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Estimation of urban bus transit marginal cost without cost data

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ABSTRACT

We develop a method to study the industrial structure of urban bus transit without using cost data. To do so, we estimate the marginal cost function under the assumption that firms compete on frequency and adjust frequency to maximize profits. Our methodology is applied to Santiago, Chile. In this case, demand is modeled with a simplified model of transit network assignment. The goal is to consider how frequency, capacity, and on-board passengers affect the bus line's demand. The marginal cost function is estimated by using the first-order conditions of the firm's profit maximization problem, using the results of the demand model as data. We conclude that the urban bus transit industry in Santiago exhibits increasing returns to scale for low levels of demand and that these returns are exhausted rapidly at a moderate demand level. Additionally, firms exhibit economies of network expansion, on average.

1. Introduction

Cost function estimation for transport firms is a central issue in analyzing transport supply (Winston, 1985). In particular, the study of economies of scale is of considerable interest to justify and design regulatory policies. Knowledge of average or marginal cost is required for setting pricing and subsidy policies in urban public transportation, as well as for designing procurement contracts.

Estimating cost functions and even the marginal cost of urban public transport in developing countries is challenging. Deregulation of the bus transit industry and weak institutional development limit the availability of information on firm's costs. For example, until 2007, all bus service providers in Santiago, Chile, were private, and the industry was regulated by means of a tendering process that awarded concessions for bus routes. Operation contracts did not require official reports on cost. Instead, the transport authority commissioned three ad-hoc studies to estimate the cost of public bus transport in Santiago (SECTRA, 2003b; SEREMITT, 2002; Universidad Católica de Valparaíso, 1999), all of which yielded dissimilar results. Additionally, because bus operators volunteered the cost information used in these studies, the data were subject to selection and incentive compatibility biases (i.e., the agents' answers were biased toward their own benefit).[1]

Weak regulation of cost information is not unique to Santiago (before 2007). In all Chilean cities, except for Santiago, the current public transport system is deregulated and has no cost information requirements. To our knowledge, there are no

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[1] Since 2007, the bus system in Santiago has been strongly regulated. Contracts set conditions on cost information provision. Therefore, the methodology developed in this paper is not suitable for the current system, but it is valid for other cities in Chile and in other countries.

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regulatory requirements for operators to submit cost information in any Mexican state or city, even in the few cities where regulation is conducted via contracts. In Bogota, Colombia, the situation is similar for the bus lines that operate outside of the bus rapid transit system, Transmilenio. In general, most cities in developing countries with deregulated bus transit have little or no requirements on cost information.

In this paper, we show that the marginal cost of urban bus transit can be estimated without cost data by using the first-order conditions of a firm's profit-maximization problem. In doing so, we assume that bus firms compete on frequency and that the market is in equilibrium for the observed frequencies. According to Gagnepain et al. (2011), bus competition takes the form of service wars with fare matching. They also affirm that competition focuses on frequency, because changes in frequency are easier to implement and more difficult to match than changes in fares. Evans (1990) provides evidence for this finding, which supports our basic assumption.

The methodology is applied to the bus system that operated in Santiago in 2001, when the Santiago transport authority regulated routes and fares, but firms fixed frequencies. In the short-term, firms could adjust only frequency to maximize profits. Although seemingly outdated, the current bus systems in other Chilean cities and in many cities of developing countries operate like that of Santiago in 2001. Hence, the methodology developed in this paper remains valid.

We model demand as a function of bus line frequencies. The form of this function depends on the available data. In the case of Santiago, the data include fares, bus network (routes), and bus trip matrices for each relevant user type (student and non-student).[2] This information is observable and usually collected by authorities for transport planning.

Previous studies of the industrial structure of bus services use other data and methods, including disaggregate cost data and standard econometrics techniques (e.g., Cambini et al., 2007; Farsi et al., 2007; Jørgensen et al., 1995; Karlaftis and McCarthy, 2002; Obeng, 1985), aggregated data (e.g., Berechman, 1983; Roy and Yvrande-Billon, 2007), and aggregated output that excludes network configuration of services (e.g., Gagnepain and Ivaldi, 2002; Piacenza, 2006; Viton, 1981; Williams, 1979). In this paper, estimation is carried out with implicit consideration of real network topology and its interaction among bus lines. The original contribution of this paper is the estimation of marginal cost function without cost information.

This paper is organized as follows. Section 2 presents the general methodology, including basic assumptions, demand modeling, cost model specification, and estimation. Section 3 presents the application of the methodology to the 2001 transit system in Santiago. Section 4 summarizes conclusions and comments.

2. Methodology

To estimate urban bus transit marginal costs without cost data, we adopt a structural approach. This means that a model for firm behavior relates data and model variables and provides the necessary equations to estimate the function or parameters of interest. The basic assumption is that firms compete only on frequency because the regulator sets fares and bus size. Therefore, the firm maximizes profits by adjusting its frequency in response to the frequencies of other firms in the network. In this way, firms play a game on frequencies. The relationship between data and variables is given by the first-order condition of the firm's profit maximization problem and the observed frequencies, which correspond to those under market equilibrium.

2.1. Firms

Consider that firm l represents one bus line with a route that includes a sequence of bus stops where passengers board and alight. In the bus network, some stops are served by more than one firm, and thus firms compete at these shared stops. Suppose that R_l is firm l's revenue function, depending on its frequency f_l, a rivals' frequency vector f_{-l}, and a vector of fares p. Fares may differ according to distance, route segment, user type (e.g., age, student status, employment status), or second-degree price discrimination (e.g., weekly or monthly travel passes). All firms face the same vector of fares, which is fixed by the regulator. Firms have a cost function C_l, which depends explicitly on a vector of passenger demand q_l. As demand depends on frequency, costs depend on frequency too, but implicitly. Thus, line l's profit function is

$$\pi_l(p, f_l, f_{-l}) = R_l(p, f_l, f_{-l}) - C_l(q_l(p, f_l, f_{-l})).$$

In equilibrium, the first-order condition for line l's profit maximization problem under competition on frequency satisfies

$$\frac{\partial R_l}{\partial f_l}(p, f_l, f_{-l}) = C_l{}'(q_l)\frac{dq_l}{df_l}(p, f_l, f_{-l}), \tag{1}$$

Eq. (1) provides a set of equations that must be satisfied in equilibrium by all lines that compete on frequency. Estimation of firms' marginal costs is carried out with these equations. Therefore, to estimate the marginal cost, it suffices to know the derivative of revenue and demand functions, with respect to frequency.

Eq. (1) represents a period-specific, short-term equilibrium, because bus firms fix frequency for short periods, during which total travel demand is homogeneous (e.g., morning peak, morning off-peak, afternoon off-peak). Although frequency

[2] The trip matrix is the standard format for representing travel demand in transportation studies. The rows represent origin zones of trips in a geographical area. Columns represent destination zones. Each cell in the matrix corresponds to the number of trips between corresponding zones.