URBAN TRAVEL DEMAND

A behavioral analysis

CONTRIBUTIONS TO ECONOMIC ANALYSIS

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A behavioral analysis

A Charles River Associates research study

THOMAS A. DOMENCICH

Charles River Associates

and

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Introduction to the Series

This series consists of a number of hitherto unpublished studies, which are introduced by the editors in the belief that they represent fresh contributions to economic science.

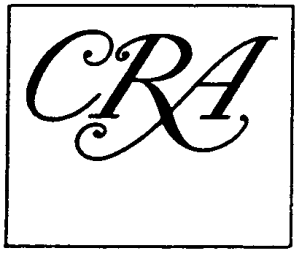
The term *economic analysis* as used in the title of the series has been adopted because it covers both the activities of the theoretical economist and the research worker.

Although the analytical methods used by the various contributors are not the same, they are nevertheless conditioned by the common origin of their studies, namely theoretical problems encountered in practical research. Since for this reason, business cycle research and national accounting, research work on behalf of economic policy, and problems of planning are the main sources of the subjects dealt with, they necessarily determine the manner of approach adopted by the authors. Their methods tend to be "practical" in the sense of not being too far remote from application to actual economic conditions. In addition they are quantitative rather than qualitative.

It is the hope of the editors that the publication of these studies will help to stimulate the exchange of scientific information and to reinforce international cooperation in the field of economics.

The Editors

Charles River Associates Incorporated is an economic and econometric research firm in Cambridge, Massachusetts. CRA has conducted research in the fields of transportation, fuels and energy, pollution control and abatement, natural resource industries, and regulation. CRA's work is generally performed for planning and policy formulating groups in industry and government.



PREFACE TO THE 1996 PRINTING

Econometric models of discrete economic decisions, grounded on utility maximization, are introduced in this book, and applied to transportation decisions of households. At the time of the initial publication in 1975, the representative *consumer* model dominated demand analysis, with response to economic variables interpreted as all coming at the *intensive* margin that determined a common level of consumption for all similarly situated consumers. This book developed the idea of a distribution of tastes or circumstances across consumers that created an *extensive* margin for choice among discrete alternatives. The original preface suggested that this approach could open to empirical analysis a realm of important economic decisions that were difficult to treat from a representative consumer perspective, such as level of educational attainment, labor force participation, occupation, location, and marital status. This prospect has been realized in the nearly two decades that have passed since the initial publication. Analysis of discrete response data starting from models of economic optimization has become a standard part of graduate courses in econometrics, and empirical studies have improved our understanding of behavior and the impacts of economic policy in many fields of economics, as well as market research, finance, transportation planning, political science, and public policy.

Reprinting of this book presents an opportunity to alert the reader to deficiencies in the original text, and to provide some guide to more recent developments in this subject. This book introduced hierarchical decision trees that factor complex discrete decisions into a sequence of simpler choices. It implemented econometric analysis of these trees by introducing *nested* multinomial logit models, and methods for estimating these models sequentially, starting at the bottom of the tree, and carrying *inclusive values* from one level of the tree up to the model for choice at the next level. The overall framework of this analysis was sound, but some details were incorrect and have been corrected in the subsequent literature. First, the empirical study reported this book, done in 1971, used an approximation to the correct formula for inclusive values. This was pointed out by Ben-Akiva (1973), who showed that it just as easy to use the exact formula. The 1975 text notes this (pp 72-77), but should have emphasized that exact definition in equation (4.59) should be used rather than the approximate definition in equation (4.62). Second, this book failed to correct the standard errors of estimates at higher levels of the

tree for the effect of using *estimated* inclusive value variables. This was pointed out by Amemiya (1977); computational formulas for the correction are provided by McFadden (1981). Third, while utility maximization was used to motivate the nested multinomial logit model, the book does not establish that this model is derivable from a distribution of utility maximizers except in the case that the coefficients of inclusive values are one. This was corrected by McFadden (1978,1981), who showed that nested multinomial logit models, with specific restrictions on the range of coefficients of inclusive values, are derivable from random utility models with generalized extreme value disturbances. Subsequent work has extended this analysis in several interesting directions. Borsch-Supan (1987) has examined the question of the consistency of nested multinomial logit models with utility maximization on restricted domains containing the data, even when inclusive value coefficients are outside the range that guarantees global consistency.

Cosslett (1988) and Dagsvik (1993) have studied *extremal stochastic processes*, and given conditions under which random utility over a continuous domain will lead to choice among subsets of the domain describable by multinomial logit models. This has applications to timing and location decisions; see Small (1992). It also provides a foundation for analysis of continuous-time discrete-response panel data. Recent work of Dagsvik (1992) shows that generalized extreme value models are dense in the space of all random utility models, providing at least a broad justification for concentration on nested logit forms as good approximations for summarizing behavior.

This book discusses the use of discrete response models for forecasting and policy analysis, and develops a method for welfare analysis in discrete choice problems. Subsequent literature has shown that in many cases, *analytic* formulas for consumer surplus can be calculated for these models; see Diamond and McFadden (1974) and McFadden (1981). This book suggests, but does not fully develop, a *microsimulation* approach to forecasting and policy analysis. Except for special cases where analytic aggregation is feasible, this approach has been found to be the most practical one in applications. The approach is developed in some detail in Cowing and McFadden (1984), and its application to transportation problems is treated in Ben-Akiva and Lerman (1985) and Train (1986).

There are a number of important developments in econometric analysis of discrete response since this book appeared. One of the issues in the use of multinomial logit models to describe discrete choice is a powerful, but restrictive, feature called *independence from irrelevant alternatives*. It has been recognized that consistency of this feature with data is an empirical question,

and test statistics can be developed for this property, some of which provide guides to alternative specifications; see Hausman and McFadden (1984), McFadden (1987), and Small and Hsiao (1985). These methods also provide tools for more general issues of model specification, such as selection of explanatory variables.

A property of multinomial logit models that is important in applications to complex response data is that data collection and estimation can be simplified by sampling from the full set of alternatives; see McFadden (1978,1984). This feature has been used successfully in applications involving astronomical numbers of alternatives; e.g., Train, McFadden, and Ben-Akiva (1987). Another strand of literature has dealt with the problem of sample selection, attrition, and deliberate over or under-sampling of alternatives to increase the information in samples; see Manski (1979), Manski and McFadden (1981), and Imbens (1992).

Discrete response sometimes needs to be considered in tandem with continuous response, either because of discrete selection that conditions the continuous response, as in the case of continuous hours of work conditioned on labor force participation, or because both the discrete and continuous decisions are of economic interest, as in the case of automobile brand choice and vehicle-miles traveled. These problems fit into the broad family of latent variable models with discrete and continuous indicators. These models merge features from continuous latent variable models and from discrete choice analysis; see Aigner *et al* (1984) for a general discussion of these models, and Dubin and McFadden (1984) for development from utility maximization of a system of combined discrete and continuous choices. Recent work employing these models has successfully merged objective travel data with psychometric indicators of perceptions and attitudes; see Morikawa (1989).

The statistical foundations of discrete response analysis have been developed in Amemiya (1981,1984), Maddala (1983), and McFadden (1984). Recent developments include the use of simulation methods to estimate computationally intractable models such as the multinomial probit model; see McFadden (1989) and Hajivassiliou and Ruud (1994). There is now considerable work on the use of semiparametric and nonparametric methods that avoid restrictive parameterizations and functional forms in discrete response analysis; see Manski (1975), Hardle (1994), and Powell (1994).

Analysis of travel demand using the discrete choice methods introduced in this book have played a major role in transportation research, particularly outside the U.S. Comprehensive treatments of travel demand applications can be found in Ben Akiva and Lerman (1985), Hensher and Johnson (1981),

and Train (1986).

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STUDIES IN URBAN AND RESOURCE ECONOMICS

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Foreword

The present volume represents a major contribution to modeling consumer behavior in the face of discrete choices. In the standard theory of consumer behavior, commodities are assumed to be finely divisible and the arguments entering into the individual's utility function are the quantities of the various commodities consumed. Demand functions, derived from the assumption of optimizing behavior by the consumer, reflect marginal adjustments by the consumer in response to changes in prices or other factors in the environment. When choices are discrete, as for example the choice of mode in the decision to travel, the standard framework is no longer applicable. An increase in the price of a travel mode will either leave the patron of that mode unaffected (i.e., he will continue to use it) or it will cause him to switch to another mode altogether; small marginal adjustments are not feasible consequences in this case.

The authors develop brilliantly the theory of choice in the face of discrete alternatives, and their application of this theory to the demand for travel makes this volume a definitive study for four reasons.

(1) Studies of the demand for travel have all too often been mechanistic and have lacked the recognition that travel decisions represent optimizing behavior by the travelers. The approach of Domencich and McFadden is essentially and admirably behavioral and relates travel decisions intrinsically to the theory of choice among discrete alternatives.

(2) The utility functions employed in the authors' theory are functions of the attributes of the various travel commodities. This factor is of vital importance if one wishes to assess the consequences of policy actions which result in changes in these attributes or even in the establishment of new modes of travel. Not only have travel demand models frequently failed in the past to rest on strong behavioral components, but even the standard utility theory has no way of coping with the question of

predicting demand for changed or new commodities. The authors' approach makes answering such questions eminently feasible, and this study will therefore be of great significance for policy-makers dealing with urban transportation problems.

(3) The authors assume quite realistically that individuals' utility functions may differ from one another in some specified stochastic manner. The introduction of this element of realism in the theory permits them to forge the link to the econometric techniques that they employ for the purpose of estimating the parameters of their model. The most important of the econometric techniques discussed and explored in detail is the logit model, and we have a rare example here of an intrinsic connection between economic theory and econometric method.

(4) The authors' procedures are ideally suited for implementation with individual data of the household survey type. Far too many travel demand studies have employed as observations some aggregate zone-to-zone flows; a procedure that not only loses resolution, as a result of the averaging that it contains, but even biases the resulting estimates.

It is not surprising that the empirical results contained in this volume are persuasive. I am certain that the economic and econometric structures presented here will not only be convincing to economists, urban planners and other professionals dealing with questions of travel demand, but will be indispensable for those who require sensible answers in realistic, practical contexts.

Richard E. Quandt

Preface

The classical economic theory of consumer behavior provides a useful, logically consistent foundation for the empirical analysis of many aspects of individual demand. However, there is a realm of behavior involving choice among discrete alternatives for which the traditional marginal analysis of economic consumer theory is not applicable. Demand for transportation, the subject of this book, is an example; others include decisions on education, labor force participation, occupation, location, marital status, and family size. The importance of such decisions in the life of a consumer is self-evident. Nevertheless, the lack of an adequate theory has until recently made this realm of behavior a non-topic in the traditional demand literature.

This book develops a theory of demand for populations of individual economic consumers which we believe is a logical and natural generalization of traditional theory to encompass choice among discrete alternatives. By considering taste variation in the population, we are able to reintroduce the marginal calculus, with the margin now interpreted as an *extensive* one among the population rather than an intensive one within the individual. The result is a logically consistent theory of consumer choice among discrete alternatives which has proved a practical tool for the analysis of travel behavior, and promises to provide a sound basis for the study of a wide variety of consumer decisions in which population taste variations are a significant factor in determining observed demands.

Two additional aspects of consumer travel decisions require re-examination of the traditional consumer model. The first is that travel is normally a means to an end for the consumer, a necessary concomitant of more basic activities. This requires an analysis of travel choices within a "household production" or "consumption activity" model of consumer decisions. The second aspect is the extraordinary complexity of the

constellation of travel decisions: mode, frequency, destination, time of travel, compounded over trip purposes and over time. The requirements of empirical tractability, and perhaps also the bounded computational capacity of the consumer, require a simplification of the decision-making process. We explore separable and hierarchical taste structures which simplify the specification of travel demand.

Although the primary objective of this book is to provide a theoretical foundation and statistical methodology for analysis of travel behavior, we have also provided a prototype empirical study demonstrating the feasibility of the methods and the usefulness of the results. The chapters detailing these results raise many points on the collection, processing, and interpretation of travel demand data which should prove useful to the practitioner of travel demand estimation. In the final analysis, both a valid, applicable theory and relevant, accurate data are required to provide satisfactory demand forecasts; neither can succeed without the other.

This book is an extensive revision by the authors of a project report by Charles River Associates ["A disaggregated behavioral model of urban travel demand" (1972)] for the Federal Highway Administration, U.S. Department of Transportation. However, the contents of this book do not necessarily reflect the official views or policy of the U.S. Department of Transportation. The authors particularly thank Joel Ettinger and Edward Weiner of the Department of Transportation for their helpful comments and cooperation during performance of the contract.

The bulk of the research was done during the 1970–71 academic year, when the first author was associated with CRA and the second author was a visiting scholar at MIT. The theoretical and statistical principles employed in this book were initially investigated by the second author, beginning in 1965, in response to a problem on highway routing decisions posed by Dr. Phoebe Cottingham. Joint research of the second author and Professor Marcel K. Richter in 1970 on the pure theory of population choice behavior clarified many of the conceptual issues involved. Major contributions to the formulation of the theory of individual transportation choices, particularly the question of separable utility and "inclusive prices", were made by Professors Peter Diamond and Robert Hall of MIT, who served as consultants to Charles River Associates.

Gerald Kraft of CRA provided overall review and guidance through-

out the research project, and his many useful comments and suggestions enhanced both the theoretical development and the empirical analysis. We are indebted also to Professors Paul Roberts of MIT and Daniel Brand of Harvard for allowing us to draw on their considerable expertise in transportation research and planning during numerous aspects of the study. The backbreaking work of data preparation was done by Gerry Smolka, Deborah Kuhn and Diogo Tiexiera. Whatever useful results were obtained in the empirical analysis can be attributed to the patience and care with which they did their work.

The multinomial logit program used in this research was first coded by Professor C.T. Ratcliffe, revised by Professor C.K. Liew, and revised again by Professors H. Varian and H. Wills.

The authors have benefitted from discussions of this research with many scholars. We particularly wish to mention Professors L. Moses, J. Ledyard, M. Wohl, G. Debreu, F.X. de Donnea, Z. Griliches, R. Radner, B. Saffran, and E. Sheshinski. Professors T. Amemiya, D. Sant, and H. Wills have suggested many useful improvements and additions to the original manuscript. The skillful typing and editing of G. Katagiri, I. Katagiri, and E. Thomas have greatly aided the authors in completing this work.

We wish to emphasize our gratitude to all the individuals who have contributed to the completion of this volume, particularly those mentioned above. Each of the authors attributes responsibility for errors solely to the other. We dedicate this book to our parents, whose family size decisions have made this collaboration possible.

Tom Domencich
Dan McFadden

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