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A hybrid-choice latent-class model for the analysis of the effects of weather on cycling demand

Yutaka Motoaki [1], Ricardo A. Daziano *

School of Civil and Environmental Engineering, Cornell University, Ithaca, NY 14853, United States

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ABSTRACT

In this paper we analyze demand for cycling using a discrete choice model with latent variables and a discrete heterogeneity distribution for the taste parameters. More specifically, we use a hybrid choice model where latent variables not only enter into utility but also inform assignment to latent classes. Using a discrete choice experiment we analyze the effects of weather (temperature, rain, and snow), cycling time, slope, cycling facilities (bike lanes), and traffic on cycling decisions by members of Cornell University (in an area with cold and snowy winters and hilly topography). We show that cyclists can be separated into two segments based on a latent factor that summarizes cycling skills and experience. Specifically, cyclists with more skills and experience are less affected by adverse weather conditions. By deriving the median of the ratio of the marginal rate of substitution for the two classes, we show that rain deters cyclists with lower skills from bicycling 2.5 times more strongly than those with better cycling skills. The median effects also show that snow is almost 4 times more deterrent to the class of less experienced cyclists. We also model the effect of external restrictions (accidents, crime, mechanical problems) and physical condition as latent factors affecting cycling choices.

1. Introduction

The negative externalities of automobile-dependent societies range from congestion and high levels of pollution to health issues due to lack of physical activity (Litman and Laube, 2002). One of the solutions to the degradation in livability provoked by automobile dependency is the adoption of non-motorized alternatives. In particular, there are several benefits associated with the use of cycling (Hillman, 1993; Sallis et al., 2004), including better air quality, no fossil fuel dependency, less noise, more efficient use of space, increased levels of physical activity, competitive speed on middle range distances, low purchase price and virtually zero operating costs (Heinen et al., 2010; Rabl and de Nazelle, 2012; Akar and Clifton, 2009).

To encourage the use of non-motorized alternatives we need to better understand the motives underlying demand. Econometric travel demand models are highly valuable for assessing the effect of policies and incentives seeking to reduce the indiscriminate use of cars. In fact, forecasting demand using discrete choice models has proved to be successful in the case of modal split among motorized alternatives. Excellent literature reviews of modeling the disaggregate demand for cycling are provided in Sener et al. (2009), Heinen et al. (2010), Li et al. (2013), Fernandez-Heredia et al. (2014) and Maldonado-Hinarejos (2014). In particular, Fernandez-Heredia et al. (2014), Habib et al. (2013) and

* Corresponding author. Tel.: +1 607 255 2018; fax: +1 607 255 9004.
E-mail addresses: ym323@cornell.edu (Y. Motoaki), daziano@cornell.edu (R.A. Daziano).
[1] Tel.: +1 607 255 2018; fax: +1 607 255 9004.

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Maldonado-Hinarejos (2014) discuss the integration of discrete choice models of cycling decisions with subjective (latent) factors, using hybrid choice models (Walker and Ben-Akiva, 2002; Ben-Akiva et al., 2002; see also Bhat et al., 2015; Kamargianni et al., 2015).

The review papers cited above discuss some of the challenges in the application of discrete choice analysis to non-motorized options. Users of the transportation system may be motivated to cycle or walk not because of the tradeoff between cost and time (the main determinant of motorized mode choice), but because of health and environmental benefits of these alternatives. Improvements in health and in environmental footprint, for example, are positive externalities that are difficult to quantify. Additionally, several factors may discourage choice of non-motorized transportation, such as poor accessibility, safety concerns (Wilkinson, 1994; Pucher and Dijkstra, 2000), and unfavorable route and weather conditions. For instance, it is often argued that the American North East has a poor climate for cycling (see the discussion in Pucher et al., 2011).

In this paper we analyze demand for cycling using a discrete choice model with latent variables and a discrete heterogeneity distribution for the taste parameters. Our technical contribution is to use the estimator of a hybrid choice model where latent variables not only enter utility but also inform assignment to latent classes. Using a discrete choice experiment we analyze the effects of weather (temperature, rain, and snow), cycling time, slope, cycling facilities ("bike paths"), and traffic on cycling decisions by members of the community of Cornell University. We note that analyzing commuting patterns in university campuses has become a relevant case study for better understanding adoption of sustainable transportation (Shannon et al., 2006; Akar et al., 2012; Akar et al., 2013; Whalen et al., 2013; Danaf et al., 2014; Rotaris and Danielis, 2014; Erdogan et al., 2015).

In the hybrid choice modeling literature, most empirical applications consider a conditional logit kernel (for example, Kamargianni and Polydoropoulou, 2013) because of the problems associated with maximizing the complex likelihood function of the model (cf. Kamargianni et al., 2015). Habib et al. (2013), for example, work with a combination of binary logit and bivariate probit models. Other researchers have been working on the incorporation of random parameters with continuous heterogeneity distributions. For example, Maldonado-Hinarejos (2014) consider a mixed logit kernel with latent variables. Nevertheless, these authors use a limited information estimator that has poorer statistical properties compared to the joint estimator. In this work we use a full information estimator for the combination of a hybrid choice model with a latent class module. Our methodological approach differs from the work of Hurtubia et al. (2014) in that we model the effect of the latent variables on the class assignment probabilities. The remainder of the paper proceeds as follows. In Section 2, we describe our data collection method and statistics of the data. In Sections 3 and 4, we describe our results from Structural Equation Modeling and Discrete Choice Modeling, respectively. In Section 5, we conclude by discussing the results and policy implications of our study.

2. The data: cycling choices in a university environment

2.1. Motivation

Universities campuses are no exceptions from an auto-dependent environment where much of the infrastructure is built for cars and other motorized vehicles rather than for bicycles and pedestrians. In the last decades, however, numerous colleges have been adopting transportation demand management plans that aim at reducing motorized trips to and within campus. Bicycling improvements are particularly appropriate and effective for transportation management on university campuses for a number of reasons. University communities consist of many young and physically active commuters. If student commuters acquire environmental transportation habits it is likely that they will retain these habits after their graduation (Balsas, 2004). Nevertheless, if one expects that bicycling improvements will raise ridership in the future, careful planning and appropriate investment in bicycle infrastructure are necessary in order to accommodate future demand. Since accurate ridership prediction is indispensable for those planning investment decisions, it is important to identify the significant factors related to the motivation for people to bicycle.

Since the institution of a Transportation Demand Management Plan in the 1990s, Cornell University has continued to promote sustainable land use and environmentally friendly transportation plans, such as encouraging mixed land use, limiting growth within core campus boundaries, and ensuring a walkable and a cycling-friendly campus environment. Despite these efforts and despite the fact that a majority of students – 84% of graduate students and 97% of undergraduates – live within 5 miles of campus, the share of bicycle as a commuting transportation mode is very small. The 2006 Cornell University Travel Survey showed that the share of bicycle as the primary commuting mode was 1.4% for undergraduate students, 4.0% for graduate students, and 3.1% for employees (the US average share of cycling was roughly 1% in 2009; Pucher et al., 2011). There are two main factors that discourage the use of bicycles as a commuting mode at Cornell. The first is topography. The Ithaca campus of Cornell is located on a hill about 400 ft. (122 m.) above downtown of the city of Ithaca. Buffalo street, which connects downtown Ithaca and the area adjacent to campus called Collegetown, has a 15% grade (slope). The second factor is weather. The climate of the area where Cornell is located – upstate New York – is characterized by hot and wet weather in summer (in July, the average maximum temperature is 80.1 °F/26.7 °C and the average precipitation is 3.54 in./8.99 cm), and cold and snowy weather in winter (in January, the average minimum temperature is 13.9 °F/ −10.1 °C, and the average snowfall is 17.9 in./45.47 cm).