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Impact of congestion pricing schemes on emissions and temporal shift of freight transport

Daqiang Chen[a,*], Joshua Ignatius[b], Danzhi Sun[c], Mark Goh[d], Shalei Zhan[a]

[a] School of Management and E-Business, Zhejiang Gongshang University, Hangzhou 310018, China
[b] Warwick Manufacturing Group, University of Warwick, CV47AL Coventry, UK
[c] Zhejiang Scientific Research Institute of Transport, Hangzhou 310006, China
[d] NUS Business School and The Logistics Institute-Asia Pacific, National University of Singapore, Singapore 119613, Singapore

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ABSTRACT

This paper examines the freight transport temporal shift and the vehicular pollutants emissions in an urban transport network with congestion pricing schemes, specifically when only freight transportation is tolled in the peak period. The equivalent minimization models of no-toll, first-best, and second-best congestion pricing scenarios are presented with an excess-demand approach based on user equilibrium analysis, in which the different pricing schemes include multiple time periods and mixed traffic. We established results for the equivalent conditions and the uniqueness conditions of the models. The findings and policy insights are discussed using simulation and sensitivity analysis of the key parameters.

1. Introduction

Economic growth and rapid urbanization have a dark side – traffic congestion. Today, policy makers concerned with sustainable development need to manage not only the issues on congestion but also, with more vehicles, tail gas emissions are now a major source of environmental pollution. This affects the urban air quality, environment, and society (Chen, 2013).

According to Raux (2010), transport contributes to 25–30 percent of the global CO2 emissions, and almost two-thirds of the total transport-related emissions are from road transport (Davis et al., 2010). In China, the transport sector accounts for 348.19 million tons of coal equivalent, and the total vehicle emissions in 2013 was 45.71 million tons (He and Qiu, 2016). In the UK, air pollution from road traffic also poses a significant public health problem, accounting for 34 percent of nitrogen oxide (NOx), 14 percent of PM10, and 13 percent of PM2.5 emissions in 2015 (Barnes and Williams, 2017). In 2000, the externalities from transport (excluding congestion) were estimated to account for 7.3 percent of the total GDP in the EU15 countries, including Norway and Switzerland, with freight transport contributing to a third of that value (Lindholm and Behrends, 2012).

To build a sustainable urban transportation system, urban authorities have introduced and implemented various mitigation strategies and traffic policies to stem congestion and transport-related pollution. However, there are limitations to the expansion of urban transportation networks. Building more roadway capacity to handle higher traffic volumes will only increase exhaust emissions and worsen the air quality (Sathaye et al., 1994). Hence, Traffic Demand Management (TDM) policies are viewed as effective, sustainable and environment-friendly ways to improve the efficiency, speed, safety, reliability, comfort, and the overall operation of the urban transport system (Meyer, 1999; Kennedy et al., 2005; Habibian and Kermanshah, 2013).

* Corresponding author.
E-mail addresses: chendaqiang@zjgsu.edu.cn (D. Chen), 281148262@qq.com (D. Sun), bizgohkh@nus.edu.sg (M. Goh), zhanshalei@zjgsu.edu.cn (S. Zhan).

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The TDM policy for sustainable urban transportation seeks to encourage commuters to change their travel behaviour and use lower-emission alternative modes, such as modal substitution, telecommuting, price incentives/disincentives, and land use–-transportation strategies (Deakin, 2001). Among the pricing incentives/disincentives alternatives of the TDM, road pricing has gained a special attention and been implemented in the metropolitan areas, including Singapore, Orange County (California State Route 91), London, Edinburgh, Hong Kong, and the cities of Trondheim, Oslo, and Bergen in Norway (De Palma et al., 2006; Noordegraaf et al., 2014). In the EU, more than 200 cities across 10 countries are now operating as low emission zones where the most polluting vehicles are either banned or levied an access fee (Wolff, 2014), with several cities implementing a congestion pricing policy to restrict certain types of vehicles (thus lowering the traffic volume) from entering the inner city (Goh, 2002; Rakowska et al., 2014). For instance, in doing so, London has succeeded in controlling the vehicular tail gas emissions, by meeting the target of lowering the normalised CO_2 emissions by 20 percent in 2014/15, two years ahead of schedule (Transport for London, 2015).

Aside from the residential trips, urban freight transportation adds to traffic and environmental woes too. In China, the urban freight transportation demand is fueled by the flurry of online shopping activity with 467 million parcel-trips delivered nationally in 2016 (Davidson et al., 2017). In order to reduce urban congestion, studies on shifting the freight transportation to the off-peak have attracted attention from academia and policy makers. For example, the off-peak freight delivery problem was investigated by Glasmeier and Kibler (1996), Vilain and Wolfrom (2000), Holguín-Veras (2008) and Dablanc et al. (2013). Additionally, a new industry-led programme to reduce the emissions of London's freight and fleet operators was launched in January 2016 (Transport for London, 2016). Given the importance and urgency of this topic, our paper chooses to address the impact of congestion pricing policy on urban transportation, especially on the temporal shift of freight transportation from peak to off-peak periods to reduce congestion, while addressing pollutant emissions. Specifically, we investigate the use of congestion tolls to control/shift the traffic volume temporally, leading to less pollutant emissions. This paper seeks to answer the following research questions:

1. How does a congestion pricing policy impact the traffic volume, travel speed, and emissions in different time periods, for two traffic types - freight transport and residential trips?
2. How does a congestion pricing scheme of the first-best and the second-best policies impact the temporal shift in traffic volume for freight transportation? Specifically, we consider the impact of the Value Of Time (VOT) to the user and traffic capacity of the road/link.

The paper is organized as follows. Section 2 reviews the extant literature. Section 3 analyses the urban transportation network, including transport demand, traffic flow, and the cost of the links and routes. In Section 4, the equivalent minimization models of the no-toll, first-best, and second-best congestion pricing scenarios are presented using an excess-demand approach. The second-best congestion pricing scenario includes different pricing schemes for multiple time periods and mixed traffic. In Section 5, a simulation study is conducted to examine the impact of the congestion pricing policies on traffic volume reallocation, time period shifting, and automobile toxic pollutant emissions reduction. The sensitivity analyses of the key parameters and managerial insights are discussed. The final section summarizes the key findings and offers some future research directions.

2. Literature review

The literature covered in this paper follows two streams: sustainable urban freight transportation, and congestion pricing with network equilibrium.

2.1. Sustainable urban freight transportation

From the definition of the Brundtland Commission, sustainable development is "(the) development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (McManus, 1996; Mebratu, 1998; Du Pisani, 2006; Goldemberg, 2007; Holden et al., 2014). Sustainable development is a major concern for policy makers and planners when considering broadly the effects on the environment (Spangenberg, 2002), economy (Ferretti et al., 2007), and society (White and Lee, 2009; Dempsey et al., 2011), with academe focusing on the trans-dimensional research of the combination (Rennings and Wiggering, 1997; Lehtonen, 2004). Transportation is vital to sustainable development, for transport facilities and activities have significant sustainability impact, such as traffic congestion, and air and water pollution, which bears on human health. A holistic perspective requires sustainability to be a broad set of integrated problems that cannot be solved by using the existing transportation decision–making practices, because the solutions to one problem may exacerbate other problems (Litman and Burwell, 2006).

Sultana et al. (2017), in a review of the sustainable urban transportation literature, highlighted the need to investigate the sustainability implications of urban freight movement in an e-shopping regime. In the e-shopping era, urban freight flow has become more uncertain and fragmented, with a greater growth of commercial vehicles and traffic. With most consumption in the last mile taking place in urban areas, the need for frequent urban freight transportation service is inevitable (Kin et al., 2017). However, this surge in urban traffic adds to urban traffic congestion and atmospheric pollution (Yannis et al., 2006), influencing a variety of social, environmental, and economic externalities.

This has compelled various methods applied to the area of sustainability in urban transportation; for instance, vehicle routing and scheduling optimization (see the review by Pillac et al. (2013)), urban freight transport planning (Ballantyne et al., 2013), and advanced freight transportation systems (Crainic et al., 2004). Figliozzi (2011) examined the different levels of congestion and time-definite customer demands on CO_2 emissions, and found that the impact of congestion or speed limits on commercial vehicle