ARTICLE IN PRESS

Economics of Transportation (xxxx) xxxx–xxxx

Contents lists available at ScienceDirect

Economics of Transportation

journal homepage: www.elsevier.com/locate/ecotra

Optimal prices and frequencies for buses in Stockholm☆

Maria Börjesson[a,*], Chau Man Fung[b], Stef Proost[b,a]

[a] Centre for Transport Studies, KTH Royal Institute of Technology, Sweden
[b] Department of Economics, KU Leuven, Belgium

ARTICLE INFO

JEL codes:
D61
H54
R41
R43
R48

Keywords:
Public transport
Bus fares
Bus lanes
Bus frequency
Public transport subsidies
Congestion pricing

ABSTRACT

Many public transport services are heavily subsidized. One of the main justifications is the expected beneficial effect on road congestion. Stockholm introduced congestion pricing in 2006 and the effects on car and public transport demand were carefully monitored. The change in prices provides unique estimates on price- and cross-price elasticities. This paper uses these data to model how the optimal pricing, frequency, bus size and number of bus lanes for a corridor depends on the presence of congestion pricing for cars. Results show that the presence of road pricing makes the current subsidies for peak bus trips too high. However, the major welfare benefits of re-optimizing the current bus supply stem from a decrease in frequencies during the off-peak period and the use of larger buses.

1. Introduction

Subsidies to public transport are a well-known and frequent example of second-best policy. As car use during peak periods has large external congestion costs, attracting car drivers into buses, metro or rail via low prices is an obvious second-best recipe. However, a pricing policy for buses should also take into account dimensions other than just substitution away from cars. First, pricing of public transport requires attention to the positive economies of density: more users allow higher frequency, implying decreased waiting costs. This is the so-called Mohring effect concerning the trade-off between waiting costs and bus operation costs (Mohring, 1972). Second, there are also discomfort and crowding effects associated with a more intensive use of existing bus supply (De Palma et al., 2015). Third, there is the optimal procurement of bus services. The bus service is subsidized, but the way in which the bus company is subsidized determines the efficiency of the bus services (Gagnepain et al., 2013). Fourth, to the extent that buses are more intensively used by lower income groups, reduced bus prices could be justified as income redistribution policy. Fifth, the average production cost of public transport is often decreasing due to large fixed costs. This is important for metro and rail services but less so for bus systems.

The major contribution of this paper is to derive optimal bus pricing, bus frequency, bus size and bus lanes for a corridor in a city for which good revealed modal choice data are available. The modal choice data are crucial as it is the main economic justification for bus subsidies. There are many studies that derived optimal pricing and frequencies for buses. Stockholm differs from most other cities in that congestion charges are levied on the corridors leading into the city. Due to the extensive monitoring program that was put in place when the charges were first introduced in 2006, data regarding traffic flows, elasticities and cross-elasticities are also well documented in Stockholm. Such data are both scarce and crucial, given that the second-best argument for bus subsidies is very sensitive to the cross-price elasticity with car use. We focus on the efficiency aspects assuming full control of the supply side by the planner and leave the procurement and redistribution dimensions aside.

Bus subsidy is neither modelled as an instrument nor as a constraint in this paper, which is different from part of the literature. Instead, the optimal bus subsidy is an outcome of the constrained optimization using combinations of car tolls, bus fares, bus frequencies, bus sizes and allocations of road space. We take this approach of modelling optimal bus subsidy for two reasons. First, if other choice variables are optimal, the choice of optimal subsidy will be the same as the optimal subsidy we compute (i.e., what follows from the combination of car tolls, etc.), so adding optimal subsidy as an instrument is

---

☆ We thank the editor as well as two referees and participants of the ITEA-2016 conference for helpful comments.

* Corresponding author.

E-mail addresses: maria.borjesson@abe.kth.se (M. Börjesson), chauman.fung@kuleuven.be (C.M. Fung), stef.proost@kuleuven.be (S. Proost).

http://dx.doi.org/10.1016/j.ecotra.2016.12.001
Received 9 December 2015; Received in revised form 28 November 2016; Accepted 8 December 2016

Please cite this article as: Börjesson, M., Economics of Transportation (2016), http://dx.doi.org/10.1016/j.ecotra.2016.12.001

uninformative; second, it is unlikely for a certain corridor to be subject to a specific budget constraint on the provision of bus service.

The bus corridor under study reaches from the inner-city Södermalm and south-east neighborhoods to the suburban areas of Nacka and Värmdö. The population of Nacka and Värmdö combined is 134000 and the number of round trips in the bus corridor is around 10000 per day. The corridor is served by approximately 200 buses in one direction during rush hour. The road network in the corridor is also heavily congested and is a candidate for metro extension (Cats et al., 2015). The Stockholm County Council is responsible the transit services in the County. However, the County Council procures the transit services from private operators, through competitive bidding processes (Vigren, 2016) . The County Council determines the fares and service frequencies (although the service frequencies are determined after consultation with the operators).

The main findings are as follows. We find that optimizing bus frequencies for the current prices increases welfare significantly. So in any bus reform exercise one may as well start by optimizing frequency. The best overall reform consists of higher peak and off-peak tolls for cars combined with higher peak bus fares and peak frequency and free off-peak bus services but lower frequencies, larger buses, and more road space for car use. Adopting these measures does not necessarily mean higher PT subsidies. Optimal pricing adds a relatively small welfare gain compared to the welfare gain obtained by optimizing frequencies.

Section 2 reviews the literature. Section 3 presents the theoretical model, and Section 4 describes the main parameters used as well as the model calibration. Section 5 uses the model to analyze the main research questions. Section 6 discusses caveats.

2. Literature review

The literature on optimal public transport pricing, frequencies and vehicle sizes is abundant. From Mohring's seminal work (1972) on optimal frequencies, Jansson (1980, 1984) extends the model to look into the optimal fleet size and vehicle size in multiple periods. Along the same line, Jara-Diaz and Gschwender (2003) includes variable cycle and travel time, and occupancy-dependent value of time in their model. Some other work (Kraus (1991), Tirachini et al. (2013), for instance) focuses more on the effects crowding externalities, confirming the importance of crowding in the evaluation of transport policies. Viton (1983) and De Borger and Wouters (1998) incorporate externalities other than congestion in their evaluation of optimal pricing and characteristics of transit supply. While the former includes noise and pollutions, the latter has accident risks in the model in addition.

Another strand of literature focuses on the effects of transit subsidies on the behavior of PT providers. Frankena (1981) investigates the effects of transit subsidies on fares, service provision and ridership. He also compares different types of subsidies such as lump sum and subsidy on ridership. Nonetheless, in this paper we focus on the social optimum instead of the behavior of PT providers.

We contribute to the extensive literature by evaluating the welfare effects of the level of PT subsidies together with pricing (of both transit and cars), frequency and size of public transit as well as the allocation of road space. This focus on subsidies with different combinations of policy instruments and welfare makes it natural to have a more in-depth comparison with Parry and Small (2009) and Basso and Silva (2014).

Parry and Small set up a generic model to determine the optimal subsidy rate for public transport that is calibrated to London (pre-congestion tolling), Los Angeles and Washington DC. Subsidies to bus as well as to rail services are studied. For bus and rail services, the optimal second-best subsidy rate for operation costs turns out to be very high: 90% or more.

For buses, there are three main motivations for bus subsidies in the peak period. First there is the decreasing average cost of an additional passenger because the frequency of buses increases less than proportionally to the number of passengers, at least when buses are not full. Second, the car congestion costs reduce when a subsidy shifts car drivers to bus transport. Third, there are the savings in waiting time for existing users when the bus frequency increases, even though the increase may be less than proportional (this is the Mohring effect).

In the off-peak period, the car congestion reduction motive disappears, while both the savings in waiting time as well as the decreasing average cost of supplying an extra passenger (buses have lower load factor) become the main justifications for subsidizing bus services. As some two thirds of the PT passengers travel during the peak, car congestion cost savings becomes the most important motivation for subsidized PT. Whenever car congestion is priced or whenever the subsidy is less able to attract car drivers into public transport (Parry and Small assume that for every two passengers attracted into public transport, one is a former car user), the optimal subsidy rate in the peak decreases strongly for buses.

While Parry and Small study optimal bus and rail subsidies for given car taxes, Basso and Silva only focus on bus subsidies but also look into a wider set of policy interventions than simply for bus subsidies. They also analyze congestion pricing of cars, dedicated bus lanes and the role of peak differentiation for bus fares. Focusing on their results for London (pre-congestion tolling), they find that congestion pricing and dedicated bus lanes (with buses breaking even) are far more efficient policies than subsidizing bus fares. The additional contribution of subsidized bus fares would therefore be small.

Basso and Silva also analyze a policy of cross subsidization between peak and off-peak bus use, where overall bus operations must break-even but where off-peak bus users subsidize peak bus users. This policy improves welfare but only marginally.

Kilani et al. (2014) find rather different results for Paris. They look into the effect of price discrimination for peak and off-peak public transport in the absence of congestion pricing for cars but without a budget constraint for public transport. They find that higher prices for peak bus users are welfare-improving. The main reason is the high level of congestion in PT, a factor that is absent in Basso and Silva and less important in Parry and Small.

An important difference between Parry and Small (2009), Kilani et al. (2014) and our paper is that in our model, frequency is explicitly optimized and not determined as a rule of thumb for the way in which additional PT demand is met.

3. Stylized model

In this model, we study one corridor that links the suburban areas of Nacka and Värmdö to the city centre of Stockholm. Passengers can use either the car or the bus and can do this in either the peak or off-peak period. All transport is from either the suburb to the CBD or back. In this corridor only buses are available as public transport, and at present, there is a dedicated bus lane. Tram and metro are not available in this corridor. Given the distance, the bike mode may also be considered but since it uses a separate bike path, there is not much interaction with the other modes. For this reason we do not consider cycling in this paper.[1]

We first present the model components; next we set up the optimization problem that is used to compute equilibria.

---

[1] Cycling shares are roughly 5% in the corridor in September-October according to the travel survey. However, it drops to less than half in the winter month. The cross-elasticity between cycling and car is very low; 90% of the cyclists state that they would choose public transport had they not been able to cycle (Börjesson and Eliasson, 2012).