

Congestion charges and labour market imperfections

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Abstract

Standard cost-benefit analyses of transport policy measures will not capture all benefits and losses if there are labour market imperfections. In the case of congestion charges, theoretical analyses have raised concerns that these effects may constitute considerable losses, possibly to the extent to that aggregate welfare is reduced, contrary to conventional wisdom. We investigate this by estimating the effects on labour income of the Stockholm congestion charges, using an estimated relationship between accessibility and income. Results show that effects on labour income are in fact positive. It turns out to be crucial that the model accounts for value-of-time heterogeneity.

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1.0 Introduction

It is a well-established result within transport economics that congestion charges can yield a considerable social surplus in congested road systems. The theoretical argument is obvious: pricing external congestion effects to make user costs better reflect social marginal costs will in general result in a positive social surplus. Moreover, suggested or implemented real-world congestion charging systems have also been shown to result in significant net social surpluses, provided that investment and operations costs are not too high, and provided that practical restrictions of the design of the charges are not too severe.

However, the standard analysis is confined to effects within the transport sector, that is, travel times and travel costs as valued by travellers¹. The standard analysis implicitly assumes that effects in other markets either do not exist or are correctly priced, and thus can be disregarded. But the transport system is closely linked to the labour market, which is subject to several market imperfections, for example distortive taxation, scale economies, agglomeration benefits and imperfect competition, all of which may create costs and benefits which are external to the worker. In an influential paper, Parry and Bento (Parry and Bento, 2001) showed that the increase in generalized travel costs due to congestion charges may cause losses due to reduced labour supply at the extensive margin which are large enough to cancel out the transport-related benefits. This discussion has continued in a stream of literature (De Borger, 2009; Parry and Bento, 2002; Pilegaard and Fosgerau, 2008; Van Dender, 2003). Arnott (2007) makes a similar point related to agglomeration benefits rather than distortive taxation.

¹ In addition, environmental benefits such as reduced emissions and noise are often included. These are almost always positive, though, so it does not change the line of reason here.

In the Parry and Bento model, the effect of congestion charges on aggregate labour income is always negative because of two key assumptions: the congestion charges increase the generalized travel costs for all travellers, and labour supply only changes at the extensive margin. But once any of these assumptions are relaxed, it is easy to construct a model where the sign of the labour income effect is indeterminate (Gutiérrez-i-Puigarnau and van Ommeren, 2009). First, generalized travel costs may in fact decrease for some groups of travellers, either because of high values of time or because of network effects such as reduction of spillback congestion (in other words, congestion reduction may spill back on links adjacent to the tolled ones)². Heterogeneity in the value of travel time may be caused by differences in wage or travel purpose. Typically, the benefits associated with high-value-of-time trips can be expected to be larger, since the wage gradient with respect to commuting radius tends to be higher for high-income workers. Second, as to how labour supply adjusts, even if generalized travel costs increase and hence decrease labour participation and labour market matching, the decreased travel times for those still commuting by car may lead to the number of working hours going up. Summarizing, not just the magnitude but also the sign of the labour income effects is indeterminate from a theoretical point of view. Determining the sign and size of the effects is hence an empirical question, and the outcome is likely to be different depending on the specific economic and geographic circumstances.

² A third mechanism is the dynamics of congestion and departure time choice. Whereas in a static analysis of congestion pricing with homogenous travelers, all travelers will perceive an increase in generalized travel costs, this is not true in a dynamic “bottleneck” model. In the analysis of the bottleneck model, which takes queue buildup and dissipation into account and drivers react by changing departure times, the conclusion is that all users will be equally well off as before under optimal time-dependent congestion pricing, even before revenues are taken into account (Arnott et al., 1994, 1993). Real cases are a combination of the two analyses, but empirical evidence suggests that shifting departure times is actually a minor response mechanisms.

Since the sign of labour income effects is indeterminate from a theoretical point of view, one needs to study a specific case to reach any conclusion. In this study, we apply the model to the Stockholm congestion charging system³. This also enables us to calibrate traveller responses and travel time savings against observed data. The approach in the paper can be outlined as follows:

1. Calculate values of time for all “individuals” in a synthetic sample, by using the results from the Swedish value-of-time study (Börjesson et al., 2012b; Börjesson and Eliasson, 2014) which relates value of time to socioeconomic characteristics. The synthetic sample is made up of individuals grouped into segments based on location and socioeconomic characteristics, and is hence a kind of “quasi-disaggregate” data.
2. Estimate a relationship between accessibility and labour income for the synthetic sample, and let this relationship be different depending on the value of time (calculated in the step 1). Taking heterogeneity in the value of time into account is crucial for two reasons. First, in the subsequent step, the congestion charges will either increase or decrease generalized travel cost depending on the value of time. Second, the effect of accessibility on income turns out to be larger for groups with high values of time. To reduce endogeneity and confounding problems, we use a first-difference approach where changes in income are related to changes in workplace accessibility. Accessibility measures are taken from a large-scale transport model estimated on travel survey data. This means that changes in

³ Eliasson (2009a) presents a cost-benefit analysis of the congestion charging system. That study concludes that the system creates a social surplus, but also points out that labour market effects are not included. In that sense, the present study can be viewed as a complement to the CBA in Eliasson (2009a).

the transport system will be properly captured by the accessibility measure, and also ensures a high degree of behavioural realism.

3. Calculate the changes in travel times and travel costs due to the introduction of the congestion charges between each pair of zones in the Stockholm region. This is done by combining a traffic network model with empirical traffic measurements. The use of empirical measurements are necessary since standard traffic network models do not take spillback congestion into account, and reductions in spillback congestion represented a large share of overall travel time savings.
4. Use these travel times and travel costs together with the calculated values of time (step 1) to calculate the change in accessibility for each individual in the synthetic sample.
5. Use the estimated relationship between accessibility and labour income (step 2) to calculate the change in labour income (including taxes) for each individual.
6. Add all these changes to see whether total labour income increases or decreases as a consequence of the congestion charges.

Note that we do not know how large share of the total labour income effect in step (6) that should be added to a conventional CBA, since part of the income effect is internal to the worker/commuter and hence already included in the consumer surplus. Still, the size and sign of the income effect will convey sufficiently useful insights to settle the question, as we shall see.

The outline of the paper is as follows. Section 2 provides a brief summary of the relevant literature, and some background information about the Stockholm congestion charges. Section 4 describes the estimated relationship between workplace accessibility and labour income, which is used for calculating the effect on aggregate income of the congestion prices. This

relationship is then applied in section 5, where the effect on labour income of the Stockholm congestion charges is estimated. Section 6 concludes.

2.0 Background and literature

2.1 The Stockholm congestion charging system

The City of Stockholm has around 0.8 million inhabitants, and is the central part of the Stockholm county, with a total of 2 million inhabitants. Around 2/3 of the City inhabitants live within the toll cordon, and the rest outside the cordon. Because of its topology, with lots of water and well-preserved green wedges, road congestion levels in Stockholm are high compared to the city's moderate size. Before the introduction of the congestion charges, the main roads arterials leading to, from and within the city centre had congestion indices typically averaging around 200 per cent (three times the free-flow travel time).

The Stockholm congestion charging system consists of a toll cordon around the inner city (Figure 1), thereby reducing traffic through the main bottlenecks located at the arterials leading into the inner city. The cost of passing the cordon between 6.30 and 18.30 weekdays is 20 SEK (approx. 2€) during peak hours (7:30–8:30, 16:30–18:00), 15 SEK during the shoulders of the peaks (30 min before and after the peak periods) and 10 SEK during the rest of the charged period. The charges were introduced in January 2006, and have reduced traffic across the cordon by around 20 per cent during charged hours, resulting in substantial congestion reductions. Around half of the disappearing car trips changed to public transport, while the other half was made up by changes in destinations, trip frequencies etc (Eliasson, 2008). Changes in departure times only made up a minor contribution to the overall decrease in traffic and congestion (Karlström and Franklin, 2009). The effects have stayed remarkably

stable, actually increasing somewhat over time when controlling for inflation and growth in population and car ownership (Börjesson et al., 2012a).

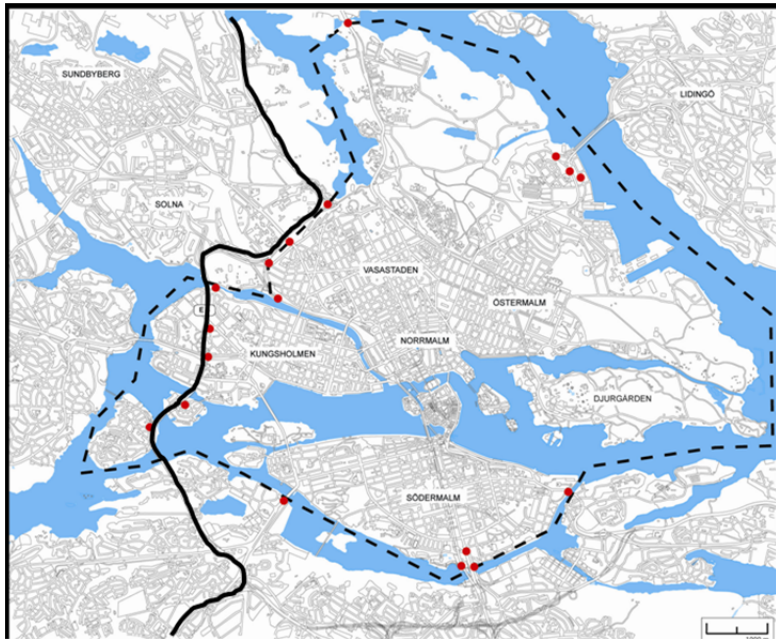


Figure 1. The Stockholm congestion charging system. The dashed line is the charging cordon, the dots are charging points and the solid line is the non-charged Essinge bypass.

Eliasson (2009a) provides a cost-benefit analysis of the charges based on measurements of traffic flows and travel times, calculating the value of travel time benefits to around 60 M€ per year. This can be compared to gross revenues of around 80 M€ per year. Revenues are earmarked mainly for a major bypass west of central Stockholm. The benefit-cost ratio of the bypass is fairly high (well above 1), so a combined analysis of the congestion charges and the bypass (that is, taking revenue recycling into account) increases the total net benefits further. Travel time benefits were calculated to be split in approximately equal shares between commuting trips, leisure trips, business trips and freight transport (the two latter categories are smaller in terms of traffic volumes but have higher values of time). The calculations were based on a uniform value of time for each traffic category, and are hence likely to underestimate the true benefits. The CBA uses a standard transport appraisal framework, and hence explicitly excludes “wider economic benefits” (or losses) in the form of labour market

effects apart from what is captured by work trip consumer surplus. The present study hence complements the standard CBA in Eliasson (2009a).

The congestion charges were accompanied by an increase in public transport capacity, to alleviate an anticipated increase in public transport crowding. The increased public transport was introduced half a year before the charges, making it possible to separate the effects from those of the congestion charges. In itself, the effect on travel behaviour (for example mode choice) of the public transport improvement was very small, especially compared to the large effects from the charges (Eliasson et al., 2009), but it is likely that it contributed to the fact that public transport crowding only increased marginally (Eliasson, 2009a; Kottenhoff and Brundell Freij, 2009).

The system, its history and its effects have been described in detail elsewhere. A description of the system and its effects can be found in Eliasson et al. (2009), and experiences from the design and evaluation processes are described in Eliasson (2009b). Eliasson (2008) summarises the main lessons in terms of design, effects, acceptability and political process. A detailed account of the political process can be found in Gullberg and Isaksson (2009).

2.2 Agglomeration benefits, tax distortions and transport CBA

One of the cornerstones of the “new economic geography” is the link between accessibility and productivity. There are several theoretical reasons why productivity is expected to increase with accessibility, often summarized in the catchphrase “sharing, matching and learning” (Duranton and Puga, 2004). The relation between accessibility and productivity is also well established empirically (Rosenthal and Strange, 2004).

Several studies have shown a connection between productivity and various measures of the spatial density of economic activity, for example Ciccone and Hall (1996), Combes et al. (2008) and Groot et al. (2011). In economic geography the effects of market accessibility on wages have been studied on a larger spatial scale by for example Redding and Venables (2004) and Hering and Poncet (2010). If the results are to be used as a complement to standard transport appraisal, however, the accessibility measure needs to be sensitive to changes in the transport system, which density measures typically are not. Studies using various measures of accessibility to labour include Kaliski et al. (2000), Graham (2009, 2007a, 2007b) and Graham and Kim (2008).

Hence, the existence of agglomeration benefits is well established. But agglomeration benefits are only partially captured by standard transport appraisal. To quote Graham and van Dender (2011): “Such benefits are in theory additional to those captured in a standard CBA because they are sourced from increasing returns that are external to the firm and thus would not feature in the willingness-to-pay approach that underpins calculations of consumer surplus.” In other words, since agglomeration benefits are external to the worker/traveller, they are not captured by the consumer surplus, and hence not by standard CBA.

Agglomeration benefits are not the only external benefits of work-related choices. Distortive taxation means that the worker will only perceive part of an increase in wages. Hence, such benefits are also only partially captured by the consumer surplus used in CBA, as pointed out already by Forsyth (1980). Venables (2007) stress that when there is both distortive taxation and agglomeration benefits, the external share of benefits will increase. Calthrop et al. (2010) show that failure to account for distortions such as agglomeration effects and tax distortions

may cause severe errors in cost-benefit analyses of transport improvements. So far, few countries have included “wider economic benefits” in their standard CBA guidelines. One exception is the UK CBA guidelines. The methodology and a number of case studies are summarized in Jenkins et al. (2011).

2.3 Congestion pricing, labour market distortions and heterogeneity in the value of time

Parry and Bento (2002, 2001) argue that a congestion charge will affect labour supply negatively at the extensive margin, since generalized travel costs increase. In the Parry-Bento model, it is the income tax wedge that is the root of the problem, but such problems may also be caused or exacerbated by the presence of (external) agglomeration effects (Arnott, 2007).

This is actually the other side of the coin of the “wider economic impacts” issue – that there are benefits in the labour market that are not captured by the standard transport appraisal framework if there is distortive taxation or agglomeration effects. In the case of congestion charges, the “wider economic impacts” may in fact be losses, since generalized travel costs usually increase by congestion charges.

The simulations in Parry and Bento (2001) rest on the assumption that an increase in travel costs caused by congestion charges will have similar effects on labour supply as an increase of income taxes. A general finding in labour economics is that income tax changes have the greatest impact on labour supply at the extensive margin, rather than at the intensive margin or through matching effects (Kleven and Kreiner, 2006). However, it is not obvious that introducing congestion charges affects labour supply in the same way as an increased income tax. In our view, it seems unlikely that a charge on car drivers in urban cores during rush hours would lead to an appreciable fraction of this population segment choosing to leave the

labour force (adjust at the extensive margin), especially in European conditions where typically a large majority of the low-skilled workers use other modes than car for commuting trips to central areas during rush hours. Effects on matching (or “destination choice” in transport model terminology) and working hours seem to be more plausible adaptations.

If travellers have heterogeneous values of time, then the standard analysis of congestion charges will typically underestimate the benefits of the policy. This was pointed out already by Vickrey (1969), but at the time, the understanding of value-of-time heterogeneity was limited, and few attempts were made to analyse what this meant for the quantitative results. Verhoef and Small (2004) give a detailed analysis of the issue. Proper estimation of value-of-time distributions, together with socioeconomic explanatory variables, have been made possible only recently (Börjesson et al., 2012b; Börjesson and Eliasson, 2014; Fosgerau, 2007, 2006). In this paper, we use the results from the Swedish Value of Time study to calculate the values of time of different socioeconomic groups.

3.0 Modeling the relationship between income and accessibility

As described in the introduction, a relationship between labour income and accessibility is needed (step 2 in the outlined approach). This section is describe the estimation of such a relationship.

There are several mechanisms that may contribute to the commonly observed positive relationship between accessibility and wages. Better accessibility can improve matching between firms and workers, increasing average productivity of workers since they can find jobs where their specific competences contribute more. There may be spillovers between workers and/or firms of several different kinds, such as knowledge spillovers or technical

spillovers, again increasing average worker productivity. There may be economies of scale of various kinds, for example through the possibility to share common resources among firms or increasing returns to scale in production.

All of these mechanisms may cause productivity and hence wages to increase with accessibility⁴. For the purposes of this paper, it is enough to estimate a reduced-form relationship between accessibility and labour income, where accessibility is measured in a way that explicitly takes travel times and travel costs into account. The relationship has the following features:

- It is estimated in terms of first differences, that is, variables are formulated as changes from one time period to another, reducing the endogeneity problems that riddle cross-sectional studies of accessibility/income relationships. To further reduce endogeneity problems and isolate the impact of changes in the transport system, the change in accessibility is decomposed into one part capturing the change in employment in each zone, and one part capturing the change in generalized travel costs. It is the latter part that is used to model the impact of the congestion charges.
- It is estimated on “quasi-disaggregate” data. The entire population is divided into segments based on location and socioeconomic characteristics, and the average labour income is calculated for each such segment. One such segment then constitutes one observation.

⁴ Note that some of these benefits will be captured by the conventional consumer surplus for commuters, while some of them will be external to the commuter and hence fall outside conventional transport CBA. Hence, the entire labour income effect cannot be added to conventional CBA.

- It is based on accessibility measures from a transport model, rather than density or size measures. If we want to capture the increase in accessibility due to a transport investment, the measure needs to be sensitive to changes in the transport system, which size or density measures typically are not. An advantage is also that the accessibility measures are based on actual commuting behaviour and actual, perceived generalized costs. Finally, the accessibility measure is an aggregation across all modes based on actual mode shares.
- Generalized travel costs account for heterogeneity in the value of travel time. This turns out to be crucial for results. A traveller with a high value of time will perceive that his generalized travel cost is reduced by congestion charges, and vice versa. Ignoring this heterogeneity would mean that one of the foremost benefits of congestion charges is ignored – that it “sorts” trips into high-value and low-value trips, and reduces the latter while prioritizing the former.
- The income/accessibility relationship is different for different value-of-time segments. This also turns out to be important. Segments with higher value of time (which is correlated with higher income, although this is not the only factor) turn out to have much larger income/accessibility elasticity than segments with low values of time. This is natural, considering that the former segments are typically higher educated and more specialized, and hence typically experience a steeper wage gradient when accepting a longer commuting radius.

3.1 Model specification

The entire working population in the study area (4 million workers in Sweden, 1.8 million in the Mälaren Valley) is divided into segments, where each segment is a combination of age (7 categories), gender (2), ethnic origin (3), educational level (4) and residential municipality

(290 for Sweden, 86 for the Mälaren Valley). The average income⁵ for each segment is observed for the years 1993 and 2002. This is regressed on initial accessibility (year 1985) and changes in accessibility, one part due to changes in the transport system (1985-1997) and one part due to changes in employment per zone (1993-2002). The choice of years is mainly a matter of data availability: in particular, getting detailed data on historical transport systems is a major effort⁶.

Let E_s^0 be the number of workplaces in municipality s at time 0 (1985). c_{rs}^0 is the generalized travel cost between municipality r and s at time 0 (described below), and ρ is a sensitivity parameter estimated in the transport model (see below). Workplace accessibility of municipality r at time 0 is then defined as

$$A_r^0 = \sum_s E_s^0 \exp(\rho c_{rs}^0)$$

The accessibility change due to changes in generalized travel costs is based on the travel cost change 1985-1997, using employment data from 1993. The change in accessibility due to changes in generalized travel costs is defined as

$$\Delta_c A_r = \frac{\sum_s E_s^1 \exp(\rho c_{rs}^2)}{\sum_s E_s^1 \exp(\rho c_{rs}^0)}$$

⁵ “Income” means wage before taxes, excluding wage overhead costs.

⁶ We have also tested using income and employment data for the years 1985 and 1997 – the same years as travel costs – with generally similar results.

c_{rs}^0 and c_{rs}^2 are generalized costs in the years 1985 and 1997. E_s^1 is the employment in municipality s in 1993.

The accessibility change due to employment changes is based on the employment change 1993-2002, using generalized travel costs from 1985. The change in workplace accessibility due to changes in employment per zone is defined as

$$\Delta_E A_r = \frac{\sum_s E_s^3 \exp(\rho c_{rs}^0)}{\sum_s E_s^1 \exp(\rho c_{rs}^0)}$$

E_s^1 is the number of workplaces in municipality s in the year 1993, while E_s^3 is the corresponding number in the year 2002.

With these variables, we can estimate a model for average income y_{nr}^3 of segment n and zone r at time 3 (2002). Note that the income at time 1 (1993) is also included.

$$\begin{aligned} \log(y_{nr}^3) = & \alpha + \beta_1 \log(y_{nr}^1) + \beta_2 \delta_n^{age} + \beta_3 \delta_n^{gender} + \beta_4 \delta_n^{ethnic} + \beta_5 \delta_n^{edu} + \beta_6 \log(A_{nr}^0) \\ & + \beta_7 \log(\Delta_c A_r) + \beta_8 \log(\Delta_E A_r) + \epsilon \end{aligned}$$

The δ :s are vectors of dummy variables, and β_2 - β_5 are the corresponding parameter vectors. Later on, we will differentiate the accessibility variables by value of time.

Above, we used generalized travel costs between municipalities. But the transport model works with traffic zones, which are much smaller: typical sizes are in the order of 0.1-1 km²

in built-up areas. Let c_{ijm} be generalized travel cost between traffic zones i and j with mode m , where

$$c_{ijm} = b_{ijm} + \theta t_{ijm}$$

b_{ijm} is the monetary travel cost, θ the value of time, and t_{ijm} is the generalized travel time (where waiting times and access times are weighted differently than in-vehicle time). Relative time weights are taken from the traffic model *LuTrans*. *LuTrans* is a large-scale transport model, a version of the national transport model *SAMPERS* (Algers and Beser, 2001), downscaled in certain respects (primarily in the number of socioeconomic groups).

Generalized costs depend on the value time in two ways. Obviously, the value of time enters the definition. But car travel costs and travel times in fact also depend on the value of time, especially when road pricing is introduced, since the route choice will be different depending on the value of time: drivers with low value of time will be more willing to take detours to avoid tolls. To account for this, segments are grouped into three equally sized categories according to their value of time. The value of time for each category is taken to be the median value of the lower, middle and upper third of the lognormal value-of-time distribution estimated in the national Value of Time study (Börjesson and Eliasson, 2014). For each origin zone, the share of the population belonging to each value of time category is calculated, based on income, the number of children and whether the zone is in Stockholm county. Separate travel cost and travel time matrices are then calculated for each category, by running the *LuTrans* model using the three value-of-time categories in the network assignment step.

To calculate the generalized travel cost between municipalities r and s , generalized travel costs between traffic zones are weighted with traveling flows T_{ijm} . These are taken from the traffic model *LuTrans*.

$$c_{rs} = \frac{\sum_{i \in r} \sum_{j \in s} \sum_m T_{ijm} c_{ijm}}{\sum_{i \in r} \sum_{j \in s} \sum_m T_{ijm}}$$

The notation $i \in r$ means that summation is taken over all traffic zones i belonging to municipality r .

3.2 Estimation results

Estimation results are reported in Table 1. All models are estimated using OLS. Model [1] is estimated on all of Sweden, without accounting for heterogeneity in the value of time. The estimated elasticity of labour income with respect to initial accessibility ($\log A_r^0$), is 0.044⁷, while the estimate for the change in accessibility due to changes in the transport system ($\log \Delta_c A_r$) is slightly lower, 0.03. The estimate for the change in accessibility due to changes in zonal employment has no significant effect. These elasticities are in the expected range; for example, Graham and van Dender (2011) state that studies relating productivity to city size have typically yielded elasticities in the range 0.02-0.10; Venables (2007) give a similar range of 0.04-0.11. But as Graham and van Dender (2011) point out, such aggregate elasticities are likely to be subject to confounding and endogeneity effects. The estimation results presented here attempts to control for these effects at least to some extent by controlling for initial accessibility and the change in the number of workplaces. The estimated effect on final

⁷ This is about the same size as a related estimate for UK, reported in Venables (2007).

income from initial accessibility can be interpreted as capturing the effect that high-income workplaces and people tend to move to high-accessibility locations. Not controlling for this would then be a source of endogeneity bias.

Some of the estimation results indicate that there is unexplained heterogeneity. In particular, the influence of initial income is conspicuously low: one would expect a strong correlation between initial income and income in the next time period. The socioeconomic variables show expected results: income increases faster for middle-age, male, high-education and native-Sweden segments.

Model [2] is estimated only on municipalities in the Mälaren Valley Region, which includes the Greater Stockholm region. While all parameters for individual (segment) characteristics are very similar to [1], it can be noticed that larger effects are indicated with respect to general accessibility and a transport-induced change in accessibility. This outcome is expected, as this region includes the largest labour market region in Sweden, with better opportunities for matching in the labour market than in other regions. This result also implies that it can be questioned whether the elasticities are constant over the sample.

Model [3] is also estimated on Mälaren Valley only, but the generalized costs in the accessibility variables have been adjusted. Instead of using a single value of travel time taken from the transport model (as in [1] and [2]), the value of time is different across segments. Segments are grouped into three value-of-time categories as explained above, so the generalized travel cost will be different for each segment. As a result the elasticity increases from 0.044 to 0.053, while the standard error is unchanged. This suggests that taking differences in the value of travel time into account makes the generalized travel cost variable

more precise. However, this makes the assumption of constant elasticities across the sample even more questionable.

Models [4a]-[4c] are separate models for each value-of-time category. Due to collinearity a number of dummy variables for segment characteristics have been omitted in these equations. The estimates indicate that the elasticity with respect to initial accessibility A_r^0 and with respect to transport-induced accessibility change $\Delta_c A_r$ increases considerably with the value of time. This confirms the expectation that workers with high income and higher education tend to have better opportunities to benefit from the variety and specialization offered by a larger labour market. Moreover, the correlation between initial income and final income is now much higher, also indicating a better model fit.

Table 1 **Estimated income equations for workers in Sweden and Mälaren Valley. Dependent variable:**
log(income) in 2002.

<i>Model specification</i>	[1]	[2]	[3]	[4a]	[4b]	[4c]
<i>Geographical region</i>	Sweden	Mälaren Valley	Mälaren Valley	Mälaren Valley	Mälaren Valley	Mälaren Valley
<i>VoT Segment</i>	All	All	All	Low VoT	Medium VoT	High VoT
Log Income 1993	0.282 (0.013)	0.328 (0.025)	0.324 (0.025)	0.671 (0.021)	0.823 (0.034)	0.947 (0.027)
Male	0.250 (0.005)	0.237 (0.009)	0.237 (0.009)	0.163 (0.015)	0.063 (0.006)	0.030 (0.008)
Age 21-30	0.520 (0.016)	0.480 (0.031)	0.484 (0.031)	0.028 (0.014)	-0.009 (0.010)	-0.013 (0.018)
Age 31-40	0.686 (0.018)	0.661 (0.035)	0.665 (0.035)	0.120 (0.015)	0.040 (0.009)	0.145 (0.015)
Age 41-50	0.775 (0.019)	0.745 (0.037)	0.749 (0.037)	0.209 (0.016)	0.085 (0.009)	0.158 (0.015)
Age 51-60	0.792 (0.019)	0.750 (0.037)	0.753 (0.037)	0.231 (0.015)	0.120 (0.010)	0.151 (0.015)
Age 61-70	0.596 (0.017)	0.562 (0.034)	0.566 (0.034)			

Age 71+	0.257 (0.017)	0.223 (0.027)	0.224 (0.026)			
Secondary education	0.120 (0.004)	0.107 (0.006)	0.107 (0.006)			
Tertiary education < 3 years	0.128 (0.004)	0.121 (0.007)	0.121 (0.007)			
Tertiary education ≥ 3 years	0.273 (0.006)	0.272 (0.012)	0.272 (0.011)			
Native Sweden	0.130 (0.004)	0.148 (0.006)	0.149 (0.006)	0.030 (0.010)	0.095 (0.008)	0.136 (0.010)
Native other Nordic	0.120 (0.005)	0.131 (0.007)	0.131 (0.007)	0.051 (0.012)	0.070 (0.009)	0.121 (0.014)
Log A_r^0	0.044 (0.001)	0.051 (0.002)	0.052 (0.002)	0.019 (0.005)	0.024 (0.003)	0.037 (0.003)
Log $\Delta E A_r$	-0.006 (0.024)	-0.110 (0.054)	-0.104 (0.054)	0.080 (0.136)	0.001 (0.070)	-0.036 (0.088)
Log $\Delta_c A_r$	0.030 (0.004)	0.044 (0.006)	0.053 (0.006)	0.025 (0.016)	0.029 (0.008)	0.062 (0.011)
Constant	4.108 (0.073)	3.730 (0.134)	3.749 (0.133)	2.239 (0.160)	1.159 (0.246)	-0.015 (0.200)
R^2	0.904	0.909	0.910	0.758	0.475	0.713
Number of observations	14817	5232	5232	1744	1744	1744

Note: Standard errors (White heteroskedasticity-consistent) are reported under parameters in parenthesis; estimates in **bold** are significant at the 95%-level; omitted categories for dummy variables are Female, Age<21, Primary education, and non-Nordic native country.

4.0 Results

We are now ready to calculate the effects on aggregate labour income of the introduction of the congestion charges. The calculation proceeds in a number of steps outlined in the introduction.

First, values of time for all “individuals” in the synthetic sample are calculated. Values of time depend on a number of socioeconomic characteristics. Figure 2 illustrates the variation of the value of time – the colours show the share of the population in each zone belonging to the “high” value of time category.

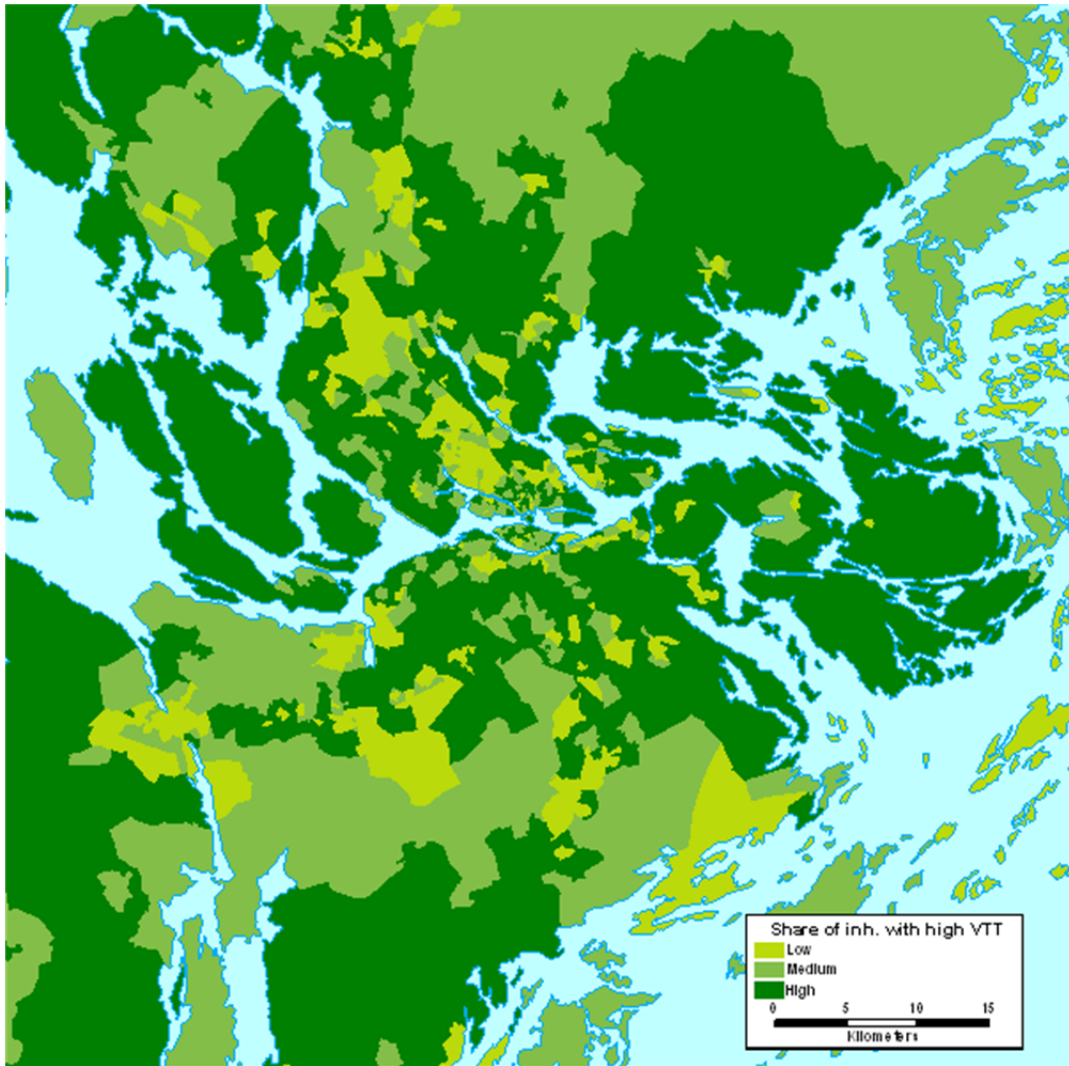


Figure 2. A map of value-of-time variation: share of inhabitants belonging to the “high” value-of-time category. The inner city of Stockholm is situated in the middle of the map.

Second, accessibility with and without the congestion charges is calculated for each residential zone using a combination of travel time measurements and the transport model *LuTrans*. The accessibility measures will also depend on the value of time, and will hence be different across individuals, even in the same residential zone. The changes in travel times due to the charges are calibrated against travel time measurements from the situations before and after the congestion charges (spring 2005 compared to spring 2006), and then a network model is used to extrapolate to un-measured links. The role of *LuTrans* is essentially to

extrapolate the full origin-destination trip matrix from travel survey observations (which is a limited sample). This trip matrix is only needed for the weights T_{ijm} in the accessibility measures. These procedures ensure that the accessibility measures real travel times and travel patterns as closely as possible, and consistent with observed data.

Third, the estimated relationship between accessibility and labour income (from models [4]-[6]) is used to calculate the change in gross labour income for each individual. Results are presented in Table 2, broken down per municipality and value of time category.

Table 2 The congestion tax system in Stockholm: Estimated effects on wage sum in 2005.

Municipality	VTT category, share of workers in municipality			Effect on wage sum by VTT category					
	Low	Medium	High	Low		Medium		High	
				Total	Per capita	Total	Per capita	Total	Per capita
				MSEK	1000 SEK	MSEK	1000 SEK	MSEK	1000 SEK
Danderyd	0.275	0.336	0.388	-3.3	-0.9	-3.6	-0.8	39.0	7.5
Stockholm	0.274	0.340	0.386	-14.7	-0.1	-31.3	-0.2	481.1	3.3
Nacka	0.292	0.338	0.370	-7.6	-0.7	-12.5	-0.9	42.5	2.9
Lidingö	0.299	0.339	0.362	-2.5	-0.4	-0.4	-0.1	18.0	2.6
Täby	0.283	0.334	0.384	-3.7	-0.4	-0.6	-0.1	24.5	2.2
Sollentuna	0.280	0.339	0.381	-0.9	-0.1	-0.8	-0.1	20.5	1.9
Järfälla	0.312	0.341	0.347	-0.7	-0.1	2.3	0.2	18.3	1.8
Solna	0.378	0.342	0.280	-7.2	-0.6	-12.2	-1.2	14.4	1.7
Sundbyberg	0.366	0.344	0.290	-2.3	-0.4	-4.2	-0.7	8.0	1.6
Huddinge	0.300	0.340	0.360	-1.3	-0.1	-2.0	-0.1	22.6	1.5
Upplands Väsby	0.314	0.343	0.344	-0.9	-0.2	-0.5	-0.1	7.2	1.1
Tyresö	0.283	0.340	0.376	-1.6	-0.3	-2.7	-0.4	7.3	1.0
Ekerö	0.256	0.340	0.404	-0.8	-0.3	-0.1	0.0	4.2	0.9
Värmdö	0.267	0.339	0.394	-1.4	-0.3	-1.4	-0.2	5.6	0.8
Vaxholm	0.273	0.339	0.388	-0.1	-0.1	0.4	0.2	1.5	0.7
Upplands-Bro	0.314	0.345	0.341	-0.2	-0.1	0.7	0.2	2.4	0.7
Botkyrka	0.327	0.342	0.331	-1.5	-0.1	-0.7	-0.1	7.1	0.6
Vallentuna	0.278	0.341	0.381	-0.3	-0.1	0.8	0.2	3.3	0.6
Österåker	0.272	0.338	0.391	-0.1	0.0	1.2	0.2	3.9	0.5
Haninge	0.313	0.343	0.344	-2.2	-0.2	-2.9	-0.2	5.0	0.4
Salem	0.280	0.341	0.379	-0.2	-0.1	-0.1	0.0	1.0	0.4
Sigtuna	0.314	0.344	0.343	-0.2	0.0	0.9	0.1	1.5	0.2
Norrtälje	0.331	0.345	0.324	0.2	0.0	0.1	0.0	1.4	0.2
Södertälje	0.339	0.343	0.318	-0.3	0.0	0.4	0.0	1.3	0.1
Nynäshamn	0.322	0.345	0.334	-0.1	0.0	0.0	0.0	0.4	0.1
Nykvarn	0.272	0.344	0.384	0.0	0.0	0.2	0.1	0.1	0.1
Total	0.294	0.340	0.366	-54.0		-69.0		741.9	

The main conclusion is that the aggregate effect on labour income is in fact positive, totalling 62 M€/year⁸. This is far from obvious, and it is impossible to know whether this should be expected to be a general result. The aggregate change in accessibility may be either positive or negative. For high values of time, the decreased travel time is worth more than the increased travel cost, and vice versa for low values of time. The sign of the accessibility change also varies with location. For several municipalities, accessibility increases even for the middle value of time category. One reason for this is network effects: when traffic decreases all over the county, even many travellers that do not pay the charge benefit from reduced congestion.

As the model estimations showed, changes in accessibility affect labour income more for high-income groups than for low-income groups. This is intuitively plausible, since high values of time are correlated with high income and high education, and such groups generally get higher wage premiums for increasing work trip length. Hence, one may have positive effects on labour income even if aggregate accessibility decreases. Obviously, these effects do not happen at once: the calculation results are indicative of what can be expected in the long run (such as the ten-year period the estimation results are based on).

Note that the entire effect on aggregate labour income cannot be added to the standard CBA, since it is already partly captured by the consumer surplus in the CBA. The actual size of the

⁸ This includes the negative effect on the “low” value-of-time category, which is based on an insignificant parameters estimate. Excluding this effect would increase the total effect and hence strengthen the general conclusion. Using the confidence intervals of the central parameters (the parameters for $\Delta_c A_r$ in Table 1) yields a 95% confidence interval for the aggregate income effect of 47 – 77 M€.

overlap between the labour income effect and the consumer surplus is very difficult to assess, since it depends on how much of the income effect that comes from increases in working hours and wage rates for commuters (which are included in the consumer surplus) and how much comes from external agglomeration effects and increases in net tax revenues (which are not). However, for the purposes of this paper, it is enough to conclude that the labour income effect is positive.

A detailed comparison between a conventional CBA and the income effects here is difficult to make, since they differ in terms of values of time and definitions of accessibility. But we can make an illustrative comparison by using that the accessibility measures are approximately consumer surplus measures (logsums), and by converting them to monetary terms their magnitude can be compared to the consumer surplus in the conventional CBA. The accessibility benefit from the conventional CBA (the conventional consumer surplus) is approximately -8 M€/year (Eliasson, 2009a). This consumer surplus calculation assumes that all commuters have the same value of time. If labour market effects are calculated using the same assumption that all workers have the same value of time, we get model [2] in Table 1. Using this model together with the homogeneous-value-of-time accessibility measures gives an aggregate labour income effect of -17 M€ - around twice the conventional consumer surplus⁹.

⁹ The overlap between these two numbers cannot be determined, because it depends on how much of the labour income effect accrues to the commuter. If all income benefits accrue to the commuter, and the marginal tax rate is around 50% (which is around the Swedish average), then these two numbers would imply that all the accessibility benefits are converted into higher income, either through working more hours or commuting longer for a higher wage, and roughly half of this effect accrues to the commuters (and hence shows up as a consumer surplus) and half of it shows up as increased tax revenues.

Accounting for heterogeneity in values of time, however, makes a big difference both for the consumer surplus and the income effect. Dividing commuters into three value of time segments gives the respective consumer surpluses of approximately -6 M€/year (low VoT), -3 M€/year (medium VoT) and 9 M€/year (high VoT), which sums to roughly zero in consumer surplus, compared to -8 M€/year using a single VoT. The corresponding income effects become (see Table 2) -5 M€/year (low VoT), -7 M€/year (medium VoT) and 74 M€/year (high VoT), summing to 62 M€/year.

Even if these numbers are approximate, we can evidently conclude that only including consumer surplus may omit major benefits (or losses) from the CBA, and that accounting for heterogeneity in value of time can completely change the analysis, both in terms of consumer surplus and in terms of income effects.

4.1 A comparison with a fuel tax increase

It is illuminating to compare the effects of the congestion charging system with the effects of a fuel tax, designed to give the same tax revenues. In contrast to the congestion charges, this does not give any appreciable travel time savings, so accessibility decreases for all groups. Consequently, the fuel tax has quite different consequences for labour income.

The size of the decrease varies between municipalities and between value-of-time categories in the same municipality. This variation can mainly be explained by the variation in the car modal share, which is linked to variations in land use pattern and supply of public transport.

While the congestion tax was estimated to increase labour income with over 60 M€/year, the fuel tax is estimated to decrease labour income with nearly 95 M€/year. On average, the

estimated effect of the fuel tax is a reduction of wage sum by around 0.4 per cent in each VTT category. However, there is a considerable variation between municipalities; the decrease in labour income is estimated to vary between 0.1 per cent and 1.1 per cent.

5.0 Conclusions

In the standard theoretical model, it is clear that congestion charges will generate a social surplus. As shown in several studies (for example Eliasson (2009a)), this will often also hold in the real world, even when technical costs have to be covered and practical considerations put restrictions on the design of the charges.

However, in an economy with labour market imperfections such as distortive taxation and agglomeration benefits, the “wider economic” effects of congestion charges not captured by standard transport CBA may be negative. As shown by for example Parry and Bento (2001), these negative effects may be so large that they cancel the positive social surplus on the transport market. But the real effects of congestion charges are complex and the mechanisms work in different directions. Increased travel costs may reduce matching and labour participation, but reduced travel times work in the opposite direction, and may also increase working hours. Different groups have different values of time, so the sign of the change in generalized travel costs may be different for different groups. Different groups have different wage premiums with respect to commuting radius, and hence different relationships between accessibility and income. This means that the sign of labour market effects is an empirical question, likely to be different between different economic and geographical conditions.

In this paper, we have assessed this by estimating a relationship between accessibility and labour income. The relationship takes differences in values of travel time into account, and

also that the income/accessibility elasticity may be different for different groups. The estimation shows that categories with high value of time have a considerably stronger relationship between accessibility and income than low value-of-time groups. Accessibility measures are constructed using output and parameters from a large-scale transport model, making them consistent with observed travel behaviour.

Applying the estimated relationship to the Stockholm congestion charges, we concluded that the labour market effects were in fact positive, amounting to around 60 M€/year. This can be compared with gross revenues, which are around 80 M€/year, the net consumer surplus, which is around -28 M€/year, and the net social benefit (net of investment costs) of a standard CBA, which is around 65 M€/year (all figures are taken from (Eliasson, 2009a)). Hence, in this case, labour market effects do not cancel the social surplus from transport effects; in fact, they add significantly to it¹⁰.

Obviously, the size of the effect on labour income should be regarded with caution for several reasons. First, the effect is a composite measure of more hours worked and higher wages due to matching, but we cannot assess the relative weight of each component. Second, and in particular, estimations of income/accessibility relationships tend to be riddled with confounding and endogeneity bias. Results do suggest, however, that the aggregate income effect from the Stockholm congestion charges are positive and of a considerable magnitude.

¹⁰ Note, though, that the whole labour income effect cannot be added to the transport CBA – part of it is captured by the work trip travel time benefits in the CBA, which accounts for around a quarter of the total travel time benefits.

6.0 References

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