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Optimal choices of fare collection systems for public transportations: Barrier versus barrier-free

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ABSTRACT

The present study focuses on two major types of fare collection systems for public transportations, barrier and barrier-free, and provides a mathematical framework to evaluate optimal choices between them, i.e., which system can be more profitable for a transit agency. In particular, we consider game-theoretic interactions between the transit agency and passengers for the barrier-free system and suppose that frequencies of free rides of passengers as well as inspections of the transit agency are given as a Nash equilibrium. Then the optimal choice of fare collection system is described as a subgame perfection solution in an extensive form game. We also conduct a comparative static analysis and examine how each parameter can affect the choice. As an application, we use the framework to explain various choices of fare collection systems in our society depending on local circumstances or transportation types.

1. Introduction

There are various fare collection systems for public transportations in the world, depending on countries and regions, types of transportations, and so on. In this paper, we focus on two major types of them, barrier and barrier-free, and provide a mathematical framework to evaluate in a formal way optimal choices between them, i.e., which system can be more profitable for a transit agency. Hence, in particular, we think of transportations such that the choice between the two systems can potentially be worth serious consideration, such as heavy rail, commuter rail, LRT and BRT.

While the detail of each system may always differ in each case, the two systems we deal with in the study, the barrier system (henceforth BA) and the barrier-free system (or the proof-of-payment system, henceforth POP), can generally be described as follows. First, the BA system requires the transit agency to install ticket gates, or turnstiles, and establish a clearly defined paid area. Therefore, by its nature, all passengers need to pay for the tickets before going on board. On the other hand, the POP system allows the platform to be barrier-free. Passengers are required to pay for fares legally, but not forced to do so physically. In order to crack down on free rides, the transit agency randomly conducts inspections for the valid proof of payment and collects fines from passengers without it.[1]

Since their different characteristics have different financial impacts, the choice of fare collection system becomes an important managerial issue for the transit agency. For example, a typical trade-off is that, in general, BA requires higher capital costs for ticket gates and facilities for enclosed platforms, while POP requires higher labor costs for inspections. In addition, fare evasion may become a serious problem particularly in POP. Although there are some reports and guidelines that

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[1] There is another type of fare collection system that allows on-board fare payments, where passengers are allowed to pay for fares via inspectors or conductors on board. We distinguish this system from POP and do not deal with it in this paper.

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discuss the issue (e.g. Toronto Transit Commission, 2000; Transportation Research Board, 2002), any rigorous mathematical framework considering economic behaviors of the transit agency as well as passengers has not been provided.[2] Our contribution is to develop a formal and consistent perspective to deal with the issue of comparisons of fare collection systems.

For the purpose, assuming a simple public transportation, we model the transit agency's revenue and cost for each fare collection system. In particular, we assume game-theoretic interactions between the transit agency and passengers for POP. Under the system, as the transit agency's inspection is conducted randomly, fare evasions of passengers become an unavoidable issue. Indeed, according to Transportation Research Board (2002) that reports the fare evasion rates of 19 transit agencies using POP in the world, they are from 0.3% to 15.0%. There are some economic studies that discuss a passenger's fare evasion as her expected utility maximization (Polinsky and Shavell, 1979; Boyd et al., 1989; Kooreman, 1993), but they do not consider such a game-theoretic interaction that POP can bring about, that is, the interdependency of the frequency of free rides of passengers and that of inspections by the transit agency. If a high volume of passengers is expected to go without tickets, the transit agency should conduct inspections frequently, and on the other hand, if inspections are made so frequently, passengers would not take a risk of free ride. We formulate such a situation by applying inspection game (Avenhaus et al., 2002; Avenhaus, 2004) and suppose their behaviors are given as a Nash equilibrium of the game.

On the other hand, we formulate the BA system simply by assuming that it entails no fare evasion. Then we consider the transit agency chooses, or should choose, the fare collection system that can be more profitable. Such an approach that compares some systems taking into account each system's incentive scheme can also be considered as a comparative institutional analysis (Aoki, 2001).

Following this introduction, Section 2 provides the analytical framework, namely, the transit agency's profit model of each fare collection system. Based on it, Section 3 conducts a comparative static analysis by which we examine how each parameter can affect the optimal choice. In addition, we specify the transit agency's optimal choice of fare collection system as a subgame perfection solution in an extensive form game. Then Section 4 applies the model to interpret our society's various fare collection choices. Finally Section 5 states concluding remarks and several open questions.

2. Analytical framework

2.1. The target and basic assumptions

As the target of our analysis, we suppose a simple public transportation that connects two stations. Then we discuss the optimal choice of its fare collection system, that is, which system, BA or POP, can be more profitable for the transit agency.

Let us denote the fare by $a(>0)$. Then suppose n passengers board the transportation per operation, from one station to another. In this paper, we do not discuss pricing of the fare. It is also assumed that the demand of the transportation does not depend on the fare collection system, that is, the both systems have common n (see also Section 5 for the assumption). We investigate the optimal choice of fare collection system under given a and n.

Let the assessment period of the analysis be t-time operations. That is, we evaluate the profitability of the transportation while it is operated t times. As its revenue, we only consider revenues from fares, and fines in the case of POP.[3] With regard to the cost, since our interest is in comparisons of the two fare collection systems, we only specify additional costs that are required for introducing either of them: we leave out the description of costs common in the both systems such as the land cost, the construction and maintenance cost of the rail tracks. Then the profit is the difference between the revenue and the cost.

2.2. Barrier system

The BA system requires the transit agency to install ticket gates and establish a clearly defined paid area. Let us denote the initial costs for them by $c_s(>0)$, and the operating and maintenance costs for them per operation by $c_m(>0)$. We suppose, for simplicity, every passenger pays for the fare, i.e., no fare evasion under BA.[4]

Hence, the revenue and the cost of BA are defined as ant and $c_s + c_m t$, respectively, and thus the total profit during the assessment period, $\pi_{BA}(t)$, is determined as:

$$\pi_{BA}(t) = ant - (c_s + c_m t) \tag{1}$$

[2] Tirachini and Hensher (2011) discuss mathematically comparisons of fare collection systems for buses. However the alternatives are on-board or off-board, or payment by cash or contactless smart card, etc., and they leave POP, which is of our main concern, out of consideration, for POP is uncommon for buses.

[3] Some real-world transit agencies do not receive fines as their own revenues, and instead they are collected by the courts or other relevant organizations. We, in this paper, assume the transit agency can count all the amount of the collected fines as its own revenue.

[4] One may be inclined to consider the possibility of fare evasion under BA as well because there are transit agencies using the BA system facing some levels of fare evasions (e.g. Reddy et al., 2011). A simple way to incorporate this is assuming that the initial investment, c_s, is a decision variable for the transit agency and the fare evasion rate is a decreasing function with respect to it, that is, $\partial x/\partial c_s \leqslant 0$, where x is the fare evasion rate. Then the revenue is expressed as $a(1-x)nt$. We note that this does not affect our result in Section 3 significantly, but of course can make BA less attractive for the transit agency. In reality, it is virtually impossible to predict accurately the relation of x and c_s, therefore the fare evasion rate would be estimated based on similar existing cases, for instance.