

# **Public transport design, scale economies and optimal pricing: the role of space**

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## **Extended Abstract**

Users' costs play a part of the economic resources that should be taken into account in the design and optimal pricing of public transport systems, which makes this one of the most interesting areas of economic analysis. The classical result of decreasing average users' costs – or scale economies – as patronage increases because of frequency adjustments yields an optimal monetary fare that falls short of operators' average cost, and is the cause of an optimal subsidy for economic efficiency (Mohring, 1972; Jansson, 1979, 1984; Jara-Díaz and Gschwender, 2005, 2009). Besides the pricing-subsidy argument, analyzing scale economies is useful *per se* because if they exist it could be desirable to increase public transport patronage.

In this research we examine the spatial sources of scale economies in public transport and their impact on optimal pricing, by looking at the variation of design when minimizing users' plus operators' costs as patronage increases. We depart from the analysis of scale economies induced by the optimal frequency adjustment (the so-called Mohring effect), and the diseconomies provoked by the increasing effect of patronage on boarding and alighting time (Jansson, 1984). Space is then introduced in the analysis following Chang and Schonfeld (1991) who defined a new design variable, namely the distance between parallel transit lines (spacing) which makes the time spent walking to the bus stops (access time) part of users' costs. The authors made two strong simplifications in order to obtain their results analytically: vehicles' cycle time does not depend on the number of users, and operators' costs do not depend on vehicle size. These assumptions are particularly damaging in the analysis of scale economies, as the extra cycle time induced by each new passenger boarding and alighting was shown to be a relevant source of diseconomies of scale in the one line case. We formulate the problem including the two omitted effects: patronage influences cycle time through boarding and alighting, and vehicle size influences operators' costs. We show that a new source of scale economies emerges while keeping the properties of the basic one-line model regarding frequency and vehicle size: density increases with patronage, diminishing access and egress times.

From this we move into the general area of optimal transit networks design, whose role in the analysis of scale economies is particularly complex. This is because a lines structure can be conceptually described with some precision by a generic characteristic, e.g. feeder-trunk or hub-and-spoke, but cannot be represented by a single variable as frequency, vehicle size or lines density. Further, changes in the design of line structures are discrete, i.e., they occur at some specific levels of total patronage. Both elements not only increase the mathematical complexity of the associated optimization problem, but also add new challenges to scale economies analyses due to the discrete nature of the changes. Here we formulate the problem in a way that follows the approach taken so far, i.e. how the design of transit networks should evolve as patronage increases and how this evolution impacts users and operators' costs. This evolution is represented by the spatial shape of transit networks, i.e. a set of transit lines organized in space to serve all trips on the many OD pairs within a city. Generally speaking the literature on lines structures in the last fifteen years shows that, for low levels of overall demand distributed in space, those structures involving transfers tend to be appropriate, e.g., hub-and-spoke or feeder-trunk systems (see, for example, Jara-Díaz and Gschwender, 2003, Daganzo, 2010, Estrada et al, 2011, Jara-Díaz et al, 2012, Badia et al, 2014 and Gschwender et al, 2016).

We study the role of patronage by introducing a simple spatial model first and then we used the transit network design formulation over a parametric city introduced by Filbaum et al (2016, 2017). We show that increasing patronage induces a series of changes in the optimal design of transit lines: essentially the reduction of transfers, distances travelled and number of stops, elements that emerge in favor of scale economies which we summarize under the concept of "directness" in route structures. We conclude that spatial effects are indeed a source of scale economies as patronage increases; further analysis including changes in technology and congestion is needed.

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