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The Mohring Effect[☆]

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Abstract

The Mohring Effect is the result that an increase in the demand for public transportation induces a decrease in the waiting time costs for all users when it is dealt with an increase in the frequency of the services. The use of the term Mohring Effect is also associated with other positive indirect effects of increased demand, such as an increase in route density that leads to reductions in access time costs. The Mohring Effect, which is, to some extent, analogous to a positive externality, is the most important argument from an economic efficiency standpoint for public transport subsidization. Recent empirical evidence shows that between 50% and 60% of the optimal subsidy for off-peak bus services in cities such as Washington, Los Angeles, and London is due to the Mohring Effect. The evidence also shows that the Mohring Effect is more significant for buses than rail and subways and for off-peak periods than for peak periods.

Keywords: Access time costs; Bus provision; Mohring Effect; Public transportation; Public transportation pricing; Public transportation subsidization; Urban transportation; Waiting time costs

1. Introduction

Herbert Mohring (1928-2012) was one of the most influential economists in the field of transportation economics. He was one of the first economists to study land values and its relationship with transportation costs in the monocentric model. He is also well known for his contribution to the theory of cost recovery for highway construction, especially for the joint work with Mitchell Harwitz that studied the conditions under which road provision is exactly financed with optimal road tolls. He has also contributed to the urban transportation policy analysis by studying the efficiency of dedicating road capacity exclusively to

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buses and comparing its benefits with those from welfare maximizing pricing policies. The present article discusses his contribution on economies of scale and subsidization in public transportation.

The Mohring Effect is the result that an increase in the demand for public transportation induces a decrease in the waiting time costs for all users when it is dealt with an increase in the frequency of the services. Its origin is in the article titled "Optimization and Scale Economies in Urban Bus Transportation" published in the American Economic Review in 1972. The term Mohring Effect has also been used in a broader way and has included other positive indirect effects of increased demand, such as reductions in access time costs from increased route density. When the average costs, including those of the users, decrease with the demand, the social welfare maximizing public transportation fare does not cover operating costs. Therefore, the Mohring Effect, which is in a way analogous to a positive externality, is the most important argument from an economic efficiency standpoint for public transport subsidization. The other arguments for subsidization, such as reductions of car travel externalities and distributional concerns, may be better addressed with instruments directly targeted at those objectives.

Recent estimations using data from large and congested cities have shown that the Mohring Effect is substantial and that it plays a key role in justifying the presence of public transport subsidization. It has also been shown that the Mohring Effect is more significant for buses than rail and subways and that is more significant for off-peak periods than for peak periods. The intuition behind these results is that the Mohring Effect is stronger for low frequencies that imply significant waiting times, and frequencies are higher in peak periods and urban rail services.

Section "The Mohring Effect in a Simple Framework" of this article discusses a simplified version of Mohring's framework that illustrates the nature of the Mohring Effect and why it is an efficiency argument for subsidizing public transportation. Section "The Mohring Effect in the Original Framework" summarizes Mohring's original model and his numerical results. Section "Empirical Evidence on the Mohring Effect" reviews the recent empirical evidence on the size of Mohring Effect and estimations on how much of current and optimal subsidies in some cities are due to the Mohring Effect. It also discusses more generally under which conditions the effect should be strong. Finally, Section "Conclusions" concludes providing a summary and some present challenges related to this topic.

2. The Mohring Effect in a Simple Framework

Mohring, in his pioneer work published in 1972, started the literature on the microeconomics of urban bus transportation. The aim of his paper, which gave rise to what is now known as the Mohring Effect, was to study scale economies in the provision of public transportation. In other words, Mohring (1972) studied the short- and long-run cost functions to characterize the nature of increasing returns to scale in bus operations and thus to assess the nature of the subsidy required if marginal cost pricing is in place.

Transportation differs from the classic analysis of pricing because consumers (i.e., travelers) play a producing role by providing their own time as a resource for production. In using bus services, they must supply their time, distributed at least into access (walking), waiting, and in-vehicle time. These time costs borne by the travelers can be substantial: estimates for the value of time for commute trips are typically around 50% of the wage rate, and the values of waiting and access time are 2 or 3 times larger.

Mohring's model considers a bus corridor or line, where the demand is spatially distributed. As the focus is on costs, demand is treated parametrically. He examines four components of costs: (1) bus company operating costs, (2) passengers' walking time costs, (3) passengers' waiting time costs, and (4) passengers' in-vehicle time costs. The sum of these components is sometimes called in the literature as the total value of resources consumed.

The variables that the bus agency optimizes are the frequency of the buses and the spacing of bus stops. A key assumption in the model, which is rooted in transportation engineering, is that the waiting time is a function of the headway between buses. Therefore, as the headway is the inverse of the frequency, the average waiting time costs are inversely related to the frequency of buses.

A primary result of the analysis, inspired in William Vickrey's previous work, is that, when bus speed is constant, the frequency that minimizes the expenditure is proportional to the square root of the demand for bus services. This has become a result commonly known as the "square root formula" for the optimal frequency of bus services, and it has been extended in various directions and found to be fairly robust (Jara-Díaz and Gschwender, 2003).

In his paper, Mohring modeled in a detailed fashion the realized bus speed as a function of frequency, the distance between bus stops, and free-flow speed. However, the Mohring Effect can be understood without this complexity. This section considers that bus speed is constant and therefore the square root formula is valid, and it assumes for simplicity that the number of bus stops as well as their location are fixed. The following section deals with more complex models.

The implications behind the square root formula are intuitive. As the average waiting time is inversely related to the frequency, and the frequency is proportional to the square root of the demand, the average waiting cost decreases with total demand. This result is the essence of the Mohring Effect: an increase in demand reduces waiting costs for all passengers, as it should be dealt with an increase in frequency.

The Mohring Effect is, therefore, one source of increasing returns to scale in bus operations because waiting costs grow less than proportionally with demand. In other words, due to the Mohring Effect, the marginal cost could be less than the average cost and the welfare maximizing bus fare does not cover operating costs. As a consequence, the Mohring Effect is a driving force of the efficiency of public transport subsidization.

The strength of the Mohring Effect and, therefore, to what extent it justifies public transport subsidization depends mainly on the frequency implied by the level of demand. Consider a simple example of a bus route with low demand for which the optimal frequency is two buses per hour. Assume for simplicity that the average waiting time is half the headway so that in this example is 15 min. If demand is doubled and the optimal frequency follows the square root formula, it increases by a factor of the square root of 2, which yields a new frequency of approximately three buses per hour. The increase in frequency from two to three buses per hour reduces the average waiting time for all passengers from 15 min to 10 min. While this can be substantial, as demand grows and the frequency is higher, the effect becomes smaller. For a frequency of 30 buses per hour, the average waiting time is 1 min, and the potential decrease in waiting costs is limited. Naturally, the real effect is complex as more interrelationships come into play. We now turn to discuss some of them.

3. The Mohring Effect in the Original Framework

As explained in the previous section, Mohring's model included bus company operating costs and passengers' walking, waiting, and in-vehicle time costs. The previous section assumes that buses travel at a constant speed for the ease of exposition, but, in Mohring's model, the speed that buses achieve is endogenous, and the analysis is more detailed. We summarize the main features of the model and his numerical results.

First, in the model, the speed of a bus depends on the number of passengers that board and alight each bus along the route and, therefore, it depends on the number of passengers and the frequency. Furthermore, the time spent in starting and stopping at the bus stops is modeled together with a probability of buses not stopping at all bus stops.

Second, Mohring studies two types of spatial distributions of demand. The "steady state" route in which demand is uniformly distributed along the bus line, and the "feeder" route in which the same average number of people per hour board buses but they all alight at the end of the route. For both travel demand patterns, the number of equidistant bus stops per mile is an optimization variable.

As a result of the complexity of the interaction between these features of the model, it is not possible to obtain closed-form expressions for the frequency and spacing of bus stops. Nevertheless, it is clear that, in contrast to the simplified version of the previous section, an increase in the bus frequency decreases both waiting and in-vehicle time. It also increases bus-operating expenditures but less than proportionally as the travel times are reduced. Finally, increasing the number of bus stops increases in-vehicle time for users and operating costs, but reduces walking costs.

To shed light on the degree of scale economies and the size of the optimal subsidy for urban buses, Mohring performed numerical analyses based on data that reflect approximately the Minneapolis-Saint Paul metropolitan area. The results are intended to cast light into the magnitude of optimal subsidies if the effects of bus pricing on highway congestion and the marginal cost of public funds are ignored.

The numerical analysis performed by Mohring is detailed, but the result that arguably better conveys the conclusion is as follows. For conditions that reflected the situation at the time in the Minneapolis-Saint Paul metropolitan area, results are that the weighted average gap between long-run marginal costs and average costs is 57% of the bus company operating costs. Therefore, the optimal subsidy at those conditions is large and justified by the reduction in user time costs of increased frequency.

The combination of the theoretical and numerical analysis summarized earlier gave rise to the Mohring Effect, which, in a broad sense, is the result that as demand increases the average user costs decrease if the public transport supply responds optimally. This could be due to increases in frequency that lead to a reduction in waiting time and in-vehicle time due to lower boarding and alighting time. It could also be due to increases in bus route density, which leads to decreased access time. The Mohring Effect, thus, is a source of the presence of economies of scale in public transport provision and one of the main efficiency arguments for subsidizing public transport

4. Empirical Evidence on the Mohring Effect

The vast majority of the empirical literature on public transportation pricing focuses on the optimality of public transport subsidization (Proost and Van Dender, 2008; Basso and Silva, 2014; Börjesson et al., 2017). In doing so, the studies have commonly estimated an aggregation of all the effects that could give rise to subsidization, and little can be said about specific effects. For example, the size of the optimal subsidy is a function of the strength of the Mohring Effect but is also determined by the degree of scale economies of the bus company operation. The subsidy also heavily depends on the unpriced externalities in urban travel. If car travel is not priced in a welfare maximizing way, lowering the public transport fare may decrease car usage and the unpriced negative externalities such as road congestion and pollution. This reduction potentially implies the need for higher subsidies. Finally, there could be negative externalities from bus travel as well, such as crowding, pollution, and congestion that could make the subsidies not efficient.

The primary empirical evidence about the size of the Mohring Effect and its role in the efficiency of public transport subsidization is a study with data from Washington, Los Angeles, and London by Parry and Small (2009). The study considers most of the relevant features that need to be taken into account in determining the efficiency of public transport subsidies. It includes several modes for traveling, demand substitution across modes and times of day, transit supply that is responsive to changes in ridership, negative externalities from motor vehicles (congestion, pollution, and accident), in-vehicle crowding in public transport, and transit-user wait and access costs. Importantly, the transit agency can adjust the route density, service frequency, vehicle size, and load factor.

The available estimations are not exactly the size of the Mohring Effect, but the marginal welfare gain of increasing the subsidy that is due to the Mohring Effect. More precisely, it is the marginal benefit minus the marginal cost of increasing the frequency and the route density in welfare maximizing fashion as a response to the increased demand that is a consequence of the fare reduction. The marginal benefit arises from the reduction in wait costs from increased service frequency and the reduction in access costs from increased route density. The marginal cost is from increased agency supply costs from increased vehicle size and the increase in passengers' crowding costs from higher load factors. Therefore, while the estimations are not the Mohring Effect per se, they are a relevant measure of how important it is in shaping the optimal pricing policy.

At the baseline situation of the study, which already had subsidies between 50% and 80%, the size of the Mohring Effect is significant. For peak operations, the marginal welfare gains due to the Mohring Effect from increasing the subsidy in 1 cent per mile in peak periods are 0.34 cents per mile in Washington, 0.29 in Los Angeles, and 0.19 in London. In off-peak periods, where frequencies are lower, the gains due to the Mohring Effect are substantially larger: 2.00 cents per mile in Washington, 1.73 in Los Angeles, and 1.74 in London. For rail, the marginal welfare gains due to the Mohring Effect are smaller and vary between 15% and 50% of the gains estimated for buses. The only exception in the study is peak-rail in London, in which higher costs fully offset the benefits due to the Mohring Effect. This is most likely because London's subway is already very frequent, crowded, and its network of lines is dense.

Parry and Small (2009) also estimate what the optimal subsidy would be and what percentage is due to the Mohring Effect. For off-peak bus services, the optimal subsidy is above 90% of operating costs for the three cities and the proportion of the optimal subsidy that is due to the Mohring Effect is between 55% and 61%. For peak bus services, the results are case specific. For London, the optimal subsidy is above 90% of the operating costs, and only 15% of that subsidy is due to the Mohring Effect. For Los Angeles, the optimal subsidy is 74%, and the proportion due to the Mohring Effect is 22%, while in Washington it is 46% and the proportion is also 46%. For rail services, the optimal subsidy in the three cities is substantial (above 78%) in all periods, but the share due to the Mohring Effect is lower. In peak periods the Mohring Effect is responsible for 0%-10% of the subsidy and for 21%-41% in off-peak periods.

In summary, the recent empirical estimations confirm Mohring's early findings that increased demand for public transportation that is met with an optimal adjustment of supply leads to a substantial reduction in user costs. This result, which is the broad definition of the Mohring Effect, justifies subsidization on efficiency grounds before taking into account the distortions that would be introduced in the process of raising public funds for subsidies.

5. Conclusions

This article argues that the concise definition of the Mohring Effect is the result that an increase in the demand for public transportation induces a decrease in the waiting time costs for all users when it is dealt with an increase in the frequency of the services. This article provides an overview of a simple framework to understand the Mohring Effect and of the original framework developed by Mohring. This article also reviews the recent empirical estimations of the size and relevance of the effect.

The Mohring Effect can be understood in a general fashion as the result that, as the demand for public transportation increases and the public transport supply responds optimally, the average user costs decrease. This could be due to an increased frequency that leads to a reduction in average waiting times, to increased route density that leads to reduced average walking times, and route structure changes that lead to lower transfer costs, among others.

Recent estimations of the Mohring Effect in congested cities of developed countries show that it is an important driving force of the efficiency of public transportation subsidization. While results are convincing, the evidence is still scant. A natural avenue for future research is to estimate the Mohring Effect in different situations and to assess empirically to what extent it is strong enough to justify public transport subsidization.

The present article has focused on the cost-side of the problem and has not dealt with the private, profit-maximizing, provision of public transport. There has been recently a debate in the literature about whether the Mohring Effect justifies subsidization when a monopoly firm supplies the service. The answer seems to depend on the assumptions on public transportation demand, user cost heterogeneity, and operating cost functions (see Gómez-Lobo, 2014, for a synthesis). Studying the relationship among the Mohring Effect, the strategic interactions between public transport providers, the regulatory framework, and the need for subsidization seems a natural place for further research.

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