Habitat International 38 (2013) 157–166

Contents lists available at SciVerse ScienceDirect

Habitat International

journal homepage: www.elsevier.com/locate/habitatint

Cross-nested logit model for the joint choice of residential location, travel mode, and departure time

Liya Yang [a,*], Guo Zheng [a], Xiaoning Zhu [b]

[a] School of Public Administration, Renmin University of China, No.59 Zhongguancun Avenue, Beijing 100872, PR China
[b] School of Traffic and Transportation, Beijing Jiaotong University, PR China

Keywords:
Residential location
Travel mode
Departure time
Joint choice
Cross-Nested Logit
GEV

A B S T R A C T

This paper aims to describe the joint choice of residential location, travel mode, and departure time. First, based on random utility maximization theory, the Cross-Nested Logit model and traditional NL models are formulated respectively. House price, travel time, travel cost, and factors depicting the individual socio-economic characteristics are defined as exogenous variables, and the model choice sets are the combination of residential location subset, departure time subset, and travel mode choice subset. Second, using Beijing traffic survey data of 2005, the model parameters are estimated, and the direct and cross elasticity are calculated to analyze the change of alternatives probability brought by factors variation. Estimation results show the Cross-Nested Logit model outperforms the three kinds of NL model. It is also found by estimation results that decision makers will change first their departure times, then their travel modes, and finally their residential locations, when exogenous variables alter. Moreover, elasticity analysis results suggest that, for long-distance commuting, it is difficult to decrease car travels even if additional charges are imposed on car users. The effect on choice probability by variations in travel time of other travel mode can be considered as negligible for alternatives within 5 km commuting distance, and this effect are greatest for alternatives between 10 and 20 km commuting distance. These findings have important implications for transport demand management and residence planning.

Introduction

There is a strong correlation between commuting travel behavior and residential neighborhood type. Brown (1986) suggested that travel behavior and residential location are not independent goods and, therefore, demand for either good needs to be modeled considering the other. Travel behavior and residential location have a profound and lasting impact on urban transport pattern, land use, and urban form change. As a consequence, the study of them has attracted considerable attention from researchers in several disciplines, including transportation (see Khattak & Rodriguez, 2005; Lerman, 1976; Vega & Reynolds-Feighan, 2009), geography (see Waddell, 1996), and urban economics (see Brown, 1986; Clark & Onaka, 1985; Kim, Pagliara, & Preston, 2005).

Travel behavior includes a series of choices, among which travel mode choice and departure time are so important that they usually influence the efficiency of the whole transportation system, especially during the peak period. As Hess, Daly, Rohr, and Hyman (2007) and Ozbay and Yanmaz-Tuzel (2007) indicated, a strong relation exits between mode choice and departure time choice, and people often make the two choices simultaneously.

Modeling the choices of residential location, travel mode, and departure time, will give us an insight into these three choice dimensions, and the interactions between them, and also be seen as a prerequisite to the process of urban planning, transportation planning and transportation demand management.

However, studies considering the three choice dimensions are rare, which partly due to the limits of the existing choice model.

Discrete choice modeling based on the random utility maximization (RUM) hypothesis is an effective tool to analyze the choice problem of residential location and travel behavior. Within the RUM-based models, the Multinomial logit (MNL) model (MacFadden, 1973) has been the most widely used structure due to its simple mathematical structure and ease of estimation (see Albert, 1993; Gabriel & Rosenthal, 1989; Guo & Bhat, 2001; Wafaa, 2005). However, MNL imposes the restriction that the distribution of the random error terms is independent and identical over alternatives. This restriction leads to the independence of irrelevant

* Corresponding author. Tel.: +86 13681125217; fax: +86 010 51682002.
E-mail addresses: yangliya@mparuc.edu.cn, liya_yang@263.net (L. Yang), zhengguo@mparuc.edu.cn (G. Zheng), xnzhu@bjtu.edu.cn (X. Zhu).

0197-3975/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.habitatint.2012.06.002

alternatives property which causes the cross-elasticities between all pairs of alternatives to be identical (Wen & Koppelman, 2001). This representation of choice behavior produces biased estimates and incorrect predictions in cases that violate these strict conditions.

The best known relaxation of the MNL model is the nested logit (NL) model (Williams, 1977), which divides the choice-set into hierarchical and mutually exclusive nests of alternatives, allowing correlation across alternatives sharing a nest. However, the NL model is not without its limitations. In analyzing the joint choice problem of residential location, travel mode, and departure time, three possible one-level nesting structures arise, either of which can only accommodate correlation along at most one of the three dimensions. For example, the first structure uses nesting by residential location, such that in the case of R residential locations, each elementary alternative (triplet of residential location, travel mode, and departure time) is assigned to exactly one residential location nest, hence acknowledging correlation in the unobserved utility terms for alternatives sharing the same residential location.

An important development in the field of discrete choice modeling was the introduction of the generalized extra value (GEV) class of models within the RUM framework (Ben-Akiva & Francois, 1983; McFadden, 1978). The GEV class of models allows flexible substitution patterns between different choice alternatives, while maintaining a simple closed-form structure for the choice probabilities. Several models have been developed within the GEV class, as recently discussed by Bekhor and Prashker (2008), Daly and Bierlaire (2006), Koppelman and Sethi (2008), and Sener, Pendyala, and Bhat (2011). Although the GEV class have been popularly applied in the filed of spatial choice, the use in the joint choice of residential location and travel behavior is very limited.

The current paper presents a new cross-nested model structure within the theoretical framework of GEV class to describe and quantify the joint choice behavior of residential location, travel mode, and departure time. The sample is mainly drawn from Beijing traffic survey of 2005. Different from the existing studies, the key feature of the cross-nested model proposed by this paper is that it accommodates correlation among all three dimensions of residential location, travel mode, and departure time.

The reminder of this paper is organized as follows. The next section reviews the main contributions to the choice of residential location, travel mode, and departure time, and the progress made on the discrete choice model. The third section presents a detailed formulation of the cross-nested model proposed in this paper. The fourth section describes the data set used for the model while the fifth section presents detailed model estimation results. The final section outlines the main conclusions and discusses briefly the policy implications of the analysis presented.

Existing research

There is a substantial and rich body of literature related to the choice of residential location and travel behavior. However, many studies have focused only on one dimension choice, on residential location (for example, Bhat & Guo, 2004; Gabriel & Rosenthal, 1989; MacFadden, 1978; Sener et al., 2011; Weisbrod, Lerman, & Ben-Akiva, 1980) or on travel behavior (for example, Albert, 1993; Bhat, 1998; De Jong, Daly, Pieters, Vellay, & Hofman, 2003; Wafaa, 2005).

The simultaneous choice of residential location and travel behavior (especially travel mode) is supported by early theoretical contributions that acknowledged the need for integrating both decisions in transport and land use models (Brown, 1986; Leroy & Sonstelie, 1983). Brown (1986) suggested that travel behavior and residential location are not independent goods and, therefore, demand for either good needs to be modeled considering the other. Desalvo and Huq (2005) suggested that high income individuals use faster modes and travel short distances to work and those commuting long-distances, use faster modes and experience lower marginal commuting costs. Vega and Reynolds-Feighan (2009) analyzed the simultaneous choice of residential location and travel-to-work mode and explored the effects of car travel variables on re-location and travel-to-work mode switching in the Dublin region.

As compared to mode choice, activity scheduling is often greatly simplified or ignored in urban travel models (TRB, 2007; Vovsha, Davidson, & Donnelly, 2005), though it represents an important component of travel behavior. Over the past several years, activity scheduling has received more attention, sine planning and policy questions have shifted toward congestion and demand management. It is essential to combine time choice model with residential location model to get more valuable and comprehensive findings guiding the work of urban planning and traffic management.

During the last three decades, most of the research presented in the literature dealing with the simultaneous choice of residential location and travel behavior has applied random utility maximization (RUM) theory and discrete choice modeling to empirically estimate joint probability choice models. McFadden's (1973) MNL model represents the most familiar and straightforward of these models. However, the MNL model suffers from the independence of irrelevant alternatives (IIA) property, which results in equivalent cross-elasticities across each pair of choice alternatives.

The nested logit model (Daly & Zachary, 1979; MacFadden, 1978; Williams, 1977) relaxes this assumption, allowing correlations to emerge across similar alternatives. However, choice alternatives in common nests still retain the IIA property (Lemp, Kockelman, & Damien, 2010).

In recent decades, the GEV class of models (MacFadden, 1978) has become a mainstay in travel behavior analysis of discrete choice behavior. The GEV models allow the random components of alternatives to be correlated, while maintaining the assumption that they are identically distributed (i.e., identical, non-independent, random components). In GEV models, the marginal distribution of the individual error terms is univariate extreme value, and different assumptions about the cumulative distribution of the vector of error terms lead to different model forms.

MNL model and NL model can be derived from GEV model. Other type of GEV models includes the paired combinatorial logit (PCL) model (Chu, 1989; Koppelman & Wen, 2003), which allocates each alternative in equal proportions to a nest with each other alternative and estimates a logsum (dissimilarity parameter) for each nest; the cress-nested logit (CNL) model, which allocates a fraction of each alternative to a set of nests with equal (Vovsha, 1997) or unequal logsum parameters (Papola, 2004; Vega & Reynolds-Feighan, 2009; Wen & Koppelman, 2001) across nests; the ordered generalized extreme value (OGEV) model (Small, 1987), which allocates alternatives to nests based on their proximity in an ordered set.

Model specification

In this section, based on the previous studies of Bierlaire (2006) and Hess and Polak (2006), a new cross-nested model structure within the theoretical framework of GEV class, was presented to investigate the joint choice of residential location, travel mode, and departure time. This model allows for a flexible correlation of the error terms and, thus can describe the correlation between the three choice dimensions of residential location, travel mode and departure time.