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Understanding the determinants of travel mode choice of residents and its carbon mitigation potential

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ABSTRACT

Effective low carbon transport policy-making needs to first understand what are the factors influencing residents' modal choice and how it can be intervened. This study uses a discrete choice model to analyse the factors influencing residents' mode choice in Beijing. A questionnaire survey was conducted in 2015, with sample data containing 865 respondents and 1704 trips collected. The results suggest that residents' mode choice is closely related to their characteristics. Moreover, our study has linked residents' mode choice with travel carbon emissions and estimated the emissions reduction potential of those policy measures aiming to improve public transport. For commuting and education trips, public transport improvements can reduce carbon emissions by 12.3~16.6% on average, but for other trip purposes, the reduction is only 2.9~6.8%. As commuting and education trips account for the largest proportion of urban residents' daily travels, it suggests that policy should primarily focus on the improvement of public transport and its particular support for major commuting routes.

1. Introduction

Accounting for nearly a quarter of global energy-related greenhouse gas emissions, the transport sector is acknowledged as one of the most challenging sectors for mitigation of climate change (IPCC, 2014). Although currently China's transport demand *per capita* is relatively low, vehicle ownership and travel demand are increasing rapidly in China's urban cities, which are in turn associated with rapidly growing transport emissions (IEA, 2013; Wang et al., 2015). In particular, the vehicles ownership in Beijing has increased by 117% in the last ten years (about 5.6 million vehicles in 2015), and ranked the first among China's cities in 2016 (NBS, 2016). The tremendous vehicle ownership in Beijing has led to severe traffic congestion and environmental pollution. Facing the big challenge, Beijing has taken many steps to develop public transport and encourage residents to use low carbon transport modes instead of private cars (Beijing Government, 2016). Public transport has been developed rapidly in Beijing with its scale and coverage increasing dramatically. For example, by the end of 2016, there were 19 urban rail transit lines with total route-length of 574 km in Beijing, which ranked the second only to Shanghai, and the total passenger volume reached to 3.7 billion person-trips (BMBS, 2017). However, faced with a large population (21.73 million), existing city transport capacity appears inadequate. A lottery system was established for issuing car licence plates in 2010, and, although this has slowed the increase in vehicle ownership, traffic congestion remains unrelieved. Inadequate public transport capacity is also combined with issues such as low levels of passenger comfort and perceived inequities in scales of charges.

To cope with the complex transport issues in Beijing, a combination of public policies are needed. Beside technical solutions, whereas, effective policy-making needs an understanding of those factors influencing residents' mode choices and how they can be intervened. Many studies have analysed this issue for cities in developed countries (Salon, 2009; Vredin Johansson et al., 2006; Kim and Ulfarsson, 2008). For cities in China, there have been only a few such works published. For examples, Yang and Zhao (2012) and Qin et al. (2014) have analysed mode choice in Beijing using discrete choice models, however, these studies were based on the data of 2005 and 2010. As Beijing's urban transport has been changing rapidly since 2010, the residents' mode choices are reasonably supposed to have significantly changed in recent years. Li and Zhao (2015) analysed the determinants of commuting mode choice in Beijing, while it only focused on the journeys to school by students aged 13–15. Yang et al. (2017) simulated the carbon mitigation effect of four key low carbon transport polices in Beijing including the public transport improvement policy, public bike policy, energy efficiency improvement policy, and electric vehicle

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development policy. While the fundamental rules of individual behaviour have not been specifically investigated in the study.

This study uses a discrete choice model to analyse the factors influencing Beijing residents' travel mode choice. A questionnaire survey was conducted in 2015 to collect the most recent data about residents' daily travel habits in Beijing. The sample contains 865 residents and 1704 trips. The evaluation model has considered influencing factors from five aspects, including objective factors (*e.g.*, travel time) and subjective factors (*e.g.*, attitudes to public transport). Moreover, our study linked residents' travel mode choice with transport carbon emissions, by applying emission factors to different transport modes. In this way, we are able to simulate and estimate the potential effects of certain public transport improvements (in policy aspects). By understanding on individual travel mode choice, the study could provide references for public policy making and share insights into low carbon transition of transport sector and relieving traffic congestion in fast-growing cities.

The remainder of this paper is organised as follows: Section 2 reviews the existing literatures and summarises the factors influencing mode choice, Section 3 describes the methodology, Section 4 presents the estimation results and discussion, and Section 5 concludes the research and discusses its policy implications.

2. Factors influencing resident's travel mode choice

Previously there have been massive studies examining public travel behaviour, especially in developed countries. Based on the existing literatures, we classify the factors influencing residents' travel mode choice into five groups: (1) travel demand characteristics; (2) travel mode characteristics; (3) socio-demographic characteristics; (4) subjective attitudes and perceptions; and (5) environmental characteristics.

First, travel demand characteristics mostly refer to trip purposes and travel time. Residents' trip purposes include commuting, shopping, leisure, and so on. O'Fallon et al. (2004) found that some residents tend to choose cars for commuting because they need to transport children to school during their commuting. Travel time is most likely to influence residents' mode choice if the trip is during the morning or evening peak period. Habibian and Kermanshah (2013) found that, during peak periods, residents are more likely to choose public transport than private cars to avoid congestion.

Second, different travel modes have different characteristics in terms of travel distances, travel time duration, cost, safety, comfort, flexibility, convenience, and so on. Among these characteristics, travel distance and travel time are highly correlated, but existing studies usually prefer to use travel time instead of travel distance since residents are found to be more sensitive to travel time duration than to distances (Salon, 2009). In most cases, residents prefer to the travel mode that has shorter time duration and lower cost (Qin et al., 2014). Studies also found that safety, comfort, flexibility, and convenience of different travel modes are important factors influencing travel mode choice (Heinen et al., 2011; Redman et al., 2013).

Third, socio-demographic characteristics have direct impacts on residents' choice of travel mode, which may refer to their gender, age, income, education, occupation, car ownership, and so on. For example, older residents are less likely to ride bikes on short trips because riding involves too much effort (Johansson et al., 2006). High-income residents may be more likely to travel by private cars because they might be faced with higher time cost and have higher demand for comfort and convenience (Hensher and Rose, 2007; deVasconcellos, 2005).

Fourth, subjective attitudes and perceptions including residents' environmental awareness and attitudes to different transport modes are important determinants. For the same travel mode, residents can have different feelings about, and preferences towards, the safety, comfort, convenience, and other aspects thereof. These differences in subjective attitudes are found to significantly influence residents' mode choices (Bamberg and Schmidt, 2003; Donald et al., 2014).

Fifth, environmental characteristics refer to the natural environment and urban environment where the travel event takes place. The natural environment refers to the weather, temperature, air quality, and so on, which significantly influence outdoor travel activities such as walking and cycling (Heinen et al., 2010). Urban environment factors include population density, spatial diversity, parking resources, public transport coverage, *etc*. For example, if parking resources are limited, residents may be unwilling to choose car travel (O'Fallon et al., 2004).

3. Methodology and data

3.1. Discrete choice model

This work uses a discrete choice model to quantitatively analyse the factors influencing residents' mode choice. The discrete choice model has been widely used for choice-analysis including travel mode choice (Salon, 2009; Qin et al., 2014) and vehicle purchasing choice (Achtnicht, 2011; Hoen and Koetse, 2014). The discrete choice model is derived from utility-maximisation theory (Train, 2003), which specifies the utility of choosing alternative $i \in \{1, ..., I\}$ as follows:

$$U_i = V_i + \varepsilon_i \tag{1}$$

Where ε_i is an independently, identically distributed extreme value, and represents the unobserved part of utility, V_i is observed part of utility, which is determined by variables X_k ($k = 1, \ldots, K$):

$$V_i = \beta_{0i} + \beta_{1i}X_{1i} + \beta_{2i}X_{2i} + \cdots + \beta_{Ki}X_{Ki} \tag{2}$$

Different specifications of ε_i can lead to different discrete choice models. This study uses MXL model (mixed logit model) because it has applied a more generalised form of ε_i, as follows (Train, 2003):

$$\varepsilon_i = \mu_i(\theta, \boldsymbol{Z}) + \omega_i \tag{3}$$

$$\mu_i(\theta, \boldsymbol{Z}) = \theta_{0i} + \theta_{1i}Z_{1i} + \theta_{2i}Z_{2i} + \cdots + \theta_{Mi}Z_{Mi} \tag{4}$$

Where ω_i is the identically distributed extreme value, $\boldsymbol{Z} = (Z_{1i}, \ldots, Z_{Mi})$ is M variables influencing ε_i. $\boldsymbol{\theta} = (\theta_i, \ldots, \theta_{Mi})$ is M random variables following a zero mean normal distribution. The probability of choosing alternative $\boldsymbol{i}$ is:

$$P_i = \int \frac{e^{Vi+\mu i}}{\sum_{j=1}^{J} e^{Vj+\mu i}} \varphi(\theta) d\theta \tag{5}$$

The MXL model is estimated by maximum simulated likelihood estimation with Stata software.

3.2. Data

In this study, travel mode choice data is needed to estimate discrete choice model. Following existing studies (e.g., Brand et al., 2013; Hunecke et al., 2007), we used a questionnaire survey for data collection, by asking the interviewees to recall their travel information from the most recent day before the date of filling out the questionnaire. As shown in Table 1, we collected information regarding trip purpose, travel time, mode choices, and the trip origin and destination. Each row in the table represents one trip. For the origin and destination, interviewees need to fill in the specific name of places (*e.g.* Tsinghua University) instead of abstract names (*e.g.* school or home). Using this place information we can derive the characteristics of different possible transport modes which can be used alternatively for the same trip (Section 3.3). Aside from travel information, the survey aimed also to collect data on the factors influencing mode choice. As summarised in Section 2, influencing factors covering five aspects of travel mode choice were collected and incorporated in the model specification (Section 3.4).

We used an intercept survey to collect data. Nine shopping malls were selected for the intercept survey. All shopping malls are within the sixth ring road of Beijing, with six located at Haidian district, one at