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Analysis of tradable bottleneck permits scheme when marginal utility of toll cost changes among drivers

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Abstract

This study proposes a Pareto improving congestion pricing using tradable bottleneck permits (TBP) scheme under the condition that marginal utility of toll cost changes among drivers. The TBP scheme is originally one of the first-best time-varying pricing schemes. However, it is not revealed that the scheme could achieve a Pareto improvement when marginal utility of toll cost changes among drivers. This study aims to analyze the effects of the TBP scheme on departure time choice of drivers and to propose a second best pricing scheme where a Pareto improvement can be achieved. In particular, we focus on a one-to-one network with a single bottleneck and employ a departure time choice model to discuss the case that there exists heterogeneity in schedule flexibility and toll resistance. Two classes for two attributes are assumed as the heterogeneity respectively: “busy/free” and “rich/poor”. Under the condition, we formulate the drivers’ utility changes caused by implementation of the TBP scheme. The cases with and without the TBP scheme are analytically compared. It is shown that the TBP scheme is not Pareto improving, where the utility of “busy-poor” drivers is decreased. In order to achieve a Pareto improvement, we propose partial implementation of the TBP scheme. In the partial implementation scheme, the bottleneck capacity is assigned to drivers with and without bottleneck permits, where the driver who has a bottleneck permit can pass through the bottleneck without congestion and a driver without it goes through congestion. As a result, we reveal conditions which can satisfy a Pareto improvement. This study finally discuss the requirements for a Pareto improvement that are derived by the proportion of the amount of issued bottleneck permits, the number of each class drivers, and the magnitude of heterogeneity.

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1. Introduction

Morning commute through traffic congestion to a central business district (CBD) is a common feature in cities around the world. The congestion is not caused so much by high demand but by a concentration of demand during a short (peak) period. In order to control the morning traffic congestion, congestion pricing is considered one of the efficient methods. The pricing concept is based on the economic theory of marginal cost and is a mechanism to improve social benefit (Pigou, 1920). Social cost can be minimized by charging drivers as much as their externalities if the externalities are static. In dynamic scheme, such as traffic congestion, queues at bottlenecks and their interactions should be considered to minimize the social cost.

Vickrey (1969) firstly proposed a departure time choice model, which describes the tradeoff between schedule delay and waiting delay. Arnott et al. (1990) showed that the congestion is eliminated and social optimal state can be achieved if drivers are charged equivalent to their waiting cost. Doan et al. (2011) showed that the optimal pricing strategy exists in a single bottleneck model. However, it is difficult to determine the appropriate charging price because drivers' information, such as their value of time and schedule constraint, is required. In order to determine the appropriate charging price without any drivers' information, Akamatsu et al. (2006) proposed tradable bottleneck permits (TBP) scheme. In the TBP scheme, the road administrator issues bottleneck permits and creates markets whereby drivers can freely trade the permits. The permits are required for drivers to pass through the bottleneck at a specified time. The permits are issued as much as the bottleneck capacity. As a result, the price of the permit for each time period is determined by market mechanism, which is equivalent to the toll of the first best pricing. The auction mechanism to determine the price of bottleneck permit has been also studied by using evolutionary approach (Wada and Akamatsu, 2013). As another pricing methodology to determine congestion charge by using market mechanism, tradable credit (TC) scheme is popular (Yang and Wang, 2011; Nie and Yin, 2013; Xiao et al., 2013). The biggest difference between the TPB scheme and the TC scheme is that drivers' information is not totally required to achieve the social optimal state in the TBP scheme. In the TC scheme, market mechanism decides only the price of the credit and road administrator has to decide time-varying credit charging rate. In the TBP scheme, on the other hand, bottleneck permits are issued for each pre-specified time period and drivers trade the permit in each market. Therefore, toll for each time range can be decided by market mechanism, and it is the social optimal pricing.

Akamatsu (2007) mentioned that the TBP scheme can minimize social cost in general networks but it is not always Pareto improving. A Pareto improvement is a property that a system harms no one and benefits at least one. A Pareto improvement should be achieved as the pricing scheme is acceptable for all drivers. As studies about a Pareto improvement in a field of congestion pricing, Daganzo and Garcia (2000) proposed a methodology that classifies drivers as "free" and "paying" alternately. Yodoshi and Akamatsu (2008) analyzed the Pareto improving condition with TBP in a tandem bottleneck network. Sakai et al. (2014) analyzed that in a merging network. This study focuses on drivers' heterogeneity and proposes TPB implementation which can be Pareto improving.

The purposes of this study are to analyze the effects of TBP on departure time choice of drivers from the aspect of a Pareto improvement. In particular, we show the time dependent utility of drivers when different schedule flexibility and marginal utility of toll cost are distributed among drivers. Firstly, by comparing the cases with and without TBP, we show that a Pareto improving is not achieved by full-TBP implementation. Then, in order to achieve a Pareto, we propose partial implementation of TBP, where drivers without TBP have to wait in a queue in a no-toll lane and drivers with TBP can pass the bottleneck without waiting using toll lane.

In section 2, we set a network and drivers' behavior, and then formulate the equilibrium conditions of departure time choice under the TBP scheme. Section 3 assumes drivers' heterogeneity and shows a Pareto improvement is not always achieved by implementation of the TBP scheme by comparing equilibrium state before and after TBP implementation. Section 4 reveals the condition that a Pareto improvement can be achieved by partial implementation of the TBP scheme. Section 5 provides the conclusion.

2. Equilibrium under TBP scheme

This section describes the problem that. We assumes a target network and drivers in . In the assumption, equilibrium conditions for the analysis in the following sections. Section 2.1 describes the target network which can

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