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The impact of travel time variability and travelers' risk attitudes on the values of time and reliability

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ABSTRACT

In this paper, we derive implementable measures of travelers' willingness to pay to save travel time (VOT) and to improve the reliability (VOR) of a given trip. We set out a simple microeconomic model of transport mode choice in which each trip is fully characterized by its price and the statistical distribution of its random travel time, assuming that travelers have expected utility preferences over the latter. We then explore how the VOT and VOR are affected by the statistical distribution of travel time and by travelers' preferences towards travel time variability.

1. Introduction

How to improve transport systems is an important public policy issue for virtually any government. In practice, public decisions on transport infrastructure usually rely on cost benefit analysis of alternative projects. Among the benefits of an improved transport system, it is now well established that travel time savings and travel time reliability gains are two important elements. In general, the appropriate appraisal of almost any transport system requires monetary estimates of both the value of travel time (VOT) and the value of travel time reliability (VOR). This is particularly the case for policy makers who may have to choose between mutually exclusive public transport infrastructure projects that include travel time savings (e.g., the construction of a new high speed rail) and/or reliability gains (e.g., the construction of a bypass that increase capacity). Therefore, this study derives theoretically-based and implementable monetary measures of the VOT and the VOR.

The VOT has a long history in microeconomic theory, dating back at least to the seminal contribution on the optimal allocation of time by Becker (1965), where time appears as an unconsumed input to prepare final goods, from which utility is ultimately derived. Accordingly, the VOT would be understood as an opportunity cost, i.e., the cost of not earning money during an out-of-work period, and, thus, would simply be given by the wage rate. Then, by explicitly incorporating both work time and leisure time into preferences, as separate arguments of the consumer's utility function, Johnson (1966) showed that the VOT was equal to the sum of two terms: the wage rate and a monetary value of the marginal disutility of work time. Accordingly, Johnson (1966) concludes that the wage rate provides an upward biased estimate of the VOT. Soon after, Oort (1969) reached the same conclusion, and claimed that travel time itself should be added to the arguments of the consumer's utility function. Going a step further towards the formal integration of time in standard microeconomic

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demand theory, DeSerpa (1971) generalized these frameworks by distinguishing explicitly between the time spent by necessity and the time spent by choice, depending on whether the time consumption inequality constraints are binding, or not, respectively. By adding scheduling considerations to both the utility function and the time consumption constraint, Small (1982) introduced the now standard scheduling model with endogenous departure time.[1]

Moreover, with the aim of providing a theoretical foundation for the so-called safety margin, Gaver (1968) and Knight (1974) were among the first to consider travel time variability by relaxing the standard assumption of a certain travel time in departure time choice models. Subsequently, assuming mean-variance preferences over a random travel time, Jackson and Jucker (1981) were able to explain data collected from a discrete choice experiment in stated preferences, in which subjects were asked to choose among risky trips with random travel times. Note that these early contributions only implicitly rely on the assumption of Von Neumann and Morgenstern (1947)'s expected utility preferences over random travel time. In this respect, notable advances resulted from Polak (1987) and Senna (1994), who derived measures of both the vot and the vor in the context of a general model of travel choice, and to Noland and Small (1995) and Noland et al. (1998), who extended Small (1982)'s scheduling model to accommodate reliability.There are at least two distinct approaches used in the literature to incorporate travel time variability in theoretical models: the Bernoulli approach (Jackson and Jucker (1981); Polak (1987); Senna (1994); Small et al. (2005); Hensher et al. (2011); Beaud et al. (2012); Devarasetty et al. (2012); Kouwenhoven et al. (2014)) and the scheduling delays approach (e.g. Noland and Small (1995); Noland et al. (1998); Batley (2007); Asensio and Matas (2009); Fosgerau and Karlstrom (2010); Engelson and Fosgerau (2011); Fosgerau and Engelson (2011); Koster and Koster (2015)), the present paper belonging to the former.[2]

However, as observed by Small (2012), after decades of study, the vot and the vor are still incompletely understood concepts. In particular, the literature is not clear on how the vot and the vor are impacted by the statistical distribution of travel time or by travelers' preferences towards travel time variability. In this study, these issues are addressed from the point of view of the theory of individual choice under financial risk (Bernoulli, 1738; Arrow (1963); Pratt (1964); Rothschild and Stiglitz (1970)). Thus, we try to further bridge the gap between the notion of travel time reliability in transport policy and the notion of financial risk in microeconomic theory. Using the Bernoulli approach, we set out a simple microeconomic model of transport mode choice, in which each trip is fully characterized by its price and the statistical distribution of its random travel time. A traveler's preferences function is assumed to be separable and quasi-linear, and is the sum of a linear function of price and the expectation of a non-linear univariate function of travel time.[3] Then, we introduce model-free definitions of the vot and the vor, the definition of the vor being new. The vot is defined as the willingness to pay for a given reduction in travel time, while the vor is defined as the willingness to pay to eliminate all variability in travel time. Hence, we explore how the vot and the vor, which are functions of travel time rather than values, are affected by the statistical distribution of travel time and by travelers' preferences towards travel time variability, i.e., their risk attitudes.

By definition, reliability-prone travelers prefer a fully reliable trip (which has a single travel time outcome) to a risky trip (which has multiple travel time outcomes) whenever both have the same price and mean travel time. For instance, reliability-prone travelers prefer a 90 min trip to a risky trip of either 60 min or 120 min, with equal probability. As one would expect, reliability proneness is equivalent to the concavity of the preferences function with respect to travel time. In other words, reliability proneness is equivalent to a decreasing marginal utility of travel time, reflecting travelers' increasing sensibility in the duration of the journey.[4] An important – and unrecognized – consequence of this is that reliability proneness implies that the vot is increasing with travel time. More generally, we show that, for all reliability-prone travelers, the vot is increased by any first-order stochastic deterioration in the distribution of travel time. This result implies, for instance, that reliability-prone travelers are willing to pay less to save 30 min on a 90 min trip than to save 30 min on a 120 min trip. Furthermore, if the marginal utility of travel time is concave, then, borrowing Kimball (1990)'s terminology, we say that travelers are prudent.[5] We then show that if travelers are reliability-prone and prudent, then their vot is increased by any second-order stochastic deterioration in the distribution of travel time. This result implies, for instance that all reliability-prone and prudent travelers are willing to pay less to save 30 min on a 60 min trip than to save 30 min on any risky trip with a mean travel time of 60 min. A key understanding these results is that reliability proneness and prudence characterize a general preference for the combination of good (e.g., a decrease in travel time) and bad (e.g., a high or an unreliable

[1] See Jara-Diaz (2000) for a comprehensive survey of this literature.

[2] Lam and Small (2001) and Borjesson et al. (2012) used both approaches. Useful reviews of the literature can be found in Wardman (1998), Noland and Polak (2002), Jong et al. (2004), Li et al. (2010), Carrion and Levinson (2012) and Engelson and Fosgerau (forthcoming). Engelson and Fosgerau (forthcoming) identify a third type of approach: mean-dispersion models. These models are defined directly in terms of statistics of the travel time distribution. They consist of measures that are linear in the mean travel time and some measure of the dispersion of travel time.

[3] The implications of non-separability between price and time for the vot are explored in Blayac and Causse (2001) and Jiang and Morikawa (2004).

[4] Our model treats travelers' reliability proneness as exogenous. This contrasts with the scheduling preferences model, in which reliability proneness may be viewed as endogenous. In particular, travelers arriving at their preferred arrival time (PAT) during a fully reliable trip would dislike the introduction of actuarially-neutral travel time variability (making the trip risky, without affecting the mean travel time), ceteris paribus, because they would then necessarily suffer schedule delay early and/or schedule delay late in some states of the world. On the other hand, reliability proneness cannot be a general property of scheduling preferences in that reliability proneness would be obtained for a given trip, while reliability aversion would be obtained for another. This may viewed by considering travelers who do not arrive at their PAT during a fully reliable trip. Here the risk may become desirable as because the arrival time would be closer to the PAT in some states of the world.

[5] The notion of prudence was introduced by Kimball (1990) to measure the intensity of saving in the face of a future risk affecting wealth.