1 Choosing as a way of life

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

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

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

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

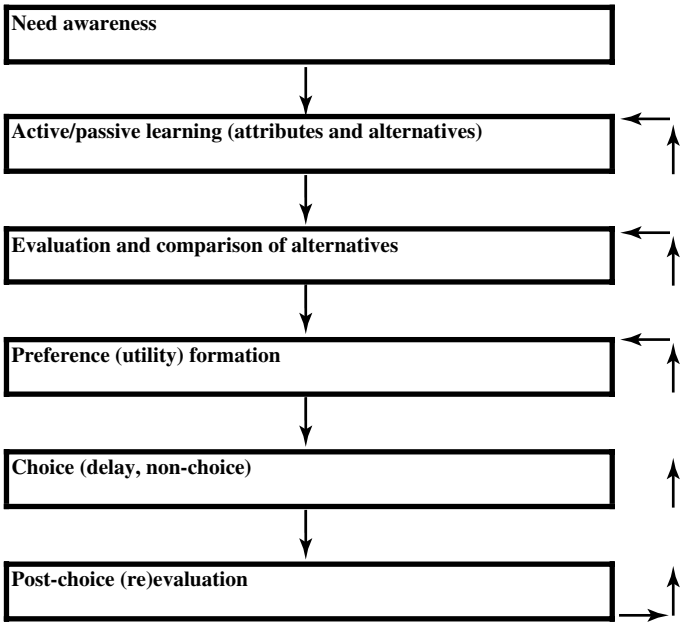

Figure 1.1 Overview of the consumer's choice process

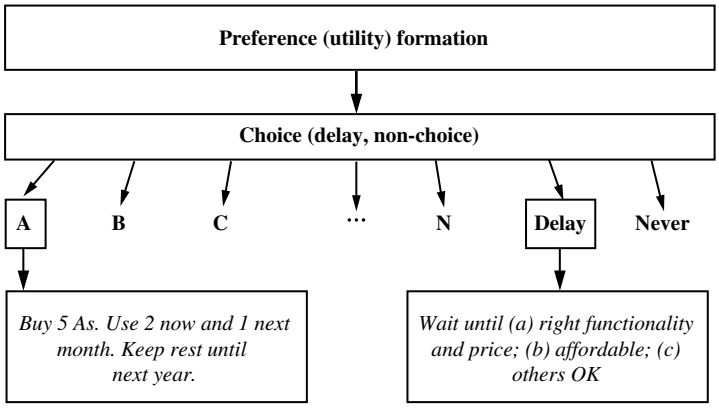

Figure 1.2 Complex decision making and the choice process

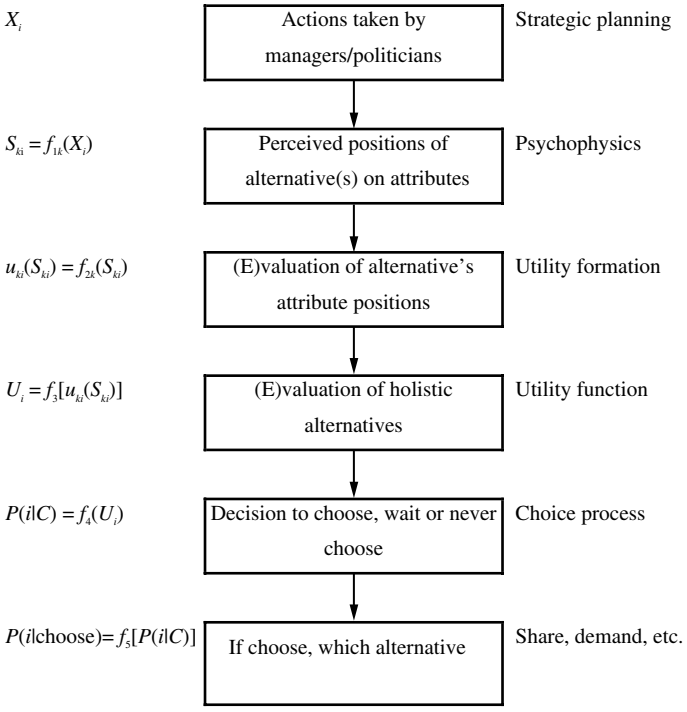

Figure 1.3 Functional relationships implied by the framework

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).