

## Prospect Theory and Choice Behaviour Strategies: Review and Synthesis of Concepts from Social and Transport sciences

Evert Jan van de Kaa<sup>1</sup>

Faculty of Technology, Policy and Management, Delft University of Technology, NL

---

Utility Theory is commonly considered as the most useful descriptive theory of human choice behaviour. Alternative concepts are only incidentally considered. This paper reviews alternative assumptions and empirical findings about human choice behaviour. To facilitate comparison and synthesis the review starts with the proposal of a generic framework of choice behaviour. The micro-economic assumptions of Utility Theory and Prospect Theory are then mapped onto this framework. These are compared with each other and other assumptions against the background of theoretical and empirical findings from behavioural economics, several other social disciplines and transport sciences. An extension of Prospect Theory with assumptions about the valuation of attributes and the employment of different decision rules yields a functional concept of choice behaviour that is able to describe most of the reviewed empirical findings to a larger extent than Utility Theory.

*Keywords:* Attribute processing rules; Decision rules; Prospect Theory; Travel choice behaviour; Utility Theory

---

### 1. Introduction

To date Utility Theory (UT) has been the most widely used and generally accepted paradigm for the understanding of human behaviour in transport. This quickly becomes evident when browsing through transport journals or conference proceedings that deal with human behaviour. UT was originally developed as a normative-rational theory (i.e. giving definite precise instructions based on reasoning) about how decision-makers should maximize their utility. However, for a long time UT has been used as a descriptive theory (i.e. a theory that approaches actual choices by assuming that the individuals behave as if they are following its theoretical assumptions). Mainstream travel behaviour research improved its descriptive quality, particularly in its Random Utility Maximization (RUM) manifestation (e.g. McFadden, 2001) for an overview. Nevertheless, over the years several scientists have disputed the descriptive quality of UT (e.g. Simon, 1955, 1978; Horowitz, 1985; Gigerenzer *et al.*, 1999).

---

<sup>1</sup> PO Box 5015, 2600 GA, Delft, The Netherlands, T: +31152781144, F: +31152782719, E: [e.j.vandekaa@tudelft.nl](mailto:e.j.vandekaa@tudelft.nl)

Several other theories about choice behaviour have been applied to travel behaviour research (e.g. Gärling *et al.*, 1998; Tertoolen *et al.*, 1998; Stern, 1999; Gärling *et al.*, 2002; Fujii and Gärling, 2003; Chorus *et al.*, 2008b). Review papers list concepts like control-theoretical 'black box' approaches, computational process models, decision tables, attitude theories and habits (e.g. Arentze and Timmermans, 2000; Stern and Richardson, 2005; Gärling and Fujii, 2006). These applications to travel research mostly address one single particular assumption or theory from the scores developed in social sciences, which is then applied by a small number of scientists in a few publications. After an early surge (e.g. Foerster, 1979; Williams and Ortúzar, 1982; Swait and Ben-Akiva, 1987), there has recently been renewed interest in the incorporation of different non-compensatory decision and/or attribute processing rules in discrete choice models (see Section 6 below).

In the social sciences in general Prospect Theory (PT) from behavioural economics may well be the most frequently encountered alternative to UT. It was originally proposed as a set of generic assumptions that offer 'an alternative account of individual decision making under risk' (Kahneman and Tversky, 1979, p. 274). PT has been extensively tested in several fields and might offer an improved description of travellers' choice behaviour. Particularly since 2002, when Kahneman received the Nobel laureate in economics, PT has been considered in several domains of travel behaviour research and is these days the most frequently applied non-utility theory in transport (see, for example, Suzuki, 2000; De Blaeij and Van Vuuren, 2003; Senbil and Kitamura, 2004; Avineri and Prashker, 2005; Michea and Polak, 2006; Hamdar *et al.*, 2008; Jou *et al.*, 2008).

Nowadays modelling travel choices is becoming more and more cross-disciplinary and classical paradigms are being increasingly called into question. There is therefore a need to draw from other disciplines and fields of research in order to improve the tools available for applied work. This paper aims to explore alternative choice concepts at the paradigmatic level. While micro-economic textbooks and articles offer concise listings of the basic assumptions<sup>2</sup> of UT (e.g. Katz and Rosen, 1999; McFadden, 2001), a similar listing of those from competing paradigms is missing. One purpose of this paper is to offer an overview of the concrete assumptions about human choice behaviour that are commonly applied in the social sciences. This overview should allow a comparison of the descriptive ability of corresponding assumptions against the background of empirical findings. Another purpose is to see whether an extension of PT with other behavioural assumptions that are at odds with those of UT might offer a theory with an improved ability to describe travel choice behaviour compared to UT and PT. If so, this could enlarge the range of theoretically explained travel behaviour and thus improve the opportunities for its understanding and prediction. Van de Kaa (2008) offers extensive foundations of the research outcomes summarized in this paper.

Following this introduction this paper is structured as follows:

- Section 2 introduces a generic framework model of human choice behaviour. It results from the functional decomposition of the function of choice behaviour into four complete and non-redundant interrelated functions: framing, judgment, evaluation-and-choice and choice behaviour strategy.
- In section 3 the assumptions of UT and PT about what people do to put these functions into operation are compiled. Both UT and PT appear feasible implementations of the framework model.

---

<sup>2</sup> I.e. premises, postulates, hypotheses and other statements about how elements of human choice behaviour can be described according to UT, PT and alternative concepts from Decision Theories and other social sciences.

- Sections 4-7 compare the assumptions of UT and PT about framing, judgment, evaluation-and-choice and choice behaviour strategy with each other and with alternative hypotheses from decision theory and other social sciences.
- In section 8 the 'best fitting' assumptions about choice behaviour as retained in the previous sections are synthesized in an Extended Prospect Theory (EPT). Successively several choice theories are compared with this EPT. EPT covers these, though only in a functional way. The section finishes with some observations on elicitation/parameter assessment and modelling.
- Section 9 offers some overall conclusions.

## 2. A functional-descriptive view on human choice behaviour

A well-balanced judgment of relevance and interrelationships of choice behaviour theories and assumptions from different sciences requires a supra-disciplinary concept of choice behaviour. This section provides an overview of the different perspectives of human choice behaviour as found in the social sciences. It starts with a definition and interpretation of the choice behaviour concept, followed by a process and functional perspective. It results in a generic functional-descriptive framework for the review of choice behaviour concepts in the following sections.

### 2.1 Human choice behaviour

Human choice behaviour is conceived here as a mental process that transforms perceptions of several optional courses of action into a choice. It is considered to cover any kind of intuitive, automatic and impulsive choice behaviour as well as conscious-deliberate decision making. It thus includes a large, heterogeneous range of processes, lasting from months for long-term, multi-alternative, multi-attribute decisions (e.g. relocation of households, vehicle ownership decisions) to split seconds for short-term choices with few alternatives and few attributes (e.g. lane-changing underway). Depending on the character and impact of the choice decision one might discern strategic, tactical and operational choice behaviour. Super fine dividing lines between these categories are not useful, as any such delineation within the continuum might rightfully be disputed. The duration, the complexity and the impact of the individual processes might better be considered as moderately correlated elements of continuums. Though the functions of these choice categories to some extent differ the same mental processes carry them out.

### 2.2 The choice behaviour process

The process that accounts for human choice behaviour consists of reasoning: 'using one's reason in forming conclusions'. It is often conceived as deliberate, conscious and logic-analytic. However, contemporary psychological theories commonly discern two 'dual' modes of reasoning. Stanovich and West (2000, p. 658-659) synthesized these modes, as described in 12 cognitive psychological theories, into a System 1: 'automatic, largely unconscious, and relatively undemanding of computational capacity' and System 2: 'encompasses the processes of analytic intelligence'. Similar more dual-process theories were proposed in many fields (e.g. Maslow, 1954; Zajonc, 1980; Mintzberg, 1989; Dijksterhuis *et al.*, 2006). Contemporary research in neuroscience corroborates this co-occurrence (e.g. Bechara *et al.*, 1997; Damasio, 2001). While System 2 may be denoted as 'cold cognition', 'rational' or 'utilitarian', System 1 is commonly called 'intuition'. Obviously this intuition covers habitual and impulsive choice behaviour as frequently discerned in transport literature (e.g. Aarts, 1996; Fujii and Gärling, 2003; Jacobsson, 2003).

Simon (e.g. 1997) considered intuition and analysis as complementary forms of thinking that are almost always present. Kahneman (2002) posited that System 2 might monitor the quality of the choice process but other findings suggest that it might rather corroborate than adjust an earlier choice (e.g. Maslow, 1954; Festinger, 1957; Svenson, 1992). Overall, Beach (1990, p. 126) might be right: 'We suspect that, as a general rule, if intuition conflicts with analysis, analysis seldom wins'. Hammond *et al.* (1987) observed that highway engineers who used their intuition made less extreme errors than when they relied on conscious analysis. Dijksterhuis *et al.* (2006) found that 'unconscious thinkers' made better choices between complex products than 'conscious thinkers' in terms of post-choice satisfaction. Many scientists from different fields found that System 1 processes play a decisive role in human choice behaviour (e.g. Stanovich and West, 1999; Schul and Mayo, 2003; Bechara and Damasio, 2005).

To summarise, there is a collective view among social scientists that two modes of reasoning exist, of which System 1 appears to be both unconscious and often dominant. This makes it impossible to develop a concept that rightfully claims to provide 'the' isomorphic<sup>3</sup> descriptive model of the human choice behaviour process. This paper, therefore, adopts a functional view as the base for its understanding and modelling rather than a process view.

### 2.3 The function of choice behaviour

Systems Theory analyses processes from a functional perspective by considering them as systems that transform inputs into outputs within an environment. The inputs of each individual choice process are perceptions of the individual's choice context and of her concurrent needs; the outputs are choices. The choice context encompasses her environment (the 'state of the world') as well as the 'state of her organism' (concurrent moods, needs, beliefs...) and thus also the character of her choice task (complexity, relevance...). The function of choice behaviour is to choose one possible course of action from a set of alternatives that, in that particular context, meets certain of the individual's concurrent needs. Limited functional decomposition (e.g. Block, 1995) into a complete set of non-redundant operations yields four mental functions:

- i. **Framing** of the perceived choice context into some reference state, choice alternatives (i.e. mental representations of possible courses of action and their expected outcomes in terms of probabilities and attributes), preferences related to the choice subject's concurrent needs, desires and goals and an aspiration level for their gratification;
- ii. **Judgment**, consisting of assessment of the sizes/characteristics of the expected outcomes (attributes and probabilities) and valuation of these probabilities and attribute characteristics.
- iii. **Evaluation-and-choice**, i.e. evaluation of relevant outcomes of alternatives (e.g. overall utilities or a rating of their preference order) and the selection, or choice, of the alternative that meets the choice criterion.
- iv. **Choice behaviour strategy**, required to coordinate the decomposed functions.

These four functions might be considered as phases of a choice process, but this does not mean that subjects follow these sequentially. At any time during the choice process an active (not necessarily conscious), context-dependent information search may be initiated resulting in adjustment of the initial input/perceptions. Accordingly, the choice behaviour strategy might be conceived as an observation at the rear rather than as the preparatory planning of a sequence of functions.

---

<sup>3</sup> I.e. equal in form, and in the nature and product of their operations (SOED, 2002).

### 2.4 A functional-descriptive choice model

Figure 1 synthesizes the functions and relationships discussed above into a framework model. It depicts choice behaviour as reactive with respect to its context, as the choice *per se* does not change the environment of the choice subject – her subsequent actions may well do, of course. This offers a generic description that covers any set of assumptions able to put the choice behaviour function into operation. It will be used in section 3 to test the completeness and consistency of operational versions of UT and PT. In sections 4-7 it will be used as a framework to evaluate findings about human choice from social sciences.

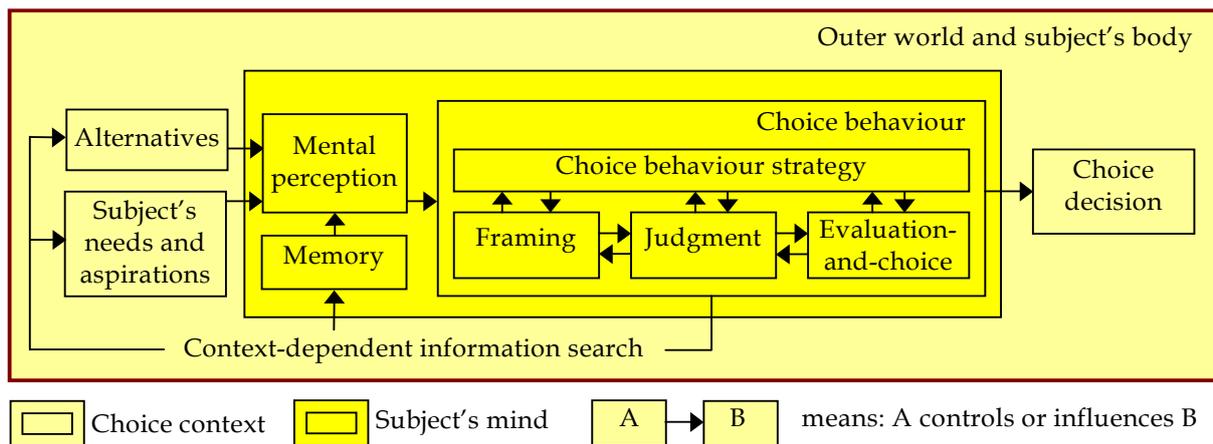


Figure 1. A functional-descriptive framework model of human choice behaviour

## 3. Assumptions of Utility Theory and Prospect Theory

This section lists the basic assumptions of UT and PT and maps them on the model depicted in Figure 1. Where required assumptions are disaggregated or completed with logical implicit assumptions. Thus the completeness and internal consistency of UT and PT are tested. Their descriptive plausibility and quality are not discussed here. One might, for example, observe that the classical normative-rational interpretation of UT<sup>4</sup> is a feasible implementation of the theory though its behavioural credibility is not particularly convincing.

### 3.1 Utility Theory

Broadly speaking three manifestations of UT may be discerned these days: Neo-Classical Theory or Consumer Theory for continuous choice options; Expected Utility Theory, an extension for the choice between probabilistic alternatives; and Random Utility Maximization (RUM), an elaboration for discrete choices that adds stochastic elements to utility. In all these theories individuals are considered to strive for the highest possible satisfaction of their needs, ordered as preferences, within their budget constraints. Further core assumptions are: temporally stable preferences that are context-independent and complete for all imaginable goods, and non-satiation of consumers: more is better. The utility of attributes of alternatives is attached to the expected state of the choice subject's assets. These and further assumptions that apply to all versions of UT may be found in microeconomic textbooks (e.g. Katz and Rosen, 1998). Several articles in economic and transport journals list most of these as well (e.g. McFadden, 2001). To

<sup>4</sup> I.e. assuming an omniscient choice subject with perfect perception, unlimited processing power etc.

complete the explicit assumptions some self-evident implicit assumptions are added to the listing of all relevant UT assumptions in Table 1.

### 3.2 Prospect Theory

PT is a descriptive theory based on findings from cognitive psychology. Kahneman and Tversky (1979, p. 274-284) posited it as a set of assumptions that offers 'an alternative account of individual decision making under risk'. Just like those of UT mentioned above they have a generic character (e.g.: in the loss domain the value of an attribute is a convex function of its level). They should not be confounded with the simplified formulations and specifications that are indispensable in the more restricted implementations used for the description and prediction of choice behaviour in concrete contexts (e.g.: in the loss domain the value of an attribute is proportionate to the attribute level raised to a power between minus one and zero). Kahneman and Tversky (1979, p. 274) initially applied PT to the choice between 'simple prospects with monetary outcomes and stated probabilities'. Later they developed restricted implementations of the constituent assumptions for the choice between prospects with certain outcomes (Tversky and Kahneman, 1991) and an unlimited number of uncertain outcomes (Tversky and Kahneman, 1992). Tversky and Kahneman called the first version 'a reference-dependent model' without classing it explicitly as PT<sup>5</sup>. They called the latter version Cumulative PT. In this paper both are included in PT as implementations of its more generic assumptions.

Van de Kaa (2004) listed the following six basic assumptions that distinguish PT from UT:

- i. Context-dependent preferences:* People's preference orders are dependent on the context of the choice situation and the way choice options are presented and perceived, 'choice is a constructive and contingent process' (Tversky and Kahneman, 1992, p. 317).
- ii. Change-oriented framing:* People frame choice options in terms of the expected change in their assets rather than on the expected state of them, 'the carriers of utility are not states (owning or not owning the wine), but changes: getting the wine or giving it up' (Kahneman, 2000, p. xiii).
- iii. Reference dependency:* 'The carriers of value are gains and losses defined relative to a reference point' (Tversky and Kahneman, 1991, p. 1039). Expected increases in satisfaction, utility or positive affect relative to some reference state<sup>6</sup> are valued as gains, decreases as losses.
- iv. Loss aversion:* losses are valued much higher than gains of equivalent size, 'the (value) function is sharply kinked at the reference point, and is loss averse - steeper for losses than for gains' (Kahneman, 2002, p. 462).
- v. Diminishing sensitivity:* 'the marginal value of both gains and losses generally decreases with their magnitude' (Kahneman and Tversky, 1979, p. 278).
- vi. Non-linear weighted probabilities:* individuals over-weight outcomes with low probabilities and under-weight outcomes with high probabilities: 'Over-weighting of small probabilities contributes to the popularity of both lotteries and insurance. Under-weighting of high probabilities contributes both to the prevalence of risk aversion in choices between probable

---

<sup>5</sup> It is occasionally called Reference-Dependent Theory (e.g. Bateman *et al.*, 1997; De Borger and Fosgerau, 2008) while others included it in PT (e.g. List, 2004; Plott and Zeiler, 2007).

<sup>6</sup> Kahneman and Tversky (1979) used 'reference point' for an attribute level to which gains and losses are compared as well as for a point in an indifference map that defines two attribute levels (Tversky and Kahneman, 1991). In the latter article and elsewhere they also use the 'reference state', indiscriminately or more often to denote any number of reference levels that is relevant in the considered context. In this paper the latter term is used, because it is more appropriate for choice between multi-attribute alternatives.

gains and sure things, and to the prevalence of risk seeking in choices between probable and sure losses' (Tversky and Kahneman, 1992, p. 316).

These assumptions focus on differences with UT. Right from the beginning Kahneman and Tversky adopted the utility or prospect-value maximization principle of UT. For several other functions of choice behaviour the consulted publications of PT yielded no explicit assumptions. From their treatment of indifference curves it follows, for example, that Tversky and Kahneman (1991) implicitly adopted the compensatory compounding of attribute values and the non-satiation principles. Thus, in their publications of PT they assumed compensatory value maximization, though elsewhere they seem rather ambiguous about the decision rule that should be applied to wind up the choice process. Some more 'missing' assumptions apparently correspond to the equivalent ones from UT. Others might be considered conditional or consequential to the six assumptions above. In Table 1 all explicit and implicit assumptions of PT are put next to those of UT.

### 3.3 Summary

A thorough inspection of the assumptions listed in Table 1 shows that both sets are internally consistent, complete and non-redundant implementations of the model depicted in Figure 1. They may thus be considered as models that after parameter estimation can simulate and predict choice behaviour. Though at a first glance PT and UT appear to differ in many respects, they have some main outlines in common: subjects are considered as self-interested, non-satiable utility/value maximizers and their choice behaviour strategy is deterministic and static (i.e. once a particular choice process has started there are no stochastic or time-dependent changes). From a descriptive point of view both theories have another overlap: they predict the same choice if all attributes in a choice set with certain outcomes are in the 'gain domain'. Some assumptions of UT can be conceived as constrained versions of those of PT. For instance, reference-independent framing of outcomes (UT) is equivalent to the assessment of a reference state (PT) where all attribute characteristics are valued as loss neutral. However, as many assumptions of UT and PT are at odds with each other their descriptive quality might strongly differ. Anyway, these assumptions of UT and PT seem useful defaults in a re-examination of findings from decision theory and other social sciences about the functions of human choice behaviour.

## 4. Framing

In UT framing is not explicitly considered. PT was conceptualised as a sequence of a framing or editing and an evaluation phase (Kahneman and Tversky 1979). The concepts and findings for framing are discussed here under the elements: reference state, choice alternatives, subject's needs and aspiration level.

### 4.1 Reference state

The assumption of reference-dependent framing of alternatives in travel behaviour research raises the question of what a relevant reference state might be (Avineri and Bovy, 2008). Interesting proposals may be found in the schedule delay literature about early and late arrivals where the reference-dependent valuation of travel time was proposed long before the term existed (e.g. Gaver, 1968). The literature examined revealed several other approaches that all yielded a better description of the behaviour than UT (e.g. Hess *et al.*, 2008). Several researchers apparently try to establish just one 'reference point'. However, the attribute levels of multi-attribute alternatives might be better framed as gains or losses relative to the corresponding

**Table 1. Assumptions of UT and PT in a functional-descriptive perspective.**

<b>Assumptions</b>	<b>Utility Theory</b>	<b>Prospect Theory</b>
<b>Perception</b>		
Subject's environment	<i>Complete, as it is</i>	<i>Dependent on subject's needs, recall, experience, attention, ...</i>
Subject's state	<i>Changeless</i>	<i>Dependent on subject's current mood, ease and content of recall,...</i>
<b>Framing</b>		
Reference state	Irrelevant	Expected 'no change' state of assets
Alternatives, outcomes, attributes	Complete range of expected states of assets, independent of reference state	Context-dependent range of expected changes (gains and losses) in assets, relative to reference state
Subject's needs	Non-satiable; Temporally stable, context-independent, complete preference order of all goods	Non-satiable; Preference order dependent on the context and the way in which alternatives are perceived
Aspiration level for needs gratification	Maximal ordinal utility within budget constraints	<i>Maximal decision value within budget constraints</i>
<b>Judgment</b>		
Expected attribute levels & probabilities	Rationally measured, calculated or belief-based expectations	<i>Subjective belief-based expectations, partly drawing on heuristic judgment</i>
Valuation of attribute characteristics	In commensurable medium; Independent of size and sign of changes in state of assets	<i>In commensurable medium; Diminishing sensitivity: concave for gains, convex for losses; Independent of size, dependent on sign: loss aversion</i>
Valuation of attribute importance	Subjective belief-based attribute decision weights	<i>Subjective belief-based attribute decision weights</i>
Valuation of expected probabilities	<i>Unweighted</i>	Subjective belief-based, inversely S-shaped weighted probability function
<b>Evaluation-and-choice</b>		
Comparison of multi-attribute alternatives	Alternative-wise, based on a compensatory compounded ordinal utility measure	<i>Alternative-wise, based on a single compensatory compounded decision value</i>
Choice criterion	Highest ordinal utility	<i>Highest overall decision value</i>
<b>Choice behaviour strategy</b>		
Choice of strategy	<i>Temporally stable, context and reference-independent</i>	<i>Dependent on context and the way in which alternatives are perceived</i>
Order of function completion	Conscious, rational, sequential	<i>Sequential: framing and judgment followed by evaluation and choice</i>
Successive choices in the same context	One choice behaviour strategy for all; Intrapersonal consistent/transitive choice behaviour	Interpersonal heterogeneity in framing and judgment; <i>Intrapersonal consistent choice behaviour</i>
Statements in italics: <i>implicit assumptions</i> that follow logically from the mapping of a complete list on the discerned functions.		

attribute levels of a reference state. Then, for all relevant attributes the individual's reference-state levels have to be estimated. For example, in a route choice situation where a commuter is confronted with different alternative routes with different travel time distributions, her reference state might encompass the mean travel time of her preferred route, its distribution over time and

presumably also a notion of an acceptable bandwidth of arrival times and a preferred departure time.

The endowment status of assets (i.e. whether 'things of value or use' belong in someone's possession) strongly influences the framing of the reference state (e.g. Kahneman *et al.*, 1986). It is often assumed that PT uses the actual state of assets<sup>7</sup> or *status quo* as the reference state (e.g. Chorus *et al.*, 2008a). However, Kahneman and Tversky (1979) considered that it might also be framed as an aspiration level. It is therefore better defined as the expected 'no change' state of assets of the subject if she sticks to her previous choices. Transfer of ownership to or from the decision maker may result in an instant endowment effect and a corresponding instantaneous reference shift (e.g. Tversky and Kahneman, 1991). The road pricing experiment reported by Nielsen (2004) offers a nice example of such a shift from the gain to the loss domain following the real-life endowment of 'expected saved' toll expenses before the experiment started compared to the payment of 'saved' expenses in arrears.

The fact that most individuals frame their alternatives relative to a reference state does not exclude systematic differences in the reference state that members of different subpopulations adopt in the considered context. For example, the differences in departure time choice between workers that are higher or lower in the hierarchy, and between people with fixed or flexible work start times (e.g. Wilson, 1988; Fujii and Kitamura, 2004), might well be explained by assuming corresponding differences in the adopted levels of a 'reference' preferred arrival time distribution. Intercultural differences in the framing of the reference state may also play a role, as found between Chinese and American citizens in a health insurance choice setting (Wang and Fischbeck, 2004). In a repeated choice task Schul and Mayo (2003) found that many subjects may keep on updating their reference state after experiencing the outcome of a previous choice, although others might systematically choose the most rewarding probabilistic alternative after a learning period in which they assess the frequency distributions of outcomes. Barron and Erev (2003) demonstrated the descriptive ability of a simple 'learning model' that accounted for loss aversion in successive choices with limited feedback. In a daily recurrent route choice experiment Avineri and Prashker (2006) found a distribution of traveller types that suggested such a heterogeneity in reference state adaptation which might encompass experienced travel time distributions, in connection with a more or less myopic framing of alternatives.

#### 4.2 Choice alternatives

In social sciences empirical choice behaviour is commonly studied by submitting an apparently intuitively selected choice set that contains few alternatives (e.g. Kahneman and Tversky, 1979; Beach, 1990). This is also standing practice in transport research (e.g. Gunn, 2001). Kahneman (2002) found that the participants in inquiries appear to take the submitted alternatives for granted. This does not mean that the subject will also interpret the alternatives as intended by the researcher. Many studies found that individuals reformulate the alternatives as departures from a relevant real-life experience. Explicit inclusion of such a reference state in the choice set, as advocated by e.g. Hensher (2001) for stated choice studies aimed at revealing the value of travel time savings, might thus improve the reliability and interpretation of the observed choices as was demonstrated by e.g. Hess *et al.* (2008).

UT assumes that people have a temporally stable, context-independent, complete preference order and are able to consider a 'universal choice set'. These UT assumptions allow preference orders found in one context to be 'extrapolated' to another. They are evidently not plausible as a real-life behavioural hypothesis. Extrapolation of choice behaviour based on these assumptions

---

<sup>7</sup> Conceived in an extensive meaning, including memories of experiences, entitlements to future services etc.

will thus be biased if, for example, many subjects chose an alternative in the surveyed context that they would not consider in the 'prediction' context. This highlights the proper assessment of the subjects' consideration choice sets as defined by Simon (1955). For discrete choice models, two-stage decision rules were proposed to simulate the individual's selection of these sets (e.g. Swait and Ben-Akiva, 1987; Cantillo and Ortúzar, 2005). Another approach is the control-theoretical concept of route choice in which 'information acquisition' reduces the 'objective' choice set into 'known alternatives', followed by a succession of perception and elimination steps that reduce the choice set into a few alternatives that remain for evaluation (Bovy and Stern, 1990). This approaches the satisficing search concept (e.g. Simon 1978). However, functionally such choice set reduction processes should be considered as elements of judgment and evaluation-and-choice instead of framing, see Horowitz and Louviere (1995, p. 51): 'consideration sets are indicators of preferences'. The development of reliable consideration choice set generation models thus remains a challenge for the analyst, see e.g. Bovy (2009) for a state-of-the-art of route choice set generation.

When people frame a choice set they apparently retrieve relevant beliefs about the alternatives in the context at hand from their memory (e.g. Klein, 1993). The actual extensive literature search of social sciences did not provide generic applicable findings about context-dependent real-life subjective choice set formation by individuals. If empirical information is lacking, travel behaviour researchers commonly consider only those alternatives that they deem most relevant in the research setting. To do so they 'are forced to intuit, to the best of their abilities, which considerations are likely to be important in a particular domain, and which are likely to be largely irrelevant' (Frederick *et al.*, 2002).

#### 4.3 Subject's needs and aspiration levels

In Decision Theory motives and goals receive little attention. A listing of 'what people want' (Nickerson 2004) essentially covers the basic needs according to Maslow (1954). Accordingly needs are conceived here in a broad sense, encompassing derivatives like wants, desires, motives and ethics propagation<sup>8</sup>. A trade-off with the perceived concurrent opportunities for needs gratification yields aspiration levels or goals related to the outcome of a particular choice process (Simon, 1955). Such a subset of needs can be conceived as a context-dependent preference order. Violations of UT's context-independent preference orders are reported from many studies in different fields (e.g. Tversky and Kahneman, 1981; Machina, 1987; Dawes, 1988; McElroy and Seta, 2003). Avineri and Prashker (2004) demonstrated it in a route choice context.

From the formal description of PT, the aspiration level of individuals seems maximization of their utility. Elsewhere Kahneman (1999, p. 14) defines it as the boundary between 'satisfactory and unsatisfactory events', which is similar to the 'satisficing' concept (Simon, 1955). A satisficing aspiration level might be inferred from the use of decision rules drawing on attribute cut-offs. These are reported abundantly from choice experiments and actual consumer behaviour in many fields, but maximizing rules are even more frequently observed. Thus a descriptive choice behaviour theory has to accept the co-existence of both principles.

#### 4.4 Summary

Context-independent, temporally stable and complete preference orders have to be rejected as an assumption for a generic descriptive theory of choice. Preference orders should be considered as dependent on the context and the way in which alternatives are perceived. The reference state

---

<sup>8</sup> Arentze and Timmermans (2009) considered a more concrete, 'operational' interpretation in their need-based model of activity modelling.

can be conceived as the expected 'no change' state of assets. Far from considering a universal choice set participants in experiments and surveys will just consider the submitted alternatives and reframe their attribute levels as expected gains and losses. In different contexts the same subject may adopt different reference states, but interpersonal differences will presumably be more prominent. No generally applicable rules for the formation of subjective consideration sets were found. Researchers have to rely on their expertise in the concerned field to intuit which feasible alternatives might serve the interests of different groups of individuals in the considered context. With respect to the subjects' needs and aspiration levels one should allow for differences between population segments that do not necessarily coincide with socio-economic groups.

## 5. Judgment

In view of its importance for valuation this section starts with a review of heuristic judgment. The assessment and valuation of attribute characteristics and probabilities is also reviewed. A summary of the findings on assumptions for the judgment function in human choice behaviour concludes this section.

### 5.1 *Heuristic judgment*

In choice behaviour people use heuristics to ease the judgment of the attributes of alternatives (Kahneman and Frederick, 2002). Tversky and Kahneman (1974, p. 1131) introduced the Availability, Representativeness and Anchoring-and-adjustment heuristics as 'highly economical and usually effective, but they lead to systematic and predictable errors'. Since 1974 many more heuristics have been proposed, see Gilovich *et al.* (2002) for an overview. Gigerenzer *et al.* (1999) presented 'take-the-best' and several more 'fast and frugal' heuristics that appear to draw on similar mental processes (see comparison in Van de Kaa, 2008). Several articles show how well heuristics-based predictions match observed outcomes (e.g. Fischhoff, 2002; Koehler *et al.*, 2002). Tversky and Kahneman's errors, or biases, are systematic differences between observed and 'rational-utilitarian' judgments. Many attempts to stimulate people to de-bias choice behaviour by shifting from a heuristic to a rational judgment appeared to have little success (e.g. Payne *et al.*, 1996; Stanovich and West, 1999; Schul and Mayo, 2003; Larrick, 2004). For a descriptive model of choice behaviour the assumption of an exclusively rational assessment of attribute characteristics and values has thus to be rejected.

### 5.2 *Assessment of characteristics and probabilities*

If time and opportunity permits, characteristics of attributes may be assessed by 'objective' measurement. Decision makers can also assess characteristics from current experience or by reading them from a stored memory, while others 'are routinely evaluated as part of perception and comprehension' (Kahneman and Frederick, 2002, p. 55). When attributes are inaccessible they can be substituted by an associatively related heuristic attribute. Assessed by the choice subject in one way or another, attribute characteristics become 'beliefs about' the objects of choice (e.g. Fishbein, 1963). These beliefs might be elicited by self-reports of choice subjects, in the same way as expected probabilities (Manski, 2004).

### 5.3 *Valuation of attributes*

Like UT, PT originally presumed the commensurability of attribute values in money. For everyday consumables and services this seems the 'natural' dimension. Most choice behaviour theories presume that choice subjects ascribe a subjective, belief-based attribute decision weight

to each attribute (e.g. Dawes, 1988; Dijksterhuis, 2004). When the values of all attributes are on similar scales and at least one attribute characteristic is monetary, the *monetary value* for any attribute (e.g. of travel time) follows from the ratio of its marginal '*psychological*' value and the marginal '*psychological*' value of money. However, many attribute characteristics are valued affectively rather than in a 'cognitive-calculative' way (e.g. Slovic *et al.*, 2002). In transport research this is extensively demonstrated in car ownership studies (e.g. Steg *et al.*, 2005). Often alternatives may be characterized with a mixture of affectively and cognitively derived values (e.g. Ajzen, 1991; Nickerson, 2004). Several neuroscientists suggest that brain functions may integrate these automatically into an affective dimension (e.g. Hoebel *et al.*, 1999; Wagar and Thagard, 2004). In surveys one might elicit such 'mixed' attribute values by self-reports on ordinal scales with the same extension and dimensions like 'good-bad' etc. (e.g. Ajzen, 1991; Svenson, 1992).

Kahneman and Frederick (2002) found that people have problems with the mapping of affectively salient attributes on a scale (like money) that has no upper limit. This is particularly annoying in studies aimed at assessing the value of public goods or attributes (like the number of traffic casualties) that have an ethical overtone (e.g. Kahneman and Knetsch, 1992; McFadden, 2001; Slovic *et al.*, 2004). Choice subjects may circumvent this cross-dimensional mapping problem by employing non-compensatory decision rules (see next section). When some attributes have an affective overtone UT's commensurability assumption thus appears too restrictive for a functional-descriptive theory of choice.

#### 5.4 Loss aversion

Loss aversion was initially assessed as a decisive driving force in the choice between monetary and other gambles (Kahneman and Tversky, 1979; 1984) and has been convincingly demonstrated in many dozens of trading and swapping experiments with coffee mugs, chocolate bars and the like, see e.g. Plott and Zeiler (2005) for a critical review. In trading experiments most subjects who had an object asked a higher selling price for it than the amount that colleagues without one were prepared to pay for its acquisition. In swapping studies most subjects who were endowed with, for example, a mug were not willing to swap it for a bar while most subjects with bars did not swap it for mugs. Underlying psychological processes apparently change the attractiveness of objects once they are at someone's disposal. The endowment effect and the associated loss aversion is not confined to objects that are possessed in the juridical sense but also to expected and imagined endowment, and even to objects of which the endowment was considered during a choice process (e.g. Carmon *et al.* (2003) for experimental evidence).

Loss aversion does not apply to 'money held for spending, goods held specifically for sale, and ... goods that are valued only because they can be traded' (Kahneman and Tversky, 2000, p. 483). In 'trading experiments' loss aversion disappears after extensive instruction or when it becomes a routine (e.g. Arlen *et al.*, 2002; List, 2004). Routine expenses in money are thus often framed and valued in a loss-neutral way (e.g. Novemsky and Kahneman, 2005). This might explain the finding of Hess *et al.* (2008) that car drivers attached a much higher value to increases in toll expenses compared to running costs.

Van de Kaa (2008) found an average loss aversion factor (i.e. ratio between selling and bidding price)  $\lambda=2.0$  ( $\sigma=0.4$ ) from over 20 re-examined trading experiments, slightly lower than Kahneman (2002, p. 462) who mentioned 2.0 - 2.5. Loss aversion was demonstrated in many simulations, surveys and field studies of real-life decision-making (e.g. Samuelson and Zeckhauser, 1988; Tversky and Kahneman, 1991; Camerer, 2000; Carmon *et al.*, 2003; List, 2004; Hu, 2007). It was also found in several transport-related choice settings (e.g. Suzuki, 2000; Katsikopoulos *et al.*, 2000; Avineri and Prashker, 2004; Geurs *et al.*, 2006; Simonsohn, 2008).

However, in most re-examined studies some 10 to 40 % of the panel members might have valued the attributes loss neutrally.

Several alternative explanations for loss aversion were considered. Venkatachalam (2004) mentions income constraints and transaction costs as possible explanations for *status quo* effects but these did not play an important role in most reviewed studies (e.g. Brown, 2005; Plott and Zeiler, 2007). Samuelson and Zeckhauser (1988) found that transition and search costs were insignificant in their studies but mentioned psychological factors like sunk costs and regret avoidance. However, such psychological commitments might also be considered as expected losses (e.g. Thaler, 1980; Carmon *et al.*, 2003). Mackie *et al.* (2001) proposed Mental Inertia as an explanation for a status quo bias in the value of travel time but Van de Kaa (2010b) showed that this could not explain the observed behaviour. Plott and Zeiler (2005; 2007) rejected loss aversion as an explanation for the findings of endowment experiments and attributed them to design inadequacies. This rejection was based on trading experiments where the difference between the selling prices of legally endowed and buying prices of non-endowed objects disappeared when both owners and buyers had the object effectively at their disposal, and on swapping experiments where the exchange asymmetry dwindled when all subjects held both the legally endowed and not-endowed object for some time. As endowment should be considered in an affective rather than juridical sense their findings corroborate rather than refute loss aversion as an explanation for the effects of endowment on choice.

### 5.5 Diminishing sensitivity

PT presumes a diminishing sensitivity for increases in both gains and losses. Empirical evidence for this has been reported for consumers in Finland (Herne, 1998), Japan (Hu, 2007) and Hong Kong (Wong and Kwong, 2005), among others. Some evidence was found in travel-related settings (e.g. De Blaeij and Van Vuuren, 2003; De Borger and Fosgerau, 2008). Diminishing sensitivity is generally attributed to hedonic adaptation. There is some evidence that 'hedonic adaptation to improvements is faster than hedonic adaptation to deteriorations' (Frederick and Loewenstein, 1999, p. 307) but thus far no empirical evidence for this phenomenon was found in connection with loss aversion.

### 5.6 Valuation of probabilities

Many studies showed that people violate the Expected Utility principle. Tversky and Kahneman (1992) assumed that this was caused by non-linear weights that people attach to probabilities in connection with diminishing sensitivity to gains and losses. Brandstätter *et al.* (2002) explained it through expected elation and disappointment. Findings from choice experiments between prospects with given probabilities fit nicely into an inversely S-shaped weighted probability function of expected probability, with unity weights for certain outcomes ( $p = 0, p = 1$ ) and for  $p \approx 0.35$  (e.g. Tversky and Kahneman, 1992; Prelec, 2000). Many experiments and real-world surveys support this shape (e.g. Camerer, 2000; Bleichrodt *et al.*, 2001; Wang and Fischbeck, 2004). Machina (1987) listed empirical formulations that roughly do the same job but these are apparently less common these days. Michea and Polak (2006) compared some of these in a train departure time choice setting and found that PT performed better than EUT though their estimated probability weight functions differed strongly from those suggested by Prelec. Levy and Levy (2002) claimed that the outcomes of their choice experiments violated PT, but Wakker (2003) showed that if the correct weighted probabilities were applied they fitted well with PT. However, the empirical evidence for the weighted probability function is constrained to  $p > 0.01$ . Slovic *et al.* (2004) referred to a study in which the feelings of choice subjects towards lotteries with probabilities winning of  $10^{-4}$  and  $10^{-6}$  were virtually the same. In a traffic safety context De

Blaeij and Van Vuuren (2003, p. 174) observed that for  $p < 0.01$  subjects 'base their decision on the possible outcomes rather than on the probabilities involved'.

### 5.7 Summary

Heuristics play a crucial role in human judgment. Subjects may value a mixture of cognitive and affective attributes on non-commensurable dimensions. These may either be intuitively integrated into some qualitative affect scale or be evaluated with a non-compensatory decision rule. Thus the assumptions of exclusively rational and/or belief-based assessment of attributes characteristics that are valued in a commensurable medium have to be rejected. A descriptive model should therefore allow for heuristic judgment and non-commensurable attribute values and include loss aversion ( $\lambda \approx 2.0$  as first shot), diminishing sensitivity and weighted probabilities. However, one should take into account that some 10 to 40 % of the population might frame and value some attributes loss neutrally.

## 6. Evaluation-and-choice

Once the values for the attributes of choice alternatives have been assessed, sufficient information is available for their evaluation against the choice subject's aspiration level. This paper follows the convention of using the term 'decision rule' to denote implementations of the evaluation-and-choice function. Evaluations may be alternative-wise, when one overall value per alternative is evaluated against some criterion, or attribute-wise, when alternatives are evaluated by comparing the values of one or more attributes to an appropriate criterion (e.g. Payne *et al.*, 1996). This distinction largely coincides with that between compensatory and non-compensatory<sup>9</sup> decision rules. The choice criterion may be either maximizing or satisficing (e.g. Simon, 1955). People may use several different decision rules in one choice process.

### 6.1 Overview of decision rules

The Weighted Additive decision rule is the most frequently considered rule in decision theory (Payne *et al.*, 1993). It assesses the sum of the products of the individual attribute values and their subjective decision weights and may be encountered under several other names. Most RUM models also assume this rule (e.g. Foerster, 1979).

In travel research settings the Strong Lexicographic<sup>10</sup> rule is frequently reported from stated choice surveys (e.g. Sælensminde, 2001; Rizzi and Ortúzar, 2003). When an attribute evokes strong affective feelings or ethical considerations, many people may express a lexicographic preference by attributing a weight to it that surpasses the sum of the other weights (e.g. Rosenberger *et al.*, 2003). Most often the supposed use of this rule will vanish if the range of values on other attributes is enlarged (Rosenberger *et al.*, 2003; Cairns and Van der Pol, 2004). For stated travel choice surveys this was confirmed by Van de Kaa (2006) and Killi *et al.* (2007). In any case this rule is functionally equal to the cognitively more demanding Weighted Additive rule.

Several other decision rules draw on the lexicographic ordering principle. There is some evidence that a sizeable number of people may use the Lexicographic Semiorde rule<sup>11</sup> in transport settings

---

<sup>9</sup> In compensatory rules low values of one attribute can compensate for high values of another, in non-compensatory rules they cannot (e.g. Foerster, 1979).

<sup>10</sup> The Strong Lexicographic rule selects the alternative with the highest value on the most important attribute or, in the case of a draw, the next important one, even if the difference in values is very small (Foerster, 1979).

<sup>11</sup> The Lexicographic Semiorde rule treats alternatives with small differences in the value of the most important attribute as equally attractive and successively evaluates the next important attribute (e.g. Foerster, 1979).

(Foerster, 1979; Yamamoto *et al.*, 2002). The differences between Elimination-by-aspects (Tversky, 1972), the Conjunctive rule where 'the chosen alternative must meet requirements for all attributes' (Swait, 2001, p. 906) and similar elimination and attribute processing strategies are subtle. All these might be modelled by eliminating the alternatives of which the attribute values do not meet certain criteria from the considered choice set and/or by disregarding some attributes.

### 6.2 Subjects' use of decision rules

There is general agreement and much empirical support for the claim that individuals use the Weighted Additive rule when the choice task is simple. Many choice theories assume that individuals organize multi-alternative choices as sequences of bi- or tri-optional evaluations (e.g. Svenson, 1992; Klein 1993), mostly including the reference state (e.g. Beach, 1990; Ajzen, 1991). This may explain the extensive use of this rule in situations where a simultaneous evaluation of all relevant alternatives would be cognitively very demanding. Another explanation for its use in such circumstances might be the high processing power of unconscious thought (e.g. Dijksterhuis, 2004). From Decision Theory, no evidence was found for the extensive use of complex non-linear compensatory rules. The use of the Weighted Additive rule is also most commonly presumed in non-compensatory two-stage rules, where the complexity of the 'remaining' choice task is reduced (e.g. Swait, 2001, in a travel choice context; Simonson, 1990; Gilbride and Allenby, 2004 in other disciplines). In Decision Theory many experiments have shown that a significant part of the subjects shifted to non-compensatory evaluations when the numbers of alternatives or attributes increased and/or under time pressure (e.g. Payne *et al.*, 1993; Timmermans, 1993; Payne *et al.*, 1996). In a traffic setting Stern (1999) found that, under increasing time pressure, a part of the survey population shifted to a lexicographic rule.

The distribution of non-compensatory decision rules in travel behaviour is commonly investigated with discrete choice models that assume their co-occurrence with compensatory assessments (e.g. Swait, 2001; Rose *et al.*, 2005; Cantillo *et al.*, 2006; Danielis and Marcucci, 2007; Pucket and Hensher, 2009). They show a better descriptive performance than models that presume a weighted-additive evaluation only. Most studies suggest that a significant part of the considered survey population employed such rules while the behaviour of the majority might have followed the Weighted Additive rule.

### 6.3 Summary

Commonly the Weighted Additive (including the Strong Lexicographic) rule, as assumed in most implementations of UT, offers the best description of evaluation-and-choice as employed by a large share of the subjects. No evidence was found for the extensive use of more complex non-linear compensatory rules. Significant minorities may use non-compensatory rules, often preceded or followed by the Weighted Additive rule in two-stage decision rules.

## 7. Choice behaviour strategy

The choice behaviour strategy arranges for the coordination of framing, judgment and evaluation-and-choice. From a normative-rational perspective on choice behaviour people might be expected to complete those functions sequentially, because they should have complete knowledge of the future states of the world and the needs of their body as well as unlimited and unflinching information processing power. Common sense says that lay people will follow a less ambitious strategy.

### 7.1 Constructed preferences

Long ago Kelley (1973, p.118) assumed 'that the layman has a repertoire of thought models for dealing with causal problems'. Where feasible the subject may select a choice behaviour strategy that had already proved itself in a similar context (e.g. Klein, 1993; Gigerenzer *et al.*, 1999). Where required she may adjust a strategy from her 'adaptive toolbox' while in novel situations she might construct one on the spot (e.g. Payne *et al.*, 1993; Payne *et al.*, 1999). As the 'proven' strategies mentioned above were once developed in a novel situation these may reflect a similar 'creative' process. Slovic (1995, p. 369) adopted this 'constructed preference' idea and stated that such processes include 'anchoring and adjustment, relying on the prominent dimension, eliminating common elements, discarding nonessential differences, adding new attributes into the problem frame in order to bolster one alternative, or otherwise restructuring the decision problem to create dominance and thus reduce conflict and indecision'. When this non-exhaustive listing is retraced to the functions of choice behaviour it appears that the sequence in which these are completed may differ between contexts and individuals. Instead of being chosen beforehand the choice behaviour strategy that is adopted apparently emerges afterwards and definitely violates the context-independency assumption of UT. This description embraces essential elements of several narrower concepts of choice behaviour from the heuristics-and-biases school (e.g. Gilovich *et al.*, 2002) and process theories of decision-making (e.g. Beach 1990; Svenson, 1992).

### 7.2 Cognitive consistency

That human beings strive for cognitive consistency is a main determinant of older social psychological theories (e.g. Festinger, 1957; Bem, 1967; Kelley, 1973). It means that people may adjust their beliefs and values to find causal explanations for their behaviour and its outcomes within a certain context. Cognitive consistency lingers in the background of Attitude theories (Fishbein, 1963; Ajzen and Fishbein, 1980; Ajzen, 1991) and it is closely linked with many choice theories. It seems clear that most people, in retrospect, will be cognitively consistent within a certain context. From a functional-descriptive perspective this implies that the corresponding choice behaviour strategy can be approximated by a causal sequence of 'final states' of the framing, judgment and evaluation-and-choice functions. Another consequence is that during recurrent choices in similar contexts people might consistently use one particular choice behaviour strategy from their 'toolbox'. This latter assumption may act as a weak substitute for the concept of a complete, temporally stable and context-independent idiosyncratic preference order. It implies that within-context interpersonal heterogeneity in choice behaviour strategies would be systematic rather than random, while remaining inconsistencies<sup>12</sup> in successive choices should be attributed to random errors.

### 7.3 Summary

The choice behaviour strategy appears to be neither stable nor context-independent and the order and sequence of function completion is not always sequential. Following the assumption that people strive after an *ex-post* cognitively consistent strategy this may nevertheless be described as a sequence of 'final states' of the framing, judgment and evaluation-and-choice functions. This

---

<sup>12</sup> In transportation literature 'consistent' is mostly used for a subject who in a sequence of choices always chooses A over C when she chooses A over B and B over C (e.g. Sælensminde, 2001; Rouwendal and De Blaeij, 2004). Following e.g. Tversky and Kahneman (1986) and Haines and Ratchford (1987) this principle is called transitivity here, as there is ample evidence for choice conditions where 'consistent and predictive intransitivities can be demonstrated' (Tversky, 1969 p. 31).

assumption implies intrapersonal consistent choice behaviour of recurrent choices in similar contexts.

## 8. An Extended Prospect Theory

From the assumptions reviewed in the previous sections a set was synthesized that in interrelationship specifies an *Extended Prospect Theory* (EPT), named in recognition of the impressive work of Kahneman and Tversky (see Van de Kaa, 2008). The constituent assumptions of EPT have a generic character. Just like those of UT and PT they should not be confounded with the more restricted implementations with simplified formulations and specifications that are indispensable for the description and prediction of choice behaviour in concrete contexts. This section compares EPT with other theories, discusses how implementations of it might be used to elicit travel behaviour and provides some thoughts about modelling.

### 8.1 Comparison of EPT and other theories of choice

This subsection aims to compare EPT with widespread theories of choice and with those that were applied in travel behaviour research. A 2009 internet search with scientific search engines revealed that these are UT, PT, the Attitude theories and several non-compensatory decision rules. The comparison below will primarily consider these theories. A dozen or so alternative theories of choice appeared less frequently. In view of their limited distribution only those found in the transport literature will be briefly discussed.

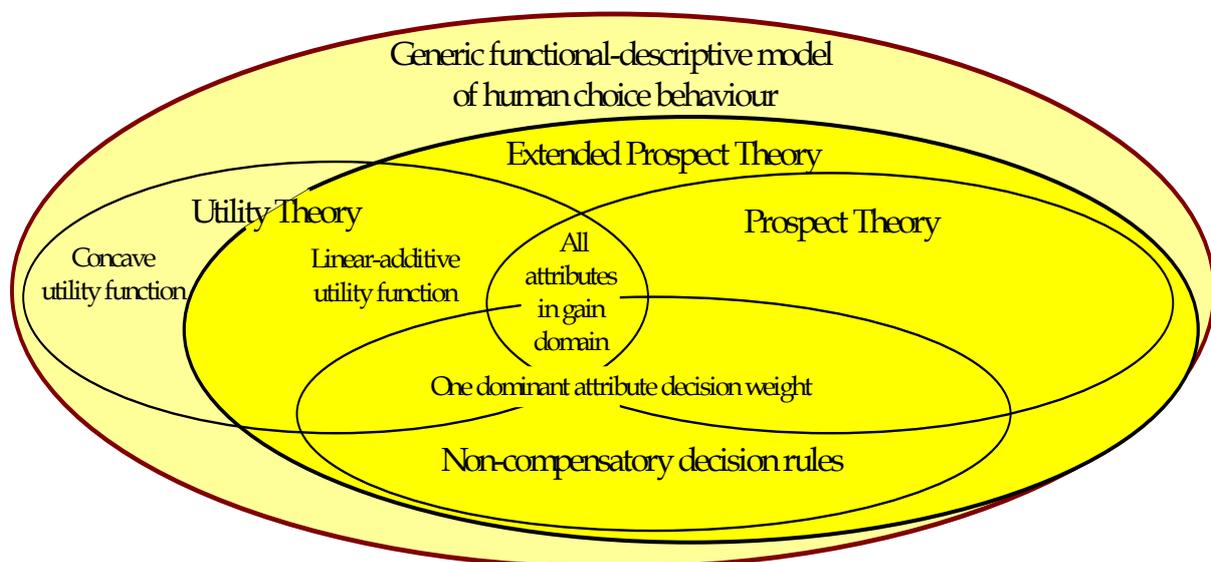


Figure 2. Venn-diagram of choice behaviour theories<sup>13</sup>

#### UT, PT and non-compensatory decision rules

EPT, PT and UT all describe self-interested subjects that employ a deterministic and static<sup>14</sup> choice behaviour strategy. As such, they can all be simulated with an appropriate discrete choice

<sup>13</sup> Note that the sizes of the different elements and overlaps in the diagram do not indicate ranges of applicability or other measures, like importance or extent.

<sup>14</sup> I.e.: once a particular choice process has started there are no stochastic or time-dependent changes.

model. Both PT and UT are commonly applied as if all individuals follow just one choice behaviour strategy. Contrary to this EPT explains within-context interpersonal differences in choice behaviour as the outcome of different combinations of applied choice behaviour strategies and valuation of attributes. As EPT allows for the context-dependent framing of either satisficing or maximizing aspiration levels and evaluation-and-choice with different decision rules it obviously covers the use of non-compensatory rules by population segments.

To illustrate the descriptive suitability of EPT on the one hand and of UT, PT and non-compensatory decision rules on the other, these are depicted in a Venn diagram (Figure 2). Obviously, all these theories can be conceived as implementations of the framework model of Figure 1. The assumptions of EPT allow for the description of choice behaviour by different individuals in the same context according to PT, UT or non-compensatory decision rules. It also shows that under particular circumstances UT and PT explain and predict the same choice behaviours of an individual.

Table 1 orders 19 assumptions of both UT and PT in functionally comparable pairs. For each of these pairs a corresponding assumption was selected for EPT. Some differences are, under most circumstances, less important. Disregarding the less prominent differences and combining some others leaves four sets of assumptions that may characterize the most important differences and agreements between EPT, UT and PT. These are juxtaposed in Table 2. Obviously, the differences between the assumptions are not discriminatory in all choice contexts. For example, for choices between alternatives with 'certain' outcomes weighing of expected probabilities does not play a role and the diminishing sensitivity principle will only have a significant impact on the valuation of attributes when the changes in levels relative to the reference state are high.

**Table 2. Discriminating assumptions of UT, PT and EPT**

Utility Theory	Prospect Theory	Extended Prospect Theory
<b>Reference-dependent framing and loss aversion</b>		
Alternatives and attributes are framed context-independent, as post-decisional states, independent of the sign of the change	Alternatives and attributes are framed as context-dependent changes (gains and losses) relative to a reference state, and individuals value losses higher than gains of equivalent size	Alternatives and attributes are framed as context-dependent changes (gains and losses) relative to a promptly updated reference state, and most individuals value losses higher than gains of equivalent size
<b>Size-dependent valuation of attributes</b>		
The shape of the utility function is independent of the sign of the change	Diminishing sensitivity: the value function is concave for gains and convex for losses	Diminishing sensitivity: the value function is concave for gains and convex for losses
<b>Valuation of probabilities</b>		
Individuals do not weigh expected probabilities	Each individual evaluates expected probabilities according to an inversely S-shaped weighted probability function	Most individuals evaluate expected probabilities according to an inversely S-shaped weighted probability function
<b>Heterogeneity in choice behaviour strategies</b>		
Each individual chooses the alternative with the highest (compensatory compounded) overall ordinal utility	Within-context interpersonal differences in framing occur, but each individual chooses the alternative with the highest (compensatorily compounded) overall value	Within-context interpersonal differences in choice behaviour strategies occur (framing of attributes, satisficing and maximizing, compensatory and non-compensatory rules, etc.)

An objection of practice to the use of PT and EPT compared to UT might be that it is less parsimonious as it requires more assumptions. But, as Simon (1978 p. 345-346) stated: 'Occam's

Razor has a double edge. Succinctness of statement is not the only measure of a theory's simplicity...utility maximization can be stated more briefly than a satisfying theory...but makes stronger assumptions about the human cognitive system'. Compared to a similar implementation of UT, a PT model might have more parameters to describe, for example, loss aversion, which might offer a better approximation of choice observations. But to arrive at a comparable approximation the UT model might be extended with empirical parameters like alternative-specific constants and/or a status quo parameter. If the underlying behavioural assumptions of the PT model are applicable to both contexts, which asks for a well-sought-out specification, its predictive value would presumably outperform any UT model with additional empirical parameters to arrive at the same goodness of fit. Actually, in many studies an abundant number of empirical parameters are estimated in RUM-models. In the British value of travel time studies, for example, the systematic component of utility was approached with a linear-additive function of cost and travel time. The model fit was boosted by splitting these two attributes into 15 others, mainly by discerning increases and decreases and, for travel time changes, by specifying different levels (Gunn, 2001). A similar linear approximation according to PT might, for example, estimate the monetary value-of-travel-time coefficient of the time attribute and a constant loss aversion factor for the time and money attributes. A similar EPT approximation might also discern population segments with different attitudes to time and money losses (e.g. Van de Kaa, 2008). Such an implementation might still be more parsimonious than the corresponding RUM specification.

#### *Attitude theories*

Attitude Theory and its extensions Theory of Reasoned Action and Theory of Planned Behaviour (Fishbein, 1963; Ajzen and Fishbein, 1980; Ajzen, 1991) from social psychology describe a linear-additive, loss-neutral compounding of belief strengths multiplied with their corresponding subjective evaluation into overall attitudes and, in later versions, into subjective norms and perceived behavioural control. The beliefs as conceived in these theories are similar to cognitive and/or affective attribute values expressed in a qualitative 'good-bad' dimension; the belief strengths are equivalent to attribute decision weights. Attitudes, subjective norms and controls are once more considered to be transformed linear-additively into one behavioural intention that is considered to be the best predictor of the actual behaviour. The process to arrive at a behavioural intention is thus functionally identical to strategic decision-making according to UT assumptions.

The applications of Attitude theories to travel behaviour research are mainly dealing with the consistency between a behavioural intention and the observed actual behaviour, where errors of commission (insufficient intention strength) and errors of omission are held responsible for inconsistencies (Gärling *et al.*, 1998; Fujii and Gärling, 2003). Without disputing this approach, one might put in a caveat that the emphasis on the causal intention-behaviour relationship might promote a dispositional bias, i.e. attributing the behaviour too much to the choice subject's stable internal motives at the expense of external/situational attribution (e.g. Bem, 1967; Kelley, 1973). In EPT behavioural intentions might be conceived as outputs of strategic decision-making, which allows e.g. for loss-averse valuation, and act as inputs into operational choice processes in their own right that might take place in a very different context. Compared to Attitude theories this may promote a more balanced causal attribution of dispositional and situational factors. Anyhow, the above-mentioned applications of Attitude Theory to travel behaviour can be interpreted as two interrelated choice behaviours and their output-input relation that fit into the wider assumptions of EPT.

#### *Other theories of choice*

The other recovered theories of choice were based on assumptions about how the individual's choice process works. Of these, computational process models are by far the most common in

transport research. These assume that people employ simple context-dependent rules like 'if-then-else' to cope with the limited capacity of their short term memory, which could, for example, be modelled as decision tables (e.g. Arentze and Timmermans, 2000). Though the unconscious might cope with more complex assessments than they assume, computational process models might well be able to accommodate the EPT assumptions. However, as the reviewed applications related the choice rules to states rather than changes in the environment they are more similar to UT.

Several more process theories are occasionally referred to in transport literature, notably Cognitive Dissonance Theory (Festinger, 1957, in Tertoolen *et al.*, 1998), Decision Field Theory (Busemeyer and Townsend, 1993, in Stern, 1999), Differentiation and Consolidation Theory (Svenson, 1992, in Stern and Richardson, 2005), Regret theory (Loomes and Sugden, 1982, in Chorus *et al.*, 2008) and Somatic Marker Theory (Bechara and Damasio, 2005, in Van Zuylen and Bogers, 2008). These theories propose several different sequences of mental processes and/or hidden emotional attributes that might explain phenomena like myopic framing, status quo adherence, non-compensatory evaluations etcetera. All mental processes hypothesized in these theories performed functions that are either represented in individual choice behaviour assumptions as conceived in EPT or in their interrelations. Thus EPT seems able to cover the range of processes described in these theories in a functional-descriptive way, though it definitely offers no clues on how human minds are doing this.

### *8.2 Applicability of EPT to travel behaviour research*

From an extensive meta-analysis EPT appeared an interesting way to arrive at a better understanding and prediction of travel-related choice behaviour (Van de Kaa, 2010a). It requires the distinction of relevant choice behaviour strategies. This section offers some clues for the design of elicitation contexts and about the frequency of occurrence of choice behaviour strategies to be encountered. For example, under a variety of circumstances people:

- Mostly demonstrate loss-averse valuation of attributes (e.g. Kahneman and Tversky, 1979);
- May differ in the framing of increased money spending as losses or as loss-neutral routine expenses (Novemsky and Kahneman, 2005);
- May successively evaluate one alternative at a time against the reference state (e.g. Beach, 1990); and
- May evaluate these bi-optional choice sets in a compensatory manner (e.g. Payne *et al.*, 1993).

For stated choice surveys of travel behaviour this supports the current practice of submitting mostly bi- or tri-optional choice sets and relating these to a recent real-life experience that might act as a reference state (e.g. Gunn, 2001). Explicit inclusion of the reference state in the choice sets (e.g. Hensher, 2001), might further improve the behavioural reliability in connection with compensatory evaluation. In contexts where subjects have little time to choose between multi-attribute alternatives, a non-compensatory elimination strategy might be applied by large population segments.

Elicitation of choice behaviour strategies from experimental or real-world choices requires a transport expert to conceive a range of choice behaviour strategies that are plausible in the domain at hand (Van de Kaa, 2006 for a demonstration). She should consider that an individual may apply the same strategy in several different contexts, and different people may apply different strategies in the same context. Moreover, assumptions about different functions might have similar effects on the outcome of the choice process. Loss-averse valuation of an attribute that is very important might result in the same outcome as application of an attribute elimination

rule, for example. The considered strategies should thus specify each function of the choice process.

Once the researcher has conceived the plausible choice behaviour strategies she might analyse the coherence between observed decisions and the information about alternatives and attributes available to the choice subject to elicit the employed choice behaviour strategy (e.g. Payne *et al.*, 1993). This may be a statistical analysis of all individual choices, resulting in a large overlap of inferred feasible strategies (e.g. Edland, 1993; Gilbride and Allenby, 2004; Stern, 1999, in a lane changing experiment). When the choice sequences of individuals are recorded in a particular context, like in a stated choice survey, a 'deterministic' analysis of individual choice sequences may be followed (Haines and Ratchford, 1987; Sælensminde, 2001; Van de Kaa, 2006). The analysis may start with statistics for the identification of intrapersonal choice sequences that cannot be explained from random choice, followed by the exclusion of sequences that can be explained from random errors in frequently observed sequences. The remaining sequences might be considered as determined by a combination of a choice behaviour strategy and attribute values. The analyst might now identify the choice sequences that can be explained from the previously conceptualised plausible choice behaviour strategies. She might attribute sequences with overlapping explanatory strategies to the most plausible or frequently observed one in that context.

When choice behaviour strategies have to be inferred from non-recurrent real-world circumstances the travel behaviour analyst has to rely on her understanding of the choice behaviour employed in the domain at hand to identify the observed choices. In novel contexts it might be sensible to precede this with a preliminary survey of how different people arrive at a choice set and organize their choices. Ex-post open interviews of what alternatives and attributes were considered and what choices were made might be appropriate here. Where feasible the interviewer should avoid why and how questions as the answers would be notoriously unreliable (e.g. Nisbett and Wilson, 1977).

### *8.3 Modelling of choice behaviour strategies in travel behaviour*

From social sciences only one article was retrieved that considered the correlation of interpersonal differences in choice behaviour strategies and personality characteristics: Levin *et al.* (2002) found significant correlations between the extent of framing effects and the subject's personality traits Openness and Neuroticism, whereas they found no correlation with, for example, gender. This and other scant evidence (Shiloh *et al.*, 2001; McElroy and Seta, 2003) suggests that the employment of choice behaviour strategies might be correlated to relatively stable personality characteristics. This could imply that the distribution of choice behaviour strategies is approximately stable across large ranges of contexts. Assumption of long-term stability of the distribution of idiosyncratic personality-context-choice behaviour strategy combinations might then reduce the inductive component of EPT implementations.

For elicitation and simulation of such distributions the discrete choice model framework as proposed by Williams and Ortúzar (1982) seems appropriate. It allows the accommodation of non-stochastic interpersonal differences in the employment of decision rules. The probability that an individual selects a particular alternative might be nested here within the probability that she employs a particular choice behaviour strategy. A one-stage mixed logit model with penalized attribute cut-offs or a two-stage conjunctive-compensatory discrete choice model (Swait, 2001; Cantillo and Ortúzar, 2005) might then be modelled as one of the feasible choice behaviour strategies in such a model structure. The authors who have studied applications of PT in travel behaviour research mostly framed it in a logit model (e.g. Michea and Polak, 2006; Avineri and

Prashker, 2005), or applied a similar stochastic approximation (e.g. Katsikopoulos *et al.*, 2000). They thus disregarded heterogeneity in choice behaviour strategies.

## 9. Conclusions

Human choice behaviour can be conceived as a mental process that transforms perceptions of several options into a choice. There is a collective view among social scientists, supported by neuroscience, that this process is predominantly unconscious, which impedes the development of an irrefutable process theory of choice. A functional analysis of choice behaviour provides a framework model to which concrete assumptions about the choice process could be attributed from economics and other social sciences. For UT and PT, listings of 19 paired assumptions were found that each offered a complete and non-redundant model of the human choice process. Several alternative assumptions from social sciences and transport research could also be related to this framework. The overview allowed a comparison of the descriptive ability of corresponding assumptions against the background of empirical findings.

The extensive body of literature from several social sciences that was reviewed in the research that underlies this paper shows that in almost all experimental and naturalistic choice contexts only a part of the subjects complied with the assumptions of UT. Almost whenever a direct comparison of concrete assumptions of UT and PT against the background of empirical findings was feasible the latter assumption explained a larger share of the observations. The review revealed many alternative process theories and models of choice behaviour, of which several showed a large overlap in assumptions with UT and/or PT but others contain some that conflict with both. Drawing on the assumption that choice subjects strive after *ex-post* cognitive consistency, Extended Prospect Theory was developed as a synthesis of those assumptions from economics and other social sciences that appeared to offer the best explanation of the empirical observations. In connection these might be appropriate as a functional-descriptive theory for human choice behaviour in transport-related contexts.

Though this EPT can offer no clues about *how* travellers arrive at their choices it provides a generic framework to assess *what* they choose in particular domains and contexts of transport and traffic. As it coordinates UT as well as its behavioural alternatives that were applied to travel behaviour research, it seems a promising approach to improve the understanding of travellers' choice behaviour.

## Acknowledgements

The author is grateful to three anonymous reviewers for valuable comments, to Piet Bovy, who challenged him in an early stage of this study to transform the predominantly explanatory character of Prospect Theory into a more operationally applicable version and to Bert van Wee for stimulating discussions and his to-the-point comments throughout the realization process of this paper.

## References

Aarts, H. (1996). *Habit and decision making: The case of travel mode choice*. Ridderprint B.V., Ridderkerk.

- Ajzen, I. (1991). The Theory of Planned Behavior. *Organizational Behavior and Human Decision Processes*, vol. 50, pp. 179-211.
- Ajzen, I. and Fishbein, M. (1980). *Understanding Attitudes and Predicting Social Behaviour*. Prentice Hall, New York.
- Arentze, T. and Timmermans, H. (2000). *Albatross, A Learning Based Transportation Oriented Simulation System*. TU Eindhoven, Eirass, Eindhoven.
- Arentze, T. A. and H. J. P. Timmermans (2009). A need-based model of multi-day, multi-person activity generation. *Transportation Research Part B*, 43 (2): 251-265.
- Arlen, J., M. Spitzer and Talley, E. (2002). Endowment Effects within Corporate Agency Relationships. *Journal of Legal Studies*, vol. 31, no. 1, pp. 1-37.
- Avineri, E. and Bovy, P. H. L. (2008). Identification of Parameters for a Prospect Theory Model for Travel Choice Analysis. *Transportation Research Record*, vol. 2082, pp. 141-147.
- Avineri, E. and Prashker, J. N. (2004). Violations of Expected Utility Theory in Route-Choice Stated-Preferences: The Certainty Effect and Inflating of Small Probabilities. *Transportation Research Record*, vol. 1894, pp. 222-229.
- Avineri, E. and Prashker, J. N. (2005). Sensitivity to travel time variability: Travelers' learning perspective. *Transportation Research Part C*, vol. 13, pp. 157-183.
- Avineri, E. and Prashker, J. N. (2006). The Impact of Travel Time Information on Travellers' Learning under Uncertainty. *Transportation*, vol. 33, pp. 393-408.
- Barron, G. and Erev, I. (2003). Small Feedback-based Decisions and Their Limited Correspondence to Description-based Decisions. *Journal of Behavioral Decision Making*, vol. 16, pp. 215-233.
- Bateman, I. J., Munro, A., Rhodes, B., Starmer, C. and Sugden, R. (1997). A test of the Theory of Reference-Dependent Preferences. *The Quarterly Journal of Economics*, vol. 112, no. 2, pp. 479-506.
- Beach, L. R. (1990). *Image Theory: Decision Making in Personal and organizational Contexts*. John Wiley & Sons, Chichester.
- Bechara, A. and Damasio, A. R. (2005). The somatic marker hypothesis: A neural theory of economic decision. *Games and Economic Behavior*, vol. 52, pp. 336-372.
- Bechara, A., Damasio, H., Tranel, D. and Damasio, A. R. (1997). Deciding Advantageously Before Knowing the Advantageous Strategy. *Science*, vol. 275, pp. 1293-1295.
- Bem, D. J. (1967). Self-perception: An alternative interpretation of cognitive dissonance phenomena. *Psychological Review*, vol. 74, pp. 183-200.
- Bleichrodt, H., Pinto, J. L. and Wakker, P. P. (2001). Making Descriptive Use of Prospect Theory to Improve the Prescriptive Use of Expected Utility. *Management Science*, vol. 47, no. 11, pp. 1498-1514.
- Block, N. (1995). The Mind as the Software of the Brain. In Smith, E.E. and Osherson, D. N. (eds.), *An Invitation to Cognitive Science*, Vol. 3, Thinking. MIT Press, Cambridge, MA.
- Bovy, P. H. L. (2009). On Modelling Route Choice Sets in Transportation Networks: A Synthesis. *Transport Reviews*, vol. 29, no. 1, pp. 43-68.
- Bovy, P. H. L. and Stern, E. (1990). *Route Choice: Wayfinding in Transport Networks*. Kluwer Academic Publishers, Dordrecht.

- Brandstätter, E., Kühberger, A. and Schneider, F. (2002). A Cognitive-Emotional Account of the Shape of the Probability Weighting Function. *Journal of Behavioral Decision Making*, vol. 15, pp. 79-100.
- Brown, T. C. (2005). Loss aversion without the endowment effect, and other explanations for the WTA-WTP disparity. *Journal of Economic Behavior & Organization*, vol. 57, no. 3, pp. 367-379.
- Busemeyer, J. R. and Townsend, J. T. (1993). Decision Field Theory: A Dynamic-Cognitive Approach to Decision Making in an Uncertain Environment. *Psychological Review*, vol. 100, no. 3, pp. 432-459.
- Cairns, J. and Van der Pol, M. (2004). Repeated follow-up as a method for reducing non-trading behaviour in discrete choice experiments. *Social Science and Medicine*, vol. 58, pp. 2211-2218.
- Camerer, C. F. (2000). Prospect Theory in the Wild: Evidence from the Field. In Kahneman, D. and Tversky, A. (eds) *Choices, Values and Frames*. Russell Sage Foundation, New York.
- Cantillo, V., Heydecker, B. and Ortúzar, J. d. D. (2006). A discrete choice model incorporating thresholds for perception in attribute values. *Transportation Research Part B*, vol. 40, pp. 807-825.
- Cantillo, V. and Ortúzar, J. d. D. (2005). A semi-compensatory discrete choice model with explicit attribute thresholds of perception. *Transportation Research Part B*, vol. 39, no. 7, pp. 641-657.
- Carmon, Z., Wertenbroch, K. and Zeelenberg, M. (2003). Option Attachment: When Deliberating Makes Choosing Feel like Losing. *Journal of Consumer Research*, vol. 30, June, pp. 15-29.
- Chorus, C. G., Arentze, T. A. and Timmermans, H. J. P. (2008a). A comparison of regret-minimization and utility-maximization in the context of travel mode-choices. Paper presented at TRB 87<sup>th</sup> Annual Meeting, Washington, DC.
- Chorus, C.G., Arentze, T.A., Timmermans, H.J.P. (2008b). A Random Regret Minimization model of travel choice. *Transportation Research Part B*, 42(1), 1-18
- Damasio, A. R. (2001). Fundamental Feelings. *Nature*, vol. 413, pp. 781.
- Danielis, R. and Marcucci, E. (2007). Attribute cut-offs in freight service selection. *Transportation Research Part E*, vol. 43, pp. 506-515.
- Dawes, R. M. (1988). *Rational choice in an uncertain world*. Harcourt Brace College Publ., Orlando, USA.
- De Blaeij, A. T. and Van Vuuren, D. J. (2003). Risk Perception of Traffic Participants. *Accident Analysis and Prevention*, vol. 35, pp. 167-175.
- De Borger, B. and Fosgerau, M. (2008). The trade-off between money and travel time: A test of the theory of reference-dependent preferences. *Journal of Urban Economics*, vol. 64, pp. 101-115.
- Dijksterhuis, A. (2004). Think different: the merits of unconscious thought in preference development and decision making. *Journal of Personality and Social Psychology*, vol. 87, no. 5, pp. 586-598.
- Dijksterhuis, A., Bos, M. W., Nordgren, L. F. and Van Baaren, R. B. (2006). On Making the Right Choice: The Deliberation-Without-Attention Effect. *Science*, vol. 311, no. 5763, pp. 1005-1007.
- Festinger, L. (1957). *A Theory of Cognitive Dissonance*. Stanford University Press, Stanford, CA.
- Fischhoff, B. (2002). Heuristics and Biases in Application. In Gilovich, T., Griffin, D. and Kahneman, D. (eds) *Heuristics and Biases*. Cambridge University Press, New York.
- Fishbein, M. (1963). An Investigation of the Relationships between Beliefs about an Object and the Attitude towards that Object. *Human Relations*, vol. 16, pp. 233-240.

- Foerster, J. F. (1979). Mode choice decision process models: A comparison of compensatory and non-compensatory structures. *Transportation Research Part A*, vol. 13, no. 1, pp. 17-28.
- Frederick, S. and Loewenstein, G. (1999). Hedonic Adaptation. In Kahneman, D., Diener, E. and Schwarz, N. (eds) *Well-being: The Foundations of Hedonic Psychology*. Russell Sage Foundation, New York.
- Frederick, S., Loewenstein, G. and O'Donoghue, T. (2002). Time Discounting and Time Preference: A Critical Review. *Journal of Economic Literature*, vol. 40, no. 2, pp. 351-401.
- Fujii, S. and Gärling, T. (2003). Application of attitude theory for improved predictive accuracy of stated preference methods in travel demand analysis. *Transportation Research Part A*, vol. 37, no. 4, pp. 389-402.
- Fujii, S. and Kitamura, R. (2004). Drivers' Mental Representation of Travel Time and Departure Time Choice in Uncertain Traffic Network Conditions. *Networks and Spatial Economics*, vol. 4, no. 3, pp. 243-256.
- Gaver, D. P. (1968). Headstart Strategies for Combating Congestion. *Transportation Science*, vol. 2, pp. 172-181.
- Gärling, T., Eek, D., Loukopoulos, P., Fujii, S., Johansson-Stenman, O., Kitamura, R., Pendyala, R. and Vilhelmson, B. (2002). A conceptual analysis of the impact of travel demand management on private car use. *Transport Policy*, vol. 9, pp. 59-70.
- Gärling, T. and Fujii, S. (2006). Travel Behavior Modification: Theories, Methods, and Programs. Invited Resource Paper presented at the 11<sup>th</sup> *International Conference on Travel Behaviour Research*, Kyoto.
- Gärling, T., Gilholm, R. and Gärling, A. (1998). Reintroducing attitude theory in travel behavior research: The validity of an interactive interview procedure to predict car use. *Transportation*, vol. 25, pp. 129-146.
- Geurs, K., Haaijer, R. and Van Wee, B. (2006). Option Value of Public Transport: Methodology for Measurement and Case Study for Regional Rail Links in The Netherlands. *Transport Reviews*, vol. 26, no. 5, pp. 613-643.
- Gigerenzer, G., Todd, P. M. and ABCGroup (eds) (1999). *Simple heuristics that make us smart*. Oxford University Press, Oxford, UK.
- Gilbride, T. J. and Allenby, G. M. (2004). A Choice Model with Conjunctive, Disjunctive, and Compensatory Screening Rules. *Marketing Science*, vol. 23, no. 3, pp. 391-406.
- Gilovich, T., Griffin, D. and Kahneman, D. (eds) *Heuristics and Biases*. Cambridge University Press, New York.
- Gunn, H. (2001). Spatial and temporal transferability of relationships between travel demand, trip cost and travel time. *Transportation Research Part E*, vol. 37, pp. 163-189.
- Haines, G. H. and Ratchford, B. T. (1987). A theory of how intransitive consumers make decisions. *Journal of Economic Psychology*, vol. 8, pp. 273-298.
- Hamdar, S. H., Treiber, M., Mahmassani, H. S. and Kesting, A. (2008). Modeling Driver Behavior as a Sequential Risk-Taking Task. *Transportation Research Record*, vol. 2088, pp. 208-217.
- Hammond, K. R., Hamm, R. M., Grassia, J. and Pearson, T. (1987). Direct comparison of the efficacy of intuitive and analytical cognition in expert judgment. *IEEE Transactions on Systems, Man, and Cybernetics*, vol. SMC-17, no. 5, pp. 753-770.

- Hensher, D. A. (2001). The valuation of commuter travel time savings for car drivers: evaluating alternative model specifications. *Transportation*, vol. 28, pp. 101-118.
- Herne, K. (1998). Testing the Reference-dependent Model: An Experiment on Asymmetrically Dominated Reference Points. *Journal of Behavioral Decision Making*, vol. 11, pp. 181-192.
- Hess, S., Rose, J. M. and Hensher, D. A. (2008). Asymmetric preference formation in willingness to pay estimates in discrete choice models. *Transportation Research Part E*, vol. 44, no. 5, pp. 847-863.
- Hoebel, B. G., Rada, P. V., Mark, G. P. and Pothos, E. N. (1999). Neural Systems for Reinforcement and Inhibition of Behavior: Relevance to Eating, Addiction and Depression. In Kahneman, D., Diener, E. and Schwarz, N. (eds) *Well-being: The Foundations of Hedonic Psychology*. Russell Sage Foundation, New York.
- Horowitz, J. L. (1985). Travel and location behavior: State of the art and research opportunities. *Transportation Research Part A*, vol. 19, pp. 441-453.
- Horowitz, J. L. and Louviere, J. L. (1995). What is the role of consideration sets in choice modelling? *International Journal of Research in Marketing*, vol. 12, pp. 39-54.
- Hu, W. (2007). Bargains or Rip-offs? Reference Price Effects in Conjoint Stated Demand. *Journal of Agricultural and Resource Economics*, vol. 32, no. 2, pp. 256-272.
- Jacobsson, C. (2003). Household planning of car use: implementation of prospective car logs. Paper presented at the 10th *International Conference on Travel Behaviour Research*, Aug. 2003, Lucerne.
- Jou, R.-C., Kitamura, R., Weng, M.-C. and Chen, C.-C. (2008). Dynamic commuter departure time choice under uncertainty. *Transportation Research A*, vol. 42, pp. 774-783.
- Kahneman, D. (1999). Objective Happiness. In Kahneman, D., Diener, E. and Schwarz, N. (eds) *Well-being: The Foundations of Hedonic Psychology*. Russell Sage Foundation, New York.
- Kahneman, D. (2000). Preface. In Kahneman, D. and Tversky, A. (eds) *Choices, Values and Frames*. Russell Sage Foundation, New York.
- Kahneman, D. (2002). *Maps of Bounded Rationality: A Perspective on Intuitive Judgment and Choice*. In Frängsmyr, T. Les prix Nobel 2002. Nobel Foundation, Stockholm.
- Kahneman, D. and Frederick, S. (2002). Representativeness revisited: Attribute substitution in intuitive judgment. In Gilovich, T., Griffin, D. and Kahneman, D. (eds) *Heuristics and Biases*. Cambridge University Press, New York.
- Kahneman, D. and Knetsch, J. L. (1992). Valuing Public Goods: the purchase of moral satisfaction. *Journal of Environmental Economics and Management*, vol. 22, pp. 57-70.
- Kahneman, D., Knetsch, J. L. and Thaler, R. H. (1986). Fairness as a Constraint on Profit Seeking. Entitlements in the Market. *The American Economic Review*, vol. 76, pp. 728-741.
- Kahneman, D. and Tversky, A. (1979). Prospect Theory: An Analysis of Decision under Risk. *Econometrica*, vol. 47, pp. 263-291.
- Kahneman, D. and Tversky, A. (1984). Choices, Values, and Frames. *American Psychologist*, vol. 39, no. 4, pp. 341-350.
- Kahneman, D. and Tversky, A. (2000). Conflict Resolution, A Cognitive Perspective. In Kahneman, D. and Tversky, A. (eds) *Choices, Values and Frames*. Russell Sage Foundation, New York.

Katsikopoulos, K. V., Duse-Anthony, Y., Fisher, D. L. and Duffy, S. A. (2000). The Framing of Drivers' Route Choices When Travel Time Information is Provided under Varying Degrees of Cognitive Load. *Human Factors*, vol. 42, no. 3, pp. 470-481.

Katz, M. L. and Rosen, H. S. (1998). *Microeconomics, International* (3rd) Ed. Boston, MA., McGraw-Hill.

Kelley, H. H. (1973). The processes of causal attribution. *American Psychologist*, vol. 28, pp. 107-128.

Killi, M., Nossum, Å. and Veisten, K. (2007). Lexicographic answering in travel choice: Insufficient scale extensions and steep indifference curves? *European Journal of Transport and Infrastructure Research*, vol. 7, no. 1, pp. 39-62.

Klein, G. A. (1993). A Recognition-Primed Decision (RPD) Model of rapid decision making. In Klein, G. A., Orasanu, J., Calderwood, R. and Zsombok, C. E. (eds) *Decision Making in Action: Models and Methods*. Ablex Publishing Corp., Norwood, CT.

Koehler, D. J., Brenner, L. and Griffin, D. (2002). The Calibration of Expert Judgment: Heuristics and Biases Beyond the Laboratory. In Gilovich, T., Griffin, D. and Kahneman, D. (eds) *Heuristics and Biases*. Cambridge University Press, New York.

Larrick, R. P. (2004). Debiasing. In Koehler, D. J. and Harvey, N. (eds) *Blackwell Handbook of Judgment and Decision Making*. Blackwell Publishers, Oxford, U.K.

Levin, I. P., Gaeth, G. J., Schreiber, J. and Lauriola, M. (2002). A New Look at Framing Effects: Distribution of Effect Sizes, Individual Differences, and Independence of Types of Effects. *Organizational Behavior and Human Decision Processes*, vol. 88, no. 1, pp. 411-429.

Levy, M. and Levy, H. (2002). Prospect Theory: Much ado about nothing. *Management Science*, vol. 48, pp. 1334-1349.

List, J. A. (2004). Neoclassical Theory versus Prospect Theory: Evidence from the Marketplace. *Econometrica*, vol. 72, no. 2, pp. 615-625.

Loomes, G. and Sugden, R. (1982). Regret Theory: An Alternative Theory of Rational Choice under Uncertainty. *The Economic Journal*, vol. 92, pp. 805-824.

Machina, M. J. (1987). Choice Under Uncertainty: Problems Solved and Unsolved. *The Journal of Economic Perspectives*, vol. 1, no. 1, pp. 121-154.

Mackie, P., Fowkes, T., Wardham, M., Whelan, G. and Bates, J. (2001). Three controversies in the valuation of travel time savings. CD-ROM Proceedings of *the European Transport Conference*, Cambridge, UK.

Manski, C. F. (2004). Measuring expectations. *Econometrica*, vol. 72, no. 5, pp. 1329-1376.

Maslow, A. H. (1954). *Motivation and Personality*, Second (1970) edition. Harper and Row, New York.

McElroy, T. and Seta, J. J. (2003). Framing effects: An analytic-holistic perspective. *Journal of Experimental Social Psychology*, vol. 39, pp. 610-617.

McFadden, D. L. (2001). Economic Choices (revised version of Nobel Prize Lecture). *The American Economic Review*, vol. 91, no. 3, pp. 351-378.

Michea, A. and Polak, J. (2006). Modelling Risky Choice Behaviour: Evaluating Alternatives to Expected Utility Theory. Paper presented at the 11th *International Conference on Travel Behaviour Research*, Aug 2006, Kyoto.

- Mintzberg, H. (1989). *Mintzberg on Management, Inside our strange world of organizations*. The Free Press, New York.
- Nickerson, R. S. (2004). Assessing the State and Enlarging the Domain of Judgment and Decision Research: Emerging Perspectives on Judgment and Decision Research (Book Review). *Journal of Mathematical Psychology*, vol. 48, pp. 199-210.
- Nielsen, O. A. (2004). Behavioral Responses to Road Pricing Schemes: Description of the Danish AKTA Experiment. *Journal of Intelligent Transportation Systems*, vol. 8, no. 4, pp. 233-251.
- Nisbett, R. E. and Wilson, T. D. (1977). Telling More Than We Can Know: Verbal Reports on Mental Processes. *Psychological Review*, vol. 84, no. 3, pp. 231-259.
- Novemsky, N. and Kahneman, D. (2005). The Boundaries of Loss Aversion. *Journal of Marketing Research*, vol. 42, pp. 119-128.
- Payne, J. W., Bettman, J. R. and Johnson, E. J. (1993). *The adaptive decision maker*. Cambridge University Press, New York.
- Payne, J. W., Bettman, J. R. and Luce, M. F. (1996). When Time is Money: Decision Behavior under Opportunity-Cost Time Pressure. *Organizational Behavior and Human Decision Processes*, vol. 66, no. 2, pp. 131-152.
- Payne, J. W., Bettman, J. R. and Schkade, D. A. (1999). Measuring Constructed Preferences: Towards a Building Code. *Journal of Risk and Uncertainty*, vol. 19, pp. 243-270.
- Plott, C. R. and Zeiler, K. (2005). The Willingness to Pay-Willingness to Accept Gap, the "Endowment Effect," Subject Misconceptions, and Experimental Procedures for Eliciting Valuations. *American Economic Review*, vol. 95, no. 3, pp. 530-545.
- Plott, C. R. and Zeiler, K. (2007). Exchange Asymmetries Incorrectly Interpreted as Evidence of Endowment Effect Theory and Prospect Theory? *American Economic Review*, vol. 97, no. 4, pp. 1449-1466.
- Prelec, D. (2000). Compound Invariant Weighting Functions in Prospect Theory. In Kahneman, D. and Tversky, A. (eds) *Choices, Values and Frames*. Russell Sage Foundation, New York.
- Pucket, S. M. and Hensher, D. A. (2009). Revealing the extent of process heterogeneity in choice analysis: An empirical assessment. *Transportation Research Part A*, vol. 43, no. 2, pp. 117-126.
- Rizzi, L. I. and Ortúzar, J. d. D. (2003). Stated preference in the valuation of interurban road safety. *Accident Analysis and Prevention*, vol. 35, pp. 9-22.
- Rose, J. M., Hensher, D. and Greene, W. H. (2005). Recovering costs through price and service differentiation: Accounting for exogenous information on attribute processing strategies in airline choice. *Journal of Air Transport Management*, vol. 11, pp. 400-407.
- Rosenberger, R. S., Peterson, G. L., Clarke, A. and Brown, T. C. (2003). Measuring dispositions for lexicographic preferences of environmental goods: integrating economics, psychology and ethics. *Ecological Economics*, vol. 44, pp. 63-76.
- Sælensminde, K. (2001). Inconsistent choices in Stated Choice data. Use of the logit scaling approach to handle resulting variance increases. *Transportation*, vol. 28, pp. 269-296.
- Samuelson, W. and Zeckhauser, R. (1988). Status Quo Bias in Decision-making. *Journal of Risk and Uncertainty*, vol. 1, pp. 7-59.
- Schul, Y. and Mayo, R. (2003). Searching for Certainty in an Uncertain World: The Difficulty of Giving Up the Experiential for the Rational Mode of Thinking. *Journal of Behavioral Decision Making*, 16, pp. 93-106.

- Senbil, M. and Kitamura, R. (2004). Reference Points in Commuter Departure Time Choice: A Prospect Theoretic test of Alternative Decision frames. *Intelligent Transportation Systems Journal*, vol. 8, pp. 19-31.
- Shiloh, S., Koren, S. and Zakay, D. (2001). Individual differences in compensatory decision-making style and need for closure as correlates of subjective decision complexity and difficulty. *Personality and Individual Differences*, vol. 30, pp. 699-710.
- Simon, H. A. (1955). A behavioral model of rational choice. *Quarterly Journal of Economics*, vol. 69, pp. 99-118.
- Simon, H. A. (1978). Rational decision-making in business organizations. In Lindbeck, A. (ed.) *Nobel Lectures in Economic Sciences 1969-1980*. World Scientific Publishing Company, Singapore.
- Simon, H. A. (1997). *Administrative behavior* (4<sup>th</sup> Ed.). New York, Free Press.
- Simonsohn, U. (2008). New Yorkers commute more everywhere: contrast effects in the field. *The Review of Economics and Statistics*, vol. 88, no. 1, pp. 1-9.
- Simonson, I. (1990). The Effect of Purchase Quantity and Timing on Variety-Seeking Behavior. *Journal of Marketing Research*, vol. 27, pp. 150-162.
- Slovic, P. (1995). The Construction of Preference. *American Psychologist*, vol. 50, no. 5, pp. 364-371.
- Slovic, P., Finucane, M. L., Peters, E. and MacGregor, D. G. (2004). Risk as Analysis and Risk as Feelings: Some Thoughts about Affect, Reason, Risk, and Rationality. *Risk Analysis*, vol. 24, no. 2, pp. 311-322.
- SOED (2002). Shorter Oxford English Dictionary on CD-ROM. Version 2.0. Oxford University Press, Oxford.
- Stanovich, K. E. and West, R. F. (1999). Discrepancies Between Normative and Descriptive Models of decision Making and the Understanding / Acceptance Principle. *Cognitive Psychology*, vol. 38, pp. 349-385.
- Stanovich, K. E. and West, R. F. (2000). Individual differences in reasoning: Implications for the rationality debate? *Behavioral and Brain Sciences*, vol. 23, pp. 645-726.
- Steg, L. (2005). Car use: lust and must. Instrumental, symbolic and affective motives for car use. *Transportation Research Part A*, 39 (2-3): 147-162.
- Stern, E. (1999). Reactions to congestion under time pressure. *Transportation Research Part C*, vol. 7, pp. 75-90.
- Stern, E. and Richardson, H. W. (2005). Behavioural Modelling of Road Users: Current Research and Future Needs. *Transport Reviews*, vol. 25, no. 2, pp. 159-180.
- Suzuki, Y., 2000, The relationship between on-time performance and airline market share: A new approach. *Transportation Research Part E*, vol. 36, 139-154.
- Svenson, O. (1992). Differentiation and consolidation theory of human decisions making: a frame of reference for pre-and-post-decision processes. *Acta Psychologica*, vol. 80, pp. 143-168.
- Swait, J. (2001). A non-compensatory choice model incorporating attribute cutoffs. *Transportation Research Part B*, vol. 35, pp. 903-928.
- Swait, J. and Ben-Akiva, M. (1987). Empirical test of a constrained choice discrete model: mode choice in São Paulo. *Transportation Research Part B*, vol. 21, pp. 103-115.
- Tertoolen, G., Van Kreveld, D. and Verstraten, B. (1998). Psychological resistance against attempts to reduce private car use. *Transportation Research Part A*, vol. 32, pp. 171-181.

- Thaler, R. H. (1980). Toward a positive theory of consumer choice. *Journal of Economic Behavior and Organization*, vol. 1, pp. 39-60.
- Timmermans, D. (1993). The Impact of Task Complexity on Information Use in Multi-attribute Decision Making. *Journal of Behavioral Decision Making*, vol. 6, pp. 95-111.
- Tversky, A. (1972). Elimination by aspects: A theory of choice. *Psychological Review*, vol. 84, pp. 327-352.
- Tversky, A. and Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. *Science*, vol. 185, pp. 1124-1131.
- Tversky, A. and Kahneman, D. (1981). The framing of decisions and the psychology of choice. *Science*, vol. 211, pp. 453-458.
- Tversky, A. and Kahneman, D. (1991). Loss aversion in riskless choice: a reference-dependent model. *The Quarterly Journal of Economics*, vol. 106, pp. 1039-1061.
- Tversky, A. and Kahneman, D. (1992). Advances in Prospect Theory: Cumulative Representation of Uncertainty. *Journal of Risk and Uncertainty*, vol. 5, pp. 297-323.
- Van de Kaa, E. J. (2004). Prospect Theory and the Understanding of Travellers' Choice Behaviour. CD-ROM *Proceedings of the 8<sup>th</sup> International TRAIL Congress*, Rotterdam.
- Van de Kaa, E. J. (2006). Assessment of the Value of Travel time from Stated Choice Surveys: The Impact of Lexicographic Answering. *Proceedings of the European Transport Conference*, Strasbourg.
- Van de Kaa, E. J. (2008). *Extended Prospect Theory. Findings on Choice Behaviour from Economics and the Behavioural Sciences and their Relevance for Travel Behaviour*. Trail Thesis Series T2008/11, TRAIL Research School, Delft (also on <http://repository.tudelft.nl/>).
- Van de Kaa, E.J. (2010a). Applicability of an Extended Prospect Theory to Travel Behaviour Research: a Meta-Analysis. *Transport Reviews*, DOI: 10.1080/01441647.2010.486907.
- Van de Kaa, E.J. (2010b). Sign-dependent Value of Time in Stated Preference: Judgment Bias or Exposure of Genuine Preference? *European Journal of Transport and Infrastructure Research*, vol. 10, no.4, pp. 347-367.
- Van Zuylen, H. J. and Bogers, E. A. I. (2008). Neuropsychological Approach of Route Choice in Uncertainty. *TRB 87th Annual Meeting Compendium of Papers DVD*, Washington D.C.
- Venkatachalam, I. (2004). The contingent valuation method: a review. *Environmental Impact Assessment Review*, vol. 24, pp. 89-124.
- Wagar, B. M. and Thagard, P. (2004). Spiking Phinias Gage: A Neurocomputational Theory of Cognitive-Affective Integration in Decision Making. *Psychological Review*, vol. 111, no. 1, pp. 67-79.
- Wakker, P. P. (2003). The Data of Levy and Levy (2002) "Prospect Theory: Much Ado About Nothing?" Actually Support Prospect Theory. *Management Science*, vol. 49, no. 7, pp. 979-981.
- Wang, M. and Fischbeck, P. S. (2004). Incorporating Framing into Prospect Theory Modeling: A Mixture-Model Approach. *The Journal of Risk and Uncertainty*, vol. 29, no. 2, pp. 181-197.
- Williams, H. and Ortúzar, J. d. D. (1982). Behavioural theories of dispersion and the misspecification of travel demand models. *Transportation Research Part B*, vol. 16, no. 3, pp. 167-219.
- Wilson, P. W. (1988). Wage Variation Resulting from Staggered Work Hours. *Journal of Urban Economics*, vol. 24, pp. 9-26.

Wong, K. F. E. and Kwong, J. Y. Y. (2005). Comparing two tiny giants or two huge dwarfs? Preference reversals owing to number size framing. *Organizational Behavior and Human Decision Processes*, vol. 98, pp. 54-65.

Yamamoto, T., Kurauchi, S. and Morikawa, T. (2002). Comparison of Non-Compensatory Models of Driver's Choice on Dynamic Park and Ride. Paper presented at the 9<sup>th</sup> *World Congress on Intelligent Transportation Systems*, Oct. 2002, Chicago.

Zajonc, R. B. (1980). Feeling and Thinking: Preferences Need No Inferences. *American Psychologist*, vol. 35, pp. 151-175.