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The impact of urban form on CO_2 emission from work and non-work trips: The case of Beijing, China

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ABSTRACT

A critical issue in the mitigation of transport CO_2 emission and the development of low-carbon cities is the need to get a better understanding of factors that shape travel behavior, and resulting carbon emission. Using an activity diary survey and GIS-based land use data in Beijing, this research investigates how urban form characteristics at neighborhood and city scales impact individual's daily travel behavior and subsequent CO_2 emission from work and non-work trips, respectively. Structural equation modeling (SEM) is adopted to examine the relationship between urban form, travel behavior, and CO_2 emission, while accounting for residential self-selection and socio-demographic attributes. Results show that residents living in neighborhoods with higher job density, proximity to an employment sub-center and greater subway accessibility tend to travel shorter distance, choose low-carbon travel modes, and emit less CO_2 from work related trips. People resident in neighborhoods with higher retail density or mixed land use tend to travel shorter distance and have less CO_2 emission from non-work trips. The research also suggests that work related trips have larger variation than non-work trips across neighborhoods, indicating the job-housing spatial mismatch might be the main factor that drives up travel demand and transport CO_2 emission in urban Beijing.

Introduction

With the accumulation of scientific evidence, climate change is now recognized as a real and daunting threat to global development and the human race (IPCC., 2013). Cities are responsible for 80% of global GHG emissions (World Bank, 2010), and transport is the fastest growing sector worldwide in energy consumption and CO_2 emission (IEA, 2009; Yan & Crookes, 2009). Clearly, reducing energy consumption in the transport sector plays a key role in achieving the climate change mitigation targets set by national and local governments around the world.

The potential of urban planning on climate change mitigation has attracted much scholarly and practical attention. A large volume of literature has existed on the effectiveness of planning tools in modifying individual travel behavior, while some studies further explore the implications for carbon emission reduction (e.g. Grazi, van den Bergh, & van Ommeren, 2008; Qin & Han, 2013a). Scholars have found that higher population density, mixed land use and pedestrian-friendly street design correlates with fewer vehicles, shorter distance and less motorized travel (Ewing & Cervero, 2010; Khattak & Rodriguez, 2005; Krizek, 2003). Nevertheless, theoretical debates have not been fully resolved with respect to the influence of urban form on travel behavior, especially when residential self-selection is taken into account (Bagley & Mokhtarian, 2002; Cao, Mokhtarian, & Handy, 2007; Chatman, 2009; Mokhtarian & Cao, 2008). Even less conclusive is the extent to which the urban form impacts on energy consumption and carbon emission from urban transport (Liu & Shen, 2011). More efforts should be made to research the relationship among urban form, travel behavior and transport carbon emission, which lies at the core of developing a sustainable city (Handy, 2005).

Moreover, much existing literature analyzed the transport CO_2 emission from people's urban travel at the aggregate level (e.g. Dhakal, 2009), which is unable to differentiate carbon emissions from different travel purposes and examine how changes in urban form attributes may impact daily travel behavior and subsequent CO_2 emission. As the influence of urban form on travel behavior

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differs by trip purposes or activities (Dieleman, Dijst, & Burghouwt, 2002), research on the role of land use characteristics on activity-based transport CO_2 emission at an individual level is very scarce. China already accounts for the largest share of the world's energy consumption and CO_2 emission, and Chinese urbanization has been unprecedented in scale and magnitude. The interaction between urban spatial restructuring and individual daily travel experienced profound changes in the past three decades, which may differ from their counterparts in advanced economies.

In Chinese cities, rampant urban expansion and spatial restructuring has dramatically increased the travel demand between residence and workplace (Fernandez, 2007). Suburbanization tends to result in residential booms in the suburbs whereas job opportunities remain concentrated in the city center (Zhao, Lü, & de Roo, 2010). Because of such job-housing spatial mismatch, residents in suburban neighborhoods often face lower job accessibility and have to endure longer commutes (Zhou, Wu, & Cheng, 2013). On the other hand, Chinese urban planning regulations stipulate basic services and facilities – such as shops, restaurants, kindergartens, and schools – to be planned and constructed on-site by residential real estate developers. Residents of suburban neighborhoods may still enjoy some extent of proximity to services and facilities as those living in inner-city neighborhoods. Therefore, it is necessary to differentiate travel purposes in order to understand the impact of urban form on transport CO_2 emission from work related and non-work related activities, respectively.

In light of this intellectual gap, this paper examines how land use characteristics at neighborhood and city scales influence CO_2 emission from individual daily travel behavior in urban Beijing, China. We developed different models for travel activities with work related purposes and non-work related purposes, and seek to understand the effects of different urban form factors on the amount of CO_2 emission from work trips and non-work trips, separately. We obtain the micro-level travel data from an activity diary survey conducted in 2007 and employ structural equation modeling (SEM) to examine how the urban form variables affect travel behavior and CO_2 emission from different trip purposes, while accounting for residential self-selection and socio-demographic attributes.

The remainder of this paper is structured as follows. After reviewing the relevant literature in next section, we propose the conceptual framework for empirical analysis and provide research design and data sources in following section. The next section presents findings from descriptive analysis, comparing travel characteristics and CO_2 emission by travel purposes across neighborhoods. The findings from the SEM analysis follow, with the conclusions and policy implications in the final section.

Urban form, travel behavior and CO_2 emission

A large amount of literature has investigated the relationship between urban form and travel behavior in various contexts. Despite developments in data collection techniques and analytic models, scholars have yet to resolve the debates regarding the complex effects of urban form on individual behavior, especially when accounting for other factors such as household attributes and residential preferences. For instance, Dieleman et al. (2002) demonstrated, in Dutch cities, that urban form and household attributes were both significant in explaining individual's travel behavior, including modal choice, travel distance, and trip purposes. Krizek (2003) also found significant influences of urban form on travel behavior: in neighborhoods with a higher density, households were more likely to make more tours with fewer stops and they tended to travel shorter distance for maintenance activities such as shopping and personal errands.

More recent studies, however, have challenged the correlation implications by arguing that residents consciously choose to live in the kinds of neighborhoods in line with their travel and residential preferences and that it is necessary to account for the residential self-selection process in the urban form-travel analysis. Using structural equation modeling (SEM), Cao, Mokhtarian, and Handy (2009) managed to demonstrate the significant influence of neighborhood characteristics on individual travel decisions for non-work trips, especially for non-motorized travel frequency, even when residential self-selection was accounted for. Yet similar SEM analyses have led to different or even inverse results. For instance, Bagley and Mokhtarian (2002) found that travel behavior was largely impacted by attitudinal and lifestyle variables, and that the influences of built environment variables have been overestimated by the new urbanism supporters. In a critical literature review, Ewing and Cervero (2010) provided a meta-analysis of existing empirical findings, showing that the relationship between urban form and travel behavior is still inconclusive.

Another trend in this literature is to extend the urban form-travel framework to include the impact of land use characteristics on energy consumption and travel-related CO_2 emission. In one of the earliest studies, Newman and Kenworthy (1989) examined the urban form-energy relations in 33 cities worldwide and found that land use characteristics, such as population density and job density, strongly correlated with gasoline usage. This work, although widely cited, has also been criticized, e.g. for not controlling for other factors (Gordon & Richardson, 1989). More sophisticated models have been adopted since this pioneering research, such as the instrumental variable (IV) approach (Grazi et al., 2008) and the structural equation modeling (SEM) approach (Brownstone & Golob, 2009; Liu & Shen, 2011). Scholars have found that locations with higher density tend to consume less oil and emit less carbon dioxide, while others showed less strong evidence. Liu and Shen (2011) suggested, in the case of the Baltimore metropolitan area, that urban form variables only had indirect effects on vehicle miles traveled (VMT) and energy consumption.

While existing literature predominately focuses on advanced economies such as the US or Europe, Chinese cities have been largely absent from the urban form-energy research, except a few recent studies (e.g. Ma, Chai, & Liu, 2011). Using a household survey in Jinan in 2010, Guo et al. (2013) conducted a comparative analysis of housing and transport CO_2 emissions in 23 neighborhoods in Jinan, China. This study found that neighborhoods with high density, mixed land use and convenient accessibility to public transit tend to reduce domestic and transport CO_2 emissions. On the basis of a household survey in case Beijing, Qin and Han (2013a) also examined the correlations between different types of neighborhoods and household carbon emissions, and derived similar results. However, these studies are mostly based on comparison analysis, using neighborhood types – rather than specific urban form attributes – as explanatory variables, and did not differentiate transport CO_2 emission from different travel purposes and explore the impact of other factors.

To conclude, compared to the growing emphasis on the role of land use and spatial planning in climate change mitigation (e.g. World Bank, 2010; IPCC., 2013), empirical literature is still insufficient and debates over the relationship between planning parameters and carbon emissions are yet to be fully resolved. Most studies either focused on automobile travel while paying little attention to CO_2 emission from different transportation modes, or fail to consider the travel activities for trip purposes when studying transport CO_2 emissions. As suggested before, the effects of urban form on travel behavior differ by trip purposes. For instance, travel for work purposes are more subject to the overall job-housing spatial balance on a metropolitan scale – such as proximity to