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Joint analysis of the spatial impacts of built environment on car ownership and travel mode choice

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ABSTRACT

Concerns over transportation energy consumption and emissions have prompted more studies into the impacts of built environment on driving-related behavior, especially on car ownership and travel mode choice. This study contributes to examine the impacts of the built environment on commuter's driving behavior at both spatial zone and individual levels. The aim of this study is threefold. First, a multilevel integrated multinomial logit (MNL) and structural equation model (SEM) approach was employed to jointly explore the impacts of the built environment on car ownership and travel mode choice. Second, the spatial context in which individuals make the travel decisions was accommodated, and spatial heterogeneities of car ownership and travel mode choice across traffic analysis zones (TAZs) were recognized. Third, the indirect effects of the built environment on travel mode choice through the mediating variable car ownership were calculated, in other words, the intermediary nature of car ownership was considered. Using the Washington metropolitan area as the study case, the built environment measures were calculated for each TAZ, and the commuting trips were drawn from the household travel survey in this area. To estimate the model parameters, the robust maximum likelihood (MLR) method was used. Meanwhile, a comparison among different model structures was conducted. The model results suggest that application of the multilevel integrated MNL and SEM approach obtains significant improvements over other models. This study give transportation planners a better understanding on how the built environment influences car ownership and commuting mode choice, and consequently develop effective and targeted countermeasures.

1. Introduction

With the increases in car ownership and usage, the transportation sector's shares of energy consumption and emissions are significant and growing enormously. Between 1970 and 2005 average annual vehicle miles travelled (VMT) per household in the US increased by 50% (Bureau of Transportation Statistics, 2007). The transportation sector accounts for approximately 33% of total CO_2 emissions from fossil fuel combustion, the largest share of any end-use economic sector (Liu and

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Shen, 2011). In addition to the environmental negative externalities, extensive transport emissions caused by the increased automobile usage also results in public health problems (Xue et al., 2015). As to the CO_2 emissions, fuel consumption and emission reduction from the transportation sector can be achieved by coordinating the "three-leg stool": fuel types, vehicle fuel efficiency, and VMT (Ewing et al., 2008). Adapting from the study conducted by Cervero and Murakami (2010), the combination of the "three-leg stool" to reduce the transport CO_2 emissions can be described as follows:

$$\text{transport emissions} = \underbrace{\underbrace{\left(\frac{\text{gallons}}{\text{mile}}\right)}_{\text{fuel consumtion}} \times \underbrace{\left(\frac{\text{carbon}}{\text{gallons}}\right)}_{\text{carbon content}}}_{\text{sustainable mobility}} \times \underbrace{\underbrace{\left(\begin{array}{c}\text{vehicle miles}\\ \text{traveled}\end{array}\right)}_{\text{activity}}}_{\text{sustainable urbanism}} \quad (1)$$

Overall, the three "three-leg stool" to deal with the growth of vehicle energy consumption and emissions can be divided into two potential solutions: sustainable mobility and sustainable urbanism. Strategies such as introduction of low-carbon fuels and new technologies that increase fuel efficiency aim to improve the first two "legs of the stool" belong to the way of "sustainable mobility" solutions. Another way to alleviate vehicle energy consumption and transport emission is through "sustainable urbanism" solutions such as re-planning our cities (i.e. by changing the built environment) so there is less demand to drive. The "built environment", as Handy et al. (2002) defined it, comprises urban design, land use and the transportation system, and encompasses patterns of human activity within the physical environment. A growing body of literature has focused on investigating the relationship between the built environment and travel behavior (Kamruzzaman et al., 2016; Jahanshahi and Jin, 2016; Ewing and Cervero, 2001, 2010). Especially, the studies related to the causal effects of the built environment on driving behavior (e.g. car ownership, mode choice, and VMT) have obtained more attentions (Zahabi et al., 2015; Ding et al., 2014a; Nasri and Zhang, 2014; Heres-Del-Valle and Niemeier, 2011; Cervero and Murakami, 2010; Van Acker and Witlox, 2010; Zegras, 2010; Manaugh et al., 2010; Bhat and Eluru, 2009; Bhat and Guo, 2007; Cao et al., 2007b). However, the debate on the influences of various built environment measures on travel behavior is far away from reaching the consensus due to the different empirical contexts, geographical scale, residential self-selection (i.e. people choose where to live based on their travel needs and preferences), and methodologies (Cao, 2015; Antipova et al., 2011; Mokhtarian and Cao, 2008; Limtanakool et al., 2006; Handy et al., 2005).

This goal of this study is to investigate the effects of the built environment on car ownership and travel mode choice simultaneously, by using a multilevel integrated MNL and SEM approach that jointly accommodates the spatial context in which individuals make travel decisions and considers the intermediary of car ownership. Moreover, a comparison among potentially different model structures was conducted. Finally, the spatial heterogeneities of car ownership and travel mode choice across TAZs were recognized, and the direct, indirect and total effects of the built environment on car ownership and travel mode choice were obtained. Hence, this study makes efforts to answer the question: how, and to what extent, does the built environment change commuter's driving behavior?

The remainder of this paper is organized as follows. The following section presents a brief overview of the existing literature. The third section presents the modeling approach used in this study. Data sources are identified and described in the fourth section. Then the proposed model is applied and empirical model results are discussed in the following section. The final section provides the conclusions and recommendations for future studies.

2. Literature review

As vehicle energy consumption and emissions increases in recent years, driving-related behavior especially car ownership and travel mode choice has received a great amount of attention in travel demand analysis because of its important roles played in transportation and land use planning (Munshi, 2016; Ding et al., 2014b, 2016; Gim, 2015; Nielsen et al., 2013; Sharma and Mishra, 2013; Mishra and Welch, 2012; Van Acker and Witlox, 2010; Zegras, 2010; Potoglou and Kanaroglou, 2008; Cao et al., 2007a; Zhang, 2004; Cervero, 2002; Bhat and Pulugurta, 1998). According to the theoretical framework of hierarchical travel behavior introduced by Ben-Akiva and Atherton (1977), people's travel decision is made by a three-stage process: car ownership should be considered as a medium-term decision, which is determined by the long-term decisions (e.g. residential location choice). Car ownership, in turn, has impacts on the short-term decisions (e.g. travel mode choice). In other words, car ownership is a key mediating linkage between the residential location and travel mode choice. However, in most existing transportation studies, car ownership is assumed to be an exogenous factor to travel mode choice with ignoring its intermediary nature (Ding et al., 2014b). To our knowledge, there are limited empirical studies that considered the intermediary nature of car ownership when exploring the built environment on travel mode choice behavior (Van Acker and Witlox, 2010; Cao et al., 2007b; Scheiner and Holz-Rau, 2007). Therefore, to be more consistent with the actual travel decision process, car ownership should be treated as a mediating factor rather than an exogenous factor.

Most studies on the impacts of the built environment on travel behavior are often conducted at a certain aggregated spatial unit such as TAZ, census tract, or the zip code level, thereby spatial issues (e.g. spatial heterogeneity, spatial dependency, and spatial heteroscedasticity) occur among travelers living within the same zone because of the locational effects (Bhat and Zhao, 2002; Bhat, 2000). However, ignoring the spatial context in which individuals make travel decisions can lead to inconsistent model results. To solve this problem, the multilevel modeling framework has been employed to the relationship analysis between built environment and travel behavior in recent years (Ding et al., 2014a, 2014c, 2016; Nasri and Zhang, 2014;

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