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Value of travel time changes: Theory and simulation to understand the connection between Random Valuation and Random Utility methods

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A B S T R A C T

This paper identifies and illustrates the theoretical connection between the Random Valuation (RV) and Random Utility (RU) methods for Value of Travel Time Changes (VTTC) analysis. The RV method has become more and more popular recently, and has been found to lead to very different estimation results than conventional RU models. Previous studies have reported these differences but did not explain them, which limited the confidence in the RV model as a useful foundation for transport policy analysis. In this paper, we first analytically show in what way exactly the two models are different and why they may generate different estimation results. Based on this deeper understanding of the connection and difference between the two models, we formulate hypotheses regarding the conditions under which differences in estimation results are expected to be smaller or larger. Using synthetic data, we empirically test these expectations. Results provide strong support for our hypotheses, allowing us to derive a number of practical recommendations for analysts interested in using the RV and RU models in their VTTC-analysis.

1. Introduction

The value of travel time changes (VTTC), which measures how people trade off travel time changes against changes in travel costs,[1] is a crucial component of cost-benefit analyses and plays an important role in transport policy design and evaluation studies (Small, 2012;Börjesson and Eliasson, 2014). The large majority of VTTC-studies infer this trade off by means of estimating discrete choice models on data obtained from Stated Preference (SP) experiments, where participants to the experiment are asked to choose between a slower but cheaper, and a faster but more expensive route or travel mode (e.g. Mackie et al., 2003; Fosgerau et al., 2007a; Börjesson and Eliasson, 2014). Traditionally, the adopted discrete choice model is of the Random Utility (RU) type (McFadden, 1974).

However, quite recently an interesting alternative to RU has emerged: this so-called Random Valuation (RV) model has been gaining attention lately, after several empirical studies have found it to be superior to RU in terms of explaining respondents' preferences (as measured in model fit). The RV model differs from the RU model in terms of how it conceptualizes behavior. The RV approach, in a context where a person can choose between a cheap but slow and a fast but expensive travel option, postulates that people decide as if they were in a “time market”: they choose the fast option when their valuation of the presented travel gain is larger than the implicit price of the travel gain which is embedded in the choice situation. The RV-method[2] was suggested by Cameron and James (1987) in an environmental economics context, although the use of the term “RV” can be attributed to Hultkranz et al. (1996). Fosgerau et al. (2007b) were the first to formally introduce the method in a VTTC-context. Since then, a number of studies have shown that there may be large differences in the VTTCs estimated by RU and RV respectively, on a given dataset; model fit differences have been found to be substantial as well

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[1] Most of the literature uses the term *travel time savings*. However, since many transport projects lead to travel time losses and, in fact, most studies do consider savings as well as losses, we use the more generic term *travel time changes*; see Ojeda-Cabral et al. (2016) for a more detailed overview of terminology.

[2] In this paper, we will use the terms ‘model’, ‘method’ and ‘approach’ when referring to RU or RV.

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(e.g., Ojeda-Cabral et al., 2016; Daly and Tsang, 2009). These studies reported VTTCs that, in comparison with a VTTC from a RV model, were often around 1.5 or 2 times greater when a RU model was estimated. Ojeda-Cabral et al. (2016) reported an extreme case where the RU estimate tripled the RV estimate. It goes without saying, that such differences have potentially very large implications for the evaluation of transport policies and infrastructure investments.

Although the theoretical relationship between the RU and RV models has been discussed in previous papers (Fosgerau et al., 2007b; Börjesson and Eliasson, 2014; Hultkranz et al., 1996, Ojeda-Cabral et al., 2016), this discussion is not complete, as we will argue below. As a consequence, the observed non-trivial empirical differences in model fit and estimated VTTC have so far come as a surprise, for which no full explanation is yet provided. Given that the RV approach is growing in popularity in the field of transport economics, we believe that a rigorous assessment of the connection and differences between the RU and RV approaches is needed. This paper provides such an in-depth exploration and interpretation of the connection between RU and RV through the use of analytical derivations and analyses on simulated data. Note that although at first sight, exploration of the differences between the two models might come across as a methodological exercise, it has clear and substantial policy relevance. More specifically, given that the differences and similarities between the two approaches have so far been ill understood at a conceptual level, there has been a hesitation to use the VTTC estimates produced by the relatively new and unknown RV model in cases where its empirical performance (e.g. model fit) turned out to be superior to that of the well-known RU model. As a consequence, the RV's penetration in the transport policy discourse has been severely limited by the absence of a clear and unambiguous understanding of how and when the model and its VTTC output differ from RU and its VTTC. This goal of this paper is to lift the confusion which so far has surrounded the RV model, and as such provide a more solid foundation based on which researchers and analysts can make safe and well informed decisions regarding which model and VTTC estimates to use for transport policy analyses, based on the model's empirical performance.

In Section 2, we highlight the importance of an element which has been missing in previous studies: whereas those studies have argued that the two methods are equivalent in the deterministic domain (i.e., when error terms are excluded), we show that this equivalence only applies in an ordinal sense (i.e., preference orderings between two alternatives are the same in both models), but not in a cardinal sense (i.e., the extent to which an alternative is preferred over another one may vary substantially across the two model types). Since, in a discrete choice context, cardinal differences determine choice probabilities (after error terms have been included), this cardinal inequivalence between RU and RV causes differences in terms of model fit and VTTC estimates. Based on this insight, we are able to formulate hypotheses about the size of the difference between the RU and RV models that one would expect for various types of data, i.e., various types of SP designs and different levels of randomness in choice behavior. These hypotheses are subsequently tested based on empirical analyses on synthetic data.

In Section 3, we formulate hypotheses concerning their differences in terms of model fit and obtained VTTCs, for different types of data. We also present the construction of the simulated data sets, estimation of the RU and RV models, and the interpretation of estimation results. In Section 4 we present overall conclusions, and we provide recommendations for future research; in addition, we discuss practical implications of the obtained insights.

2. Random Utility and Random Valuation: the theoretical connection

The RU model assumes that a person faced with a choice between multiple options, chooses the option that offers the greatest total utility. This total utility is usually conceived in term of a summation of a deterministic (or: 'systematic', 'observed') utility and a random error. For sake of exposition, we initially focus only on this deterministic part of utility. Deterministic utility V_i of each option i is a usually linear-additive function of its observable characteristics (in our case, travel time and cost) and associated parameters: $V_i=\beta_c c_i+\beta_t t_i$; here, β_t and β_c are the estimable marginal utilities of travel time (t) and cost (c), respectively. The value of travel time changes (VTTC) is equal to the marginal rate of substitution between time and cost, which is of a convenient form when systematic utility is specified linearly, as above: $\text{VTTC} = \frac{\partial V}{\partial t} / \frac{\partial V}{\partial c} = \beta_t / \beta_c$.

The Random Valuation (RV) model (Cameron and James, 1987; Hultkranz et al., 1996, Fosgerau et al., 2007b) is applicable when, in the choice context, there is an implicit 'price' for the good we want to value such as in our case a change in travel time. This is the case in a binary choice context where alternatives are described in terms of a price attribute and a quality attribute (in our case travel time); note that many recent SP-experiments have adopted such a binary, two attribute choice context, including several European national VTTC studies, including those in the UK, Denmark, Sweden and Norway (Mackie et al., 2003; Fosgerau et al., 2007a; Ramjerdi et al., 2010; Börjesson and Eliasson, 2014). The implicit price (denoted Boundary VTTC or BVTTC) can then be defined as follows. Throughout the paper, we will assume a choice context in which option 1 is slower but cheaper than option 2 (i.e. faster and more expensive): i.e. $t_1 > t_2$ and $c_1 < c_2$. Then, the price threshold or BVTTC, is equal to: $\text{BVTTC}=\frac{-(c1-c2)}{(t1-t2)}= -\frac{\Delta c}{\Delta t}$, where Δt and Δc are the differences in travel time and cost, respectively, between options 1 and 2. The RV model assumes that people choose whether they accept the price of time (BVTTC) which is implicitly embedded in the choice situation, or not. If the individual's VTTC is larger than the BVVTC, the faster but more expensive option is chosen. As in the RU model, additive errors are introduced in the RV model to accommodate randomness; hence the individual's choice probabilities will be driven by the difference between the VTTC and the BVTTC, such that $y = 1\{\text{VTTC}<\text{BVTTC}+\epsilon\}$ (see further below for details).

The RV model has been said to be equivalent to the RU model in the deterministic domain, i.e. before randomness in the form of errors is introduced (Fosgerau, 2007; Ojeda-Cabral et al., 2016). However, these studies implicitly referred to ordinal equivalence. Indeed, in the deterministic domain, the two models can easily be shown to be equivalent in an ordinal sense. To see this, consider an individual whose VTTC equals $\frac{\beta_t}{\beta_c}$. Take the above described binary choice situation involving a cheap and slow alternative (1) and a fast but expensive alternative (2), with an implicit price that equals $\frac{-(c_1-c_2)}{(t_1-t_2)}$. Now it can be easily seen that $\frac{-(c_1-c_2)}{(t_1-t_2)} > \frac{\beta_t}{\beta_c}$ if and only if $\beta_t t_1+\beta_c c_1 > \beta_t t_2+\beta_c c_2$. In other words, if BVTTC > VTTC in the RV model this necessarily implies that $V_1 > V_2$ in the RU model; both inequalities imply that the cheaper but slower option is chosen. This makes the two models equivalent in an ordinal sense.

Given the equivalence (in an ordinal sense) between RU and RV in the deterministic domain, previous research has related the observed differences between the two models in model fit and obtained VTTC-estimates, to the way in which randomness is introduced in the two models. However, here we show that the difference and connection between the two models in the deterministic domain is more subtle than the ordinal analysis