatment of the design thus produces two choice sets. Responses were aggregated across respondents to generate relative choice frequencies for the choice of A or B and the choice of C or D, given A or B. Iteratively reweighted least-squares analysis (Woodworth and Louviere, 1985) was used to estimate the model of sequential choice behaviour.

	A	B	C	D
	1 2 3	1 2 3	1 2 3	1 2 3
1	Profiles of alternative A	Profiles of alternative B	Profiles of alternative C	Profiles of alternative D
2				
3				
⋮				
16				

Figure 1. The design principle.

3.4 Results

The results of the analysis are displayed in tables 1(a) to 1(c). First, the choice between profiles A and B was modelled. The results of this choice are portrayed in table 1(a), which shows that all parameter estimates are highly significant at the 5% probability level. Moreover, all estimates have the expected sign. The utility of a shopping centre for the purchase of convenience goods increases if the parking facilities close to the supermarkets improve. Its utility decreases with increasing travel time. Travel time is the most important variable influencing the choice

Table 1. Parameter estimates of the choice model.

Attribute	Parameter estimate	Standard error	t-Value
(a) <i>Convenience goods</i>			
Constant	1.936	0.134	14.48
Selection convenience goods	1.234	0.129	9.58
Parking at supermarket	-1.218	0.115	-10.56
Travel time	-2.058	0.125	-16.41
(b) <i>Specialty goods</i>			
Constant	2.601	0.182	14.33
Selection specialty goods	1.951	0.134	14.52
Parking	-1.192	0.131	-9.13
Travel time	-0.950	0.121	-7.84
(c) <i>Sequential choice</i>			
Constant	2.301	0.277	8.33
Selection convenience goods	0.593	0.428	1.39
Parking at supermarket	2.188	0.511	4.28
Travel time	-1.663	0.432	-3.85
Selection specialty goods	2.337	0.160	14.61
Parking	-1.774	0.172	-10.31
Additional travel time	-1.417	0.150	-9.46

behaviour of interest. Utility increases with increasing selection. The value of the ρ^2 -statistic is 0.82, and the likelihood of the model is significantly lower than that for the baseline model.

The results obtained for the model of shopping-centre choice for the purchase of specialty items are portrayed in table 1(b). The model performs satisfactorily. All attributes are highly significant at conventional levels of probability. All estimates are also in the anticipated directions. The utility of a shopping centre for specialty goods increases with increasing range of items offered, decreases with less parking facilities, and decreases also with increasing additional travel time. The value of the ρ^2 -statistic is 0.727, and the likelihood of the estimated model is significantly less than that obtained for the null model.

The assumed dependence structure between successive steps in the choice sequence may be tested by estimating a universal logit model which includes the effects of the attributes of A or B on the choice of C or D. The estimated parameters are presented in table 1(c), which demonstrates that two of the three cross effects are significant beyond the conventional levels of probability. Thus, the choice of a shopping centre for the purchase of specialty items appears to depend upon the choice of a shopping centre for the purchase of convenience items. The estimated effects suggest that, if the selection of convenience goods increases, then the utility of a shopping centre for the purchase of specialty goods also increases, *ceteris paribus*, although not significantly at the 5% probability level. As parking facilities close to supermarkets increase, the utility of a shopping centre for the purchase of specialty items also increases. And, last, as additional travel time increases, the utility of the centre in terms of specialty goods decreases.

Table 1(c) also demonstrates that the effects of the attributes of the shopping centres in terms of specialty items are all highly significant. The most important attribute is selection, followed by parking facilities and incremental travel time. All signs are as anticipated. Utility increases with increasing selection; utility also increases with better parking facilities; last, utility decreases with increasing incremental travel time. The value of the ρ^2 -statistic is high, at 0.81. The estimated model also clearly outperforms the baseline model.

In order to assess the goodness of fit of the independence model and of the sequential choice model, a variety of goodness-of-fit statistics was calculated. Different statistics rely on different subsets of assumptions; hence, by calculating various statistics, the conclusion is not dependent on some arbitrarily selected

Table 2. Goodness-of-fit of independence model.

Goodness-of-fit measure	Value
<i>(a) Independence model</i>	
Correlation coefficient	0.968
Robinson's agreement measure	0.983
Standardized root mean square	0.374
Theil's inequity coefficient	0.044
Mean percentage error	85.650
Minimum discrimination information index	0.887
<i>(b) Sequential model</i>	
Correlation coefficient	0.989
Robinson's agreement measure	0.994
Root mean square	0.036
Theil's inequity coefficient	0.015
Mean percentage error	47.299
Minimum discrimination information index	0.465

goodness-of-fit statistic. The calculated goodness-of-fit statistics for the independence model are presented in table 2(a). The statistics for the sequential choice model are shown in table 2(b). A comparison of table 2(a) with table 2(b) indicates that the sequential choice model outperforms the independence model regardless of the goodness-of-fit statistic. Thus, the results of the present study support the proposed model.

4 Conclusion and discussion

In this paper, we have sought to extend the decompositional choice approach in order to estimate models of sequential choice behaviour. It has been shown that simple extensions of the principles underlying decompositional choice modelling may be used to derive models of sequential choice behaviour and decisionmaking.

The results of the sequential choice model are satisfactory. The goodness of fit of the model is high. The estimated parameters all have signs that are consistent with a priori theoretical expectations. Moreover, the model allows us to test directly the dependence structure in the sequence of choices. If these positive results can be replicated in other studies and contexts, we have a potentially valuable extension of the decompositional choice approach to the modelling of sequential choice processes.

The suggested approach is easy to implement. As long as the number of successive choices and the number of attribute levels are limited, designs that permit the estimation of the sequential choice model are readily available or are easy to construct. The experimental task is easy to comprehend.

A future research agenda would involve further extensions of the model. The version described in this paper refers to the case of generic attributes. The modelling of possibilities would be further enhanced if alternative-specific models could be developed along similar lines. Likewise, important progress would be made if the present approach could be extended to multistage choice processes. Finally, in the present approach, we have imposed some a priori ordering on the choice process. For many real-world choice processes, this structure seems to be valid. However, in other cases, the sequence ordering is not necessarily known, or cannot be assumed, a priori. More generalized approaches are required for these cases. We hope to report on these developments in the near future.

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