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Valuing crowding in public transport: Implications for cost-benefit analysis

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ABSTRACT

This paper investigates the valuation of crowding in public transport trips and its implications in demand estimation and cost-benefit analysis. We use a choice-based stated preference survey where crowding levels are represented by means of specially designed pictures, and use these data to estimate flexible discrete choice models. We assume that the disutility associated with travelling under crowded conditions is proportional to travel time. Our results are consistent with and extend previous findings in the literature: passenger density has a significant effect on the utility of travelling by public transport; in fact, the marginal disutility of travel time in a crowded vehicle (6 standing-passengers/m^2) is 2.5 times higher than in a vehicle with available seats. We also compare the effects of different policies for improving bus operations, and the effect of adding crowding valuation in cost-benefit analysis. In doing that, we endogenise the crowding level as the result of the equilibrium between demand and supplied bus capacity. Our results indicate that important benefits may be accrued from policies designed to reduce crowding, and that ignoring crowding effects significantly overestimate the bus travel demand the benefits associated with pure travel time reductions.

1. Introduction

Fast growing transport needs are a common concern for urban areas in both the developed and developing worlds. To address this issue, many cities have already implemented improved high-capacity transit systems (BRT, tramway or Metro). Often these systems are designed using an engineering standard of six (and sometimes more) passengers/m^2 for the average supplied capacity. This design standard is an average across all vehicles of a service during the peak period, which is exceeded in a significant fraction of the operating buses/trains in some route segments. For instance, in Santiago, Chile, the average density across all trains in the most loaded segment during the morning peak hour exceeds 6 passengers/m^2. As many individuals are not willing to use the system under such crowded conditions, they choose travelling by car or shift to car as soon as it becomes available. This prevents public transport modal shares from growing, increasing congestion and emissions. Moreover, although passenger density below a maximum design threshold of say 6 passenger/m^2 may not be considered problematic at the design level, it is relevant because crowding may influence users' preferences even for low levels of passenger density.

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Crowdedness is usually left aside in most public transport demand models used for strategic planning. When planners evaluate transit network improvements, such as bus exclusive lanes, their goal is to increase the demand for public transport. Usually, this approach neglects the negative effects of crowding caused by the new induced demand. Notwithstanding, Tirachini et al. (2013) discussed its effects on operating speed, waiting time, travel time reliability, route and bus choice, and optimal levels of frequency, vehicle size and fare. The need for a more detailed understanding of crowding on travel decisions and its impact on project evaluation or cost-benefit analysis (CBA) is becoming an urgent priority. In this paper we focus on the valuation of crowding and its effect on mode-choice modelling. We estimate bus travel demand using a mode choice model that includes crowding effects and analyse the impact of using a wrong model, without crowding effects, in estimating demand and users benefits.

The general objectives of this paper are two: (i) to measure the willingness-to-pay (WTP) for crowding reductions in existing transit systems, and (ii) to study empirically the implications for CBA of making the demand for public transport endogenous with respect to the crowding level. The study is based on data from Santiago, Chile.

Most work addressing the valuation of crowding in public transport systems has used choice-based stated preference (SP) methods (e.g. Li and Hensher, 2011). But Guerra and Bocarejo (2013) and Haywood and Koning (2015) applied contingent valuation to find the willingness to pay (WTP) for reducing overcrowding in the Bogota bus system and in the Paris Metro system, respectively. Li and Hensher (2011) reviewed public transport crowding valuation research, focusing on studies conducted in the UK, USA, Australia and Israel. Most studies have used logit models with SP data from commuters, and focused mainly on in-vehicle congestion costs. Nevertheless, Douglas and Karpouzis (2005) also estimated crowding costs at the platform (related to waiting time) and in the access-way/entrance to train stations (related to walking time). The way crowding is represented in SP experiments is highly relevant. Wardman and Whelan (2011) suggest that passenger density is a better indicator of in-vehicle congestion, given that a same load factor may have different levels of crowding across different types of vehicles/wagons with varying seat composition.

Our study was performed within a mode choice SP framework. In the choice experiment respondents had to choose between two transport modes, which could be bus, Metro or car. Each alternative was described by a number of attributes (e.g. cost, travel time, waiting time), and one of them was related to crowding. Specifically, pictures depicting passenger densities on board of vehicles served to represent the level of crowding. Valuations were derived from the estimation of mixed logit (ML) models (Train, 2009) using these data.

To explore the effects of crowding valuation in CBA results, three transport policies - typically proposed for improving bus corridor operations - were modelled: increasing bus frequency, increasing vehicle capacity, and building exclusive bus lanes. We used the estimated modal choice model to solve the equilibrium problem for bus demand (induced by the dependence of the bus utility function on crowding levels that, in turn, depend on bus demand). By doing so, we identified the pure effect of each policy and the effect of endogenous crowding levels in CBA. We found, for instance, that increasing bus travel times overestimated demand and user benefits if the endogenous effect of crowding was not taken into account.

The rest of the paper is organised as follows. Section 2 presents the SP survey experimental design and the information collected. Section 3 discusses our discrete choice modelling approach and presents the main estimation results. Section 4 discusses the effect of including crowding on the cost-benefit analysis of three common measures to improve the performance of a bus corridor. Some final comments are given in Section 5.

2. Survey design

Prior to the experimental design, we conducted focus groups that served to define which attributes would be most important to consider and which could be their levels of variation. Alternatives were finally described by six attributes: transport mode, travel time, travel cost, average waiting time, waiting time variability (coefficient of variation), and crowding level inside the vehicle (bus or train).

The experimental design in SP surveys is represented by a matrix that summarizes the choice scenarios that respondents will have to face in the survey. In this matrix, columns represent the attributes of the alternatives, and rows represent different choice scenarios. There are several ways to define the design matrix. The more traditional (and more suitable matrix for linear models) consists in an orthogonal design, which ensures that all columns are orthogonal to each other (i.e. linear independent). This design minimizes the variance of the estimated parameters in the case of linear models. However, for nonlinear models and in particular for logit models, the levels of the variables (attributes) are not relevant, but the differences between them are. Therefore, the design is built orthogonal in differences (called optimal designs). For nonlinear models, where X is the matrix of independent variables, in general, the covariance matrix of estimated parameters (Ω) is not proportional to $(X'X)^{-1}$ as in the case of linear models. Moreover, Ω depends on the specific model to estimate.

Based on these considerations the so-called *efficient designs* (Rose and Bliemer, 2009; Ortúzar and Willumsen, 2011, Ch. 3) minimize Ω as function of the attribute levels in every choice scenario of the design. This means adjusting the design matrix to minimize Ω. To do so, Ω needs to be transformed to a scalar by some metric. Different metrics to transform Ω lead to different methods in the efficient design family. For instance, if the metric is the trace of the matrix, the design is called *A-efficient*; if the metric is the determinant of the matrix, the design is *D-efficient*. One difficulty of this type of designs is that Ω cannot always be derived analytically and requires numerical methods.