Stated Choice Methods

Analysis and Applications

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1.1 Introduction

Understanding the behavioural responses of individuals to the actions of business and government will always be of interest to a wide spectrum of society. Whether a simple application such as gauging the effect of an increase in the price of a specific good or service, or a more complex one such as evaluating the introduction of a new product with private and public impacts, understanding and predicting the nature of individual and aggregate responses is vital to the evaluation of the resulting costs and benefits. Choosing to do or not to do something is a ubiquitous state of activity in all societies. Choosing manifests itself in many ways such as supporting one outcome and rejecting others, expressed through active responses (e.g., choosing to use products or services through purchases), or through passive responses, such as supporting particular views (e.g., choosing to support a conservation rather than a logging position in a dispute over wood chipping). Individuals' choices are influenced by habit, inertia, experience, advertising, peer pressures, environmental constraints, accumulated opinion, household and family constraints, etc. This set of influences reflects the temporal nature of choice outcomes and segments within the constraint set (e.g., income classes of households).

Our objective in writing a book on stated choice methods, analysis and applications, is to demonstrate the benefits of developing a formal structure within which to investigate the responsiveness of potential and actual participants in markets for particular goods, services and positions. Our challenge will be to describe, in simple terms, the practical benefits of using the tools of data specification, modelling and application that have evolved through research activity over the last thirty years. Many disciplines have contributed to the advances made in these areas, most notably econometrics, transportation, marketing, decision science and biostatistics. The one common thread in these diverse and often non-overlapping literatures is a search for better theory and methods to explain individual and aggregate choice behaviour, and predict behavioural responses to changing opportunities. An important corollary is the desire to develop practical analytical tools, so that the benefits of research can be transferred to practitioners in a timely manner, allowing for incremental updates as knowledge of individual choice behaviour improves.

Great progress has been made in developing frameworks within which to explore, understand, analyse and predict individual choice behaviour. The objective of this book is to fill a gap in reference sources for those who seek to understand, gain expertise in and apply stated choice methods and models. Like any reference work, there are limits to what can be covered in a single source; hence, from the outset we impose bounds on our topic, largely determined by our own personal biases and views as to the interesting and important advances in theory, analytical tools and applications. The topics included are:

- random utility theory,
- the associated family of discrete-choice models such as multinomial logit, nested logit, heteroscedastic extreme value logit, random parameter or mixed logit, and multinomial probit,
- families of controlled experimental designs consistent with various members of the discrete-choice modelling family, and
- data enrichment and comparison of preference data sources via integration of revealed preference and stated choice data, as well as the combination and comparison of various sources of stated choice and preference data.

1.2 Decision making and choice behaviour

> The traditional economic model of consumer behaviour has disappointingly few implications for empirical research. (Muth 1966: 699)

The theoretical underpinnings of discrete-choice models contain elements of the traditional microeconomic theory of consumer behaviour, such as the formal definition of rational choice and other assumptions of traditional preference theory. However, the essential point of departure from the traditional theory, germane to the subject matter of this book, is the postulate that utility is derived from the *properties* of things, or as in the now classical work of Lancaster (1966, 1971), from the characteristics (in an objective dimension) which goods possess, rather than the goods *per se*. Goods are used either singly or in combination to *produce* the characteristics that are the source of a consumer's utility.

This section takes Lancaster's contribution as a point of departure and modifies it to make clear the connection between the spirit of Lancaster's precise approach and the approach in this book. The connection with the traditional characteristics approach remains strong, although Lancaster and others (e.g., Rosen 1974) concentrated mainly on developing a detailed subset of the elements of what we will term the paradigm of choice.

To appreciate the connection between the 'standard Lancaster approach' (SLA) and our modifications, let us briefly outline the SLA for the case in which goods are divisible (Lancaster 1966, 1971) and indivisible (Rosen 1974). Furthermore, so that one can interpret (and assess) the arguments in terms of their relationship to discrete-choice models, it is appropriate to formally state the paradigm of choice now and discuss its elements later. Formally the paradigm of choice underlying discrete-choice models can be expressed as a set of three interconnected equations:

$$s_k = f_{kr}(t_r) \tag{1.1a}$$

$$u_j = g(s_{kj}) \tag{1.1b}$$

$$P_j = h(u_j) \tag{1.1c}$$

and

$$P_j = h\{g[f_{kr}(t_r)]\}, \tag{1.1d}$$

where s_k is the perceived (marginal) utility of consumption service k,
t_r is the observable value of objective characteristic r,
u_j is the overall utility (preference) associated with the jth alternative,
s_{kj} is the level of attribute k (representing consumption service k) associated with alternative j,
P_j is the likelihood of choices allocated to alternative j, and
f, g, h are linear or non-linear functions, yet to be determined.

The standard Lancaster approach postulates that goods (X) are transformed into objective characteristics, t, through the relation

$$t = \mathbf{B}X, \tag{1.2}$$

where B is an R by J matrix which transforms the J goods (i.e., alternatives in a choice set) into R objective characteristics (i.e., attributes of alternatives). Hence, **B** defines the consumption technology, assumed to be objective since it is invariant for all consumers (e.g., the number of cylinders in the engine of a particular make and model of car is the same for everyone). A range of mappings can exist, such that several goods can produce one characteristic, and several characteristics can be produced by one good. Lancaster asserts that the relevant characteristics should be defined not in terms of an individual's reaction to the good (which we will refer to as consumption service), but rather in terms of objective measures; that is, in terms of the properties of the good itself. Lancaster did not say that there could not be differences between consumers in the way in which they perceive an objective characteristic. However, if such differences exist, they relate to the formation of a preference function for t that is outside the domain of his theory.

The rationale given for the emphasis on t is that economists are primarily interested in how people will react to changes in prices or objective characteristics embodied in the goods that produce t, and not in how the function $U(t)$ is formed. This further implies that the functions h, g and f_{kr} in equations (1.1a) to (1.1c) can be reduced to a composite function $B(.)$ with no loss of information and a one-to-one correspondence in content and form between s_k and t_r, u_j and s_{kj}. The latter implies that utility is a function of commodity characteristics:

$$u = U(t_1, t_2, \ldots, t_R) \tag{1.3}$$

where t_r is the amount of the rth characteristic that a consumer obtains from consumption of commodities, $r = 1, \ldots, R$.

The particular formulation outlined above assumes that goods are infinitely divisible, frequently purchased and of low unit value. Yet many goods are not perfectly divisible, especially goods relevant to discrete-choice applications, which often deal with goods that are infrequently purchased or evaluated. Rosen (1974) developed a goods characteristics model for indivisible (or discrete) goods in which he assumed that alternatives were available for a continuous range of objective characteristics. This latter assumption enabled him to eliminate Lancaster's transformation from goods to characteristics, and to state a model directly in terms of prices and quantities of characteristics (still defined objectively by Rosen). If Hicks' (1946) composite good theorem holds, we can hold the prices of all other goods constant except those under study. That is, we can assume one intrinsic group of goods (e.g., modes of transport, brands of cereals, an endangered wildlife species, residential accommodation) yields objective characteristics $(t_1, t_2, \ldots, t_R)$ and define all other (composite) goods consumed as d. Then Rosen's model can be stated as

$$\text{maximise} \quad U(t_1, t_2, \ldots, t_R) \tag{1.4}$$

$$\text{subject to} \quad p(t_1, t_2, \ldots, t_R) + d = M, \tag{1.5}$$

where the price of d is arbitrarily set equal to one dollar, M is the consumer's income, and $p(t_1, t_2, \ldots, t_R)$ represents the price of one good yielding objective characteristics $t_1, t_2, \ldots, t_R$ which are actually acquired. The budget constraint, defined in terms of the objective characteristics, is non-linear. If goods are not divisible, $p(t_1, t_2, \ldots, t_R)$ need not be linear, and hence it is not appropriate to define objective characteristics in terms of characteristics per dollar (or any other unit price), but rather in terms of their absolute levels. Thus, price must be represented as a separate dimension, as seen in the discrete-choice models discussed in later chapters.

Rosen's model is more appropriate to a discrete-choice theoretic framework, although it continues to link utility directly to the objective characteristics of goods. The paradigm of choice links utility to goods and thence to objective characteristics via a complex function of function(s), as suggested in equation (1.1d). The latter is our point of departure from the Lancaster–Rosen contribution, but we retain the spirit of their approach and use it as the starting point for developing the full set of relationships outlined in the paradigm of choice. In particular, random utility theory based discrete-choice models focus primarily on equations (1.1b) and (1.1c), and accept the need to map attributes or consumption services into objective characteristics and, vice versa, to develop predictive capability. In practice, analysts commonly assume a one-to-one correspondence between s_k and t_r, such that s_k is a perfect representation of t_r.

The relationship between utility and the sources of utility is clearly central to the decision on selection of commodities. We now conceptually outline alternative ways to represent the sources of utility, given that we accept the limitations of using the Lancaster–Rosen standard approach. We present three modifications, subsequent ones building directly on the preceding, and use the final modified formalisation as the link with the basic choice model developed in chapter 3. The discrete-choice model is essentially an analytical representation of equations (1.1b) and (1.1c), with alternative assumptions on g and h.

The objective properties of commodities may not be an appropriate measure of services if we assume that individuals act as if they maximise utility based on their perceptions of characteristics. Thus, a 'modified Lancaster–Rosen approach' can be derived by assuming that individuals consume commodities by consuming the services provided by the commodities; that is, utility is a function of services rendered by commodities:

$$u = U(s_1, s_2, \ldots, s_K) \tag{1.6}$$

where s_k is the amount of kth consumption service that a consumer obtains from consumption of commodities, $k = 1, \ldots, K$. Furthermore, given the uncertainty of the level of service offered by commodities, a 'further modified Lancaster–Rosen approach' can be derived by assuming that individuals consume commodities by consuming the *expected services* provided by the characteristics associated with commodities; that is, utility (assuming deterministic utility maximisation) is a function of the expectation of consuming a required level of service provided by characteristics which group to define a commodity:

$$u = U(se_1, se_2, \ldots, se_K) \tag{1.7}$$

where se_k is the expected amount of kth consumption service that a consumer obtains from consumption of commodity characteristics, $k = 1, \ldots, K$.

Equation (1.7) represents an individual's decision calculus and the expected levels of service, the latter assumed to be known by the individual agent with the degree of 'certainty' that an individual attaches to the expectation. The analyst, in contrast, does not have access to the same level of information used by the consumer in processing a decision leading to a choice. The analyst is unable to 'peep into an individual decision maker's head' and accurately observe the set of attributes which define the expected level of service on offer. We can make this restriction explicit by defining the utility function observed by the analyst as given in equation (1.8):

$$u = U((se_o + se_{uo})_1, \ldots, (se_o + se_{uo})_K), \tag{1.8}$$

where subscripts o and uo indicate the division of consumption services that an individual associates with the consumption of commodity characteristics that are, respectively, observed and unobserved by analysts. In practice, the unobserved component (denoted as ε in the discrete-choice literature – see chapter 3), is assumed to be distributed across the population in some defined way, and a specific sampled individual is randomly allocated a value on the pre-specified distribution (e.g., a normal or extreme value distribution – see section 3.4).

Equations (1.3), (1.6), (1.7) and (1.8) are not independent, and can be combined to define components of a paradigm of choice. Let us call the objective characteristics 'features', and the quantitative dimension in which consumption services are defined 'attributes'. Many attributes may map exactly into a feature; but an attribute may be functionally related to more than one feature and vice versa. For example, a feature on a mobile phone might be 'call holding while attending another call'; two attributes related to this feature would be 'making an inquiry call to another extension while holding an outside call' and 'holding an existing call while dealing with an incoming outside call'.

Throughout this book the separation of supply 'price' into a vector of features and demand 'price' into a vector of attributes is used to account for the important distinction between the value of a commodity to an individual and the objective nature of the commodity. The latter provides a useful way to identify the possible source of bias in using supply 'prices' as determinants of choice because such prices have an indirect influence via their role in the definition of demand price. An important element of choice models is the translation of features into attributes, allowing one to assess the impact of a change in the objective properties of commodities; and the translation of an attribute-level change into a feature-level change to determine the appropriate supply change. In some circumstances, attributes and features only differ in terms of magnitude (e.g., actual and perceived travel time), whereas in other cases they may differ in dimension (i.e., two different characteristics). Thus the term 'characteristics' is usefully defined on both feature and attribute dimensions, and the mapping of features into attributes and/or attributes into features may involve one or more characteristics. The paradigm of choice is summarised below:

$$u = U[(se_o + se_{uo})_1, (se_o + se_{uo})_2, \ldots, (se_o + se_{uo})_K], \tag{1.9}$$

$$(se_o + se_{uo})_k = f_k(t_1, t_2, \ldots, t_R), k = 1, \ldots, K, \tag{1.10}$$

or

$$s_k = f(t_{11}, t_{21}, \ldots, t_{R1}, t_{12}, t_{22}, \ldots, t_{RJ}), \tag{1.11}$$

or

$$(se_o + se_{uo})_k = f_k(t_{11}, t_{21}, \ldots, t_{R1}, t_{12}, t_{22}, \ldots, t_{RJ}), r = 1, \ldots, R,\ j = 1, \ldots, J. \tag{1.12}$$

In equation (1.10), t_r is the rth feature, assumed independent of the jth commodity, and is an appropriate formulation when explicit commodities cannot be formally defined in a choice framework (i.e., if each mix of features is a (potentially) unique commodity).

Alternatively, because a particular consumption service (defined in terms of attributes) can be obtained from various bundles of features and varying levels of features, service can be defined across a range of R features in a framework of J commodities, as shown in equation (1.10). Equation (1.9) is a commodity-independent relationship between attributes and features. Equation (1.11) is a commodity-specific relationship. To complete the paradigm, two additional expressions are required. The first, equation (1.13), indicates the dependence of t_{rj} on the unit offering by the jth commodity of the total quantity of feature r:

$$t_{rj} = g_{rj}(y_{rj}), \ldots, r = 1, \ldots, R,\ j = 1, \ldots, J, \tag{1.13}$$

where y_{rj} is the quantity of feature r available in one unit of commodity j. The final equation (1.14) relates the total amount of the rth feature obtained from the jth commodity to the quantity of the commodity consumed (i.e., G_j):

$$tr_j = g_{rj}(G_1, G_2, \ldots, G_J), j = 1, \ldots, J. \tag{1.14}$$

The approach assumes that a particular consumption service (defined on one or more attributes) can be met by one or more objective characteristics (defined on one or more features and translated into a perceived set of attributes), and that a particular objective characteristic can exist in one or more commodities.

The paradigm of choice, together with alternative specifications of the relationship between u_j, s_{kj} and t_r, is consistent with the general approach to consumer behaviour in economics, although the analysis of the relationship between consumption of commodities and sources of utility begins earlier in the individual's decision process than is normally considered within the traditional economic paradigm. We accept that a consumer does not directly acquire objective characteristics or consumption services, but rather purchases commodities. Commodities are acquired in those amounts that provide the quantities of t_{rj}s that provide the amount of desired s_ks (or $(se_o + se_{uo})_k$) that maximises utility. This is equivalent to saying that

$$\begin{aligned}&(\text{'price' } j)(\partial u/\partial \text{ expenditure on } j)\\&\quad = \sum_j \sum_k (\partial u/\partial((se_o + se_{uo})_k).(\partial(se_o + se_{uo})_k/\partial t_r)(\partial(se_o + se_{uo})_k/\partial t_{rj})\\&\quad . \ (\partial t_{rj}/\partial G_j), \quad G_j > 0.\end{aligned}$$

In words, given a positive level of consumption of the jth commodity, the value of a commodity j, equal to the product of the price of j and the marginal utility derived from the expenditure on j, is equal to the product of the marginal utility of the kth attribute, the marginal rate of substitution between the kth attribute and the rth objective characteristic, the marginal rate of substitution between the kth attribute and the rth objective characteristic contained in commodity j, and the marginal rate of substitution between the rth objective characteristic contained in the jth commodity and the quantity of the jth commodity consumed, all other things being equal.

We are now in a position to take the paradigm of choice as central to the formulation of a conceptual framework for studying choice behaviour, adding assumptions as needed to qualify the particular analytical form of the model's specification of the relationship between P_j, u_j and s_{kj}. The next section expands on this conceptual framework, integrating ideas drawn from a diverse set of literatures with an interest in decision making. The paradigm is broader in practice than the contributions from economics, with very strong contributions from psychology, decision science, marketing and engineering.

1.3 Conceptual framework

A general order or stages in a consumer's decision process are summarised in figure 1.1. The consumer first becomes aware of needs and/or problems to be solved, which is followed by a period of information search in which he or she learns about products that can satisfy these needs or solve the problems. During search and learning, consumers form beliefs about which products are available to attain their objectives, product attributes germane to a choice and attribute values offered by products, as well as any associated uncertainties. Eventually consumers become sufficiently informed about the product category to form a utility function (or decision rule) which involves valuing and trading off product attributes that matter in the decision. Given a set of beliefs or priors about attributes possessed by product alternatives, consumers develop a preference ordering for products, and depending upon budget and/or other constraints/considerations make decisions about whether to purchase. If they decide to purchase, consumers finally must choose one or more alternatives, in certain quantities and with particular purchase timings.

Figure 1.2 concentrates on the last decision stage, during which consumers form utilities or values and begin to compare products to form overall (holistic) preferences for an available set of alternatives. Figure 1.3 formalises this process as a series of interrelated processes, links each process to a formal stage in the decision-making process and describes the general area of research connected to that topic in marketing, psychology and/or economics/econometrics. The conceptual framework outlined

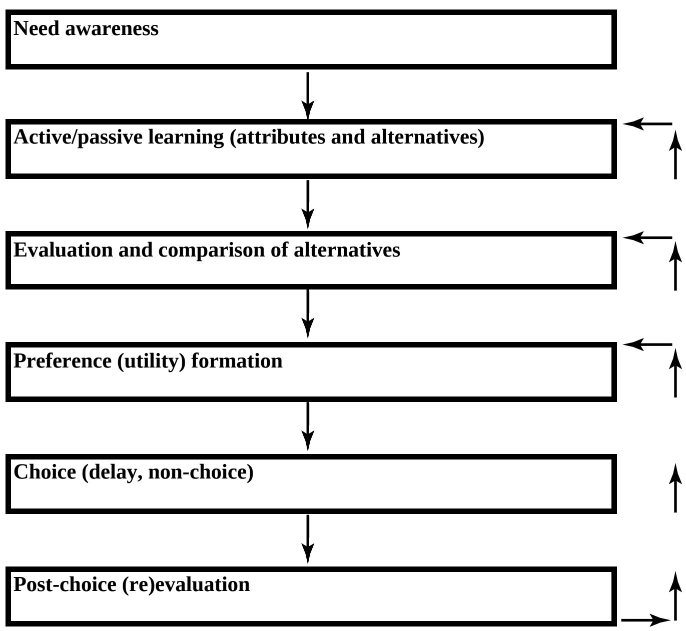

Figure 1.1 Overview of the consumer's choice process

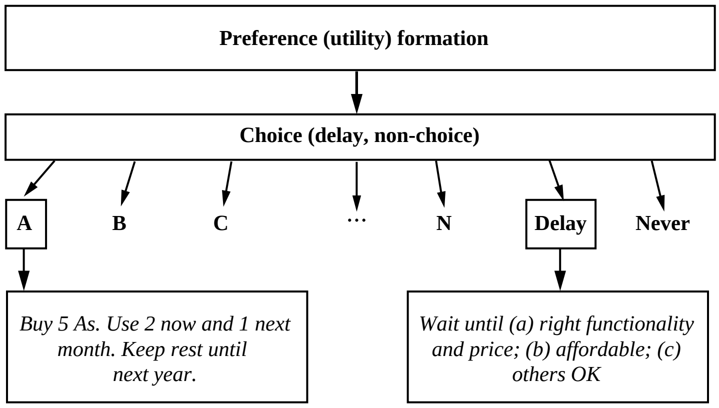

Figure 1.2 Complex decision making and the choice process

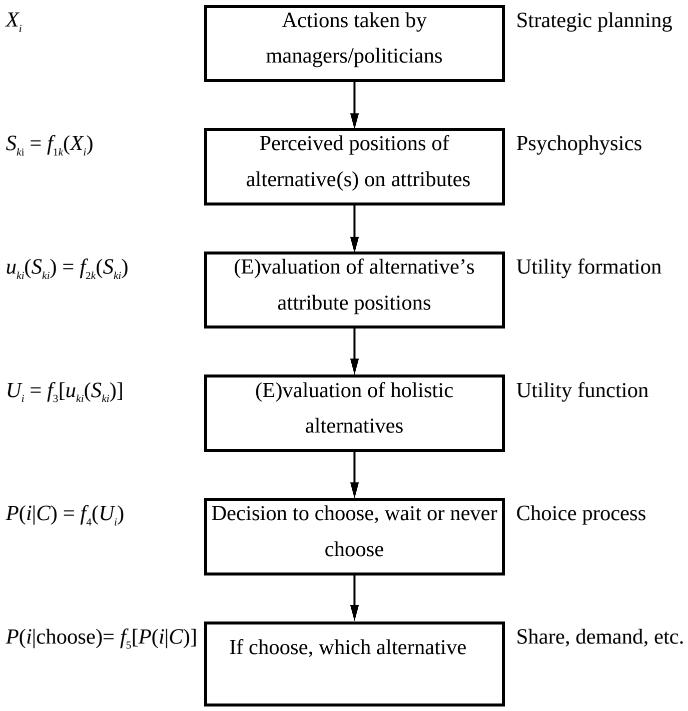

Figure 1.3 Functional relationships implied by the framework

in figures 1.1 to 1.3 is consistent with economic theory, accommodates random utility type choice and decision processes; and most importantly, allows one to 'mix and match' measures from various levels in the process, assuming such measures are logically or theoretically consistent with the framework and each other. The advantage of the latter integration is that it allows explanation of the choice behaviour in terms of:

1. physically observable and measurable (engineering) characteristics,
2. psychophysical variables (beliefs/product positions),
3. part-worth utility measures, or
4. holistic measures of each alternative's utility.

Depending on one's research and/or analytical objectives, explanatory variables at one level can serve as instruments or 'proxy' variables for measures at other levels. Such instruments can be used to reduce specification errors and/or improve estimation efficiency. Equally important, the conceptual framework suggests the potential contribution of many types of data to understanding choice; this catholic view of preference data is a focal point of this book. In particular, stated choice methods and measures used to model intermediate stages in the decision-making process can be integrated with parallel revealed preference or market methods and models. For example, the framework permits choices to be explained by direct observation and measurement of physical product characteristics and attributes and/or managerial actions such as advertising expenditures. Direct estimation alone, however, may obscure important intermediate processes, and overlook the potential role of intermediate models and measures in an overall behavioural framework that explains consumer choices.

1.4 The world of choice is complex: the challenge ahead

A major objective in writing this book is to bring together, in one volume, tools developed over the last thirty years that allow one to elicit and model consumer preferences, estimate discrete-choice models of various degrees of complexity (and behavioural realism), apply the models to predict choices, and place monetary (and non-monetary) values on specific attributes (or, better said, levels of attributes) that explain choices.

1.4.1 Structure of the book

The sequence of chapters has been guided by the authors' beliefs about the most natural steps in the acquisition of knowledge on the design, collection and analysis of stated choice data for problems involving agents making choices among mutually exclusive discrete alternatives. Subsequently we shall discuss the contents of each chapter in some detail, but first it is useful to present an overview of the book's structure. Figure 1.4 contains a flowchart depicting the overall structure of the book, which is broadly divided into (1) methodological background (chapters 2–7), (2) SP data use and study implementation (chapters 8 and 9), (3) applications (chapters 10–12) and (4) external validity of SP methods (chapter 13).

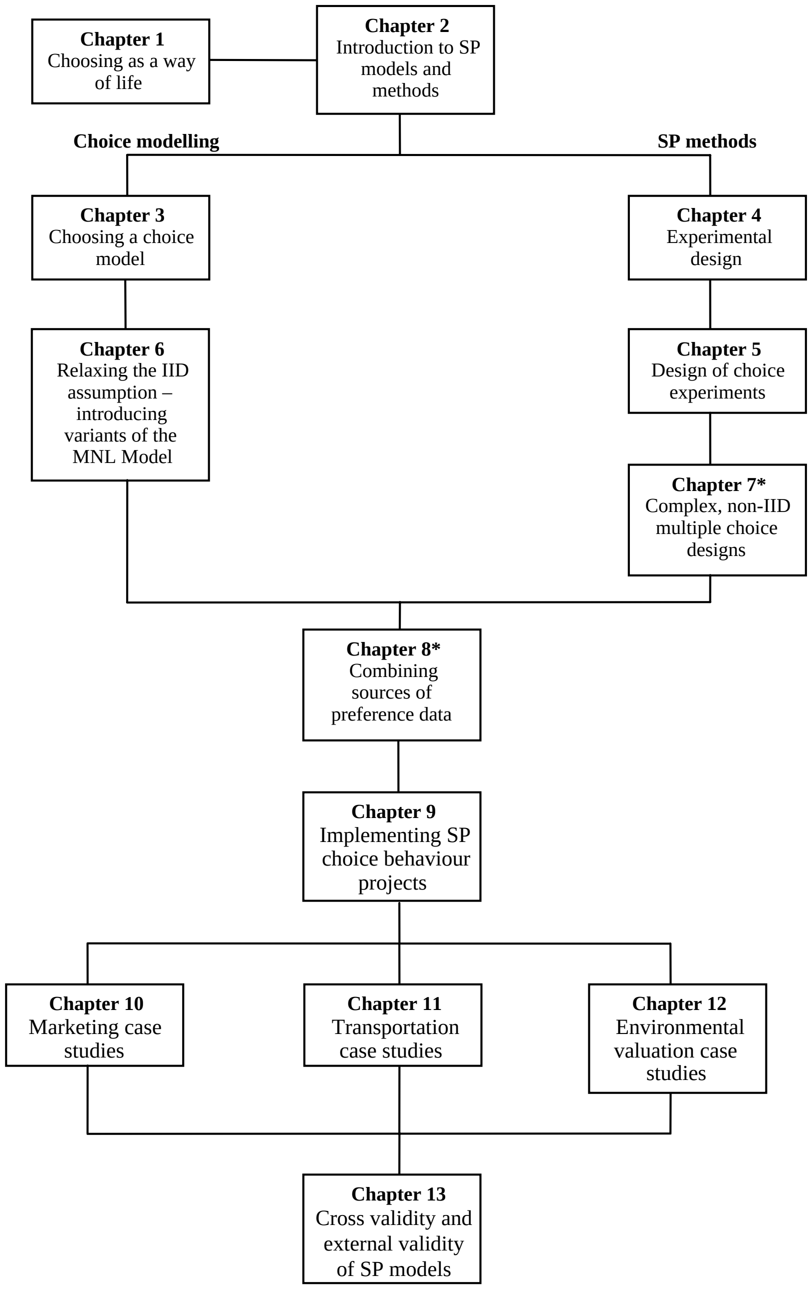

Figure 1.4 Overview of book structure (* denotes advanced material)

The chapters constituting the methodological component of the book are further subdivided (see figure 1.4) into (1) an introduction (chapter 2), (2) topics in choice modelling (chapters 3 and 6) and (3) experimental design for SP choice studies (chapters 4, 5 and 7). Appendix B to chapter 6 provides a catalogue of advanced choice modelling techniques, and should serve as a reference for the more advanced reader. The same can be said for chapter 7, which deals with complex designs to support estimation of the more complex choice models. Note that the advanced status of chapter 7 is denoted by an asterisk; all chapters so denoted are to be considered advanced material.

Chapter 8 is a useful how-to for students, researchers and practitioners interested in the combining of multiple data sources. Since this topic may not be of interest to everyone, it is designed as stand-alone material that can be accessed as need arises. Chapter 9, on the other hand, is intended as a primer on how to design and implement SP choice studies; after some overview considerations, a case study is followed through from conception to model estimation. Most readers should find this material useful.

Depending upon one's profession, one of the three application chapters should be of greater relevance (chapter 10 for marketing, 11 for transportation and 12 for environmental valuation). However, we strongly urge readers to study all three chapters because each deals with different aspects of preference elicitation and policy analysis that every choice modeller should be acquainted with.

The question of how good SP methods are at capturing 'real' preferences often arises in both academic and commercial applications. Some disciplines and individuals, in fact, have a strong bias against SP methods due to the perception that preferences elicited in hypothetical settings must be reflecting artificial preferences generated by the respondent 'on the spot', so to speak; these disciplines rely strongly on revealed preference, or RP, choices to infer preferences. In chapter 9 we discuss many of the things the SP practitioner should do to safeguard against real biases that can affect an SP choice study, but in chapter 13 we address directly the issue of the external validity of SP methods. We show how SP and RP preference elicitations can be compared using the methods of chapter 8 and other, less formal, methods. Practically speaking, we show through a significant number of examples that SP and RP preferences seem to match up surprisingly well in different choice contexts, cultures and time periods.

We now take a more detailed look at the book's contents.

1.4.2 Detailed description of chapters

Chapter 2 provides an introduction to alternative types of data available for studying choices. The particular emphasis is on the distinction between data representing choices in observed markets and data created through design to study new responses in real and potential markets. Another important distinction is the nature of the response metric (i.e., ratio, interval, ordinal and nominal) and the meaning of such responses as guided by the theoretical antecedents from axiomatic utility theory (Keeney and Raiffa 1976), order-level axiomatic theory (Luce and Suppes 1965), information integration theory (Anderson 1981) and random utility theory (RUT). This book adopts RUT as the theoretical framework for studying human behaviour and explaining choice behaviour. In contrast, some of the antecedents, such as axiomatic utility theory, are heavily focused on a theory about numbers and measurement.

One important and often not realised strength of the random utility theoretic approach is that it can study choice behaviour with choice responses obtained from any of the available response metrics. To be consistent with random utility theory, one data metric (e.g., an interval scaled rating) must be able to be transformed to a weaker ordering (e.g., an ordinal scale where the highest ranked = chosen (1) vs the rest = non-chosen (0)), and when re-analysed, produce statistically equivalent results up to a scale transformation (see chapter 9). This is known as the principle of invariance over any arbitrary monotonic transformation of the data. Only if this principle is satisfied can we accept the behavioural validity of stronger ordered response data such as ranking and ratings.

Chapter 3 develops the behavioural framework within which revealed and stated choices are modelled. Specifically, the idea of random utility maximisation is introduced, and used as the theoretical context in which to derive a family of estimable discrete-choice models. We devote time to a formal derivation of one of the most basic discrete-choice models, the multinomial logit (MNL) model, the 'workhorse' of choice models. Having grasped the behavioural and econometric properties of the MNL model, including possible ranges of policy outputs such as direct and cross share elasticities, probability predictions, marginal rates of substitution between pairs of attributes, we are ready in later chapters (especially chapter 6) to relax some of the strong assumptions supporting the relatively simple (and often robust) MNL model, in order to obtain gains in empirical validity. The majority of the enhancements to the MNL specification discussed in this book are associated with properties of the variances and covariances of the unobserved influences on choice, and the distribution of taste weights or parameters associated with the observed attributes defining sources of indirect utility.

Chapter 4 is the kernel of our presentation of experimental designs, the construct used to develop an empirical data framework within which to study choices. Agents consider combinations of attributes and associated levels across a set of alternatives in a fixed or varying choice set, and make choices. The analytical toolkit used to design experiments is presented in chapter 4 in some detail. Factorial designs, fractional factorials, design coding, main effects plans and orthogonality are some of the essential concepts that have to be understood in order to progress to the design of choice experiments with appropriate statistical properties. Without them, the analyst may be unable to study the full complexity of agent choice, unravelling the many sources of variability in behaviour.

Researchers studying choice processes soon come to realise how complicated the design of choice experiments is and how tempting it becomes to simplify experiments at the high risk of limiting the power of the choice instrument in explaining sources of behavioural variability. Confoundment of influences on choice behaviour is an often occurring theme in stated choice modelling, in large part attributable to poor experimental design. Some of the candidates of poor design include limited selection of attributes and levels, and selection of a fraction from a full factorial, which prevents uncorrelated testing of non-linear effects such as quadratic and two-way interactions amongst attributes potentially influencing choice. The accumulated experience of the authors is imparted in the book through many practical suggestions on the balance between parsimony and complexity necessary to provide behavioural realism in choice modelling. This starts with the quality of the data input into the modelling process. Choice experiments are discussed in detail in chapter 5. They provide the richest form of behavioural data for studying the phenomenon of choice, in almost any application context. An example of a choice experiment is given in figure 1.5. A more complex choice experiment is shown in appendix A1.

Chapters 1–5 provide sufficient material to enable the reader to design a choice experiment, collect the data and estimate a basic choice model. All of the major

Say a local travel agency has contacted you and told you about the three vacation packages below. Assuming that both you and your spouse would have time available to take a vacation together in the near future, please indicate your most preferred vacation option or whether you'd rather stay home.

PACKAGE	Package A	Package B	Package C	Stay
Type of Vacation				
Location	Large urban area	Mountain resort	Ocean side resort	
Duration	Weekend	One week	Two weeks	
Distance From Home	1500 miles	1000 miles	300 miles	
Amenities and Activities	Sightseeing Theater Restaurants	Hiking Horse riding Lake swimming	Beach activities Diving lessons Parasailing	
Distance to nearest urban area of 300,000 people or more		10 miles	100 miles	
Travel Arrangements				
Air travel cost (per person, round trip)	$400	$350	$300	
Accommodations				
Hotel (per night, double occupancy)	$120	$150	$75	
Quality of hotel restaurant or nearest other restaurant	**	***	*	
Which package would you and your spouse choose for your next vacation together, or would both of you rather stay at home if these were the only options available? (✓only one)	A ❑1	B ❑2	C ❑3	Stay home ❑4

Figure 1.5 Example of a choice experiment

behavioural response outputs are deliverable from this model, such as choice elasticities, marginal rates of substitution between attributes as empirical measures of valuation of attributes in utility or dollar units (the latter possible if one of the attributes is measured in dollars), and aggregate predictions of choosing each alternative in a choice set.

The multinomial logit model remains the most popular choice modelling framework for the great majority of practitioners, for some very convincing reasons. Amongst these are:

- its simplicity in estimation – the solution set of estimated parameters is unique (there is only one set of globally optimal parameters),
- the model's closed-form specification, which enables easy implementation of predictive tests of changing market shares in response to scenarios of changing levels of attributes without complex evaluation of integrals,
- the speed of delivering 'good' or 'acceptable' models on the accepted tests of model performance (i.e., overall goodness of fit, *t*-statistics for the parameters of each attribute, and correct signs of parameters),
- accessible and easy to use packaged estimation software, and,
- where one has very rich and highly disaggregate data on attributes of alternatives and agents, the model is often very robust (in terms of prediction accuracy) to violation of the very strong behavioural assumptions imposed on the profile of the unobserved effects, namely that they are independently and identically distributed (IID) amongst the alternatives in the choice set.

These appealing features of the multinomial logit model are impressive and are not lightly given up.

However, the many years of modelling of discrete choices has produced many examples of applied choice problems in which the violation of the IID condition is sufficiently serious to over or under predict choice shares, elasticities and marginal rates of substitution between attributes. Chapter 6 introduces the set of models that have been proposed in the literature as offering behaviourally richer interpretations of the choice process. At the centre of these alternative choice models are degrees of relaxation of the IID assumption.

IID implies that the variances associated with the component of a random utility expression describing each alternative (capturing all of the *unobserved* influences on choice) are identical, and that these unobserved effects are not correlated between all pairs of alternatives. If we have three alternatives, this can be shown as a 3 by 3 variance–covariance matrix (usually just referred to as a covariance matrix) with 3 variances (the diagonal elements) and $J^2 - J$ covariances (the off-diagonal elements):

$$\begin{bmatrix} \sigma^2 & 0 & 0 \\ 0 & \sigma^2 & 0 \\ 0 & 0 & \sigma^2 \end{bmatrix}.$$

The most general variance–covariance matrix allows all elements to be unique (or free) as presented by the following matrix for three alternatives:

$$\begin{bmatrix} \sigma_{11}^2 & \sigma_{12}^2 & \sigma_{13}^2 \\ \sigma_{21}^2 & \sigma_{22}^2 & \sigma_{23}^2 \\ \sigma_{31}^2 & \sigma_{32}^2 & \sigma_{33}^2 \end{bmatrix}.$$

There are $J^*(J-1)/2$ unique covariance elements in the above matrix. For example, the second element in row 1 equals the second element in column 1. The multinomial probit model (MNP) and the mixed logit (or random parameter logit) (ML, RPL) models are examples of discrete-choice models that can test for the possibility that pairs of alternatives in the choice set are correlated to varying degrees. For example, a bus and a train may have a common unobserved attribute (e.g., comfort) which makes them more similar (i.e., more correlated) than either is to the car. These choice models can also allow for differences in variances of the unobserved effects. For example, the influence of reliability (assumed to be important but not measured) in the choice of transport mode is such that it varies much more across the sample with respect to the utility of bus than train and car. For identification requirements, some covariance and variance elements are set equal to zero or one.

When we relax only the MNL's assumption of equal or constant variance, then we have a model called the heteroscedastic logit model (HL), discussed in detail in chapter 6 (appendix B). It is also referred to as the heteroscedastic extreme value (HEV) model. The covariance matrix has zero valued off-diagonal elements and uniquely subscripted diagonal elements:

$$\begin{bmatrix} \sigma_{11}^2 & 0 & 0 \\ 0 & \sigma_{22}^2 & 0 \\ 0 & 0 & \sigma_{33}^2 \end{bmatrix}.$$

The degree of estimation complexity increases rapidly as one moves away from MNL and increasingly relaxes assumptions on the main and off-diagonals of the variance–covariance matrix. The most popular non-IID model is called the nested logit (NL) model. It relaxes the severity of the MNL condition between subsets of alternatives, but preserves the IID condition across alternatives within each nested subset, which we henceforth refer to as IID within a partition. The popularity of the NL model stems from its inherent similarity to the MNL model. It is essentially a set of hierarchical MNL models, linked by a set of conditional relationships. For example, we might have six alternatives, three of them being public transport modes (train, bus, ferry – called the *a*-set) and three being car modes (drive alone, ride share and taxi – called the *b*-set). The NL model is structured such that the model predicts the probability of choosing each of the public transport modes conditional on choosing public transport. It also predicts the probability of choosing each car mode conditional on choosing car. Then the model predicts the probability of choosing car and public transport (called the c-set):

$$\begin{bmatrix} \sigma_a^2 & 0 & 0 \\ 0 & \sigma_a^2 & 0 \\ 0 & 0 & \sigma_a^2 \end{bmatrix} \begin{bmatrix} \sigma_b^2 & 0 & 0 \\ 0 & \sigma_b^2 & 0 \\ 0 & 0 & \sigma_b^2 \end{bmatrix} \begin{bmatrix} \sigma_c^2 & 0 \\ 0 & \sigma_c^2 \end{bmatrix}.$$

Since each of the 'partitions' in the NL model are of the MNL form, they each display the IID condition between the alternatives within a partition (e.g., the three public transport modes). However the variances are different between the partitions. Furthermore, and often not appreciated, some correlation exists between alternatives within a nest owing to the common linkage with an upper-level alternative. For example, there are some attributes of buses and trains that might be common owing to both being forms of public transport. Thus the combination of the conditional choice of a public transport mode and the marginal choice of public transport invokes a correlation between the alternatives within a partition. Chapter 6 shows how this occurs, despite the fact that all the covariances at the conditional level (i.e., the a-set above) are zero.

The possibility of violation of the IID condition translates into requirements for the design of choice experiments. Chapter 5 assumes that the model form is consonant with the IID assumption, and hence that certain relationships between alternatives in the design can be simplified. If behavioural reality is such that the possibility of correlation between alternatives and differential variances may exist, then the design of the choice experiment must be sufficiently rich to capture these extra relationships. IID designs run the risk of being unable to separate the effect of such influences. Chapter 7 addresses this issue by introducing non-IID choice designs.

One of the most important developments in stated choice methods is the combining of multiple preference data drawn from either the same or different samples. The opportunity to draw on the richness of multiple data sources while hopefully minimising the impact of the less-appealing aspects of particular types of data has spawned a growing interest in how data can be combined within the framework of random utility theory and discrete-choice models. Given the importance of this topic, chapter 8 is devoted entirely to showing how data can be combined while satisfying the behavioural and econometric properties of the set of discrete-choice models. The breakthrough is the recognition that preference data sources may differ primarily in the variance (and possibly covariance) content of the information captured by the random component of utility. If we can identify the differences in variability and rescale one data set relative to another to satisfy the covariance condition, then we can (non-naively) pool or combine data sets and enrich the behavioural choice analysis.

The popular enrichment strategy centres on combining revealed preference (RP) and stated preference (SP) data, although some studies combine multiple stated preference data sets. The appeal of combining RP and SP data is based on the premise that SP data are particularly good at improving the behavioural value of the parameters representing the relative importance of attributes in influencing choice, and hence increasing the usefulness of resulting marginal rates of substitution between pairs of attributes associated with an alternative. RP data, however, are more useful in predicting behavioural response in real markets in which new alternatives are introduced or existing alternatives are evaluated at different attribute levels. Combined models can rely on parameters imported from the SP component for the observed attributes, except the alternative-specific constants (ASCs) of existing alternatives. These ASCs should be aligned to actual market shares in the existing (or base) market; hence, the SP model stated choice shares are of no value and actually misleading (since they reflect the average of conditions imposed by the experiment, not those of the real market). This nullifies the predictive value of a stand-alone, uncalibrated SP model. It is extremely unlikely that the stated choice shares will match the market shares for a sampled individual (especially when new alternatives are introduced) and very unlikely for the sample as a whole. Thus the appeal of joint RP–SP models to service a number of application objectives.

Chapters 1–8 provide the reader with a large number of tools to design a choice experiment and estimate a discrete-choice model. The translation of this body of theory into action, however, often remains a challenge. Chapter 9 is positioned in the book to bring together the many elements of a complete empirical study in a way that reveals some of the 'hidden' features of studies that are essential to their efficient and effective implementation. In many ways this chapter is the most important in bringing all the pieces together, and provides a very useful prelude to chapters 10–12, which present examples of applications in transportation, marketing and environmental sciences.

We expect that this book will provide a useful framework for the study of discrete-choice modelling as well as choice behaviour. We are hopeful that it will be a valuable reference source for many in the public sector, private industry, private consultancies and academia who have discovered the great richness offered by stated choice methods in understanding agent behaviour and in predicting responses to future new opportunities. We know that the methods are popular. What we sincerely hope is that this book will assist in improving the practitioner's knowledge of the methods so that they are used in a scientific and rigorous way.

Appendix A1 Choosing a residential telecommunications bundle

In the future there will be competition for all types of telecommunications services. In this section, we would like you to consider some hypothetical market situations where such competition exists. Assume for each situation that the competitors and features shown are the only choices available to you. For each situation, compare the possible range of services offered by each company and choose which type of services you would select from each company.

Please note, if you choose two or more services from the same company, you may qualify for a bundle discount. This bundle discount is a percentage off your total bill from that company.

*We have enclosed a **glossary** to explain the features that are included in the packages offered. Please take a few minutes to read the glossary before completing this section. The following example will show you how to complete this task.*

EXAMPLE:

Step 1: Compare the features offered by each of the five companies.

FEATURES	Bell South	Sprint	AT&T	NYNEX	GTE	
LOCAL SERVICE						
Flat Rate	$12.00	$14.00			$12.00	
LONG DISTANCE SERVICE						
Fee		$0.15 peak - $0.12 off peak	$0.20 peak - $0.16 off peak	$0.15 peak - $0.12 off peak		
CELLULAR SERVICE						
Monthly Service Charge	$20.00	$40.00	$40.00	$20.00	$40.00	
Free Minutes	30 minutes	60 minutes	30 minutes	30 minutes	30 minutes	
Home Air Time Charges	$0.45	$0.45	$0.65	$0.45	$0.65	
Roaming Charges	$0.45	$0.45	$1.00	$0.45	$1.00	
"Rounding" of Charged Air Time	Nearest minute	No rounding (exact)	No rounding (exact)	Nearest minute	No rounding (exact)	
Free Off Peak Minutes	Weekends free	Weekends not free	Weekends free	Weekends free	Weekends free	
DISCOUNTS AND BILLING						
Multiple Service Discounts if 2 or More Services	10% off total bill	5% off total bill	10% off total bill	5% off total bill	5% off total bill	
Billing	Separate bills per service	Separate bills per service	Separate bills per service	Combined, single bill	Combine[illegible]	
Which provider would you choose or remain with for your residential services? *(check one box in each row)*						
a. Local Service (✓ *one only*)	☑ 1	☐ 2	N/A	N/A	☐ 5	
b. Long Distance Service (✓ *one only*)	N/A	☑ 2	☐ 3	☐ 4	N/A	None
c. Cellular Service (✓ *one only*)	☐ 1	☐ 2	☐ 3	☑ 4	☐ 5	☐ 6

Step 2: Indicate which company you would choose for each service by checking one box in each row.

Figure A1.1 Choosing a residential telecommunications bundle