BOUNDED RATIONAL CHOICE BEHAVIOUR: APPLICATIONS IN TRANSPORT

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EDITED BY

SOORA RASOULI

Urban Planning Group, Eindhoven University of Technology, Eindhoven, The Netherlands

HARRY TIMMERMANS

Urban Planning Group, Eindhoven University of Technology, Eindhoven, The Netherlands

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List of Contributors

Theo Arentze	Urban Planning Group, Eindhoven University of Technology, Eindhoven, The Netherlands
Erel Avineri	Engineering and Management of Infrastructure Systems, ACITRAL – Afeka Center for Infrastructure, Transportation and Logistic, Afeka – Tel-Aviv Academic College of Engineering, Tel Aviv, Israel
Eran Ben-Elia	Gurion University of the Negev, Department of Geography and Environmental Development, Beer-Sheva, Israel
Xiqun Chen	Department of Civil and Environmental Engineering, University of Maryland, College Park, MD, USA
Caspar G. Chorus	Faculty of Technology, Policy and Management, Delft University of Technology, Delft, The Netherlands
Andrew T. Collins	Institute of Transport and Logistics Studies, The University of Sydney Business School, The University of Sydney, Sydney, Australia
Benedict G. C. Dellaert	Department of Business Economics, Erasmus School of Economics, Erasmus University Rotterdam, Rotterdam, The Netherlands
Ke Han	Department of Civil and Environmental Engineering, Imperial College London, London, UK
David A. Hensher	Institute of Transport and Logistics Studies, The University of Sydney Business School, The University of Sydney, Sydney, Australia

Oliver Horeni	Verkehrsverbund Oberelbe Gmb, Dresden, Germany
Stephane Hess	Institute for Transport Studies, University of Leeds, Leeds, UK
Davy Janssens	Transportation Research Institute, Hasselt University, Diepenbeek, Belgium
Ifigenia Psarra	Urban Planning Group, Eindhoven University of Technology, Eindhoven, The Netherlands
Soora Rasouli	Urban Planning Group, Eindhoven University of Technology, Eindhoven, The Netherlands
WY Szeto	Department of Civil Engineering, The University of Hong Kong, Hong Kong
Harry Timmermans	Urban Planning Group, Eindhoven University of Technology, Eindhoven, The Netherlands
Yi Wang	Department of Civil Engineering, The University of Hong Kong, Hong Kong
Geert Wets	Transportation Research Institute, Hasselt University, Diepenbeek, Belgium
Chenfeng Xiong	Department of Civil and Environmental Engineering, University of Maryland, College Park, MD, USA
Lei Zhang	Department of Civil and Environmental Engineering, University of Maryland, College Park, MD, USA
Junyi Zhang	Graduate School for International Development and Cooperation, Hiroshima University, Higashi Hiroshima, Japan
Wei Zhu	Department of Urban Planning, Tongji University, Shanghai, China

Preface

The development of scientific disciplines has all the properties of man-made artificial systems. Although one would expect that scientific evidence is the main driver of the survival and perseverance of theories and models, academic networks are institutionalised in terms of journals, conferences and other means of dissemination. Quality tends to be peer-reviewed, but the process is subjective or inter-subjective at best. Like in any social system, highly respected scholars serve as sources of inspiration, but at the same time tend to be the gatekeepers of the historical development of the discipline and acceptance standards. For very good reasons, new approaches are typically critically assessed under much or too much scrutiny, implying they may not receive the attention they deserve. There are signs of self-selection as chances of acceptance may decrease if one deviates too much from the state of the art. Incremental contributions tend to be applauded; divergent views need more convincing.

Although the transport community is known for its balance between accumulative research within long-standing modelling approaches, supported and sustained by continuous training and dissemination practices, and constructive openness to new ideas, some fundamental foundations of transport research were largely left unchallenged or were never put on the agenda for decades. The notion of equilibrium and the principle of rational choice behaviour have been the cornerstones of the disciplines for the last 40 years. Without any doubt, these concepts have played a pivotal role in the development of the models that have become commonly used in transportation planning practice. In turn, accepted practice cannot be disentangled from these basic principles.

At the same time, however, the principle of fully rational behaviour lacks behavioural realism. Nevertheless, compared to other disciplines, attempts to explore the possibilities of formulating alternative models of activity-travel behaviour, derived from principles of bounded rationality, have been limited in number in the travel behaviour community. In part, this may be because transportation is primarily an applied engineering science, and as such less concerned with more fundamental explanations of observed behaviour. However, the very nature of the decision-making processes underlying activity-travel behaviour, characterised by a relatively stable of antecedent conditions and instrumental in kind, may not need a more subtle and varied set of behavioural principles and mechanisms.

In any case, although models of bounded rationality have been around in travel behaviour research since its inception, they never have played a central role in this research community. This book, based on a special session organised at the Transportation Research Board Annual Meeting and subsequent invited chapters, represents an attempt to put the spotlight on promising models of bounded rationality. There are several reasons why these models should be put on the centre stage. First, we have the feeling that conventional theories and discrete choice models, based on principles of fully rational behaviour have entered the last stage of their lifecycle. They have fully matured and there is little evidence of much further progress. Second, the application of models of transport demand forecasting has gradually shifted from long-term investment in infrastructure policy decisions to short-term transport management decisions. It implies a refocusing of modelling approaches on concepts such as uncertainty, adaptation and inertia, which do not particularly lend themselves the basic premises of classic economic theories. Third, choice behaviour itself is changing in the sense that increasingly more transport-related choices have become instantaneous choices made under time pressure. It changes the very nature of the underlying decision-making process and may necessitate different modelling frameworks. Fourth, the still rapidly increasing computer power and availability of varied, real time data sets in principle no longer limits to the specification and conceptual richness of models.

This incentive to focus attention to models of bounded rationality does not reflect any claim that such models are necessarily better than conventional utility-maximising models. Our position is that the relevance of any model depends on the processes that it is supposed to represent and how much value is attached to face and construct validity versus its predictive performance. Ultimately, the transportation and travel behaviour community is served when systematic model comparisons are made and debate challenges the limitations of any particular model as opposed to uncritically cherishing its merits. The challenge is to develop models of bounded rationality with equal rigour and if that turns out impossible to discuss the implications for underlying methodological issues. We trust that this book contains sufficient food for thought and will contribute to additional future work on making models of bounded rationality full competitors of our currently dominant models.

Soora Rasouli and Harry Timmermans
Eindhoven, August 2014

Frontiers in Modelling Bounded Rationality in Travel Behaviour Research: Introduction to the Collection of Chapters

The core business of transportation planners and engineers is to design, engineer and maintain infrastructure and transportation policies that reflect the needs of people and firms, meet particular norms and costs requirements and achieve particular societal objectives related to the environment (noise, emissions, etc.). The assessment of these design and policies requires travel demand forecasting models and models that predict traveller response to changing land use and transportation systems. Behavioural forecasts can then be turned into the performance indicators that are deemed relevant to evaluate a design or policy.

It is no surprise, therefore, that in light of the relevance of travel demand forecasting models in design processes transportation research has a rich history in developing and applying various types of travel forecasting models. For long, the four-step model has dominated travel demand forecasting. This approach predicts travel demand according to four separate and independent steps: trip generation, trip distribution, transport mode choice and trip assignment. More recently, several types of cross-sectional activity-based models of travel demand have gradually replaced the four-step model in academic research (Rasouli & Timmermans, 2014a). Practice has followed, although the rate of dissemination of activity-based models varies considerably from country to country. On balance, at this moment in time, the four-step models still dominate transportation practice, while academia has moved to develop the next generation of activity-based models of travel demand: dynamic activity-based models.

Zooming in on the kind of models that underlie these competing approaches, the trip distribution module of four-step models has traditionally been based on production-constrained or doubly-constrained spatial interaction models. Basically, production-constrained models assume that the probability of a trip arriving at a particular destination is proportional to the attractiveness of the destination, negatively proportional to some travel distance or travel costs function and negatively proportional to the sum of attractiveness/impedance ratios of competing destinations. Doubly constrained models are based on the same set of assumptions, but are scaled such that both the production and attraction of trips for all origins and all destinations are equal to the observed total number of trips departing from the origins and arriving at the destinations. Many different specifications of the attractiveness and deterrence function exist, but a detailed discussion of the development of spatial interaction models is beyond the scope. Useful introductions and reviews of spatial interaction models can be found in Hayes and Fortheringham (1984) and O'Kelly (2009).

One of the criticisms of four-step models, and consequently against spatial interaction models, concerned their lack of behavioural foundations. The models were copied from physics and represent in statistical terms macroscopic aggregate relationships between spatial units (zones, districts). Although the mathematical expressions have been given various economic interpretations (e.g. Anderson, 2011), zones do not make any decisions, and the total number of trips is not the outcome of an individual travel decision. Thus, spatial interaction models describe regularities in aggregated decision outcomes of individuals, not the decisions of individuals themselves.

Based on the argument that models capturing individual and household decisions processes and choice behaviour are superior forecasting tools compared to models that describe statistical regularities in aggregate distributions, developments in categorical data analysis led to the formulation of models of individual choice behaviour. The multinomial logit model soon became the benchmark in modelling transport mode, destination and route choice decisions. Many more advanced discrete choice models followed to relax the limiting assumptions underlying the MNL model, allowing for substitution effects. Although it should be noted that the mathematical expression of the MNL can logically be derived from several different, even fundamentally conflicting, theoretical constructs, the MNL model and many of its variants have been predominantly linked to random utility theory.

Random utility theory assumes that individuals derive a utility from the chosen alternative. This utility consists of a deterministic part and an error term. Consequently, individuals are assumed to have stochastic preferences. In addition, they are assumed to maximise their utility when choosing a single alternative from the available options. Assumptions about the error terms of the utility functions then, *ceteris paribus*, dictate the probability of choosing a particular alternative.

Random utility theory can be viewed as an example of rational decision-making. The term 'rational' has received multiple definitions and interpretations, but in the context of travel demand forecasting, it is commonly been used to indicate that the concept of utility maximisation refers to the best or optimal choice. Rational means that the decision-maker will systematically evaluate all available choice alternatives and select the best, based on reason (i.e. a cognitive process), from the possible choices. Models based on the principle of rationality assume that an individual will define the set of attributes that is important to the decision-making problem. Next, an individual will cognitively assess the outcomes of his possible decision for each alternative in the choice set and choose the best option. The cognitive decision-making process involves processing the various attributes and arrive at some overall judgement by integrating the evaluation of the various attributes according to some integration function. The notion of cognitive processing of attributes implies the negation of affective responses in decision-making.

Implicitly, models of rational choice behaviour assume that individuals have no limitations in processing attributes and choice alternatives. A true optimal choice can only be made if an individual has full and perfect information of all relevant attributes of all alternatives in his/her choice set. A more realistic set of assumptions, however, would state that individuals have partial, imperfect, biased cognitive representations of reality. Of course, they can still act rationally and maximise the utility based on their subjective beliefs and mental representation of reality.

On the other hand, an individual is said to demonstrate bounded rational behaviour if he/she does not systematically consider all attributes deemed relevant for the decision problem at hand, does not systematically consider all relevant choice options and/or does not choose the best choice alternative. Such simplified representation and limited processing may occur due to time budget constraints, low involvement in the decision problem, relying on habits or too high mental effort.

Choice models have been developed for decision under conditions of certainty and under conditions of uncertainty. In transportation and travel behaviour research, the vast majority of choice models have assumed that individuals have full and perfect information about the choice alternatives and their attributes. Even though attributes may be inherently uncertain, single attribute values have been used in the choice models. Only recently, the travel behaviour community has slightly increased its interest into decision-making under conditions of uncertainty. The equivalent to the random utility model of rational behaviour is the expected utility model, which is based on a similar set of assumptions and adds the assumption that individuals weigh their attribute utility with the (subjective) probability of states of the world and that they choose the alternative that provides the maximum expected utility. Because the results of many experiments violated the model predictions, several other models for decision-making under uncertainty have been advanced in economics, social psychology and decision sciences, and some of these have also found their way into travel behaviour research. Prospect theory and more recently regret theory have been most popular in this regard. A recent overview of studies based on prospect theory can be found in Li and Hensher (2011), while Rasouli and Timmermans (2014b) summarised a wider set of modelling frameworks. In the models, the notion of bounded rationality has focused on the inclusion of reference points and the curvature of the utility or value function.

We realise that a more fundamental stance on rational versus bounded rational behaviour can be taken. However, the notion of simplifying the choice task serves well to position different modelling approaches that have tried to develop models of decision-making and choice that can be viewed as alternatives to the dominantly used random utility models and their underlying premises.

This volume contains a set of chapters that describe the latest developments in a particular model or modelling approach of bounded rationality. We have organised this book into two main sections. First, models of bounded rationality for decision-making under conditions of certainty will be presented. Next, in a smaller section, the focus of attention will shift to alternatives to expected utility-maximising models of decision-making under uncertainty.

To set the stage, we provide a review of the history of models of bounded rationality in urban planning and transportation research, which has addressed choice and decision problem under certain conditions. This chapter serves to discuss modelling approaches and model specifications that are not discussed elsewhere in this book. Consequently, this chapter also allows readers to position and value the approaches and models that are discussed in the various chapters, against this earlier literature. In line with this introduction, the chapter uses the different ways of simplifying the choice problems as the organisational principle to discuss the models of bounded rationality.

Regret-based models have been developed as an alternative to classic utility-maximising models, both for conditions under certainty and uncertainty. These models are based on the premise that individuals minimise regret when choosing between alternatives. Under conditions of certainty, it implies that regret associated with a choice alternative is a function of attribute differences between the considered choice alternative and one or more other alternatives in the choice set. Another important development in choice modelling is the concept of behavioural mixing: the notion that different individuals may employ different decision rules when arriving at a choice. In the second chapter of this book, Hess and Chorus present the results of a modelling approach that combines the notion of behavioural mixing with the most recent generalised version of the random regret model, which has the random utility-maximising model, random regret minimisation model and hybrid models as special cases. Thus, their model accounts for heterogeneity in decision rules across individuals and attributes. A latent class structure is estimated, in which the classes represent different decision rules. Results support the potential value of the suggested approach.

The generalised random regret minimisation model expresses regret in terms of a function of attribute differences between choice alternatives. It has this feature in common with relative utility models, which were introduced in travel behaviour about a decade ago. It raises the question about the similarity of these modelling approaches. Zhang addresses this issue in his contribution to this volume. After discussing the motivation behind the formulation of relative utility models, the original model specification and the formulation of elaborated models, he shows how not only regret minimising models, but also other context-dependent choice models and prospect theoretic models can be accommodated in this modelling framework. Results of examples of the application of various specifications of relative utility-maximising models show that these models often outperform classic random utility-maximising models, but that overall differences in explanatory power tend to remain limited. To some extent, this may reflect the insensitivity of our current apparatus to detect differences in model performance, but it also expresses the fact that critical differences in predicted choices between different models tend to be small.

As discussed, bounded rational behaviour can be reflected in individuals simplifying the choice task by considering only a subset of attributes when making choices. Recently, advanced choice models addressing the issue of attribute non-attendance have been developed. While much of this work has been focused on information processing in stated preference and choice experiments, there is no reason to assume that similar reduction of task complexity will not be operant in real-world choice and decision-making. Collins and Hensher provide a detailed review of the historical evolution of various attribute non-attendance models that have been suggested, primarily in the transportation and in the environmental economics literature. They present and illustrate a random parameters attribute non-attendance model to simultaneously infer attribute non-attendance and handle preference heterogeneity. Using stated choice data on route choice of commuters under travel time uncertainty and one or more time and cost attributes, their results indicate that attribute non-attendance becomes more prevalent with an increasing number of attribute levels, a decreasing number of choice alternatives and an increasing number of attributes.

Zhu and Timmermans also address the problem that individuals may not consider all potentially relevant attributes when making a decision. Rather than assuming a single threshold, they define a series of successive activation levels. In addition to the use of activation thresholds, defined at the attribute levels, an overall threshold is estimated, which differentiates the choice alternatives into accepted and rejected alternatives. Different overall thresholds then represent different non-compensatory decision rules, such as disjunctive, conjunctive and lexicographic rules. For this reason, they call their model a heterogeneous decision rule framework. The probability that a particular rule will be used is a probabilistic function of mental effort, risk perception and expected outcome. This approach is unique for travel behaviour research where choices are usually modelled in terms of some performance measure of decision outcomes and not in terms of cognitive processes. Differences in mental effort occur because the different non-compensatory decision rules involve a different degree of processing the attributes. Risk perception depends on the setting of the threshold. Little mental effort may imply some opportunity costs related to the expected regret that results from making an inferior decision. Shannon's entropy measure is used to represent risk perception. Finally, expected outcome measures the extent the use of a decision rule leads to preferred outcomes. Results of applications of the model to aspect of pedestrian movement show that it represents observed data slightly better than utility-maximising multinomial logit models.

As indicated, attribute non-attendance models have been predominantly developed in the context of stated choice experiments. Although it is likely that individuals also apply simplifying decision heuristics in real-world settings, some differences between real-world decision-making and decisions in quasi-laboratory settings prevail. In stated choice experiments, subjects have to understand the experimental task, relate it to their personal decision context, process the attributes and their levels, and the choice alternatives and choice sets, and then try to apply their internalised preference structures to the reconstructed experimental task. Selectivity and representation bias may occur in this process. By contrast, when faced with a decision to be made, in real-world settings individuals need to apply their preference functions to attribute levels of the choice alternatives that are retrieved from their memory, which holds a cognitive representation of the environment, build up over time as a function of experiencing the outcomes of previous decisions and possibly other active and/or passive sources of information. Contextual circumstances, such as the degree of the involvement in the decision and the available amount of time to make the decision, will dictate the amount of retrieval from memory, leading to simple, highly reduced or quite detailed mental representations of the decision problem. In their chapter, Horeni, Arentze, Dellaert and Timmermans sketch a conceptualisation of this problem, develop a computer-based tool to measure mental representations and, based on a case study on shopping choice behaviour, provide evidence that mental representations vary significantly between individuals and choice contexts. In addition to providing a framework for attribute non-attendance and corresponding mental representations, which has been addressed mainly from a technical perspective in the literature, another key element of their approach concerns the representation of benefits and causal relationships between attributes. It suggests that in addition to heterogeneity in observed characteristics and decision rules, additional heterogeneity due to different, context-dependent mental representations of reality and the specific decision problems should be addressed in models of activity-travel behaviour.

Utility-based choice theories and models are based on the postulate that individuals derive some utility from the attribute levels of the choice alternatives and then choose the alternative that will maximise their utility. Thus, observed choice outcomes are interpreted to reflect maximum utility; it is assumed that valid preference functions can be derived from observed choices. Regardless of the question whether this claim is justified, by contrast the theoretical considerations underlying computational process models of travel behaviour highlight the notion that by making repeated choices individuals learn their environment and experience which decisions are more satisfying and which are less satisfying under a given set of circumstances. Over time, individuals are believed to develop a set of decision heuristics, which indicate which decision or action to take under a set of conditions. In principle, different formalisms can be used to represent these conditional action or decision rules. In transportation, decision tables have been predominantly used. Janssens and Wets suggest a novel and improved approach by combining commonly used decision tables and Bayesian Belief Networks. More specifically, their proposal is not to derive the decision tables from the observations as is usually done, but rather from the Bayesian network, which is built upon the original data. The potential advantage is that the model is more stable because the Bayesian network already captures the correlations among the conditions triggering the choice. The authors apply the suggested approach to the original Albatross data and find mixed results. The derived decision tree indeed turned out to be structurally more stable and less vulnerable to the variable masking problem. However, at a more detailed level, the classic decision table extraction approach has benefits.

From an activity-based perspective of travel demand, models of travel demand forecasting predict the (combined) choice of activity, travel party, destination, transport mode, departure time, activity duration and route. The limited number of studies, grounded on principles of bounded rationality, has typically examined problems of individual choice behaviour for one of these choice facets. Slightly more scholars have examined the problem of dynamic route assignment from the perspective of bounded rationality. The notion of bounded rationality in this domain of study has also been subject of varying and often too vague definitions, missing mathematical rigour. Szeto, Wang and Han deliver a good introduction to the dynamic traffic assignment, the alternative meanings of the notion of bounded rationality in this field of study and the latest developments. Bounded rationality in route choice implies that the travel times of all selected routes between the same origin-destination are all the same within some defined acceptable tolerance threshold from the minimum travel time. They present (heuristic) solution methods for this objective and discuss existence and uniqueness of solutions. Finally, an extension to the joint departure time route choice problem is discussed.

The challenge of these approaches is the find a close form mathematical specification that is consistent with the attempted behavioural principles and which at the same time can be estimated. Consequently, there are limits to these kinds of model in general, and particularly in modelling complex dynamic processes and systems. To enrich the models, some agent-based model systems of decision-making processes that are based on principles of bounded rationality have been suggested. Two of these are included in this volume. First, Psarra, Arentze and Timmermans outline an agent-based model and illustrate its properties using numerical simulations that simulate dynamic choice behaviour in response to endogenous and exogenous change. Agents learn about their environment when making choices. Consequently, agents become aware of the choice alternatives in their environment, develop choice sets and build up context-dependent cognitive representations about the attributes of the alternatives in their choice set. It leads to dynamically updated beliefs about the state of the world. Over time, if a choice alternative has not been visited forgetting is also simulated, implying that choice alternatives have different activation levels. In addition to this cognitive mechanism, agents build up affective beliefs, which are defined as a function of the discrepancy between expected and experienced utility and act on those. At the same time, agents have context-dependent aspirations, which may also change over time if after trying different behaviour they cannot be met. Endogenous change is triggered as a function of stress, which builds up if experienced utility is lower than the corresponding aspiration level. The agent-based system thus is capable of simulating very different dynamic behavioural trajectories of activity-travel behaviour, depending on the parameters setting. It will simulate the emergence of habitual behaviour from a state of complete unawareness of the environment if the agent's environment allows a balance between aspiration levels and the utility that can be derived from the environment. It may also simulation lowering of aspirations levels or a change of residential and/or job locations if the current long-term decisions do not allow achieving aspirations levels associated with their activity-travel behaviour. The model system incorporates several mechanisms that assume agents do not maximise their utility and have perfect knowledge, but rather act in a bounded rational way. The numerical simulations reported in their chapter focus on the impact of memory-activation parameters, habit strength and the strength of emotional response. Results illustrate the effect of trade-offs between past and recent emotional experiences, and between cognitive and affective responses. They indicate that higher dependence on emotional responses results in more exploration and decreasing aspiration values. Similarly, relying only on recent emotional experiences and ignoring accumulated past experiences leads to more disappointment and consequently exploratory behaviour.

Xiong, Chen and Zhang present another computational process that also departs from rationality assumptions of classic models of activity-travel behaviour by imitating travel behaviour in terms of information acquisition, learning, adaptation and decision heuristics. Similar to Psarra et al., agents learn by acquiring information from different sources. Travel experiences reinforce positive behaviour and not visiting particular location leads to decay and forgetting of alternatives. An interesting feature of their model is that information acquisition and other mental efforts are explicitly modelled in terms of perceived search costs that are judged against subjective search gains to direct search behaviour. Agents apply a set of heuristics to activate their knowledge and identify alternatives. Principles of Bayesian updating are used to simulate learning and forgetting based on the recentness and representativeness of past experiences. Prior beliefs are assumed to follow a Dirichlet distribution. Different production rules, derived by applying various machine learning algorithms, are used to direct short-term departure time and route search, while long-term travel mode search is simulated using a hidden Markov process. The behaviour of the computation process model is illustrated for a small hypothetical network using stated adaptation data. Results witness the richness of the model in the sense that quite different dynamics can be simulated. Both these computational process models, however, also clearly demonstrate that the enhanced richness of the models and the inclusion of various process mechanism also imply that the impact of any particular variable cannot be directly assessed. Computational process models imply different causation regimes and may lead to quite different dynamics (from chaotic behaviour, via bifurcations to habitual behaviour) dependent on parameter settings.

All above chapters relate to choice behaviour under conditions of certainty. Although it should be noted that relative utility and regret theory have also been developed for decisions under conditions of risk and uncertainty and that the theoretical foundations of particularly regret theory may appear stronger for that case, the number of studies in travel behaviour research applying these models to decision-making under risk and uncertainty is very limited indeed (Rasouli & Timmermans, 2014b). The equivalent of utility maximisation for the case of decision-making under conditions of uncertainty is maximisation of expected utility. Interestingly, because in many different fields of study, a huge body of empirical evidence has accumulated showing that the principle of maximisation of expected utility is often not congruent with human decision-making, it is often viewed as a normative theory of decision-making and alternative descriptive theories and models have been suggested. The most widely applied theory in this context is (cumulative) prospect theory. It asserts that outcomes of decision-making processes depend on the framing of the decision problem, that individuals differentiate between gains and losses and that risk attitudes work out differently in these two regimes. Consequently, models have a reference point and need non-linear specifications to account for the typical violations of expected utility maximisation that have been documented in the literature. Seminal work on prospect theory in travel behaviour can be traced back to Avineri and his co-authors in their attempts to operationalise the key concepts of prospect theory in a travel behaviour context and judge the relevance of prospect theory for route choice departure choice and other choice problems in travel behaviour research. In this book, Avineri and Ben-Elia provide an excellent overview of the theoretical foundations of (cumulative) prospect theory, discuss the model specifications that have been applied and give a detailed account of the design and results of accumulated research in travel behaviour research that is based on these theoretical foundations that deviate from rational behaviour under conditions of risk and uncertainty. The potential of prospect theory for particular decision-making in travel behaviour research is clearly articulated, but limitations are also identified, leading to further research needs.

This collection of chapters represents the frontier in travel behaviour research in endeavours to increase the behavioural realism of our model apparatus that is used to predict transport demand. The different approaches and models witness, all in their own right, how principles of bounded rationality can be incorporated into theories and models of choice and decision-making, both under conditions of certainty and uncertainty, as they are related to the different facets of activity-travel behaviour. These contributions, however, also evidence that increased realism tends to come with increased complexity. The number of parameters tends to increase. Moreover, while conventional models come with performance indicators such as willingness to pay and consumer surplus and straightforward equations for calculating (cross-)elasticities, for some of the models discussed in this volume, equivalent equations will be difficult or impossible to generate. Moreover, as discussed, some of these models of bounded rationality violate properties of classic models such as regularity, which the travel behaviour research community seems to have embraced, regardless of empirical evidence on the contrary. Furthermore, the estimation of some models of bounded rationality is far from standard, and may require dedicated software development. The lack of software to estimate a model of course should never be an excuse for not accepting or further exploring it, but it does indicate that substantial investment in the development, dissemination and discussion of alternative modelling approaches is needed.

Soora Rasouli
Harry Timmermans
Editors

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