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Traffic and emissions impact of congestion charging in the central Beijing urban area: A simulation analysis

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ABSTRACT

Congestion charging is being considered as a potential measure to address the issue of substantially increased traffic congestion and vehicle emissions in Beijing. This study assessed the impact of congestion charging on traffic and emissions in Beijing using macroscopic traffic simulation and vehicle emissions calculation. Multiple testing scenarios were developed with assumptions in different charging zone sizes, public transit service levels and charging methods. Our analysis results showed that congestion charging in Beijing may increase public transit use by approximately 13%, potentially reduce CO and HC emissions by 60–70%, and reduce NOx emissions by 35–45% within the charging zone. However, congestion charging may also result in increased travel activities and emissions outside of the charging zone and a slight increase in emissions for the entire urban area. The size of charging zone, charging method, and charging rate are key factors that directly influence the impact of congestion charging; improved public transit service needs to be considered as a complementary approach with congestion charging. This study is used by Beijing Transportation Environment and Energy Center (BTEC) as reference to support the development of Beijing's congestion charging policy and regulation.

1. Introduction

Congestion charging is a typical travel demand management approach used to reduce personal vehicle travel in congested areas. Many large cities, such as Singapore, London, and Stockholm (Beevers and Carslaw, 2005; Eliasson et al., 2009; Tuan Seik, 2000) are using this approach to address urban traffic congestion issues. In recent years, Beijing has developed serious traffic congestion. For example, in 2014 the average speeds on Beijing's urban roadway network during the morning and evening rush hours were approximately 28 km/h and 25 km/h, according to the Beijing Transportation Information Center (BTIC); these speeds are much lower than the roadway free-flow speeds. Beijing has adopted intelligent traffic signal control, traffic restrictions, a license-plate lottery system and many other tools in order to mitigate traffic congestion. However, the effects of these tools are still limited. Recently, the Beijing Municipal Commission of Transport proposed development of a congestion charging policy in the central urban area to further address traffic congestion issues.

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In the meantime, urban air pollution is another challenging issue in Beijing. According to China's Ministry of Environmental Protection, there were as many as 110 days with moderate or severe air pollution in Beijing during 2014. Motor vehicles are currently one of the largest air pollution sources in Beijing, accounting for more than 30% of the total $PM_{2.5}$ emissions (Beijing Municipal Environmental Protection Bureau, 2014); traffic congestion and vehicle emissions are closely related. Therefore, to evaluate the impact of a congestion charging policy, both traffic and vehicle emissions changes need to be considered.

Congestion charging policies have been studied in depth since the concept was proposed by Pigou (1932). Some studies focused on the economic perspective by employing margin cost analysis (Vickrey, 1969; Walters, 1961) and cost-benefit analysis (Eliasson, 2009; Raux et al., 2012). The traffic impact of congestion charging is another typical research focus. The effects on demand management and relief of congestion in the charging zone have been demonstrated convincingly in real-world examples such as Singapore (Tuan Seik, 2000), London (Sabounchi et al., 2014) and Stockholm (Eliasson et al., 2009). Some of these studies have suggested the importance of public transit service in congestion charging. Jansson (2008) indicated that improved public transport, which reduces private car use, is a necessary condition for successful implementation of congestion charging. Kottenhoff and Freij (2009) indicated that public transport might increase the acceptability and feasibility of a congestion charging policy in Stockholm.

With an increased emphasis on air pollution and vehicle emission and their proven association with traffic congestion (Barth and Boriboonsomsin, 2008; De Vlieger et al., 2000; Johansson-Stenman, 2006; Zhang et al., 2011), some studies have focused on assessing the emissions impact of a congestion charging policy. Johansson (1997) indicated that a road-user should pay a toll not only according to one's own emissions, but also corresponding to the increased emission and fuel consumption of other road-users. Eliasson (2008) evaluated environmental effects of the pilot test of congestion charging in Stockholm, using vehicle emissions modeling and origin-destination (OD) matrix estimation, indicating that the emissions reduction were greatest in the inner city (between 10% and 15%), and that carbon dioxide emissions were reduced 2–3% across Stockholm County. Beevers and Carslaw (2005) indicated that emissions reduction was significantly associated with an increase in vehicle speed and a decrease in vehicle kilometers traveled (VKT), resulting from congestion charging in London, using a traffic emissions model; the study noted that total nitrogen oxide emissions have also increased by about 1.5% on the inner ring road (a ring road forms the boundary of the charging zone). Percoco (2013) evaluated the emissions impact of road charging policies in Milan with a regression discontinuity design, showing that the charges significantly decreased concentrations of carbon monoxide and particulate matters, but only in the short term, due to motorbikes not being charged. Daniel and Bekka (2000) simulated the effects of congestion charging on emissions for a metropolitan highway network in Delaware with traffic simulation and an emissions model, predicting that vehicle emissions would decrease as much as 10% on a citywide scale and 30% in highly congested areas. Mitchell et al. (2005) indicated that depending upon the charging rate, the charges would reduce traffic emissions up to about 70%, and illustrated a diminishing marginal return in emissions reduction as the charge increased.

Most research studies reviewed above indicated that congestion charging has a significant effect on the emissions reduction in the charging zone, and that traffic simulation and vehicle emissions models were typical methods used to assess the impact of congestion charging. Although some studies indicated that emissions outside the charging zone increased slightly during congestion charging, the studies on this phenomenon were relatively insufficient based on their areas of focus or available data. As such, the impact on emissions outside the charging zone, and even within the entire city, deserves more attention. Besides, few studies have looked at how the impact on traffic and emissions varies with different charging strategies, even though this is very useful in policy formulation. The purpose of this study is to (1) assess the impact of congestion charging on traffic and emissions in the charging zone, outside of the charging zone, and the Beijing urban area as a whole and (2) compare potential impacts of various charging strategies to support development of a reasonable congestion charging policy.

2. Methodology

We analyzed the traffic and emissions impact of a congestion charging policy in the central urban area of Beijing using a combination of macroscopic traffic simulation and a vehicle emissions model, considering the impact of the size of the charging zone, level of public transit service (PT LOS) and charging methods. As shown in Fig. 1, we first defined two modes of travel, private cars and public transit, in a macroscopic traffic simulation platform, with feedback between traffic assignment and mode choice. Then we converted charging fees to time impedance using a monetary value of time concept, and established the congestion charging model for Beijing's central urban area. Next, we analyzed multiple scenarios with different charging zones, PT LOS, charging methods and charging rates, obtained the characteristic parameters of charging and traffic under different scenarios, and completed an emissions calculation of carbon monoxide (CO), hydrocarbon (HC) and nitrogen oxide (NO_X). Finally, we analyzed the emissions impact of the congestion charging in Beijing by adopting multi-factor analysis of variance (MANOVA), and discussed the development of the congestion charging policy with the consideration of emissions reduction.

2.1. Study area and charging scenarios

Beijing's roadways can be classified into four categories: five ring roads (the 2nd to 6th ring road); nine radial toll expressways that connect the central Beijing urban area and suburban areas; eleven China National Highways that depart from