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Overcoming the Downs-Thomson Paradox by transit subsidy policies

Wei (Walker) Wang [a,b], David Z.W. Wang [b,*], Fangni Zhang [c], Huijun Sun [d], Wenyi Zhang [d], Jianjun Wu [e]

[a] School of Economics, Ocean University of China, China
[b] School of Civil and Environmental Engineering, Nanyang Technological University, Singapore
[c] Department of Civil and Environmental Engineering, The Hong Kong University of Science and Technology, Hong Kong, China
[d] Key Laboratory for Urban Transportation Complex Systems Theory and Technology of Ministry of Education, Beijing Jiaotong University, Beijing, China
[e] State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University, Beijing, China

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ABSTRACT

Consider a competitive highway/transit transportation system in which travelers either drive on the bottleneck-constrained highway or take scheduled trains from home to the workplace in the morning peak hours. This paper explores the impact of bottleneck capacity expansion on transit operating schemes (fleet size and fare) and travelers' departure time and mode choices. Due to the potential occurrence of the Downs-Thomson (D-T) Paradox after highway capacity expansion, the paper investigates whether the D-T Paradox can be circumvented by implementing transit subsidy policies. The effects of different transit subsidy schemes are explored: subsidizing the transit company (cost subsidy) or the passengers (passenger subsidy) with the financial support from either government funding or road pricing revenue. For each combination of subsidy method and financial sourcing, the condition for overcoming the D-T Paradox is established.

1. Introduction

Downs (1962) remarked on the possibility that adding road capacity cannot relieve traffic congestion at all. Retiming of trips, route shifting, and mode shifting from public transportation modes have been observed after the road expansion and are attributed for its failure. In an independent study, Thomson (1977) noted that driving and transit are close substitutes in many cities. The increase of road capacity, by attracting enough transit riders to drive, could lead to a decline in transit service or rises in fares due to the scale economies of transit service. The users of both modes may end up worse off. This phenomenon is then analytically formulated by Mogridge et al. (1987) and is named the "The Downs-Thomson Paradox (D-T Paradox)" thereafter. Furthermore, many other paradoxes have been studied in the transportation literature, including Braess paradox (Braess, 1968, 2005; Lin and Lo, 2009; Zhao et al., 2014; Di et al., 2014; Zverovich and Avineri, 2015; Hwang and Cho, 2015; Wang et al., 2016), emission paradox (Nagurney, 2000), capacity paradox (Yang and Bell, 1998), stochastic assignment paradox (Sheffi and Daganzo, 1978; Yao and Chen, 2014), transit assignment paradox (Szeto and Jiang, 2014) and so on. This paper focuses on examining the D-T Paradox introduced by Downs (1962) and Thomson (1977).

A substantial literature has been developed both analytically and empirically to investigate when and why the D-T Paradox occurs; see Arnott and Small (1994) and Zhang et al. (2014, 2016) for synthesis reviews. In particular, much attention is

* Corresponding author.
E-mail address: wangzhiwei@ntu.edu.sg (D.Z.W. Wang).

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paid to the mode shifting between transit and driving and how transit service changes when the road is expanded. For example, Mogridge (1997) suggested that the transit service should be improved with the highway capacity expansion to raise commuters' travel utility in the two-mode system. Similarly, Arnott and Yan (2000) showed that the travel cost might increase after the expansion of highway capacity if the transit operator does not consider the impacts of its decision on highway travelers. It is further suggested by Basso and Jara-Díaz (2012) that the occurrence of the D-T Paradox highly depends on the status quo of the transit side. In the same spirit, Zhang et al. (2014, 2016) analyzed the effects of road expansion when the transit service is operated in different administrative regimes. Zhang et al. (2014, 2016) showed that the paradox is likely to occur when the transit operator is self-sustaining and the two modes are perfect substitutes. Based on these studies, this paper takes one step further to re-examine the D-T Paradox in a more general setting where trip retiming, crowding effect, and policy remedies are in effect.

First, previous studies on the D-T Paradox only consider travelers' mode shifting while the effect of trip retiming is neglected. However, the benefits from urban highway expansion would generally be underappreciated if shortening of the rush hour is not noticed. To explore this, the direct benefit of shortening rush hour and indirect adverse impacts from induced travel demand need to be compared. This paper formulates the bi-modal equilibrium following Kraus (2003, 2012) in which travelers either drive on the bottleneck-constrained highway or take scheduled trains, and each traveler makes decisions of his/her departure time choice and mode choice simultaneously to minimize the total travel cost.

Second, the discomfort in mass transit during the peak hour is a noticeable factor that influences individual's departure time and mode choices which is under-investigated by the studies on the D-T paradox. Crowdedness both at train stations and in the carriages could bring passengers unpleasant travel experiences, and a bunch of literature has been developed to investigate its impact on people's travel, e.g., Horowitz and Sheth (1977), Huang (2000, 2002), Tian et al. (2007, 2009), Wang et al. (2014), Tian and Huang (2015), Lu et al. (2015). Particularly, previous studies (e.g., de Palma et al., 2015; Zhang et al., 2015) have shown that the crowdedness in the transit mode will lead to a tendency that transit users depart early or late to avoid the over-crowdedness or switch to driving. This paper investigates the D-T Paradox by taking into account the effect of body congestion in carriages on travelers' departure time and mode choices following the framework of Wu and Huang (2014).

Moreover, while existing literature mostly focuses on the occurrence of the paradox, this study attempts to find the way out, i.e., how to overcome the D-T paradox. The major objective of this study is to bridge this research gap through specifically studying the prevention of the D-T Paradox with various transit subsidy policies while travelers' departure time choice and crowding effects in transit services are explicitly considered. If the transit operation is subsidized by the government funding or the revenue of road toll levied from car usage, the adjustment of the transit operator in response to the expansion of highway capacity (raise fare or reduce frequency or both) would change, then the D-T Paradox may be avoided.

In many countries and regions, different types of transit subsidy policy have been proposed, i.e., allowing commuters to deduct monetary expenses of taking public transport from the income tax liability, subsidizing transit fares, reducing indirect tax rates for transit company and so on. To date, there is no standard definition of transit subsidies in the existing research works, all of the above examples can be seen as transit subsidies (Tscharaktschies and Hirte, 2012). OECD (2005) states that "*a subsidy in general is a result of a government action that confers an advantage on consumers or producers in order to supplement their income or lower their costs*". Frankena (1981) proposed three kinds of transit subsidy policy: (i) one-time subsidy - amount of money which is exogenously determined and independent on the operating performance of transit company, (ii) cost subsidy - amount of money which is dependent on the operating cost of transit company, and (iii) passenger subsidy - amount of money which is exogenously determined and distributed to each transit commuter. In this paper, we

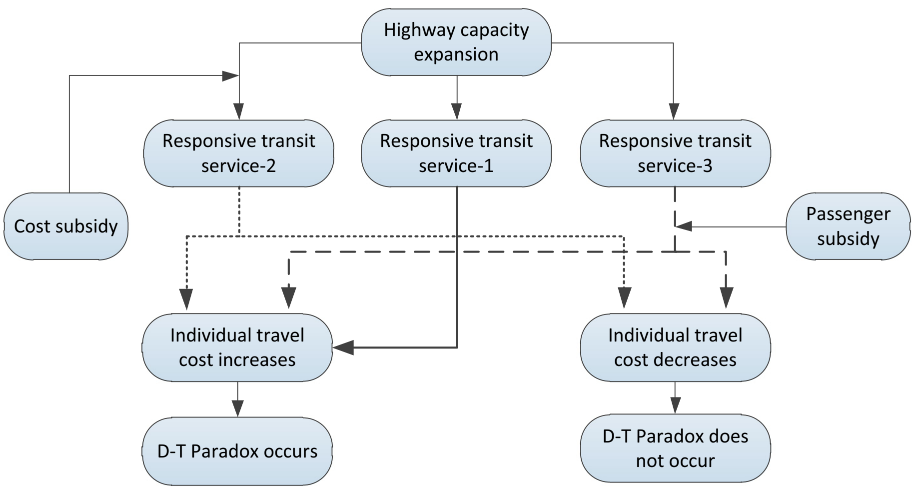

Fig. 1. The impact of transit subsidy policies on the D-T Paradox.