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Public transit service frequency and fares with heterogeneous users under monopoly and alternative regulatory policies

Junlin Zhang[a,*], Robin Lindsey[b], Hai Yang[a]

[a] Department of Civil and Environmental Engineering, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China
[b] Sauder School of Business, University of British Columbia, 2053 Main Mall, Vancouver, British Columbia, V6T 1Z2, Canada

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ABSTRACT

We present a model of public transit service under monopoly when potential users differ in their willingness to pay and value of time. The transit operator chooses service frequency and the fare to maximize a weighted sum of profit and consumers' surplus. Profit-maximizing and social-surplus-maximizing frequency decisions are compared using a unified framework that includes results of previous studies as special cases. The prevalence of the Mohring Effect and the need for subsidization are investigated. Four types of regulatory policies are then considered: fare regulation, frequency regulation, goal or objective function regulation, and fiscal regulation whereby the operator receives a subsidy based on consumers' surplus or demand. A numerical example is used to assess the relative efficiency of the regulatory regimes, and illustrate how the solutions depend on the joint distribution of willingness to pay and value of time.

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1. Introduction

Beginning with the seminal work of Newell (1971) and Mohring (1972), an extensive literature has developed on the provision of public transit service under different objectives and regulatory regimes. This work has addressed a number of aspects and questions about transit service such as choice of fare and service quality, the efficiency and welfare-distributional effects of alternative types of regulation, and the need for subsidies to cover system costs.[1] There has been a debate (van Reeven, 2008; Basso and Jara-Díaz, 2010; Savage and Small, 2010; Karamychev and van Reeven, 2010) about whether a profit-maximizing operator will oversupply or undersupply service, and whether or not the Mohring effect (Mohring, 1972) is relevant in support of transit subsidies. It is clear from this debate that the answers depend on the functional forms of transit demand, user cost, and transit operating cost functions.

Two limitations run through much of the literature. First, restrictive or simplifying assumptions have been made on the functional forms of demand and cost functions. Second, individuals are assumed to be homogeneous other than for their willingness to pay (WTP) for a transit trip. In reality, of course, individual transit usage depends on various factors including access and waiting time, in-vehicle travel time, comfort levels, privacy, and safety. Individuals value these characteristics differently due to differences in their incomes, vehicle ownership, trip purpose, personal preferences, and so on (Savage, 2010).

* Corresponding author.
E-mail address: junlin.zhang@connect.ust.hk (J. Zhang).

[1] Among leading contributions are Jansson (1980, 1993), Pedersen (2003), Basso and Jara-Díaz (2010), and Moccia and Laporte (2016).

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One recent exception to the assumption that users are homogeneous is Gómez-Lobo (2014) who allows for heterogeneity in individual valuation of service frequency. Gómez-Lobo (2014) argues that, if service frequency is treated as a quality attribute, previous analyses of private transit frequency provision including those in the aforementioned debate can be viewed as special cases of Spence (1975) and Sheshinski (1976). Using a model of a generic commodity, these authors showed that a monopolist's profit-maximizing choice of quality deviates from the social optimum if marginal consumers and inframarginal consumers differ in their average valuations of quality.[2] If marginal customers have the higher average valuation, the monopolist supplies excessive quality. Conversely, if inframarginal customers have the higher average valuation, the monopolist supplies too little quality. In the transit market, the value individuals attach to service frequency depends on their value of waiting time (VOT). This suggests that a private transit operator will provide too little frequency if marginal users have a lower VOT than inframarginal users, and vice versa.

Gómez-Lobo (2014) provides some useful insights and intuitive conjectures into private provision of service frequency when users differ in their VOT. However, his analysis falls short of a complete treatment that accounts for correlation in the potential traveling population between VOT and WTP for transit trips. Moreover, the model used by Spence (1975) and Sheshinski (1976) is not directly applicable to transit. Their generic commodity is excludable and rivalrous, and all production takes place within a firm. Transit service differs in three respects. First, transit users provide time as an essential input into the production of trips. Second, transit service is excludable, but if it is not congested it is a club good and hence not rivalrous. Multiple individuals can use the same service without necessarily increasing the operator's costs. Conversely, if transit does get congested the service quality then degrades. Service quality is thus endogenous, and not directly under the operator's control. Third, and related, unlike a firm that decides how many units of a commodity to produce, a transit operator does not directly control the number of trips taken. Rather, the operator provides the means of taking trips (i.e., buses, trains, trams, etc.) and individuals choose how much to use the service. The generic commodity model thus needs to be adapted to the market for transit.

In this paper we focus on how user heterogeneity in WTP for transit trips and valuation of service quality (i.e., VOT) affects a transit operator's frequency and fare decisions, and determines whether service is undersupplied or oversupplied. We also analyze alternative regulatory policies and investigate the need for subsidies. Our model features a general user cost function that depends on service frequency, a general transit operating cost function that depends on frequency and ridership, and a general bivariate probability or frequency distribution of WTP and VOT. Following Jørgensen and Pedersen (2004), we assume that the operator maximizes the sum of its profit and a scalar multiple of, or weight on, consumers' (i.e., passengers') surplus. Profit maximization is a limiting case where the weight is zero. Social-surplus maximization obtains when the weight is one. To maintain tractability, we exclude congestion in the form of travel time delay or disutility from crowding.[3]

Our analysis comprises five parts. First, we show that some standard results in the literature such as marginal-cost pricing go through with our more general model, whereas others — such as the square root rule for determining frequency — do not. Second, we derive a general condition under which the Mohring effect exists. We also derive a formula for the degree to which transit operating expenses are recovered from fare revenues under marginal-cost pricing. The formula depends on the degree of economies of scale in user costs with respect to frequency, and economies or diseconomies of scale in transit operating costs.

Third, we derive conditions under which a profit-maximizing operator undersupplies or oversupplies frequency relative to the social optimum. Consistent with Spence (1975) and Sheshinski (1976), the direction of bias depends on the difference in the average VOT of marginal and inframarginal users. These conditions synthesize the results derived by van Reeven (2008), Basso and Jara-Díaz (2010), Savage and Small (2010), and Karamychev and van Reeven (2010).

Fourth, we analyze and compare transit operations under four types of regulation: fare regulation, frequency regulation, goal regulation, and fiscal regulation. Goal regulation entails setting the weight on consumers' surplus in the operator's objective function. Goal regulation can reach the social optimum if the weight is set to match that of the planner's goal. With fiscal regulation, the operator is given a subsidy based on some performance measure. We show that fiscal regulation based on consumers' surplus can achieve the social optimum, whereas regulation based on ridership generally cannot when users differ in their VOTs.

Finally, we explore a numerical example featuring a particular bivariate distribution of WTP and VOT. We solve each regulatory policy for different values of the weight on consumers' surplus, and compare the efficiency of each policy relative to the social optimum. We also undertake sensitivity analysis with respect to the degree of heterogeneity in VOT, the correlation between WTP and VOT, the degree of heterogeneity in WTP, and the value of other time.

The remainder of the paper is organized as follows. Section 2 lays out the model. Section 3 derives the transit operator's choice of frequency and fare, and compares the properties of the solution to results derived in previous studies. Section 4 identifies a general condition under which the Mohring effect exists, and provides a tree diagram for determining when a profit-maximizing operator supplies more or less frequency than in the social-surplus maximizing solution. Section 5 defines the four regulatory policies and proves the equivalence between goal regulation and fiscal regulation based

[2] Marginal customers are indifferent about the commodity, and receive zero consumers' surplus from purchasing it. Inframarginal consumers gain positive surplus, and would continue to buy the commodity if the price were raised slightly.

[3] Recent analyses of transit crowding are found in Tirachini et al. (2013), de Palma et al. (2015), and de Palma et al. (2017).

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