Prospect Theoretic Contributions in Understanding Traveller Behaviour: A Review and Some Comments

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Prospect Theoretic Contributions in Traveller Behaviour Studies: a Review and Some Comments

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Abstract

Over the last 15 years we have seen a small but growing interest in Prospect Theory (PT) as an alternative behavioural paradigm within which to represent traveller behaviour. Some elements of PT such as gains and losses have become so popular in travel choice studies that authors increasingly indicate that they are applying Prospect Theory, which they are not. In its strictest interpretation, PT has a number of essential elements that must be included if the link with PT can be claimed. This paper reviews recent transportation studies which report an association with Prospect Theory as a way of gaining a greater appreciation of what is and what is not an application of Prospect Theory. We set the scene by providing an overview of Prospect Theory using studies in the fields of psychology and behavioural economics, where Prospect Theory was originally established and further developed, and then identify travel behaviour studies which satisfy the PT conditions. A number of specific issues are identified to highlight the connection to PT including empirically estimated prospect theoretic parameters and referencing. Some behavioural limitations of the reviewed transport PT studies are also presented, including the absence of willingness to pay estimates, and no investigation of individual preference heterogeneity.

Keywords: Prospect Theory, travel behaviour research, route choice, departure time choice, preference and risk attitudes

1. Introduction

Prospect Theory is regarded as a leading behavioural paradigm to understand decision making under risk. Prospect Theory (PT) has been widely applied in behavioural economic and psychological studies (see e.g., Camerer and Ho 1994; Tversky and Fox 1995; Wu and Gonzalez 1996; Abdellaoui 2000; Birnbaum 2004; Harrison *et al*. 2009). A number of review papers discuss empirical findings, theoretical issues, and practical applications of PT (see e.g., Starmer 2000; Schmidt and Zank 2008; Fox and Poldrack 2008), using evidence from controlled laboratory experiments.

Prospect Theory proposed by Kahneman and Tversky (1979) is often referred to as 'Original PT' (OPT), which offers three significant differences relative to normative Expected Utility Theory (EUT): i) the use of non-linear probability weighting to transform original probabilities to explain Allais' paradox, the violation of EUT (Allais 1953) mechanism in EU models where probabilities of occurrence are directly used as weights; ii) *reference dependence*, i.e., different value functions for gains and losses with respect to the reference point, often the current wealth position (Laury and Holt 2000), rather than a utility function defined over final wealth in EU models (i.e., $U = f(x+w)$ where x is the payoff of a lottery ticket, and w is the current wealth position). The advantage of referencing is that different risk attitudes can be revealed (e.g., many psychological studies found concavity over monetary gains indicating risk-averse attitudes and convexity over monetary losses suggesting risk-seeking attitudes); iii) *loss aversion*, i.e., the disutility of a loss is valued higher than the utility of an equivalent gain. Based on OPT, Tversky and Kahneman (1992) developed Cumulative Prospect Theory by adopting the functional form for decision weights from Rank-Dependent Utility Theory (RDUT) developed by Quiggin (1982), in which the transformed probabilities are influenced by the rank of the outcomes in terms of preference. By incorporating rank-dependent decision weights, CPT is capable of revealing personality characteristics (pessimism or optimism) (Diecidue and Wakker 2001). Prospect Theory allows a new dimension to model risk attitudes, i.e., on the basis of non-linearity in weighted probabilities, which are solely captured though sensitivity towards outcomes (i.e., the curvature of utility) in Expected Utility (EU) models (Wakker 2000).

Tversky and Kahneman (1992) provided parametric formulae for the value functions under the constant relative risk aversion (CRRA) assumption, as well as a one-parameter probability weighting function. The value function in the gain domain for $x \geq 0$ is $V = x^{\alpha}$; in the loss domain where $x < 0$, $V = -\lambda(-x)^{\beta}$; α and β are the risk attitude parameters over gains and losses respectively; and λ is the coefficient of loss aversion postulating that a loss is treated more serious than a gain of equal size)[1]. The probability weighting function suggested by Tversky and Kahneman (1992) is given in equation (1). There are a number of alternative weighting functions, e.g., a two-parameter weighing function proposed by Lattimore *et al.* (1992) given in equation (2), and another version of a one-parameter weighting function derived by Prelec (1998), given in equation (3).

[1] The corresponding values estimated by Tversky and Kahneman are 0.88 for α, 0.88 for β and 2.25 for λ.

$$w(p_m) = \frac{p_m^\gamma}{[p_m^\gamma + (1-p_m)^\gamma]^{\frac{1}{\gamma}}} \quad (1)$$

$$w(p_m) = \frac{\tau p_m^\gamma}{\tau p_m^\gamma + (1-p_m)^\gamma} \quad (2)$$

$$w(p_m) = \exp(-(-\ln p_m)^\gamma) \quad (3)$$

$w(p)$ is the probability weight function; p_m is the probability associated with the m^{th} outcome for an alternative with multiple possible outcomes; and γ is the probability weighting parameter to be estimated which measures the degree of curvature of the weighting function. τ in formula (2) measures the elevation of the probability weighting function ($w(p)$).

In an OPT model, the value function is directly weighted by a probability weighting function (i.e., $OP(V) = \sum_m w(p_m)V(x_m)$), where the transformed probabilities are independent of outcomes. However, in a CPT model, the transformation $\pi(p)$, often referred to as decision weights, is preformed over the cumulative probability distribution, where all potential outcomes are often ranked in increasing order in terms of preference (from worst to best, see equation 4)[2]. Hence, the cumulative prospect value is defined as: $CP(V) = \sum_m \pi(p_m)V(x_m)$.

$\pi(p_m) = w(p_m + p_{m+1} + ... + p_n) - w(p_{m+1} + ... + p_n)$ for m=1, 2, …, n-1; and
$$\pi(p_n) = w(p_n) \quad (4)$$

A full PT model must address the following criteria in a systematic and parametric manner: i) *non-linear probability weighting*; in an OPT model, the probability weighting function is independent of outcomes; while in a CPT model, the decision weights are *rank-dependent*; ii) *reference dependence*, i.e., separate value functions defined over gains and losses; iii) *risk attitudes* (i.e., the curvatures of value functions over gains and losses); and iv) *loss aversion*. In addition to the above characteristics, CPT also allows for different probability weight functions for probabilities of gains and probabilities of losses (i.e., *sign dependence*). For the one-parameter probability weighting function in equation (1), γ^+ and γ^- represent the probability weighting parameter in the gain and loss domains respectively. As an example, Tversky and Kahneman (TK) estimated a probability weighting parameter of 0.61 for gains (γ^+) and 0.69 for losses (γ^-) in their CPT model. However, some CPT studies assume the same weighting parameter for gains and losses, and even a same risk attitude parameter (e.g., Harrison and Rutström 2008). Although there are some variations in those PT studies, a focus is to understand risk attitudes and the shape of probability

[2] Outcomes can also be ranked from best to worst (see e.g., Diecidue and Wakker 2001)

weighting empirically. Table 1 summarises some empirical findings of PT models developed over monetary gains/losses.

Table 1: PT models developed over monetary gains/losses

				PT Parameter Estimates				
							TK's one-parameter weighting (equation 1)	
Study	**CPT or OPT**	**Gain or loss or both domain**	**Sample**	**Risk: gains**	**Risk: Losses**	**Loss aversion**	**Probability weighting: gains**	**Probability weighting: losses**
Tversky and Kahneman (1992)	CPT	Both	25 students	0.88	0.88	2.25	$\gamma^{+} = 0.61$	$\gamma^{-} = 0.69$
Harrison and Rutström (2008) *^	CPT	Both	207 subjects	1-0.76 =0.24	1-0.76 =0.24	0.44	$\gamma^{+} = 1.01$	$\gamma^{-} = 1.01$
Harrison *et al.* (2009)*	OPT	Gain	531 subjects	1-0.46 = 0.54	-	-	$\gamma^{+} = 1.38$	-
Harrison and Rutström (2009)	OPT	Both	158 students	0.71	0.72	1.38	$\gamma^{+} = 0.91$	$\gamma^{-} = 0.91$
							Prelec's two-parameter weighting (equation 2)	
Gonzalez and Wu (1999)	CPT	Gain	10 students	0.49	-	-	$\gamma^{+} = 0.44$ $\tau^{+} = 0.77$	-
Abdellaoui (2000)	CPT	Both	46 students	0.89	0.92	Not reported	$\gamma^{+} = 0.60$ $\tau^{+} = 0.65$	$\gamma^{-} = 0.65$ $\tau^{-} = 0.84$
Abdellaoui *et al* . (2005)	CPT	Both	41 students	0.91	0.96	Not reported	$\gamma^{+} = 0.83$ $\tau^{+} = 0.98$	$\gamma^{-} = 0.84$ $\tau^{-} = 1.30$

Notes:

*: Harrison and Rutström (2008) and Harrison *et al.* (2009) used another version of CRRA ($V = x^{1-\alpha} / (1-\alpha)$).

^: The constants for these PT parameters are reported here, given that Harrison and Rutström (2008) used some socio-demographic characteristics (age, gender, etc.) to explain heterogeneity in risk attitudes.

Recently, a number of transport studies (in particular travel behaviour research) have recognised the appeal of Prospect Theory and attempted to incorporate PT in modelling processes to explain traveller behaviour (see e.g., Avineri and Prashker 2005; Schwanen and Ettema 2009a). de Palma *et al.* (2008) theoretically investigated the possibility of integrating non-EU models (e.g., CPT) within the framework of discrete choices. van de Kaa (2008) provided a comprehensive review of Prospect Theory. Cherchi (2009) encouraged the integration of psychology theory (in particular Prospect Theory) into transport economic studies to better understand individual decision making and to relax the dominant assumption in the transport field of rational decision makers ('rationality in preference, perception and process').

The main purpose of this paper is to review and evaluate recent transportation studies which report an association with Prospect Theory. We start with an overview of Prospect Theory using studies in the fields of psychology and behavioural economics, and then evaluate travel behaviour studies which satisfy the PT conditions. A number of suggestions related to improving the behavioural explanation of PT models are also provided, drawing on the broader literature on travel behaviour research, along with conclusions.

2. Prospect Theory in Traveller Behaviour Research

The dominant theory in the transport field is Random Utility Maximisation (RUM), which assumes rational behaviour. Research in psychology and behavioural economics has found evidence that violates this ‘rational’ assumption of decision making. Utility maximisation is not the only decision rule for decision makers, other psychological components (e.g., attitude, personality and belief) are also critical to people’s choices, especially when risk and uncertainty are involved. The ‘rational’ assumption has also been criticised by transportation researchers (see e.g., Mahmassani and Chang 1985; Fujii and Kitamura 2000; Avineri and Prashker 2003, Batley and Ibáñez 2009). RUM assumes that the individual’s choice is made under certainty (Batley and Ibáñez 2009), which is often not possible given that variability in key attribute drivers such as travel, crowding and arriving on time, is embedded in many travel systems. Given the limitation of RUM, a growing number of travel behaviour studies have investigated other behavioural paradigms such as Expected Utility Theory, Rank-Dependent Utility Theory and Prospect Theory. The following sections review recent studies which have employed PT to model travellers’ behaviour.

2.1 Prospect Theory in Route Choice Models

Avineri and Prashker (2005, also see Avineri and Prashker 2003 for a similar version) is one of the early studies which adopted Prospect Theory in the context of route choice between two unlabelled alternatives (A and B) with different travel time distributions. During the laboratory experiment, a respondent was asked to choose one of the routes (A or B) from work to home. The travel time (in minutes) of the chosen route simulated from the distribution is shown after a choice is made (see Figure 1 for an experimental example). In Avineri and Prashker’s CPT model, travel times and associated probabilities are drawn from hypothetical travel time distributions and the reference point is assumed to be 31.5 minutes. Based on the PT parameters (e.g., risk attitudes and probability weighting) estimated by Tversky and Kahneman (1992), the prospect theoretic values of Routes A and B are calculated and the market share is predicted. Avineri and Prashker also compared the predictions of CPT and other models (e.g., RUM and reinforcement learning[3]).

[3] As a static model, PT cannot address feedback-based decisions with a dynamic process which involves information acquisition and learning (Barron and Erev 2002).

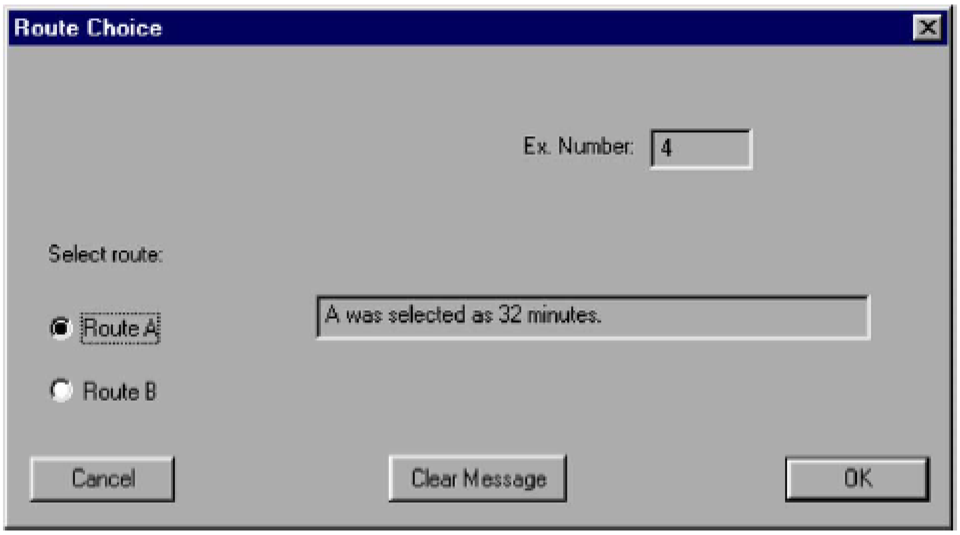

Figure 1: a choice set from Avineri and Prashker (2005)

Avineri (2004) provided a numeric example in a Prospect Theory framework in calculating cumulative weighted values of prospects in the context of two bus lines with different headway distributions. Different waiting time values ranging between 0 minutes and 10 minutes were assigned to their associated probabilities for two risky prospects (A and B), based on the assumed headway distributions. Using parameters defining risk attitudes and probability weighting, estimated by Tversky and Kahneman (1992) and assumed reference points, the cumulative weighted values of two prospects can be calculated. By applying different reference point values of waiting time (0 - 20 minutes), Avineri (2004) found that the cumulative weighted values of risky routes are sensitive to the change in reference points. It appears that Avineri did not obtain parameter estimates from new data, but adopted them from other research in a non-transport context.

Gao *et al.* (2009) investigated travellers' route choices in a risky network based on Expected Utility Theory (EUT) and CPT models using simulated choice data. Implied path predictions under EUT and CPT are compared, revealing significant differences in path share predictions under two behavioural paradigms. Gao *et al*. suggested that CPT is a better framework relative to EUT. Gao *et al.* (2009) specified the econometric specification for a routing policy choice model with a CPT utility function, and estimated it within a multinomial logit framework; however like Avineri's studies, Gao *et al.* used the parameter estimates from Tversky and Kahneman (1992) directly.

Michea and Polak (2006) investigated train travellers' decision making within different behavioural frameworks including Cumulative Prospect Theory, using stated preference collected by Bates *et al.* (2001), where the respondents were asked to choose between two train services with different travel time variability (see Figure 2). Michea and Polak compared different models and reported that their CPT model delivers better model fit relative to the model based on Expected Utility Theory.

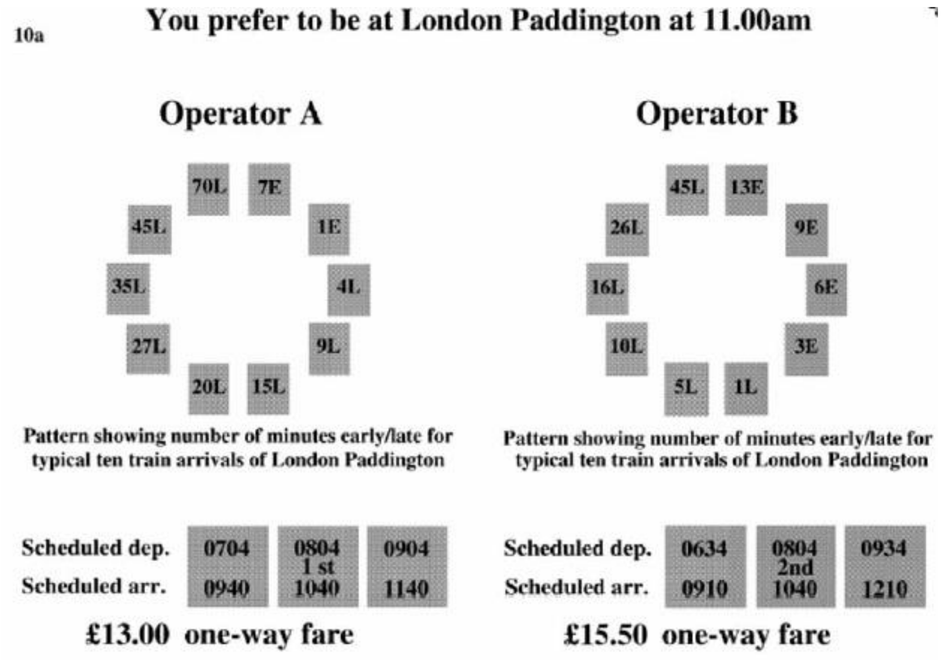

Figure 2: a SP task from Bates *et al.* (2001)

Michea and Polak's utility expression is given in (5).

$$U_i = \sum_{j=1}^{n} [\pi_j (\beta SDE_{ij}^{\theta_1} + \gamma SDL_{ij}^{\theta_2} + \phi F_i + \nu D_i)] + \varepsilon_i \tag{5}$$

where

$$\pi_k = w(\frac{10-k+1}{10}) - w(\frac{10-k}{10})$$

π is the cumulative probability weighting function; *SDE* and *SDL* are schedule delay early and late, calculated using multiple travel times (either early or late) out of 10 travel times for each alternative within a choice set; *F* is the price of train travel; and *D* is the mean arrival lateness.

Although, Michea and Polak (2006) estimated some PT parameters parametrically, the way that they specified their CPT model (see equation (5)) is not appropriate. First, decision weights should be applied to their corresponding prospect values which are defined over probabilistic gains/losses (i.e., $\sum_m \pi(p_m)V(x_m)$, where x_m is a gain or loss with the p_m chance of occurrence (less than 100 percent for an alternative within a choice set). In the Michea and Polak study, however, for each alternative within a choice set, the *F* attribute is fixed (100 percent for an alternative within a choice set); hence it should not be weighted by decision weights. Another problem related to Michea and Polak's decision weights is that there is no the rank of outcomes, either in an increasing or decreasing preference. Last, within a prospect theoretic framework, the non-linearity in parameters should be associated with gains and losses, not with calculated *SDE* and *SDL* as Michea and Polak did.

2.2 Departure Time Choice

Jou *et al*. (2009) investigated car commuters' departure time choices, based on their suggested shape of PT value functions for losses and gains (see Figure 3), where two reference points are defined (the earliest acceptable arrival time (t_E) and the work starting time (t_w)). Arriving between t_E and t_w would incur a gain; otherwise it would be a loss. If it is a gain, a car commuter would continue to depart at the same departure time for the next trip; otherwise the departure time is expected to be switched.

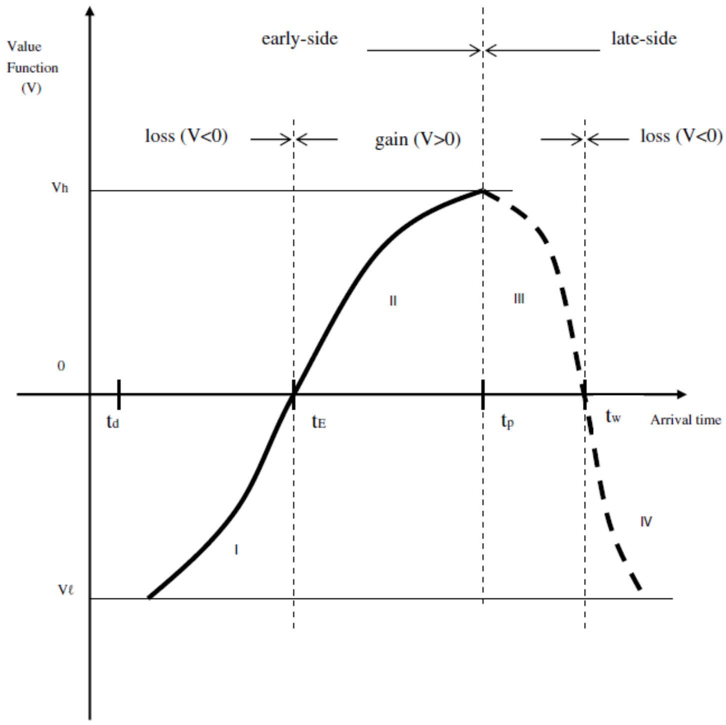

Figure 3: Value functions for gains and losses suggested by Jou *et al*. (2009)

Jou *et al*. collected data on a car commuters departure time decision using trip diaries, where travel characteristics were obtained (e.g., departure time, actual arrival time, work starting time, etc.) along with socioeconomic characteristics (e.g., age, gender, etc.). The survey sampled tended to leave home at the same time for the trip studied (82%). Using the referencing technique of Prospect Theory within a linear utility specification, four equations are specified for two gain domains (segments II and III) and two loss domains (segments I and IV). The major finding is asymmetry in commuters' responses to gains and losses, consistent with Prospect Theory.

Senbil and Kitamura (2004a) used two prospect theoretic decision frameworks in the context of departure time choice. The first type is the same as Jou *et al.* (2009) shown in Figure 3, originally proposed by Jou and Kitamura (2002), in which gains would be incurred when a commuter arrives between the earliest acceptable arrival time and the work starting time. Another prospect theoretic value function suggested by Senbil and Kitamura (2004a) is given in Figure 4, where only gains (i.e., arriving between the earliest acceptable arrival time (PAT) and the work starting time (WST)) are considered.

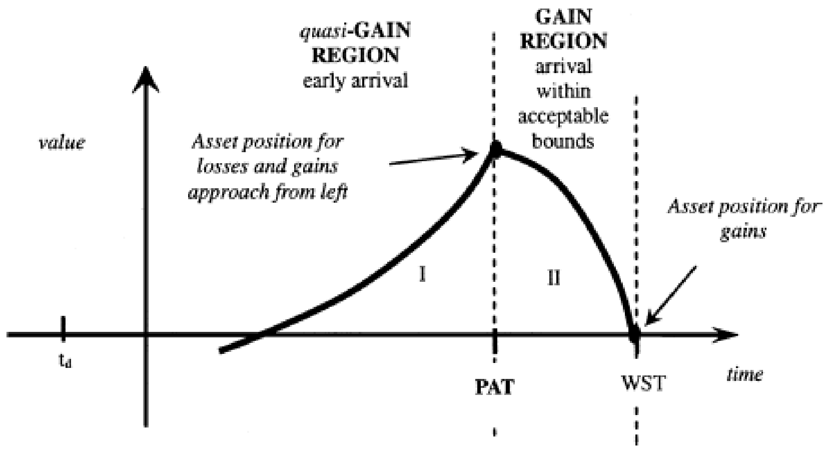

Figure 4: Prospect theoretic decision frame suggested by Senbil and Kitamura (2004a)

Commuters were asked to provide the departure and arrival information for three consecutive commute days, including the work starting time, preferred arrival time, slowest/average/fastest travel times, etc. They were also asked to report each day whether they would change their departure times on the next day. Based on estimation of the parameters of the value functions, Senbil and Kitamura (2004) concluded that the departure time decision is consistent with Prospect Theory, e.g., risk averse attitudes in the gain domain.

Using the same data of Senbil and Kitamura (2004a), Senbil and Kitamura (2004b) applied probit regression models to capture observed heterogeneity in the departure time choice, using a number of socio-economic variables (e.g., age, gender). For example, Senbil and Kitamura (2004b) found that older car commuters are less sensitive to gains/losses. Another finding is that commuters with flexible arrival times are more sensitive to gains and losses.

2.3 Other Applications

Within a prospect theoretic framework, Schwanen and Ettema (2009a) investigated working parents' choice of who is going to pick up their child(ren) on the basis of different travel times and associated probabilities of occurrence. An example of Schwanen and Ettema's experiment is given in Figure 5, where two alternatives are provided: travelling to the nursery oneself or let a partner pick up the child(ren). Each alternative has two potential outcomes. Schwanen and Ettema (2009a) set the reference point as the time that the child(ren) should have been collected, where three reference values (i.e., 17:35 h, 17:45 h and 18:00 h) were used for three blocks of questions. Schwanen and Ettema assumed that arriving earlier than the time that the child(ren) should have been collected is a gain, and vice versa.

A. Pick up your child yourself		B. Let your partner pick up your child	
It is possible that you:	Chances are:	It is possible that your partner:	Chances are:
- arrive exactly **at** the time your child should have been collected	1 in 2 (50%)	- arrives exactly **at** the time your child should have been collected	4 in 5 (80%)
- arrive **5** minutes **later** than the time your child should have been collected	1 in 2 (50%)	- arrives **10** minutes **later** than the time your child should have been collected	1 in 5 (20%)

I choose to: ☐ Pick up my child myself
☐ Have my partner pick up our child

Note: This question was included in the first block of questions in which times were framed relative to the time at which the children should have been collected (in the general introduction to the experiment described as equal to 17:45h). Questions in other blocks were framed against one of the other two reference points (see text)

Figure 5: a SP choice example from Schwanen and Ettema (2009a)

A series of binary logit models are specified according to Prospect Theory, where Tversky and Kahneman's one-parameter probability weighting function is applied and the risk attitude parameters are assumed to be same for gains and losses. Schwanen and Ettema claimed that Cumulative PT is used in their study; however they applied probability weighting independent of the rank of outcomes. Given this, the model that Schwanen and Ettema actually specified is an Original PT model. Using the binary time lottery choice data, the risk attitude parameter is estimated between 1.09 and 1.10, 1.27-1.37 for the loss aversion parameter, and 0.82-0.84 for the probability weighting parameter. Schwanen and Ettema (2009a) suggested that analytical frameworks for understanding traveller behaviour should be both psychologically and socially realistic.

Schwanen and Ettema (2009b) modelled the combinations of five value functional forms (e.g., linear, quadratic, power (CRRA)) and four probability weighting functions (e.g., power and Tversky and Kahneman's one-parameter weighting function), using the same dataset introduced in Schwanen and Ettema (2009a). The comparison of model performance suggested that their full Prospect Theory model (i.e., the power value function with the one-parameter weighting) is the best model among the 20 possible combinations for this choice data.

Avineri (2006) modelled network equilibrium within a prospect theoretic framework. Avineri assumed a simple two-route network from a fixed origin to a fixed destination, where the travel times for two routes are calculated by an equation proposed by the Bureau of Public Roads, with a number of assumptions such as the traffic volume on each route, the route capacity, the distribution of random component of travel time, etc. Each of the travel times is assigned a probability, and gains/losses are the deviations from an assumed reference point (i.e., 30 minutes) so as to have risky prospects. Using the behavioural parameter estimates from Tversky and Kahneman (1992), the prospect theoretic values of two routes are calculated, along with the volume of traffic for each route under equilibrium (i.e., the same prospect theoretic value). Avineri also found that varying the reference point value significantly has a significant impact on such equilibrium.

Connors and Sumalee (2009) investigated network equilibrium based on the prospect theoretic values of risky links in a hypothetical network. Given that link travel times are regarded as random variables in Connors and Sumalee's model, the continuous analogue of TK's discrete CPT is derived, using the probability density function of continuous distribution of alternative links. Connors and Sumalee (2009) made a number of assumptions on the values of key parameters of Prospect Theory, for example, the risk attitude parameters are assumed to be 0.52, the loss aversion parameter is assumed as 2.25, and the probability weighting parameter is assumed to be 0.74 for Prelec's one-parameter weighting function. Connors and Sumalee found that the change in reference point values has a strong influence on the equilibrium achieved. Han *et al.* (2005) claimed that Prospect Theory was integrated to model strategic dyad behaviour of information providers and travellers; however only the probability weighting element was included, i.e., the two-parameter probability weighting function proposed by Prelec (1998) ($w(p_m) = \exp(-\tau(-\ln p_m)^{\gamma})$) where the values of τ and γ were assumed.

Reviewed transportation studies associated with Prospect Theory are summarised in Table 2. Only Schwanen and Ettema (2009a,b) address all key elements of Prospect Theory and empirically estimate PT parameters using collected choice data, even though they confuse OPT with CPT. Other studies either failed to accommodate all components of PT and/or used the values of parameter estimates from the existing literature (e.g., Tversky and Kahneman1992). We now take a closer look at some of these issues.

Table 2: a summary of transportation PT studies

Study	Application	Modelling Method	CPT or OPT	Risk attitude and loss aversion parameters	Probability weighting parameter	Reference point	Sign dependent (if CPT)
Avineri and Prashker (2003)	Route choice	N/A	CPT	Used the values from TK(1992)	Used the estimated values from TK(1992)	The reference point is assumed as 31.5 minutes' travel time.	Yes
Avineri and Prashker (2005)	Route choice	N/A	CPT	Used the values from TK(1992)	Used the estimated values from TK(1992)	The reference point is assumed as 31.5 minutes' travel time.	Yes
Avineri (2004)	Route choice	N/A	CPT	Used the values from TK(1992)	Used the estimated values from TK(1992)	Different reference points were tested	Yes
Gao *et al.* (2009)	Route choice	Logit	CPT	Used the value from TK(1992)	Used the estimated value from TK(1992)	The shortest travel time across all paths of a risky network	No, only the loss domain is considered.
Jou *et al.* (2009)	Departure time choice	Logit	Referencing only	Linear functional form	No probability weighting	Two references points are defined: the earliest acceptable arrival time and work starting time	No
Senbil and Kitamura (2004a)	Departure time choice	Probit	Non-linear value functions of PT	Decision frame 1^: 0.26 for gains 0.39 for losses Decision frame 2^: 0.25 for gains 0.18 for Quasi-gains	No probability weighting	The earliest acceptable arrival time, preferred arrival time and work starting time	No
Senbil and Kitamura (2004b)	Departure time choice	Probit	Non-linear value functions of PT	Decision frame 1: 0.34 for gains 2.07 for losses Decision frame 2: 0.37 for gains 0.20 for Quasi-gains	No probability weighting	The earliest acceptable arrival time, preferred arrival time and work starting time	No
Schwanen and Ettema (2009a)	Who should pick up the children	Logit	OPT*	1.09-1.10 for gains and losses; 1.27-1.37 for the loss aversion parameter	Estimated to be 0.82-0.84 for TK's probability weighting parameter	The time that the child(ren) should have been collected.	No
Schwanen and Ettema (2009b)	Who should pick up the children	Logit	OPT	0.80 for gains and losses; 1.28 for the loss aversion parameter	Estimated to be 1.12 for TK's probability weighting parameter	The time that the child(ren) should have been collected.	No
Avineri (2006)	Network Equilibrium	N/A	CPT	Used the values from TK(1992)	Used the estimated values from TK(1992)	The reference point is assumed as 30 minutes' travel time.	Yes
Connors and Sumalee (2009)	Network Equilibrium	N/A	CPT	The risk attitude parameters are assumed to be 0.52 and the loss aversion parameter is assumed as 2.25.	The parameter is assumed as 0.74 for Prelec's one-parameter weighting function.	Different reference points are tested.	No

Notes:
*: Schwanen and Ettema (2009a) claimed that Cumulative PT is used in their study; however they applied probability weighting function independent of the rank of outcomes, which is OPT.
^: Decision frames 1&2 are shown in Figures 3 and 4 respectively.
N/A: In those studies, the PT parameters (e.g., risk attitudes, probability weighting) are either assumed or borrowed from Tversky or Kahneman (TK) (1992), and then gains/losses and associated probabilities are assigned into a PT framework to calculate the value of risky prospects.

3. Comments on the Traveller Behaviour Studies

In the previous section, we summarised recently published studies where Prospect Theory was employed to model travellers' behaviour and decision making. A number of problems associated with the ways that PT has been applied in those studies are discussed in this section.

3.1 Lack of Empirical Estimates of Prospect Theoretic Parameters

For the values of PT parameters, Connors and Sumalee (2009) assumed the values of risk attitudes and probability weighting; while some studies (including Gao *et al*. 2008 and a series of studies conducted by Avineri and his colleagues) directly used parameter estimates from Tversky and Kahneman (1992) (TK), i.e., 0.88 for risk attitudes in the gain and loss domains, 2.25 for loss aversion and 0.61 and 0.69 for probability weighting in the gain and loss domains, for modelling travellers' decision making. TK employed 25 graduate students as subjects, and used binary lottery tickets in their experiment. Hence their empirical findings (parameters of risk attitudes, loss aversion and probability weighting) are defined over monetary gains and losses. Using TK's parameters will produce the value functions for gains and losses shown in Figure 6, where the increase in monetary gains (losses) leads to more satisfaction (dissatisfaction) and respondents tend to be risk averse over certain gains while risk seeking over certain losses for a very small niche sample. TK also estimated an inversed S-shaped weighting (see Figure 7). By combining the curvatures of the value functions and probability weighting functions, a fourfold pattern of risk attitudes is revealed: risk seeking for low-probability gains and high-probability losses and risk aversion for high-probability gains and low-probability losses, which is a common finding of Prospect Theory studies based on monetary gains and losses (Fox and Poldrack 2008)[4].

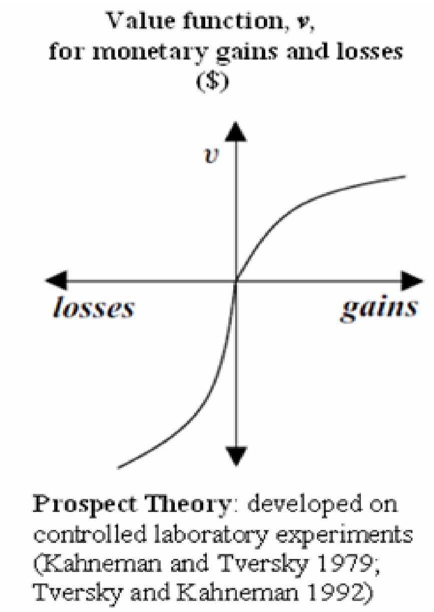

Figure 6: Typical PT value functions over monetary gains and losses

[4] The practice of 'trying to replicate' TK evidence is worrying given the small sample of 25 students that they based all of their findings on.

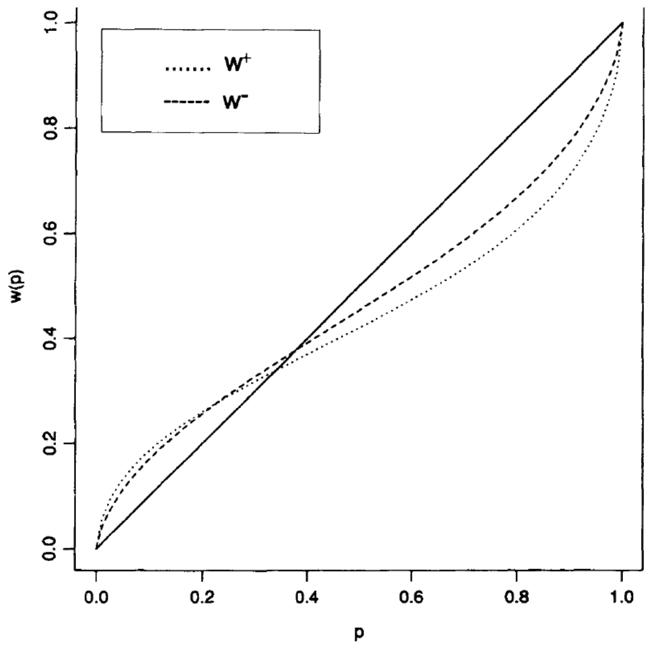

Figure 7: Probability weighting functions for gains (W^+) and losses (W^-) from Tversky and Kahneman (1992)

It is expected that TK's parameter estimates are incapable of explaining travellers' behaviour, given that they used students as their subjects and monetary lottery tickets as their experiment. Hence, applying TK's parameter estimates in travel behaviour studies is likely lead to biased or even incorrect findings and conclusions. For example, Gao *et al.* (2009, p. 12) concluded that their CPT model predicts the twofold attitudes toward travel time losses: "risk seeking under high probability and risk averse under low probability". However, the underlying reason for this conclusion is the use of TK's parameters. Leclerc *et al.* (1995) found the opposite risk attitudes towards travel time losses (i.e., risk averse), relative to monetary losses (i.e., risk loving), suggesting that the time-related decision is not the same as the money-related decision. Given this, Gao *et al.*'s conclusion (based on TK's findings) is questionable.

Evidence also suggests that PT parameters are data specific. Table 1 reveals significant variations in parameter estimates from PT studies developed on monetary gains/losses; for example, the risk attitude parameter in the gain domain is 0.88 in Tversky and Kahneman (1992) which changes to 0.49 in Gonzalez and Wu (1999). Therefore, even using PT parameter estimates from other studies in the same field may also result in misleading behavioural explanation and hence inappropriate policy implications. Hensher and Li (2010) estimated a range of Rank-Dependent Utility models based on one stated preference data set in the context of route choice, and found that model fit varies when different risk attitude parameter values are delivered. This also leads to different willingness-to-pay (WTP) values, which will have a crucial influence on pricing, cost-benefit appraisal and demand forecasting. Hensher and Li (2010) claimed that the risk attitude and probability weighting parameters must be estimated parametrically for models with non-linearity in utility and/or probability weighting.

3.2 Selective Use of Prospect Theory Components

A number of reviewed transportation studies integrated some selective element(s) of Prospect Theory in the modelling process. Jou *et al.* (2009, p.783) claimed that their model “embodies the central features of prospect theory”. However, Jou *et al.* assumed a linear specification without embedding risk attitudes, while no probability weighting is applied to the value function, given the way that their data were collected. Hence, the asymmetry revealed by Jou *et al.* (2009) is not through a PT framework where the curvatures of the value function and the probability weighing function play a central role in identifying the attitudes towards risk over gains and losses, but based on a utility maximisation framework with referencing.

In the transport literature, Gunn (2001), Suzuki et al. (2001) and others highlight the early studies which investigated the asymmetrical response towards gains and losses in travel time and/or travel cost. Recently, there has been a growing interest in stated choice studies to referencing in choice experiments and model estimation, in which typically the reference point is defined as the status quo (the recently experienced preference (RP) alternative, e.g., the recent trip of an driver) and the utility function is defined over gains and losses around the reference alternative (see e.g., Hess *et al.* 2008; Lanz *et al.*, 2009; Hensher 2008, Masiero and Hensher 2009; Hess and Rose 2009). This technique is also referred to as ‘pivoting’. Train and Wilson (2008) concluded that the key advantages of pivoting include: (i) more realism in the stated preference experiments since hypothetical alternatives are around the RP alternative (status quo), and (ii) better specificity in the context of the choice task. Rose *et al.* (2008) also suggested that the reference dependence specification leads to improved model fit. However, these transport studies using the referencing or pivoting technique assumed a deterministic environment (e.g., there is only one travel time (100 percent of occurrence) for an alternative within a choice set), in which the reference point is the RP alternative (which we refer to as ‘between-alternative referencing’), unlike PT models where usually a given certain value (e.g., the time that the child(ren) should have been collected in Schwanen and Ettema (2009a)) is assumed as the reference point and gains/losses are defined within an alternative as the differences of all possible outcomes from the given value (which we refer to as ‘within-alternative referencing’). Given the differences, the other elements of Prospect Theory (e.g., risk attitudes and probability weighting) are not considered in previous transport studies in which gains and losses are relative to the RP alternative (see e.g., Hess *et al.* 2008; Hensher 2008).

In Senbil and Kitamura (2004a, b), a crucial element of Prospect Theory is missing, namely the probability weighting function; while in Han *et al.* (2005), only the probability weighting element of PT is integrated in their model. The probability weighting function and risk attitudes for gains and losses (i.e., non-linearity in value functions) must be addressed simultaneously for PT models, given that the combined curvature of those two elements represents the true risk attitude (see fourfold pattern of risk attitudes of Prospect Theory). Onay and Öncüler (2007, p.101) concluded that a concave utility function or a convex probability weighting function implies risk aversion, and “the latter source of risk aversion is called probabilistic risk aversion”. Harrison *et al*. (2009) using a mixed model under both Expected Utility Theory (EUT) and Prospect Theory (PT), found a concave utility function (risk aversion) according to EUT while a convex utility function (risk seeking) under PT. A probability weighting function was applied separably in the PT utility function, which was estimated as a convex curve. Harrison *et al*. (2009, p.16) explain that the convex probability weighting function "will be to partially offset this risk seeking, [and] the net effect on behaviour will be to make it more similar to that of the EUT decision-makers than the different curvatures of the utility function would imply". That is, the combined curvature of the value and probability weighting functions represents the full and true picture of the attitude towards risk.

The evidence from behavioural economic and psychological studies (e.g., Tversky and Kahneman 1992; Fox and Poldrack 2008, Harrison *et al.* 2009) suggest that all components of PT (i.e., reference dependence, risk attitudes and probability weighting) should be accommodated systematically to achieve the full benefits of Prospect Theory, given individual decision making is a rather complex process. Cherchi (2009) also claimed that the key challenge to travel behaviour studies is to accommodate all those elements jointly. Among our reviewed travel behaviour studies, Schwanen and Ettema (2009a, b) address all elements of a prospect theoretic model parametrically. However, Schwanen and Ettema's studies also have some limitations as a travel behaviour study, which are discussed in the following sections.

3.3 Reference Point Issues

The reference point is a vital component to a PT model. Harrison and Rutström (2008) emphasised that it is critical to specify the reference point in PT models, which capture the elements of subjectivity and context. By varying the value of the reference point based on a single dataset, Harrison and Rutström estimated different log-likelihood ratios along with different risk attitude and loss aversion parameters and claimed that it is inappropriate to assume the reference point to be fixed and deterministic. Timmermans (2009) also suggest that the specification of the reference point is 'endogenous, and stochastic, situation-dependent'. The reference point represents the facts of a decision maker (DM). Hence, an experimenter cannot assign a value of status quo to a DM, which is individual specific. However, Avineri and Prashker (2005) assumed a reference point of 31.5 minutes travel time (which is the mean travel time of two hypothetical routes (33 and 31 minutes) in the experiment) for all subjects.

Schwanen and Ettema (2009a,b) assumed the time that the child(ren) should have been collected as the reference point in their PT models, and a gain (loss) is defined if arriving earlier (later) than this time. However, we argue that dissatisfaction would also be incurred when arriving too early (see Figure 8). However, Schwanen and Ettema's model cannot address the situation of extremely early arrival. Jou *et al.* (2009) and others proposed multiple reference points to accommodate this (see Figure 3). Gao *et al.* (2009) suggested the reference point should be treated as a discrete latent class variable, and then estimate the probabilities of a traveller belonging to three possible reference points: the free flow (minimum possible) travel time, the worst travel time and the mean travel time.

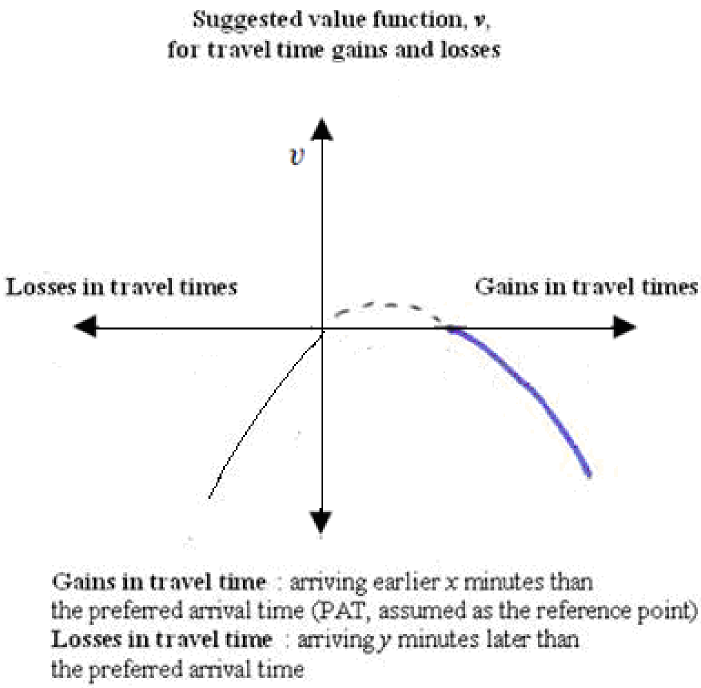

Figure 8: Suggested PT value functions for travel time gains and losses

4. Major Limitations of Reviewed Traveller Behaviour Studies

In the reviewed transportation studies, Prospect Theory or some element(s) of PT are applied (i) to calculate the prospect theoretic value of risky route, along with route share predictions or network equilibrium; (ii) to understand commuters' responses to travel time gains and losses; (iii) to explain the choice data with a common conclusion being that better model fit is delivered by PT relative to EUT; or (iv) to empirically estimate the curvatures of value functions for gains/losses and probability weighting, along with the loss aversion parameter. However, placing these studies in the broader literature on traveller behaviour research highlights some important elements that are missing.

4.1 Absence of Willingness to Pay (WTP) for travel time savings and travel time variability reductions

Valuation of travel time savings (VTTS) has played a central role in transport infrastructure appraisal, traffic modelling and network performance for decades. Recently, a growing number of studies have investigated the significance of travel time reliability in travellers' behaviour. To empirically estimate the willingness to pay values for travel time savings and/or reduced variability is a key focus of many travel behaviour studies established within a utility maximisation framework (see Li *et al.* 2010 for a review). However, none of the reviewed PT studies in this paper provided empirical evidence on willingness to pay. Prospect Theory was originally developed in the area of psychology, to understand individual attitudes; however transportation studies focus on the role of preference. With respect to data collection, a commonly used experiment in psychological research is simply binary lottery tickets, with one attribute only (i.e., monetary prices which are associated with probabilities of occurrence), similar to Schwanen and Ettema's time lottery experiment (see Figure 5). Given there is no trade-offs between attributes, the only way to include WTP outputs is to directly ask individuals to put a value on a specific attribute, i.e., the contingent valuation (CV) method. However CV is little used in transportation studies and there is a huge literature criticising CV and supporting the stated choice (SC) method (see Hensher 2010)

Stated choice (SC) modelling is recognised as the state of the art and practice method to obtain empirical estimates of the WTP for various attributes such as the value of travel time savings, and value of reliability (or trip time variability). In an SC survey, individuals are asked to choose among different alternatives, the attribute levels of which vary according to a statistical design aimed at maximising the precision of the estimates. As such, SC methods allow the analyst to mimic actual choices with a high degree of realism, and for this reason most experts believe that it is an appropriate elicitation method for the valuation of intangibles (McFadden 1998; Louviere *et al.* 2000; Hensher *et al.* 2005).

McFadden (2000), Ben Akiva *et al*. (2002), and other economists agree that it is important to include the psychological perspective of the decision-making process in understanding traveller behaviour. To date, as far as we are aware of, only Li *et al.* (2009), Hensher *et al.* (2010) and Hensher and Li (2010) have developed hybrid models with alternative behavioural paradigms (e.g., Expected Utility Theory and Rank-Dependent Utility Theory) to accommodate both preference and attitudes in modelling individuals' choices, and also empirically delivered WTP values for travel time savings and improved reliability, in which important issues related to stated preference experimental design and model estimation are discussed.

4.2 Individual Heterogeneity

Anderson *et al.* (2009) investigated significant heterogeneity in risk attitudes at the individual level in an EUT framework, based on a non-linear mixed logit model, using data collected from controlled laboratory experiments, where respondents were asked to choose risky lottery tickets. Loomes *et al*. (2002) is another study which also addressed heterogeneity in risk attitudes based on a gambling experiment. Anderson *et al.* used a normal distribution to represent the random parameter (i.e., risk attitude), and Loomes *et al*. used a lognormal distribution. Two experimental economics studies suggest that individual heterogeneity in risk attitudes may exist. However, among our reviewed transport PT studies, none of them investigated unobserved heterogeneity; and only simple logit (or probit) models are used in some studies (e.g., Schwanen and Ettema 2009a; Senbil and Kitamura 2004a).

The mixed multinomial logit (MMNL) or random parameter logit (RPL) model is the dominant approach to reveal individual heterogeneity, in particular in travel behaviour studies based on utility maximisation. The MMNL model also has other advantages over the multinomial logit (MNL) model such as allowing for correlation among random parameters (Train and Sonnier 2005), and autocorrelation of one parameter over multiple choice situations which is important for panel data which is commonly used in travel studies (Gopinath *et al* 2005). Using the MMNL model, Hensher and Li (2010) found significant heterogeneity in the travel time parameter, based on a Rank-

Dependent Utility framework. Hensher *et al.* (2010) revealed stronger heterogeneity in preference (i.e., the travel time parameter) than in the risk attitude and probability weighting parameters within an Extended Expected Utility framework. Both studies reported higher mean WTP values under MMNL than under MNL. Given the limited evidence, there remains the need for further research in general and in travel behaviour studies in particular, to apply more advanced models (e.g., MMNL) within alternative behavioural frameworks (e.g., Prospect Theory).

5. Conclusions

Prospect Theory has been regarded as a superior framework to understand decision making relative to traditional Expected Utility Theory in many fields, offering an appealing way to understand individual attitudes. Over the past decade, some transportation studies have incorporated the idea of PT in the contexts of route choice and departure time choice in particular. By contrasting PT studies in psychology and behavioural economics where Prospect Theory was originally established and further developed, we found that the majority of reviewed transport PT studies fail to properly address all key elements of PT.

A bigger concern is the limitations of PT in explaining traveller behaviour, given the focus of PT is to understand attitudes. Willingness to pay (WTP) cannot be estimated from a 'pure' PT model, which has one attribute only. From a statistical point of view, PT may deliver improved model fit; however we argue that behavioural implications are also important, in particular WTP for travel time savings and reduced variability, crucial to transport infrastructure appraisal, pricing and demand forecasting. Given the advantages of PT in understanding attitudes towards risk, we recommend that PT should be incorporated in traveller behaviour studies as a supplement, while preference needs to be addressed simultaneously. The way to including both preference and attitudes is to develop hybrid models with the co-existence of PT and RUM, which has multiple attributes (e.g., travel time and cost), non-linearity in parameters (risk attitudes) and probability weighing. Hensher *et al.* (2010) and Hensher and Li (2010) have begun this journey within a mix of Extended Expected Utility Theory (EEUT) and RUM, and a mix of Rank-Dependent Utility Theory (RDUT) and RUM, where unobserved heterogeneity is also investigated using mixed multinomial logit models, unlike reviewed PT studies where simple logit or probit models are used.

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