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The effect of public transport quality on car ownership – A source of wider benefits?

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ABSTRACT

This paper discusses the potential impact of public transport service levels on car ownership and it is discussed whether this connection can be seen as a source of wider economic benefits that would ensue from improving the public transport system. To study the interrelationship between public transport demand and car ownership, a model is estimated using data from 21 Swedish counties from 1986 to 2015. It is concluded that car ownership is affected by the service levels in the public transport system, and that this effect results in additional benefits from improving the public transport system.

1. Introduction

In many parts of the world, there is a continual demand for new infrastructure from policy makers; as a result, many projects are carried out despite their undesirability for society, as assessed using the standard tools of cost-benefit analysis (CBA). Often, the reason given for ignoring the results of a CBA is that the project will bring "wider benefits" – that is, effects not accounted for by a conventional CBA. From a theoretical perspective, such additional effects might very well exist, but the empirical knowledge of the conditions under which they can be expected to be significant is not clear.

It is worth noting that thus far, the discussion on wider benefits has focused on the effects of investments in infrastructure. However, in order to allocate resources efficiently, it is also necessary to recognize that projects that include other improvements (changes) in the transport system might also have wider impacts. Such projects might include increasing the frequency and/or coverage of public transport, or reducing fares.

It is well known that car ownership is one of the most important factors determining the demand for public transport (Balcombe et al., 2004; Holmgren, 2007; Webster & Bly, 1980). However, although it is reasonable to argue that access to good public transport (i.e. having a low generalized cost of using public transport) would reduce the need and demand for owning a car, far less research has been done on this relationship.

If there is such an effect, it would be a potential source of wider benefits (compared with what is included in a typical CBA in the transport sector today) that would stem from improvements made to the public transport system. Part of this effect would be in the form of increased long-run demand (i.e. willingness to pay) for public transport, since reduced car ownership would further increase demand beyond what would be caused by the initial improvement in the public transport system. (Note that since this effect occurs in the primary market, it is not part of what is traditionally labelled "wider benefits", but since it might not be included in a standard CBA, there is an argument for calling it that.) In addition, wider benefits of investing in public transport might occur from the reduced demand for cars (if the market for cars is not functioning perfectly) and from reduced car use (if the market for car use is not functioning perfectly, e.g. due to non-internalized external effects).[1]

The focus of this paper will be on the first of these effects – that is, on the potential additional effect on the demand for public transport caused

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[1] An additional wider impact is the fact that improved public transport services, under the right circumstances, reduce the need for special transport services for older people and people with disabilities (Hansson and Holmgren, 2017).

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by feedback from car ownership. More specifically, the aim of this paper is to estimate the effect of public transport quality on car ownership, and demonstrate how the presence of such a connection affects the full benefits of investing in the public transport system.

To achieve this aim, a model of public transport demand and car ownership was estimated using data from Sweden. The data is yearly data from 21 Swedish counties from 1986 to 2015. The data on the public transport sector (number of trips made, supply of vehicle kilometres, revenues) was partly provided by the governmental agency Transport Analysis[2] and partly obtained by the author from annual reports from the County Public Transport Authorities (CPTAs).[3] Data on other variables (income, price of petrol, CPI, car ownership) was obtained from Statistics Sweden.[4]

Better understanding of the full impacts of changes in the transport system is important when trying to design a future sustainable transport system in which public transport has a larger market share than today. This kind of knowledge is useful when evaluating the impact of different measures to improve the public transport system such as introducing optimal prices (Jansson et al., 2015) or improving the balance between price and service levels (Holmgren, 2010, 2014).

2. The concept of wider benefits

The concept of wider benefits is somewhat elusive. It is clear that such benefits must be wider in relation to something else. A natural starting point is CBA, since it is the most commonly used method of systematic evaluation in the transport sector, as well as other sectors (see Mackie et al., 2014, for a discussion of the role of CBA in transport appraisal). A definition of CBA in a standard textbook reads, "CBA is a policy instrument that quantifies in monetary terms the value of **all consequences** of a policy **to all members of society** [bold added]" (Boardman et al., 2014, p. 2).

In light of this definition, it is natural to ask: what is wider than all consequences to all members of society? The term "wider benefits" sometimes refers to the positive impacts of transport investments that are presently not included in the standard CBA frameworks applied in most countries. However, it is most commonly used to refer to a specific type of impact, i.e. productivity effects due to agglomeration caused by investments in transport infrastructure.

Duranton and Puga (2004) classify the microeconomic mechanisms connecting improved transport infrastructure and increased productivity as sharing, matching and learning. *Sharing effects* occur when firms are able to utilize existing facilities to a greater extent and thereby spread fixed costs over a larger production volume. *Matching effects* can be seen when the labour market increases in size, so that firms can employ workers better qualified for the job they are hired to do, and people find it easier to find jobs that are suitable for their skills. *Learning effects* refer to a situation in which proximity – whether physical or through low transport costs – makes it possible to share information and knowledge, as well as to transfer skills between workers. These effects are often referred to as agglomeration effects. Previous empirical studies of productivity effects induced by transport improvements have resulted in estimates of agglomeration (or similarly defined measures of density) elasticities ranging from 0.007 (Isacsson et al., 2015) to 0.2 (Montolio & Solé-Ollé, 2009), with other contributions falling somewhere in between (e.g. Börjesson et al., 2019; Graham et al., 2009; Ahlfeldt & Feddersen, 2017; Holl, 2011). *Agglomeration elasticity* is interpreted as the percentage change in productivity following a change in employment density or city size. A recent large study of Norwegian transport improvements – a context reasonably similar to that of this paper – reported effect sizes of around 0.03 (Tveter, 2018). In a large review, Melo et al. (2009) found that the empirical elasticities reported in 34 studies (although these did not necessarily study changes to transport networks directly) exhibited a 5th and 95th percentile range of [–0.09 – 0.292], with an average of 0.058 (see also Elburz et al., 2017, and Holmgren & Merkel, 2017, for overviews and meta-analysis of previous results).

The relationship between agglomeration effects and the conventional consumer surplus is not entirely straightforward. As shown by Eliasson and Fosgerau (2019), a transport improvement that leads to improved workers-to-jobs accessibility and a denser labour market will tend to give rise to agglomeration benefits, although not all of these are external to the workers' decision on whether or not to take a commuting job. In particular, the matching effect is partly internal; the (after-tax) wage increase earned by a worker who chooses to commute to a job for which she is better matched has already been taken into account. The implication is that adding the entire change in output arising from agglomeration effects leads to double-counting, since part of the matching effect is already captured by the consumer surplus. In most cases, it is not possible to disentangle the effects of matching from sharing and learning (pure spillovers).[5]

In general, a change in the transport system will potentially have several impacts. Assuming that the change reduces the generalized cost (i.e. monetary costs plus time costs) of travelling between two places (e.g. X and Z) for at least some people, it can be called an improvement of the transport network. Whether or not this improvement of the transport network brings about net benefits is ultimately a matter of weighing the value of generalized cost reductions against the total cost of the improvement. Using an improvement of a bus system as an example, the first and most obvious effect is that the people who used the bus before the improvement, whether regularly (mostly commuters) or irregularly, will be better off after the improvement is made. In addition, some people who used other modes of transport to travel between X and Z before the change will find that taking the bus will now lower their travel costs, and therefore switch to using the bus. Some of these individuals will use this reduction in generalized cost to increase their leisure time, while others might use (at least part of) it to work more, resulting in increased production. Furthermore, some people who were previously not working at all, or working close to home, might now find it profitable to commute by bus and take a job further from home. In the longer run, firms and households might relocate as they realize that the size of the market and/or labour market has changed (Nash & Laird, 2009). All of these effects can be observed as changes in traffic volumes in the primary market (i.e. the bus market in the example) and, if all (relevant) other markets are well functioning, the value of the improvement can be easily estimated (Jara-Diaz, 1986; Mohring, 1993; Mohring & Williamson, 1969). Under such an assumption, CBA of a transport improvement is a relatively simple task, although the presence of distorted secondary markets potentially makes appraisal more difficult.

Assuming there is only one distorted secondary market, the benefit from that market (due to a change in the primary market) is (e.g. Mohring, 1993):

$$Gain = (P - MC)\Delta Q \tag{1}$$

That is, in order to have welfare impacts from a secondary market, the price on that market must deviate from the marginal cost (MC), which is the standard definition of a distorted market, and there must be a change in the quantity traded on that market.

In the present case, a change in the bus market (primary market) will be discussed and the focus will primarily be on a different kind of wider

[2] https://www.trafa.se/.

[3] Older data.

[4] https://www.scb.se/.

[5] At this point, it might be worth mentioning that agglomeration effects might in fact be negative (Nash & Laird, 2009), and that there might be additional costs of building infrastructure such as encroachment effects (Ivehammar, 2006). Therefore, it might be more appropriate to talk about wider impacts.

benefit. Going back to the discussion in the beginning of this section, "wider benefit" will here be interpreted as being a benefit that is currently overlooked. Focusing on the primary market, and simplifying things to just consider one time period, the change in welfare (ΔW) resulting from a policy (project, investment, etc.) is given by the following equation (e.g. Zerbe & Dively, 1994):

$$\Delta W = \Delta CS + \Delta PS + (1 + MCPF)\Delta GB + \Delta EE \tag{2}$$

where:

ΔCS = Change in consumer surplus.
ΔPS = Change in Producer surplus.
ΔGB = Change in government sector budget.
ΔEE = Change in external effects.
MCPF = Marginal cost of public funds.

Consumer surplus is the difference between the value of a good to consumers (i.e. their willingness to pay), and what they are actually paying for it. *Producer surplus* is the difference between revenue and variable costs for the producer, and *external effects* are negative or positive impacts of the market activity accruing to individuals not involved in the decisions on the market (e.g. emissions). *Marginal cost of public funds* is the additional cost to society that occurs when people change their behaviour due to taxation.[6]

If Q is the number of public transport trips undertaken in an area (or between two locations) during a period of time, it is usually assumed that Q can be expressed as a function of the generalized cost (GC)[7] of making public transport trips; therefore (when all other factors affecting public transport demand are kept constant) we have:

$$Q = f(GC) \tag{3}$$

The marginal willingness to pay for public transport trips is then given by the inverse demand function:

$$GC = f^{-1}(Q) \tag{4}$$

This relationship is commonly illustrated in a diagram such as that provided in Fig. 1, where two different (inverse) demand functions are shown.

First, consider the steepest demand function. Assume that the initial position is where $GC = GC_0$ and $Q = Q_0$. If there is an improvement in the public transport system, defined as a reduction in GC from GC_0 to GC_1, there will be an increase in the number of trips made, from Q_0 to Q_1. The

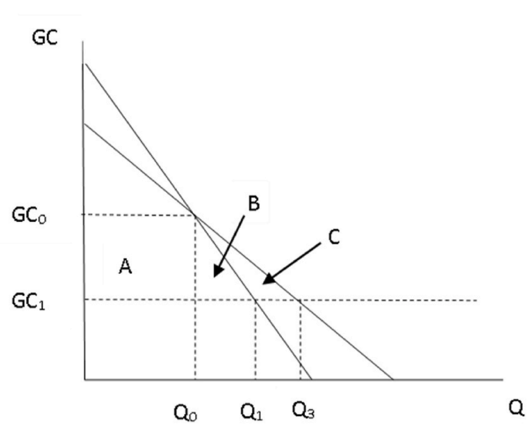

Fig. 1. Consumer benefits of a transport improvement.

[6] See Zerbe and Dively (1994) or Boardman et al. (2014) for textbook introductions to these concepts.

[7] GC is usually defined as monetary costs plus time costs. (e.g. Button, 2010).

benefits to consumers can then be represented by the areas A (benefits to consumers before the change) plus B (benefits to the new users of the service).[8]

Now, consider the fact that in empirical estimations of public transport demand functions, car ownership is often not included as a variable, despite the fact that when it is included it usually has a strong impact on public transport demand (Webster & Bly, 1980; Balcombe et al., 2004; Holmgren, 2007). In addition, when included, it is treated as an exogenous variable (Webster & Bly, 1980; Balcombe et al., 2004; Holmgren, 2007). Furthermore, models of car ownership usually does not include public transport GC as an explanatory variable (Clark, 2007; de Jong et al., 2004; Whelan, 2007).[9] Assume for the sake of argument that this is incorrect – that is, that there might instead be an impact not only of car ownership on public transport demand, but also in that the quality of the public transport system might affect car ownership (this assumption will be tested later in the paper). If this is the case, the impact in terms of public transport usage of a reduction in GC for public transport will increase due to a reinforcement effect from reduced car ownership. This effect might take some time to occur; therefore, this full (or augmented) effect will be referred to in this paper as "long-run impact" or "full impact.

The difference is illustrated in Fig. 1, where the less steep (inverse) demand curve represents the effect after including the full adjustment. In that case, the benefits to consumers from the reduction in GC described above will be represented by the areas $A + B + C$. Area C is therefore an additional benefit to consumers (the total benefit to society will also be increased by the increase in revenues going either to a private public transport producer or to the public sector, depending on who is providing the service).

3. An empirical model of the public transport market and car ownership

Expanding the demand function (3) and making it more general, the demand for public transport trips can be expressed as follows:

$$Q = f\left(GC_{1,}\ldots GC_M, Y, X\right) \tag{5}$$

Where GC_1 trough GC_M represent the generalized cost of travelling with M different modes, Y is the income and X represents different socio-economic factors. For empirical purposes, it is assumed that:

$$Q_{i,t} = d_i \cdot F_{i,t}^{\alpha 1} \cdot V_{i,t}^{\alpha 2} \cdot PP_t^{\alpha 3} \cdot Y_{i,t}^{\alpha 4} \cdot P_{i,t}^{\alpha 5} \cdot C_{i,t}^{\alpha 6} \cdot e^{\varepsilon_{i,t}} \tag{6}$$

Where:

$Q_{i,t}$ = Number of public transport trips made in county i, in time period t.
$F_{i,t}$ = Public transport fare in county i, in time period t.
$V_{i,t}$ = Vehicle kilometres supplied in the public transport system in county i, in time period t.
PP_t = Price of petrol in time period t, at 2017 price levels.
$Y_{i,t}$ = Average income in county i, in time period t, at 2017 price levels.
$P_{i,t}$ = Population in county i, in time period t.
$C_{i,t}$ = Car ownership in county i, in time period t (no. of cars per 1000

[8] As shown in (2), other welfare effects will occur; however, for illustrative purposes, the focus will be on the effects on consumers.

[9] There are examples where this problem is mitigated, e.g. Klein & Smart, 2017, who include a variable describing public transport accessibility and Liu et al., 2014, who include variables describing properties of the urban area, which is likely to be correlated with GC of public transport. See also ECON (2009) who evaluate the Norwegian national transport model used in forecasts and evaluations of transport investments. They explicitly point out (p.35) that the car ownership module of the model does not include the effect of public transport quality (GC).

inhabitants).

d_i = County-specific effects representing variables that differ between counties but are constant over time.

$\alpha_1 - \alpha_6$ = Parameters to be estimated.

$\varepsilon_{i,t}$ = Error term.

Population (P) is included, since it is likely to have an effect on the number of trips made in an area. As discussed before, car ownership (C) usually has a strong negative impact on public transport usage and is therefore included in the model.[10] (See e.g. Webster & Bly, 1980, Balcombe et al., 2004, and Holmgren, 2007, for discussions on variables affecting public transport demand.)

In this case, the public transport fare (F) and vehicle kilometres produced are used as a proxy for the generalized cost of travelling by public transport. F obviously affects GC directly, while an increase (decrease) in V is assumed to result in a shorter (longer) waiting time and/or shorter (longer) walking time, thereby reducing (increasing) GC (see Holmgren, 2018; Webster & Bly, 1980). When it comes to the GC of using other transport modes, the price of petrol (PP) is included in order to capture variation in the cost of using private car (or motorcycle). This is obviously not a perfect measure of the GC for using private car, since it does not capture the time cost. Geography – including the layout of cites – will greatly affect the time costs of using private car. Differences between counties will, therefore, largely be captured by the county-specific effects, (d_i). The county-specific effects will also capture the impact of other omitted variables that differ between counties but are constant over time.

The demand function (6) can be expressed as follows:

$$lnQ_{i,t} = lnd_{i,t} + \alpha_1 lnF_{i,t} + \alpha_2 lnV_{i,t} + \alpha_3 lnPP_{i,t} + \alpha_4 lnY_{i,t} + \alpha_5 lnP_{i,t} + \alpha_6 lnC_{i,t} + \varepsilon_{i,t} \tag{7}$$

Furthermore, it is assumed that in the long run:

$$v^*_{i,t} = b_i + u_{i,t} \tag{8}$$

$$\begin{aligned}\Delta lnQ_{i,t} &= \alpha_1 \Delta lnF_{i,t} + \alpha_2 \Delta lnV_{i,t} + \alpha_3 \Delta lnPP_i + \alpha_4 \Delta lnY_{i,t} + \alpha_5 \Delta lnP_{i,t} + \alpha_6 \Delta lnC_{i,t} + \Delta\varepsilon_{i,t}\\ \Delta lnC_{i,t} &= \theta\beta_1 \Delta lnF_{i,t} + \theta\beta_2 \Delta lnV_{i,t} + \theta\beta_3 \Delta lnPP_i + \theta\beta_4 \Delta lnY_{i,t} + (1-\theta)\Delta lnC_{i,t-1} + \Delta\theta\mu_{i,t}\\ v_{i,t} &= \delta b_i + (1-\delta)v_{i,t-1} + \delta u_{i,t}\end{aligned}$$

where:

$v^*_{i,t} = \frac{V_{i,t}}{Q_{i,t}}$, the target (long-run) relationship between V and Q.

b_i = County-specific parameters to be estimated.

$u_{i,t}$ = Error term.

The county-specific terms (b_i) can be seen both as a capacity requirement and as a level of ambition in terms of service levels in different counties. In the short run, the counties are assumed to adjust their supply so that:

$$v_{i,t} - v_{i,t-1} = \delta\left(v^*_{i,t} - v_{i,t-1}\right) \tag{9}$$

Which is to say, in each time period, there is an adjustment towards the target level v^*. Substituting (8) into (9) and solving for $v_{i,t}$ gives the equation to be estimated:

Table 1
Results from estimation of the demand equation (7).

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Vehicle kilometres	0.255897	0.107111	2.389077	0.0172
Car ownership	−2.431236	0.959362	−2.534221	0.0115
Fare	−0.255775	0.022123	−11.56128	0.0000
Population	0.091816	0.119107	0.770870	0.4411
Income	0.612178	0.189005	3.238955	0.0013
Price of petrol	0.076289	0.036304	2.101420	0.0361
R-squared	0.213507	Durbin-Watson stat		2.174596
Adjusted R-squared	0.204911			

$$v_{i,t} = \delta b_i + (1-\delta)v_{i,t-1} + \delta u_{i,t} \tag{10}$$

It is assumed that the desired (target) level of car ownership will be determined by income and GC for public transport as well as GC for car, so that:

$$C^*_{i,t} = c_i \cdot F^{\beta 1}_{i,t} \cdot V^{\beta 2}_{i,t} \cdot PP^{\beta 3}_t \cdot Y^{\beta 4}_{i,t} \cdot e^{\mu_{i,t}} \tag{11}$$

Adjustments towards the target are made so that:

$$lnC_{i,t} - lnC_{i,t-1} = \theta\left(lnC^*_{i,t} - lnC_{i,t-1}\right) \tag{12}$$

The short-run model to be estimated is therefore as follows:

$$lnC_{i,t} = \theta lnc_i + \theta\beta_1 lnF_{i,t} + \theta\beta_2 lnV_{i,t} + \theta\beta_3 lnPP_{i,t} + \theta\beta_4 lnY_{i,t} + (1-\theta)lnC_{i,t-1} + \theta\mu_{i,t} \tag{13}$$

4. Estimation and results

In order to reduce the risk of obtaining spurious results, (7) and (13) are estimated in first-difference form. The model is therefore as follows:

The model is estimated using 2SLS,[11] and the estimated parameters for the public transport demand function and the car ownership function can be seen in Tables 1 and 2, below.[12]

From Table 1, it can be seen that all variables – except population – are significant on the 5% level and have the expected signs. Since the variables are expressed in logarithmic form, the coefficients can be interpreted as short-run (i.e. before capacity and car ownership adjustment) elasticities.

As an example, a 1% increase in fares will result in a 0.26% decrease in public transport trips. These results are in line with the literature, although the effect of income is on the high side. However, that is not strange, since this is a short-run effect, before car ownership has adjusted.

Table 2 shows the results from the estimation of the car ownership equation (13).

[10] Note that there is sometimes problems with high correlation between car ownership and income (0.39 in the present case), making many authors exclude one of them from the model (Holmgren, 2007). However, income is likely to affect public transport usage indirectly, through car ownership and directly, through changed demand for mobility (Holmgren, 2013). Excluding one of the variables will therefore result in biased estimates.

[11] In addition to the exogenous variables, $lnC_{i,t-2}$, $lnC_{i,t-3}$, $V_{i,t-2}$, $V_{i,t-3}$were used as instruments. See Wooldridge (2010) for a discussion on using instrument variables when estimating dynamic models in a panel data setting.

[12] The supply function parameters will not be needed in the analysis and, since the parameters are county specific, they are not presented.

Table 2
Results from estimation of the car ownership equation (13).

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Income	0.134297	0.010247	13.10627	0.0000
Price of petrol	0.008178	0.002659	3.075482	0.0022
Fare (public transport)	0.006886	0.015139	0.454856	0.6494
Vehicle kilometres	−0.006506	0.003241	−2.000725	0.0459
Car ownership t–1	0.372820	0.061596	6.052674	0.0000
R-squared	0.208349	Durbin-Watson stat		1.854028
Adjusted R-squared	0.200867			

The vehicle kilometres variable is statistically significant, indicating that there is an effect of changes in public transport supply on car ownership. However, the public transport fare is not significant.

Table 3
Estimated elasticities.

Elasticities with respect to	SR	LR
Fare	−0.256	−0.356
Income	0.612	0.127
Price petrol	0.076	0.134
Population	0.092	0.128
Vehicle kilometres	0.256	County specific

5. Short- and long-run elasticities of public transport demand

Equation (8).[13] and (11) can be inserted in the demand function (7) to obtain the long-run demand for public transport after both supply and car ownership adjustments.[14] Doing so and solving for Q will result in the following:[15]

$$Q^{*} = d_i^{\frac{1}{1-\alpha2-\beta2\cdot\alpha6}} \cdot b_i^{\frac{\alpha2+\beta2\cdot\alpha6}{1-\alpha2-\beta2\cdot\alpha6}} \cdot F^{\frac{\alpha1}{1-\alpha2-\beta2\cdot\alpha6}} \cdot PP^{\frac{\alpha3+\beta3\cdot\alpha6}{1-\alpha2-\beta2\cdot\alpha6}} \cdot Y^{\frac{\alpha4+\beta4\cdot\alpha6}{1-\alpha2-\beta2\cdot\alpha6}} \tag{14}$$

The results presented in Tables 1 and 2 can then be used in the long-run demand equation (14) to determine the long-run elasticities of demand. These are presented in Table 3, together with the short-run elasticities that were shown in Table 1.

In the long run, the fare elasticity increase (in absolute terms) from −0.26 to −0.36, due to capacity adjustments and subsequent adjustments in car ownership. The impact of changes in the price of petrol and in population will also result in larger long-run impacts after the capacity and car ownership have adjusted. Vehicle kilometres is an endogenous variable in the model, so the interpretation of what a change in that variable means is not obvious. It should be seen as the impact on demand from a one-time change in vehicle kilometres without changing the capacity constraint/service quality goal. Given such an interpretation, the short-run demand elasticity with respect to vehicle kilometres is 0.26. The long-run impact will differ between counties, depending on capacity target b_i.

The effect of income changes is interesting. Previous studies exhibit large variation in this regard; the effect is even found to be negative, making public transport an inferior good. Obtaining very low (including negative) income elasticities is usually due to a lack of consideration of car ownership impacts (Holmgren, 2007). In this case, the full income effect (after taking car ownership into consideration) is, as expected, much lower than the short-run effect. The fact that it is still positive is important, since otherwise public transport would face a bleak future if income is expected to continue to rise. This result is consistent with the work of Holmgren (2013), who studied the feedback effect of car ownership on public transport demand but did not consider the additional effect caused by capacity adjustments.

Table 4
Estimated differences in benefits when using the model with full adjustment.

Scenario	Difference in benefits
(1) No CPF[a], no price change	10%
(2) No CPF, price change	39%
(3) CPF, no price change	11%
(4) CPF, price change	990%

[a] CPF=Cost of Public Funds.

6. The size of additional benefits

In the sections above, it was shown how the full effect on demand differs from the short-run effect. That information will now be used to illustrate the differences in the benefits calculated with the full (adjustment augmented) demand model and those calculated with the short-run model.

The change that is analysed in this paper is a 10% reduction in generalized cost. Since $\frac{\partial GC}{\partial F} = 1$, the effect of such a change on demand can be found by analysing the impact of a change in fares, regardless of whether or not the actual change comes from a change in fares. However, the effect on benefits will differ. Therefore, both the case where fares are reduced and the case where the reduction in *GC* is caused by something else will be considered.

The long-run impact are calculated using (14) and the information presented in Table 3, and the short-run equivalents are calculated using the estimated coefficients presented in Table 1. The exogenous variables are assumed to be constant for this calculation.

Assuming that all external effects on the primary and secondary markets are internalized, the one-time period benefits of a change will be as follows:

$$B = \Delta CS + (1 + MCPF)\Delta G$$

or

$$B = \Delta CS + (1 + MCPF)\Delta R$$

where R is the revenue generated from public transport operations. Note that it is also assumed that the revenue goes to the public sector, which is (generally) the case in Sweden. If the revenues were instead collected by a private producer, they would appear in the calculations of benefits as a change in producer surplus. Since the size of the MCPF is usually discussed a great deal and, in any case, varies between countries, the benefits from the different cases are calculated with and without the MCPF. The results of the benefit calculations are shown in Table 4.[16]

In the first scenario, the original reduction in *GC* does not come from a reduction in fares, and it is assumed that there is no MCPF. In this case, the difference in benefits is found to be 10%. When the reduction in *GC* is actually achieved by reducing fares, the relative difference is larger (39%). In this case, a large part of the benefits to consumers (area *A* in Fig. 1) will be negated by an equal loss in revenues for the public transport provider, hence cancelling each other out. Since this effect is equal for both the long-run (full adjustment) model and the short-run, the fall in the denominator in the calculation of the relative benefits results in a larger percentage difference.[17]

[13] The capacity requirement is restated as $V = b_iQ$.

[14] The variable $V_{i,t}$ in the demand function (7) is exchanged for the (restated) capacity requirement (b_iQ) and long run car ownership $(c_i \cdot F_{i,t}^{\beta1} \cdot (b_iQ)_{i,t}^{\beta2} \cdot PP_t^{\beta3} \cdot Y_{i,t}^{\beta4})$ is inserted instead of variable $C_{i,t}$. The resulting expression is the solved for Q.

[15] Subscripts *i* and *t* are dropped when unnecessary. Note that the fare variable was left out of the car ownership equation when deriving (14), since it was found not to be statistically significant.

[16] In order to simplify the calculations, the change in consumer surplus is calculated using the rule of the half, i.e.:$\Delta CS = (GC_0 - GC_1)Q_0 + \frac{1}{2}(GC_0 - GC_1)(Q_1 - Q_0)$ If the demand function is not linear, this is an approximation of the change in consumer surplus (e.g. de Rus, 2010).

[17] $Relative\ difference = \frac{B_{Full\ model} - B_{SR\ model}}{B_{SR\ model}}$

If an MCPF of 0.3 (which is used in official CBA for the transport sector in Sweden) is used in the calculation, a difference of 11% can be observed when the change in *GC* does not come from a fare reduction. If the *GC* reduction is achieved by reduced fares, the relative difference is dramatic, however. This huge difference (990%) can be explained by the fact that when there is a fare reduction in combination with the MCPF, the loss in benefits generated from revenues from the original passengers (those who would have travelled even without the change) is so large that it makes the total benefit calculated by the short-run model very small. The relative difference is therefore large.

7. Concluding discussion

It is concluded that public transport service level has an impact on car ownership, as well as vice versa. Therefore, the long-run impact on public transport demand of changes in the transport system (and in exogenous variables such as income) will be different from the short-run impacts, due to the feedback from changes in car ownership. As a consequence of this, the benefits of improving the public transport system will be greater than those calculated from a demand function that does not take this feedback into account. Since this feedback is not usually considered, the willingness to pay for the trips generated by this feedback can be seen as a wider benefit of improving the public transport system. The calculated size of this effect is non-trivial, ranging from 10% to 39% (of the estimated benefits without the feedback) in the most plausible scenarios. It is also worth noticing that if there are distortions in the market for car trips and/or in the market for cars, the additional benefits will be higher (assuming that the price is lower than the marginal cost).

Credit author statement

Johan Holmgren is the sole author of the paper. He had the original idea for the paper, collected the data, conducted the analysis and wrote the paper.

Declaration of competing interest

None.

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