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Providing quantified evidence to policy makers for promoting bike-sharing in heavily air-polluted cities: A mode choice model and policy simulation for Taiyuan-China

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ABSTRACT

Developing countries are facing increasing challenges to make urban mobility sustainable and to tackle the continuously growing air pollution and congestion caused by the rapid increase in car ownership. As part of a broad strategy to achieve sustainable urban mobility, bike-sharing services could contribute to car usage decrease, especially for short-distance trips. However, most of the developing countries have limited quantified evidence regarding the factors affecting bike-sharing choice and this hinders policy makers from effectively promoting bike-sharing usage. The case study city is Taiyuan, which operates one of the most in demand bike-sharing schemes in China. This research investigates the factors affecting mode choice behavior with a focus on bike-sharing, and explores the effectiveness of different policy options aiming at increasing bike-sharing ridership. Nested logit and mixed nested logit models are developed using both stated preference and revealed preference data. Policy effectiveness is studied by examining modal split changes. The results reveal the significant negative impact of air pollution on bike-sharing choice. Nevertheless, improving air quality is found to be less effective in promoting bike-sharing ridership than improving bike-sharing service itself (e.g. through access time saving, travel cost saving); although it is more effective in suppressing private car usage.

1. Introduction

Developing countries are facing increasing challenges to tackle the continuously growing air pollution and congestion caused by the rapid increase in car ownership. As part of a broad strategy to achieve sustainable urban mobility, bike-sharing services can help to reduce car usage, especially for short-distance trips. Research outcomes have shown that the benefits of bike-sharing are numerous; avoiding parking and maintenance troubles with private bikes, offering more convenient connection to public transport, reducing travel time and costs especially in city centers, improving body health, and opening up opportunities for more social and leisure experiences (DeMaio and Gifford, 2004; Jäppinen et al., 2013; Ricci, 2015).

Following the success in Europe and North America (DeMaio, 2009; Shaheen et al., 2010), bike-sharing schemes have been introduced in many cities in developing countries as well. However, although there are many mode choice studies for developed countries there is a lack of knowledge in the factors affecting bike-sharing choice in developing countries. This gap has significantly hindered policy making to effectively promote bike-sharing usage. More importantly, findings from developed countries may not be directly applied to developing countries as culture and local/geographical characteristics are significantly different (Maurer, 2012; Faghih-Imani et al., 2015; Kamargianni, 2015).

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This research addresses the aforementioned gap by investigating the factors affecting mode choice behavior in heavily air-polluted cities in developing countries, while focusing on bike-sharing. It also explores the effectiveness of different policy options aiming at increasing bike-sharing ridership. Particular focus is placed on the impact of air pollution on mode choice, since such an effect has rarely been captured when the scope was largely limited to developed countries. Air pollution may play an important role in affecting mode choice behavior in developing countries, which usually have more severe air pollution levels over prolonged periods of time. Specifically, this study tests if an increase in air pollution level would depress the willingness to cycle and to what extent an improvement in air quality would increase bike-sharing demand.

Mode choice models are developed including nested logit and mixed nested logit (Hess et al., 2004; Ortúzar and Willumsen, 2011) to address inter-alternative correlation and panel effect. For models development, stated preference (SP) and revealed preference (RP) mode choice data is combined to obtain results with less behavioral bias (Hensher and Bradley, 1993; Ben-Akiva et al., 1994). Our case study city is Taiyuan (China), which currently operates one of the most in demand bike-sharing schemes in China. The models are compared across each other and the one with the best performance is selected to study policy impacts on modal split changes in the SP environment.[1] This research focuses on short-distance trips (within 2 km), since it is the most prevalent bike-sharing traveling range in China (Gu Dong, 2016).

The paper is structured as follows. Section 2 reviews the current literature on factors affecting cycling and bike-sharing choices to draw insights and identify knowledge gaps. Section 3 presents the case study information and data sources. Section 4 explains the modeling framework and describes the model specifications in detail. Section 5 discusses on model estimation results, followed by a policy impact analysis in Section 6. Section 7 concludes research findings and policy implications.

2. Literature review

Previous studies have identified several factors affecting bike-sharing choice as well as cycling choice. These factors can be classified into three categories: 1. Natural and built environmental conditions, 2. Trip and mode attributes, and 3. Socio-economic characteristics.

2.1. Natural and built environmental conditions

Natural environmental conditions, such as weather, temperature, air-pollution, seem to heavily affect cycling choice. Some researchers incorporated different weather conditions (e.g. sunny, rain or snow) in their mode choice models (Daito and Chen, 2013; Kamargianni, 2015), while others also accounted for temperature impact (Parkin et al., 2008; Saneinejad et al., 2012; Motoaki and Daziano, 2015; De Chardon et al., 2017). In general, these studies came to similar conclusions; namely that adverse weather conditions and colder temperature would significantly discourage travelers from cycling. Many studies also analyzed the impact of topography. In particular, steeper roads would significantly discourage the choice of bicycle (Waldman, 1977; Rietveld and Daniel, 2004; Parkin et al., 2008; Mateo-Babiano et al., 2016; De Chardon et al., 2017), although Motoaki and Daziano (2015) argued that the impact of hills on the cycling route choice heavily depended on the fitness of cyclist. Additionally, the effect of air pollution has been studied, but, to our knowledge, among the great number of studies for developed countries, only Zahran et al. (2008) covered this effect via a cross-sectional analysis at the US county level and found pollution could decrease the number of cycling commuters on the road.

In relation to built environmental and land use impacts, cycling-related infrastructures have attracted significant attention in the existing literature. Many studies have focused upon the importance of increasing the number of cycle lanes and bike-sharing stations in promoting the use of cycling or bike-sharing, in terms of reduced travel time, increased safety and convenience (Akar and Clifton, 2009; Larsen and El-Geneidy, 2011; Hankey et al., 2012; Daito and Chen, 2013; Kamargianni and Polydoropoulou, 2013; Deenihan and Caulfield, 2015; Kamargianni, 2015; Maness et al., 2015; Wang et al., 2015; Mateo-Babiano et al., 2016; De Chardon et al., 2017). However, there were also papers that found an insignificant relationship between the number of cycling facilities and cycling choice (Rodriguez and Joo, 2004; Moudon et al., 2005; Xing et al., 2010). Some other relevant factors such as population density in community, the existence of university campuses and number of parks were also studied (DeMaio and Gifford, 2004; Rodriguez and Joo, 2004; Barnes and Krizek, 2005; Moudon et al., 2005; Parkin et al., 2008; Maurer, 2012; Whalen et al., 2013; Kamargianni and Polydoropoulou, 2014).

2.2. Trip and mode attributes

Trip characteristics are also important factors that determine mode choices. Cycling has been found to be more associated with recreational-purpose trips (Moudon et al., 2005; Xing et al., 2010; Mateo-Babiano et al., 2016). Faghih-Imani et al. (2015) found that cycling trips occurred more during noon and evening periods for meal purposes, while most of the morning cycle trips were for commuting. Moreover, since bicycles move more slowly than motorized vehicles, there was overwhelming evidence showing the negative relationship between cycling choice and trip distance (Parkin et al., 2008; Zahran et al., 2008; Akar et al., 2013; Faghih-Imani et al., 2015; Wang et al., 2015). Xing et al. (2010) even argued that perceived trip distance had the largest influence compared to other variables. Meanwhile, some trip characteristics, such as travel time, travel cost, and comfort level, may be seen as factors affecting transport mode choice. Many researchers studied the impacts of the attributes associated with bike-sharing and

[1] This study does not forecast market demand in the real world.