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A rank-dependent expected utility model for strategic route choice with stated preference data

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ABSTRACT

Route choice behavior under real-time traffic information needs to be adequately modeled for the proper analysis of a transportation system in the presence of Advanced Traveler Information Systems (ATIS). This paper focuses on strategic route choice, where a traveler is able to plan ahead for traffic information that s/he will receive in the future. A Stated Preference (SP) survey was conducted with interactive maps showing two types of networks with risky travel times, one type eliciting risk attitude and the other allowing for strategic route choice with a detour to an incident-prone road segment and real-time traffic information. The preliminary analysis suggests that a traveler's risk attitude is probability-dependent. A rank-dependent expected utility (RDEU) model is adopted to account for such a phenomenon, where the decision weight of a probabilistic outcome depends on its ranking among all outcomes and a non-linear transformation of the cumulative probability. A latent-class mixed Logit model for panel data is specified with a RDEU component and two latent classes, strategic and non-strategic route choice. The estimated strategic class probability is significantly different from 0 and 1 respectively, suggesting that a route choice model under real-time information should consider both types of behavior. The estimated RDEU parameters show significant diminishing sensitivities to both outcome and probability and explain the probability-dependent risk attitude.

1. Introduction

With advances in surveillance, telecommunication and personal electronic device technologies, real-time traffic information has increasingly become available to travelers through, for example, smartphones equipped with location services, or in-vehicle GPS units subscribing to real-time traffic information. Such information is valuable because it could potentially help reduce uncertainties in the transportation system due to accidents, fluctuating demand, vehicle breakdown, road construction, bad weather, and other incidents. It follows that effective analysis and prediction of traffic demand in the presence of Advanced Traveler Information Systems (ATISs) requires proper accounting for the effects of real-time information on individual route choice behavior.

En route information on revealed traffic conditions could potentially prompt travelers to change route. For example, a Variable Message Sign (VMS) indicating an incident downstream along the freeway could induce some travelers to take an earlier exit and follow a parallel arterial. This type of on-the-spot response to real-time information has been studied extensively in the literature (for recent reviews, see Abdel-Aty and Abdalla, 2006; Chorus et al., 2006). Travelers are assumed

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to make successive path choices at intermediate decision nodes, where the attributes of the alternative paths might be updated due to the revealed real-time traffic conditions. The availability of the information and any detours does not affect the traveler's route choice until the information is actually revealed.

However, travelers need not only respond to information on the spot; they can also plan ahead for information that will be available in the future. Suppose a traveler is faced with a choice of two branches of roads, one with no real-time information, and the other presenting information to travelers at certain points in the network where detours are available. Even though the real-time information itself is not available to the traveler when s/he must choose a branch, the knowledge that such information will be available can affect the traveler's choice.

Strategic thinking, in this context, refers to the traveler's recognition that certain detours can be taken in response to future information. The perceived quality of a route can be greatly affected by this consideration, and subjects whose choices reflect this are considered to exhibit strategic choice behavior.

Discrete choice models for strategic route choice are developed in Gao et al. (2008, 2010) and their differences from conventional non-strategic route choice and/or expected utility models compared. Later on empirical evidence of strategic route choice behavior is presented in Razo and Gao (2010), where a simple hypothetical network is implemented as an interactive graphical map. Subjects use the map to make route choices based on travel times and real-time information. Subjects' choices are analyzed using risk and travel time metrics, and a latent-class Logit model is estimated with the mean travel time and travel time standard deviation as explanatory variables. The data analysis and model estimation both supported the hypothesis that some subjects did in fact account for future information when choosing a route.

Another interesting finding from Razo and Gao (2010) is that travelers' risk attitudes changed with the probability of travel delay. The developed Logit systematic utility function thus includes three different parameters for the travel time standard deviation, one for each of the three levels of delay probabilities used in the survey. The model fits the data satisfactorily, however it cannot be used for prediction where the delay probability can be any value.

In this paper, we adopt a rank-dependent expected utility (RDEU) specification of the systematic utility function to model travelers' subjective perception of probabilities. RDEU is proposed by Quiggin (1982) and one of the most popular descriptive models of decision under risk. The better known cumulative prospect theory (CPT) by Tversky and Kahneman (1992) is a combination of their original prospect theory (Kahneman and Tversky, 1979) and RDEU. In RDEU, the decision weight of an outcome is determined not only by its own probability, but also the probabilities of outcomes that rank higher. A commonly accepted inverted S-shaped weighting function (Tversky and Kahneman, 1992) is used in this paper together with a power function for the value function. A similar model is applied to analyze airline route choice in de Lapparent (2010).

The key difference between the RDEU framework and the CPT framework is that RDEU does not compare potential outcomes to a reference point. In the RDEU models developed here, all outcomes are considered losses. We do not adopt the reference-dependent CPT in this paper, mainly because it is not clear whether any reference points other than 0 exist in our route choice survey, or how they could be determined if so. de Palma et al. (2008) suggest that the determination of reference points is one of the major obstacles to the application of CPT and that they likely vary over individuals as well as choice contexts. Most previous CPT-based empirical travel studies either present the survey questions explicitly in terms of gains or losses (Katsikopoulos et al., 2000, 2002; Schwanen and Ettema, 2009; Xu et al., 2011) see, e.g., possess natural reference points (the preferred arrival time in departure time choice) (Senbil and Kitamura, 2004; Jou et al., 2008) see, e.g. or assume a reference point arbitrarily (Avineri, 2004; Avineri and Prashker, 2005; Ben-Elia and Shiftan, 2010) see, e.g. Alternatively the model developed in this paper can be viewed as a loss-only CPT model with 0 as the reference point. Similarly, Gao et al. (2010) presents a loss-only CPT model validated through synthetic data, yet using the lowest origin-destination travel time as the reference point.

The remainder of the paper is organized as follows. Section 2 describes the survey set up and preliminary findings with regards to strategic route choice and risk attitudes. The RDEU model applied to travel time outcomes is presented next in Section 3. A latent-class mixed Logit model with panel data is specified in Section 4, with two latent classes: strategic and non-strategic decisions. Section 5 presents the estimation results of the parameters for the value and weighting functions as well as the latent strategic class probability. Conclusions and future directions are given in Section 6.

2. Stated Preference (SP) survey

2.1. Survey design

The survey was designed to measure two aspects of the subjects' route choice behavior: risk attitude and strategic thinking. Since strategic route choice is only relevant in networks with risky travel times, it is crucial to properly understand and model risk behavior when addressing strategic thinking.

To this end, the survey was designed using two map types: a "simple risk" map and a "strategy" map. The simple risk map (Fig. 1) presents subjects with a clear choice between a path with deterministic travel time (Link B, the safe route) and a path with random travel time (Link A, the risky route). Since there are no detours or real-time information available, there is no opportunity for strategic choice, and this map type measures a subject's risk attitude only. A wide range of travel time scenarios is presented using the same map topology, to collect a large number of data points for each subject.