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Unobserved and observed heterogeneity in risk attitudes: Implications for valuing travel time savings and travel time variability

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ABSTRACT

In this paper, we incorporate the attitude towards risk into a scheduling model to account for travel time variability, using a choice experiment of car commuters choosing from risky alternatives. The parameters that represent unobserved and observed heterogeneity in risk attitudes are jointly estimated within a non-linear utility framework. The model outputs are compared with the results from the model under the assumption of risk attitude homogeneity and we find differences in the willingness to pay for time savings and reduced travel time variability. These findings illustrate that risk attitude heterogeneity plays a role in choice behaviour.

1. Introduction

Travel time variability is an important measure of service quality. Bates et al. (1987) classified travel time variability into inter-day, inter-period and inter-vehicle variability. The research focus is on the impacts of day-to-day travel time variations on travel choice behaviour (Bates et al., 2001; Polak et al., 2008; Ramos et al., 2014). Travel time savings is not sufficient to measure the total benefits of infrastructure improvement projects, in which the benefits of reduced travel time variability or improved reliability should be considered (Ettema and Timmermans, 2006; Fosgerau and Karlström, 2010; Taylor, 2017). OECD (2017) highlighted the significance of including travel time variability in the economic analysis. Several countries such as Australia and New Zealand have already included the value of travel time variability in the cost-benefit analysis for project appraisal (de Jong and Bliemer, 2015).

Most travel time variability studies used a linear utility function, which implicitly assumes a risk neutral attitude. This assumption may be appropriate in a deterministic or riskless decision-making environment, for example, there is only one travel time with 100% chance of occurrence for repeated journeys. However, this may not be realistic given that travel time variability is inherent to most transport systems. Given a departure time, there is a chance of arriving early, on time or late (i.e., a travel time distribution). In the presence of travel time variability, the attitude towards risk (risk averse or taking) plays an important role in decision making under risk.

Noland and Small (1995) developed a scheduling model in which travel time variability is represented by the expected schedule delay early/late, based on earlier theoretical contributions by Small (1982) and Polak (1987). Polak (1987) also discussed risk-averse and risk-taking behaviour in the context of departure time choice. Using a non-linear scheduling model with an exponential utility specification, Polak et al. (2008) addressed unobserved heterogeneity in risk attitudes. With respect to the non-linear utility specification, this study adopts a power specification to develop the non-linear scheduling model for parameter estimation.

In the transport literature, a growing number of studies have incorporated alternative behavioural theories (mainly Expected Utility Theory (EUT), Rank-Dependent Utility Theory (RDUT) and Cumulative Prospect Theory (CPT)) which allow for non-linearity

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in utility, as a way of representing the attitude towards risk (see e.g., Avineri and Prashker, 2003; Michea and Polak, 2006; Schwanen and Ettema, 2009; Dixit et al., 2015). Under RDUT and CPT, a non-linear probability weighting function transforms the probabilities of all possible outcomes (e.g., arriving early, late and on time) into decision weights; while the original probabilities are directly used under EUT. A scheduling model takes into account the consequences of travel time variability (i.e., arriving earlier/later than the preferred arrival time), in which only the probabilities of arriving early and late are used to calculate the expected values of schedule delay early and schedule delay late. Therefore, the non-linear scheduling model of this study is based on EUT. Within this non-linear utility framework, unobserved and observed heterogeneity in travellers' risk attitudes are jointly estimated, along with the values of travel time savings and travel time variability. In the literature, only Andersen et al. (2012) have empirically addressed both unobserved and observed risk attitude heterogeneity. In this paper, we also investigate the influence of unobserved and observed risk attitude heterogeneity on willingness to pay (WTP), which is the first in the literature to the author's knowledge.

2. Recent research on travel time variability: alternative behavioural theories

This section briefly summarises recent travel time variability studies based on alternative behavioural theories, with the empirical estimation of risk attitude parameters. Amongst the reviewed non-linear utility studies published after 2010, Expected Utility Theory is the predominant framework for understanding travel choice behaviour under risk (Hensher et al., 2011, 2013a, 2013b; Li and Hensher, 2012; Li et al., 2012; Dixit et al., 2013; Wijayaratna and Dixit, 2016; Balbontin et al., 2017), followed by Rank-Dependent Utility Theory (Hensher and Li, 2012; Li and Hensher, 2013; Razo and Gao, 2014; Wang et al., 2014; Dixit et al., 2015) and Cumulative Prospect Theory (Huang et al., 2016; Wen et al., 2017). A common finding of these studies is risk-taking behaviour over travel time variability. Half of them also estimated the WTP values (Hensher et al., 2011, 2013a, 2015; Hensher and Li, 2012; Li and Hensher, 2012; Li et al., 2012; Huang et al., 2016; Balbontin et al., 2017). Six studies accommodated unobserved between-individual heterogeneity in risk attitudes (Hensher et al., 2011, 2013a, 2013b; Li and Hensher, 2012; Li et al., 2012; Li and Hensher, 2013). For observed heterogeneity in risk attitudes, Dixit et al. (2013, 2015) and Wijayaratna and Dixit (2016) tested a number of socioeconomic characteristics, while only *Age* and *Race* (African Americans vs. non-African Americans) are statistically significant.

None of the existing travel time variability studies addressed both unobserved between-individual heterogeneity and observed heterogeneity in risk attitudes (see e.g., Li et al., 2010; Carrion and Levinson, 2012; Ramos et al., 2014; Shams et al., 2017 for reviews). In this paper, we accommodate unobserved and observed risk attitude heterogeneity in a non-linear scheduling model. An essential component of Rank-Dependent Utility Theory and Cumulative Prospect Theory is non-linear probability weighting which transforms the cumulative probability distribution based on the rank of all possible outcomes for an alternative. However, in a scheduling model, travel time variability is represented by the expected schedule delay early/late (i.e., the minutes of arriving earlier/later than the expected arrival time weighted by their probabilities of occurrence). Under Expected Utility Theory, decision makers compare "the weighted sums obtained by adding the utility values of outcomes multiplied by their respective probabilities" (Mongin, 1997, p.342). Therefore, this study applies Expected Utility Theory to develop the non-linear scheduling model, which adopts the power utility specification (i.e., $U = \frac{x^{1-\alpha}}{1-\alpha}$) and directly use the original probabilities of early/late arrival to weight their corresponding outcomes.

Expected Utility Theory is a conventional framework for modelling risky choice behaviour. A basic EUT model is given in Eq. (1), with the constant *relative* risk aversion form estimated as the power specification. Constant absolute risk aversion (CARA) and constant relative risk aversion (CRRA) are two main options for representing the attitude towards risk, where the CARA model form postulates an exponential specification for the utility specification, and the CRRA form is a power specification. CRRA is usually a more plausible description of the attitude towards risk than CARA (Blanchard and Fischer, 1989).

$$EU = \sum_m \left(p_m \frac{x_m^{1-\alpha}}{1-\alpha} \right) \tag{1}$$

x_m is the mth outcome of an alternative with multiple possible outcomes; p_m is the probability associated with the mth outcome; and α is a parameter which needs to be estimated, and the value of $(1-\alpha)$ reveals the attitude towards risk.

In psychological studies, the attribute of x for an alternative is often money, which is a source of utility and its parameter estimate would be positive. The value of $(1-\alpha)$ is estimated to be less than 1, suggesting a curvature of decreasing marginal *utility*. However, travel time or variability is a source of disutility, $(1-\alpha) < 1$ suggests decreasing marginal *disutility*. This difference is shown in Fig. 1, which is similar to different risk attitudes in the gain domain and in the loss domain under Prospect Theory. Tversky and Kahneman (1992) provided parametric formulae for the value functions, that is $V = x^{\alpha}$ in the gain domain and $V = -\lambda(-x)^{\beta}$ in the loss domain. The corresponding values estimated by Tversky and Kahneman (1992) are 0.88 for α, 0.88 for β and 2.25 for λ. The estimates of α and β, both less than 1, revealed a risk-averse attitude over monetary gains and a risk-taking (or risk-seeking) attitude over monetary losses.

In Fig. 1a, suppose there are two scenarios with an equal expected value of $10: A (sure): winning $10 with 100% chance of occurrence; B (risky): a 50:50 chance of winning $0 or winning $20. If $(1-\alpha) < 1$, the utility incurred by the sure one would be higher than that incurred by the risky one because of a curvature of decreasing marginal utility. Therefore, the sure one would be preferred and chosen, even with the same expected value of $10. This choice behaviour implies risk aversion.

In Fig. 1b, suppose there are two scenarios: A (sure): arriving 10 min later than the preferred arrival time (PAT) with 100% chance of occurrence; B (risky): a 50:50 chance of arriving on time or 20 min later than the PAT. If $(1-\alpha) < 1$, the disutility incurred by the sure scenario would be higher than that incurred by the risky one due to decreasing marginal disutility, and hence the risky one

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