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Reward and Coarse Toll in Competitive System with Two Modes

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Abstract

The morning congestion problem has been an important society issue. It is necessary to alleviate traffic congestion on rush hours. Dynamic tolls have been proposed to solve the congestion problem on a road with bottleneck. Compared fine toll and uniform toll, a coarse toll is easier to implement and operate in rush hours. In this paper, a congestion problem between a residential area and the CBD has been considered. There have two transport modes including automobile and railroad. Automobile users have to suffer the queue when the road has a bottleneck. Some commuters prefer to travel by railroad because of its convenience and lower cost. It users do not have to pay the schedule delay cost. However, congestion pricing is a negative incentive and travellers' public acceptability of such a measure is typically low. Giving positive incentives is likely to have little resistance, while similar results may be expected. Reward can be regarded as a potential of positive financial incentives to solve traffic congestion. We mainly talk about two different policies on road and railroad. Coarse toll has been levied on the road with bottleneck. A reward has been implemented on the railroad. The reward comes from the coarse toll revenue which has been levied on the road, and it is allocated towards the commuters who travel by railroad. Two types of railroad fare have been considered: when it is set equal to the marginal cost and when it is set equal to average cost. These models allow us to show that toll policy to be more efficient as long as toll revenue is directed towards public transport when the railroad fare is equal to average cost.

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Keywords: bottleneck; congestion pricing; reward; coarse toll; modal split

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1. Introduction

In recently years, traffic congestion has become one of the most important society issues. How to alleviate traffic congestion has been an important question to the transportation scholars. Increasing road capacity and reducing traffic demand are the two ways to alleviate this phenomenon. According to Adams laws 'you cannot pave your way out of traffic congestion', providing more road space has been proven to be self-defeating in congested areas, because the increased capacity will soon be absorbed by induced travel demand. Therefore, taking the congestion pricing as a transportation demand management has become a very important significance in theory and practice.

Congestion pricing has received far more attention than quantity control in both theory and practice. The influential work is done by Pigou (1920) who suggests that vehicles using congested roads should bear a tax equal to the difference between marginal social cost and marginal private cost. Subsequently, this model has been extended by many others (Arnott et al., 1993; Tao et al., 2012). For reasons of equity, accessibility and liberty, congestion pricing has a negative connotation for the majority of drivers as shown by studies conducted in various cities. There exist many researches to study congestion toll revenue in the literature. Litman (2005) argues that toll revenues should benefit society as whole and not only motorists. If toll revenues are automatically allocated towards road restoration and new road construction, or used to reduce motorists' fees, these measures risk causing an increase in automotive use due to increased supply in road infrastructure, thus worsening existing congestion.

Different from the static congestion pricing, some authors propose dynamic tolls for the bottleneck model to describe the congestion behaviour of morning commute (Vickrey, 1969; Arnott et al., 1993). In these analyses, commuters must choose their departure times to minimize the sum of travel delays and schedule costs. There exist three tolls on the bottleneck model: the fine toll, uniform toll and the coarse toll.

The Nobel laureate Vickrey (1969) proposes a fine toll model to describe the bottleneck model. After that, this model has been extended by many others (Lindsey et al., 2004; Gonzales et al., 2012). It is well known that if the toll rate charged at the bottleneck can be changed continuously, an optimal toll scheme can be found to eliminate the queuing delay in the system. Under an optimal toll, each commuter pays the amount of toll equal to the queuing delay cost at the no-toll equilibrium. As a result, the queuing delay is totally eliminated, and the arrival time is evenly distributed throughout the morning rush hours. However, a fine toll cannot be implemented in real life, because of its confusion which is caused by frequently changing toll rate.

A uniform toll is constant throughout the peak, and causes no change in the departure rate in the bottleneck model. It can only limit congestion cost by reducing demand (Vincent, 2012). The optimal uniform toll equals the marginal external cost when the queue is not eliminated (Arnott et al., 1993). A uniform toll hence raises the price, and lowers the number of users and consumer surplus. Accordingly, this scheme is comparable to tolling in the textbook static-congestion model, which may cause inequity and be perceived as another flat tax. In this way, uniform toll often receives the public's resistance.

Unlike the two former tolls, a coarse toll is easier to implement and operate in rush hours. It is between uniform and fine toll: it somewhat changes the departure pattern, but also raises the price. This makes it important to control for price sensitivity of demand when considering a coarse toll (Vincent, 2012). At equilibrium, the arriving pattern under a coarse toll scheme is much more difficult to derive than a fine toll, because of the changes in trip costs at the beginning and ending time of the tolling period. The equilibrium under a coarse toll is first studied by Arnott et al. (1990).They obtain a stable traffic equilibrium pattern based on the expected utility hypothesis. The problem is revisited by Laih (1994), who provides a convenient way to calculate the optimal flat toll without discussing the explicit evolution of the queue. The result is based on the assumption that drivers who choose to pass the bottleneck after a certain tolling period can wait on a set of secondary lanes without impeding other drivers who do pass the bottleneck in that tolling period. For simply, we refer to their models and treatments as the 'ADL model' and the 'Laih model' respectively.

However, there usually exist two or more transport modes in reality. Some commuters prefer to travel by mass transit because of its convenience and lower cost (Buehler, 2001). Those papers (Tabuchi, 1993; Danielis, 2011) usually concentrate on fine toll and uniform toll. In this paper, coarse tolls have been considered on a road when there has mass transit as a transit mode, and they have been analysed to affect the distribution of travel demand between two modes. Implementing coarse tolls would be considered to avoid confusion by the frequently change