Transportation Research Part E 109 (2018) 277–292

Contents lists available at ScienceDirect

Transportation Research Part E

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

The economics of seat provision in public transport

Daniel Hörcher*, Daniel J. Graham, Richard J. Anderson

Railway and Transport Strategy Centre, Department of Civil Engineering, Imperial College London, United Kingdom

A R T I C L E I N F O

Keywords:
Public transport
Seat provision
Crowding
Capacity optimisation
Externality pricing

A B S T R A C T

Seated and standing travelling imply significantly different experience for public transport users. This paper investigates with analytical modelling and numerical simulations how the optimal seat supply depends on demand and supply characteristics. The paper explores the implications of seat provision on the marginal cost of travelling as well. In crowded conditions, we distinguish two types of external costs: *crowding density* and *seat occupancy* externalities. We derive, using a realistic smart card dataset, the externality pattern of a metro line, and identify the distorting role of the occupancy externality that makes the welfare maximising fare disproportionate to the density of crowding.

1. Introduction

Public transport is often modelled as a homogeneous service, as perceived by simultaneous users of the same vehicle at a given occupancy rate. There is, however, a fundamental service feature that may split users into two groups, based on the travel cost they bear. Some of them are seated, some others are standing, either deliberately or due to the lack of vacant seats. Empirical studies in the literature found that the generalised user cost of travelling may be 25–50 percent higher for the representative standing passenger (Wardman and Whelan, 2011; Li and Hensher, 2011), which implies that most people prefer sitting. Operators are facing a trade-off in seat provision: the more seats they fit into a vehicle, the more people will have the possibility to avoid standing, but the less area will be available for those who are still unable to sit. This paper investigates the supply-side consequences of the generic tension between people's preference for seated travelling and the in-vehicle space constraint.

Despite the obvious impact of standing on passenger experience, and the growing number of empirical efforts to measure the disutility (Wardman and Whelan, 2011), the supply-side literature of public transport economics rarely considers the difference between sitting and standing. In case of pricing, the pioneering study of Kraus (1991) reveals that seated passengers impose an externality on standees, as in the absence of the seated trip one standee could travel more comfortably. Assuming a radial commuter service heading to the city centre, Kraus shows that the occupancy externality increases with travel distance, as the earlier someone boards the train, the more likely that she will occupy a seat on the busy sections of the line. This externality works in the opposite direction to the delay cost during boarding the vehicle, which is more significant for those passengers who board a crowded vehicle, thus causing delays for more fellow users (Mohring, 1972).

In case of capacity supply, Tirachini et al. (2014) are the first authors who include the number of seats as a decision variable in a numerical simulation of bus operations and multimodal pricing. They simultaneously optimise seat supply with vehicle size and frequency, and conclude that buses should have as many seats as possible. In other words, the best way to alleviate crowding is simply to increase frequency delivering additional benefits in terms of reduced waiting times for passengers, in line with the square root principle of Mohring (1972).

* Corresponding author at: South Kensington Campus, SW7 2AZ London, United Kingdom.
E-mail address: d.horcher@imperial.ac.uk (D. Hörcher).

https://doi.org/10.1016/j.tre.2017.11.011
Received 5 June 2017; Received in revised form 25 October 2017; Accepted 22 November 2017
1366-5545/

This paper contributes to the literature of public transport research with the first systematic analysis of the main driving forces behind the choice of interior seat supply. Our second research goal is to investigate how decisions on seat provision affect the marginal external cost of travelling, considering the difference between the disutility of standing and seated service usage. As the crowding externality is an important component of the optimal fare under marginal cost pricing, the insights presented in this paper may improve our understanding of efficient pricing in public transport, and pave the way for new policies in the industry.

In the first part of the paper we derive a general seat supply rule stating that in the optimum, the marginal benefit of allowing a passenger to travel seated should be equal to the marginal cost that the remaining standees bear due to the reduction in the available standing area. Then we extend the model and allow service frequency to be simultaneously optimised with seat supply, as a response to growth in demand. We show that as soon as the waiting time benefit of frequency adjustment falls below a threshold level, the operator should respond to further growth in demand by limiting the number of seats. This may serve an explanation why high-frequency metro operators tend to offer more standing area than long-distance rail, or even short-distance bus operators. In addition, we show that demand fluctuations along a public transport line served by uniform capacity also point in the direction of reduced seat supply, controlling for aggregate scale effects.

In the second part of the analysis we model the impact of seat supply on the marginal cost of travelling. We identify two crowding-related externalities. First, the presence of the marginal user increases the density of crowding, thus causing inconvenience for fellow passengers. Second, less obviously, if the marginal user has a chance to travel seated, she imposes an occupancy externality on standing travellers, as one them could be seated in the absence of the marginal trip. The second externality suggests that crowding charges under marginal cost pricing[1] should be differentiated between OD-pairs based on the probability of finding a seat. We analyse the interplay between the two externalities, assuming homogeneous user preferences. The simulation exercises of the paper are calibrated with crowding cost parameters estimated from revealed preference smart card data from Hong Kong (Hörcher et al., 2017).

Our approach is purely economic in nature and admittedly neglects all aspects of boarding and alighting dynamics, mechanical design, and the length of leg space (seat pitch) between seat rows. All these considerations could be important extensions of the analysis. Another limitation of our analysis is that we ignore the possibility of failed boarding. Modelling failed boarding requires a dynamic peak demand setting, otherwise in a static model excess demand would imply ever increasing queues on the platform. Early attempts to model optimal supply (including endogenous seat supply) in a dynamic framework are already available in the literature: de Palma et al. (2015) investigated the effect of variable seat supply on welfare in a numerical simulation, and found that reducing seat supply on the most crowded services (the ones closest to the desired arrival time) can be as powerful as applying dynamic fares[2]. Although dynamic modelling delivers a valuable perspective on crowding analysis, this paper will focus on undiscovered insights in a static framework. The static simulations presented in this paper do not produce optimal crowding densities high enough to make failed boarding a reasonable threat.

The paper is structured as follows. Section 2 presents an analytical setting, from which we derive the intuition behind optimal seat supply and the marginal cost of travelling in crowding. Section 3 takes a closer look at the seat supply rule and the ways how endogenous frequency and demand fluctuations may impact the optimum. Section 4 is devoted to the analysis of the magnitude of the two externality components in a real network setting. That is, Sections 3 and 4 extend the baseline model in the direction of capacity and pricing, respectively.

2. Baseline model

In this section we develop a simple model as an illustration of (1) the trade-off between various consequences that variable seat supply implies, and (2) the consumption externalities when the effect of crowding on seated and standing passengers is differentiated. The main contribution of this part is the analytical treatment of seat supply and its effect on marginal external crowding costs.

Assume that the average user cost of standing and sitting are denoted by functions $c_{st}(Q,S,\sigma)$ and $c_{se}(Q,S,\sigma)$ respectively, where the disutility of crowding associated with the density of passengers depends on three main factors: the number of passengers (Q), the available in-vehicle floor space (S), and the number of seats installed in the vehicle (σ). In this setting we assume that passengers have equal chance to find a seat and are assumed to gain perfect information about the probability of finding a seat prior to their decision on consumption[3]. That is, crowding appears in user cost function c_u as the average of c_{st} and c_{se}, weighted by the proportion of standing and seated passengers:

$$c_u(Q,\sigma;S) = \frac{Q-\sigma}{Q}c_{st}(Q,\sigma;S) + \frac{\sigma}{Q}c_{se}(Q,\sigma;S), \tag{1}$$

where the vehicle's interior space is fixed in the short run. Let us assume that passengers always prefer sitting over standing, and demand is always higher than the number of seats supplied.[4] Thus, total crowding cost in the system equals to

[1] Optimal pricing in public transport should be based a number of social costs and exogenous constraints in reality. What is derived in this paper is admittedly limited to the optimal *crowding surcharge*, i.e. the layer in the optimal fare that internalises the crowding externality. Other components of the optimal fare in a particular application may of course distort the externality patterns plotted later on in this paper.

[2] The most powerful policy is, of course, the joint optimisation of fares and seat supply on each train.

[3] This model setup with uniform probabilities does not hold for reserved seat services. In that case, users have certainty about the comfort level they will face, and differentiated prices can be charged for this certainty. The deeper analysis of reserved seat services can be an important extension for future research.

[4] Otherwise $Q-\sigma$ takes a negative value in Eq. (1), thus resulting in a user benefit when certain seats remain unused. In the realistic but in this section neglected case when $Q < \sigma$, so that all passengers find a seat, the only consumption externality may stem from frictions between seated users. Wardman and Murphy (2015) provide