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Dynamic simulation modeling and policy analysis of an area-based congestion pricing scheme for a transportation socioeconomic system

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ABSTRACT

This paper evaluates the impact of an area-based congestion pricing scheme in terms of its effectiveness on mitigating traffic congestion by using a system dynamics model. Unknown parameter values are calibrated using data available from the area-based pricing scheme implemented in the London metropolitan area. The key features of our model are that individual behavior is affected by the level of congestion, the cost of driving, and the supply/capacity and demand associated with metro transit. Perceptions of users are captured by three separate linguistic variables and fuzzy set theory is used to evaluate the combined effects of individual perceptions on the travel mode selection and the switching behavior between travel modes. As part of our analysis we explore three premises, i.e., that revenues generated from a congestion pricing scheme can substantially improve alternative transportation modes, that the improvement of these modes can have a positive effect on the mitigation of traffic congestion, and that a congestion pricing scheme cannot effectively resolve congestion problems in short term due to the existence of material and information delays. We assess various policies and determine appropriate values for critical parameters to find the best results in terms of implementing the area-based pricing scheme.

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1. Introduction and research premises

The objective of this paper is to provide policy insights when taking into account the dynamic effects of implementing an urban area-based congestion pricing scheme. These insights are based on a simulated version of a modeling framework developed by Liu et al. (2010a,b) that uses a system dynamics modeling approach. This study focuses on the effects of different factors that influence the dynamics of traffic congestion and examines both the short-term and the long-term mitigating effects of an area-based congestion pricing scheme. Our contribution lies in obtaining a fundamental understanding of the dynamic consequences associated with an area-based pricing scheme when perceptions are vague, when tradeoffs

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exist among different modes of transportation, and when one explicitly considers key dynamic feedback mechanisms and delays. From a practitioner's point of view, the approach allows for the investigation of policies and the explicit consideration of decision makers' optimistic and pessimistic points of view.

Our model is calibrated based on information and data for the traffic congestion pricing policy implemented within the London metropolitan area, that are mostly available in annual reports published by Transport for London (TFL, 2011b). This has allowed for the estimation of parameters for which data are not available and the determination that the model results are consistent with the data.

The system dynamics model is simulated to evaluate three premises that relate to critical issues facing policy makers in the realm of mitigating urban traffic congestion. These are:

- *Premise 1: Revenues generated from a congestion pricing scheme can substantially improve the alternative transportation modes and the services necessary to satisfy the population's mobility needs.*
- *Premise 2: Improvement of alternative transportation modes can have a positive effect on the mitigation of traffic congestion in a charging zone area.*
- *Premise 3: A congestion pricing scheme cannot effectively resolve congestion problems in the short term due to the existence of material and information delays.*

The context and background of this research is provided next.

1.1. Context and background

Congestion pricing is a type of road pricing scheme that has been implemented in several metropolitan areas around the world including perhaps most famously in the city of London. This policy is one of the 'transportation demand management (TDM)' strategies that aim to mitigate traffic congestion while still satisfying increasing travel demand without expanding road capacity (for more on TMDs see the Victoria Transport Policy Institute Report (VTPI, 2010)). Congestion pricing is defined by the Victoria Transport Policy Institute (VTPI, 2011) as variable road tolls that are higher under congested conditions and lower at less congested times and locations. The main purpose of the scheme is to reduce peak-period traffic volumes to optimal levels. The charging rates *can* be dynamic and change depending on the level of congestion that exists at a particular time or can vary based on a fixed schedule such as during weekday peak hours only. In general, congestion pricing can be implemented in various ways (VTPI, 2011), such as pricing a particular point on the road such as a bridge or a tunnel or a roadway section, or on a larger scale, area-based or zone-based traffic congestion pricing, where vehicles are charged a fee for entering or exiting an area, or travel within the area (De Palma and Lindsey, 2011).

The best known area-based congestion pricing scheme is the one implemented by the city of London, which was initiated in 2003 (Leape, 2006; Maruyama and Sumalee, 2007; Santos and Shaffer, 2004). From 1975 to 1998, Singapore implemented an Area Licensing Scheme (ALS) to mitigate congestion in the central business district, which is actually a cordon-based rather than area-based pricing scheme because drivers were required to present their ALS license when entering into the pricing area not within it (Goh, 2002). In 2007, Stockholm started to implement a cordon-based congestion charging system with the purpose of reducing traffic congestion and improve the environmental situation in central Stockholm (Eliasson, 2009; Eliasson et al., 2009).

Extensive research has been performed to explore the effectiveness of different congestion charging policies. Among which two pricing schemes i.e., the cordon-based congestion pricing and area-based congestion pricing are the ones that have been broadly studied and used. De Palma and Lindsey (2011) describe cordon-based congestion pricing, as a charging scheme that drivers have to pay a toll to cross a cordon in the inbound, outbound or possibly in both directions. The cordon-based scheme has been studied the most in the literature despite its lower benefits compared to other congestion charging schemes (Maruyama and Sumalee, 2007; May and Milne, 2000), since evaluating and modeling this scheme in a traffic assignment model is relatively easy using a linear addition of all relevant link costs and since it has a high potential to be implemented in practice (Maruyama and Sumalee, 2007).

On the other hand, in an area-based or zone-based traffic congestion pricing scheme, drivers are charged a fee to enter or exit an area, or to travel within the area for a certain period typically one day (De Palma and Lindsey, 2011). There is a growing literature that systematically compares the benefits of different charging scheme especially, cordon- and area-based charging methods. In summary, The primary advantages of area-based congestion pricing compared to facility-based pricing of individual roads or small-scale road networks, are threefold: (i) it is simple to implement, (ii) it has the ability to intercept more trips from entering the area under the charging scheme and therefore it has a very direct impact on congestion and revenues from the pricing scheme, and (iii) it is less susceptible to traffic diversions (De Palma and Lindsey, 2011). Hyman and Mayhew (2002) using a simplified model of travel demand and supply, show that the area-based charging provides lower revenues and also fewer benefits for road users in terms of travel time, compared with the hybrid policies based on terminal and distance-based charging. Additionally, Maruyama and Sumalee (2007) use a static trip-chain equilibrium model to compare cordon-based and area-based pricing schemes based on the case study of Utsunomiya, Japan. The authors show that the area-based pricing has a higher number of optimal tolls and a higher level of social welfare benefits. Balijepalli et al. (2008) show that the strategy of combining cordon and area-based pricing schemes through tolling drivers at the cordon and also charging residents with discounted fees can maximize social benefits. Using Washington, DC, as a case study,

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