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Examining the effects of the neighborhood built environment on CO_2 emissions from different residential trip purposes: A case study in Guangzhou, China

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ABSTRACT

This study developed structural equation models (SEMs) to examine the effects of the neighborhood built environment on CO_2 emissions from different trip purposes. CO_2 emissions were calculated using the Travel O-D Point Intelligent Query System (TIQS) and a 2015 travel survey in Guangzhou. The results showed that there were several differences in the influence mechanism of the neighborhood built environment on CO_2 emissions for different trip purposes. Most of the built environment elements tested in this study had significant effects on CO_2 emissions. Certain effects were direct effects, while others were indirect effects that influenced mediating variables, such as car ownership, mode choice or trip distance. In terms of total effect, the distance to city public centers had a positive effect on CO_2 emissions from commuting trips but had a negative effect on that from recreational and daily shopping trips. In contrast, residential density had a negative effect on CO_2 emissions from commuting trips but had a positive effect on that from social, recreational and daily shopping trips. Bus stop density was positively correlated with CO_2 emissions from commuting trips, a counterintuitive but not implausible outcome. Additionally, bus stop density had a significant negative correlation with CO_2 emissions from social and daily shopping trips. In addition, land-use mix had a negative effect on CO_2 emissions from commuting, social and daily shopping trips, while metro station density and road network density had significant negative effects on CO_2 emissions for all trip purposes. These results suggest that it is necessary to design targeted interventions in the built environment to encourage residents to change their travel behavior, reduce CO_2 emissions, and achieve low-carbon development.

1. Introduction

Land use and transportation planning have a long-term and structural role in shaping the built environment, which has a profound impact on people's daily work, life and travel. New Urbanism began in the United States in the late 1980s and advocated for rebuilding the relationship between land use and transportation (Newman & Kenworthy, 1996). One of the core concepts of New Urbanism is the reduction of the environmental impact of urban development by land use control (Crane & Crepeau, 1998). In the same period, the Compact City Policy in Europe was also an advocate of high-density and mixed-use neighborhoods. This policy, through urban planning strategies, encouraged more non-motorized travel and shorter travel distances, reducing the use of cars (Van Acker & Witlox, 2010). Over the past thirty years, planners around the world have been trying to improve the built environment to enable people to travel using sustainable green and low-carbon travel modes, such as public transport, cycling and walking (Banister, 2011). However, at the same time, the development of Chinese cities is continuing along the present American path of suburbanization and decentralization and is manifesting the characteristics of spread development that occurred in the second half of the 20th century in the United States. In many large cities in China, land use patterns with low density, functional simplification and decentralized development have appeared in new towns and suburbs. These land use patterns are characterized by large blocks and wide roads and abandon the traditional neighborhood development model that was oriented towards transportation modes of public transit and walking, leading to a significant increase in residents' travel distance and car use (Cao, 2015; Zhao, 2010; Zhao, 2013).

The transportation sector is the world's second largest carbon

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emissions sector. In 2014, the total carbon dioxide emissions of global transportation reached 7384.89 Mt., accounting for 23.31% of emissions from all sectors (IEA, 2016). Studies have found that transportation is the sector that has the fastest growth rate of carbon emissions and is the most difficult in which to achieve carbon reduction (Brand, Tran, & Anable, 2012; Marsden & Rye, 2010). With the continuous development of its social economy, China's carbon emissions from transportation will continue to grow for a considerable time (Yang, Li, & Cao, 2015). Although some studies have explored the characteristics and influencing factors of China's carbon emissions from transportation at the macro, national level (Wang, Zhang, & Zhou, 2011; Yang et al., 2015), few have examined the relationship between the built environment and the travel-related carbon emissions of residents based on the character of Chinese cities, especially considering the effect of residential self-selection (Cao & Yang, 2017; Liu, Ma, & Chai, 2017; Ma, Liu, & Chai, 2015). Meanwhile, many studies only focus on the direct effects of the built environment but ignore the indirect effects. The effects of built environment elements on residents' carbon emissions may not always be direct but rather affect via some intervening factors, such as car ownership. In addition, very few studies have explored and compared the impact mechanisms of CO_2 emissions from different trip purposes, which are likely not to be consistent with one another (Barla, Miranda-Moreno, & Lee-Gosselin, 2011; Brand, 2009; Brand, Goodman, Rutter, Song, & Ogilvie, 2013; Ko, Park, Lim, & Hwang, 2011).

To narrow these research gaps, this study uses Guangzhou as a case to examine the effects of the neighborhood built environment on travel-related CO_2 emissions. This study is based on questionnaire data. It primarily answers the following two scientific questions: (1) After controlling for the effect of residential self-selection, how does the neighborhood built environment affect the travel-related CO_2 emissions of residents through intermediary factors? And, (2) for different trip purposes, are there differences in the influencing factors and mechanisms of CO_2 emissions? For example, are there some built environmental elements that curb travel-related CO_2 emissions for certain trip purposes, but increase emissions for other trip purposes? The remainder of this paper is organized as follows. Section 2 briefly reviews previous research on the built environment, travel behavior, and CO_2 emissions related to travel behavior. Section 3 introduces the methodology and data used in this analysis. Section 4 examines the estimation results of the models and analyzes the effects of the neighborhood built environment on travel-related CO_2 emissions. Section 5 provides primary conclusions and policy recommendations.

2. Literature review

The built environment is mainly composed of land use, urban design and the transportation system (Handy, Boarnet, Ewing, & Killingsworth, 2002). Cervero and Kockelman (1997) first proposed "3D" to measure the built environment, which included density, diversity, and design. Destination accessibility and distance to transit are considered to be two other "D"s of the built environment. In some studies, demand management, including parking supply and cost, is also considered to be a sixth "D". Though not part of the built environment, demographics are also considered as a seventh "D" in some travel studies and are controlled as confounding factors (Ewing & Cervero, 2001; Ewing & Cervero, 2010).

Numerous studies have explored the relationship between the built environment and travel behavior (Boarnet, 2011; Crane, 2000; Handy et al., 2002; Handy, Cao, & Mokhtarian, 2005), most of which have focused on trip frequencies, trip lengths, mode choices or modal splits and person miles traveled (PMT), vehicle miles traveled (VMT) or vehicle hours traveled (VHT) (Ewing & Cervero, 2001; Ewing & Cervero, 2010). Although the findings of these studies are not entirely consistent with each other, certain commonalities exist. According to summarized research by Ewing and Cervero (2001) on 20th century studies, trip frequencies were mainly determined by the socio-demographics of travelers, followed by the built environment; trip lengths were mainly affected by the built environment, followed by socio-demographics; mode choice was influenced by both socio-demographics and the built environment, but the effect of the former may be greater; for overall vehicle miles traveled or vehicle hours traveled, the effect of the built environment was much more significant than socio-demographics. Almost ten years later, these researchers conducted a new meta-analysis of the literature on the built environment and travel and found similar results to those of the previous study. In this new study, more built environment variables were analyzed simultaneously, and more confounding effects were controlled for. It found that the combined effects of several built environment variables on travel could be quite large (Ewing & Cervero, 2010). However, these studies rarely focused on the environmental costs of travel, such as carbon emissions, which is also an outcome of travel behavior (Cao, 2017; Cao & Yang, 2017).

Existing studies of the subject are mainly carried out in developed countries in North America, Europe and Oceania and are based on questionnaire data. Brownstone and Golob (2009) found that residential density was negatively correlated with transportation energy consumption. A study by Barla et al. (2011) in Queensland, Australia, found that travel-related CO_2 emissions of residents who lived in suburbs of the city with relatively low residential density were generally higher than those who lived in central urban areas with higher residential density. Ding, Wang, Xie, and Liu's (2014) case study of Washington D.C. confirmed that the built environment, at both the home and workplace, played an important role in work-related VMT and its related greenhouse gas emissions, while densities at the workplace had a greater impact. A study by Zahabi, Miranda-Moreno, Patterson, Barla, and Harding (2012) in Montreal, Canada, showed a quantitative relationship exists between the built environment and carbon emissions: if residential density, land-use mix and public transport accessibility increased by 10%, respectively, household greenhouse gas emissions from transportation would decrease by 3.5%, 2.5% and 5.8%, respectively. Similarly, Hong and Goodchild's (2014) study in the Puget Sound region of the United States also found that a 100% increase in residential density, land-use mix and intersection density in urban areas could reduce the elasticity of transport emissions by 31.2–34.4%. Moreover, Hong (2015) further noted that there was a non-linear relationship between residential density and transportation carbon emissions. When the density reached a certain level, the effect of increasing residential density on reducing carbon emissions would not be significant. Ding, Liu, Zhang, Yang, and Wang (2017) further measured the effects of the built environment on VMT and vehicle energy consumption and found that they varied significantly between commuting and non-commuting trips. This also suggests that the effects of the built environment may not be the same for different types of travel and, thus, it is significant to further study the impacts on different types of non-commuting trips, such as social, recreational and daily shopping trips.

Because the built environment, urban form and the characteristic of transport carbon emissions in China are quite different from those in Western cities (Dodman, 2009; Yang et al., 2015), and the travel-related attitudes and preferences of Chinese residents are relatively unique (Wang & Lin, 2014), the conclusions drawn from studies of Chinese cities are different from those of Western countries. Several studies in China observed that the relationship between residential density and travel-related CO_2 emissions was not significant (Jiang, He, & Zegras, 2011; Xiao, Chai, & Liu, 2011). In terms of public transport, Ma et al.'s (2015) study in Beijing found a negative correlation between subway accessibility and CO_2 emissions from commuting, while Xiao et al.'s (2011) research found that bus accessibility had a positive impact on travel-related CO_2 emissions. These studies suggest that a consistent conclusion has not been reached.

In general, most of the above studies did not consider the residential self-selection effect and only measured the direct effect of the built environment on travel-related CO_2 emissions. If the self-selection effect is not be controlled for, it is likely to misestimate the impact of the built