Cost-benefit analysis of the Stockholm congestion charging system

Jonas Eliasson, Transek AB

Abstract

The Stockholm congestion charging system went live Jan 3rd 2006. The system consists of a cordon around the city center, with a time-varying charge being levied for each crossing in any direction. This paper presents a cost-benefit analysis of the system.

The calculation of the value of social costs and benefits is based on observed, real-world data (rather than model-forecasted data). The most important data sources are

All these data sources are supplemented with existing forecasting tools to calculate the social value of changes in travel times, travel costs etc.

The system is shown to yield a significant social surplus, well enough to cover both investment and operational costs, provided that it is kept for a reasonable lifetime: investment costs are recovered (in terms of social benefit) in about four years.

Introduction

The so-called *Stockholm trial* consisted of two parts: a congestion charging scheme that was in place between 3 Jan and 31 July 2006, and an extension of the public transport supply that was in place between 31 August 2005 and 31 December 2006.

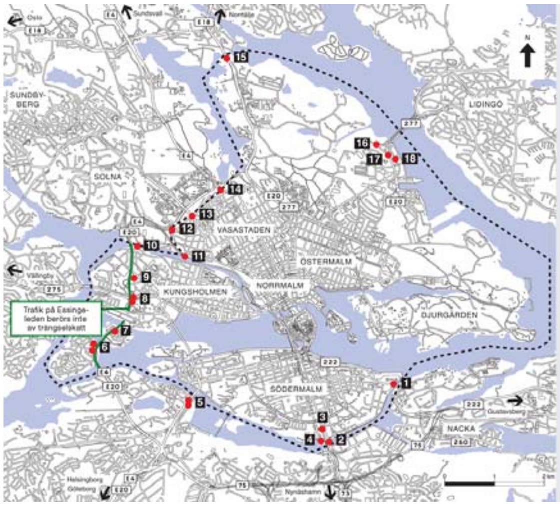
Initially, the trial was meant to consist only of a congestion charging scheme, but for mainly political reasons, it was complemented by the extension of public transit. The congestion charging scheme was originally meant to be a ”full-scale trial for several years”, and was a part of an agreement between the Social Democrats, Lefts and Green on the national level following the election in the autumn of 2002. For various reasons – most importantly legal complaints regarding the technologu procurement process - the period with congestion charges became considerably shorter than was initally planned.

The purpose of this paper is to present a cost-benefit analysis (CBA) for the congestion charging system. In addition to this, we also present a CBA for the extended public transit services, but this analysis is less detailed.

What separates this CBA from most other CBAs for transport investments is that it rests mainly upon *measured data* – that is, not on modeling results. Most of the data stem from extensive traffic measurements during April 2005 and April 2006. The underlying assumption is that the effects that could be seen during the period when the charges were in place would remain also in the future. Obviously, these are only short-term effects, and it can be argued that long-term effects will be higher – and there are also relevant arguments for that long-term effects will be lower. Long-term effects are discussed in section X. In the calculations, we further assume that the changes in traffic between 2005 and 2006 were only due to the introduction of the congestion charges. This assumption is discussed in section X, where we show that even if there are other factors affecting the traffic between the two years, they are likely to be small in comparison.

In section 2, the result of the CBA for the congestion charging system is presented and some interesting results are highlighted. Most of the remainder of the paper simply consists of a description of how the various posts in the CBA have been calculated. After that, a brief CBA for the extended public transit services is presented. We end with a discussion.

The charging system



Time	(SEK) Amount
06.30-06.59	10 kr
07.00-07.29	15 kr
07.30-08.29	20 kr
08.30-08.59	15 kr
09.00-15.29	10 kr
15.30-15.59	15 kr
16.00-17.29	20 kr
17.30-17.59	15 kr
18.00-18.29	10 kr
18.30-06.29	0 kr

There are 18 control points located at Stockholm city entrances and exits. Vehicles are registered automatically by cameras that photograph the number plates. Those vehicles equipped with an electronic onboard unit (transponder) for direct debit payment are also identified through this means.

The cost for passing a control point is SEK 10, 15 or 20 depending on the time of day (see the table). The cost is the same in both directions. The maximum amount payable per vehicle and day is SEK 60. No congestion charge is levied in the evenings or at night nor on Saturdays, Sundays, public holidays or the day before a public holiday. Various exemptions (for e.g. taxis, buses, alternative-fuel cars and for traffic between the island of Lidingö and the rest of the county) mean that about 30% of the passages are free of charge.

There is no opportunity to pay at the control points. More than 60% of the payments are made automatically through transponder/direct debit. The rest are either paid at local shops (7-eleven etc.) or through bank transfers, either direct transfer or using a “virtual shop” on the Internet where you can pay using e.g. a VISA card.

CBA results

The table below shows yearly costs and gains. The effects have been divided into consumer surplus effects, ”other” effects directly affecting the citizens, public costs and revenues and finally marginal cost and shadow price of public funds. Note in particular that the investment cost is not included in the table below; we discuss it further below.

million SEK per year	**Loss/gain**
Shorter travel times	496
More reliable travel times	78
Loss for evicted car drivers, gain for new car drivers	-68
Paid congestion charges	-763
Consumer surplus, total	***-257***
Less greenhouse gas emissions	64
Health and environmental effects	22
Increased traffic safety	125
Other effects, total	***211***
Paid congestion charges	763
Operational costs for charging system (incl. reinvestment and maintenance)	-220
Increased public transit revenues	184
Necessary increase in public transport capacity[1]	-64
Decreased revenues from fuel taxes	-53
Decreased road maintenance costs	1
Public costs and revenues, total	***611***
Marginal cost of public funds, shadow price of public funds	***118***
Total socioeconomic surplus, excl. investment costs	***683***

10 Swedish crown (SEK) is about 1.10 Euros.
Below, we explain each post and how it has been calculated in some detail. Let us just note a few things:

- The table shows that the congestion charges produce a net social benefit of a little less than 700 mSEK/year (around 80 mEuro/year).
- Consumer surplus is negative, as expected, but the value of the time gains is high compared to the paid charges – time gains amount to around 70% of the paid charges, which is very high compared to most theoretical or model-based studies. This is mainly due to ”network effects”, i.e. significant amounts of traffic that do not cross the cordon and hence do not pay any charge still gain from the congestion reduction.
- ”Other” effects – environmental effects and improved traffic safety – is valued to 211 mSEK/year.
- The total public financial surplus is 611 mSEK/year, of which 542 mSEK is net revenues from the charges and 184 mSEK is increased revenues from public transport fares.
- The yearly cost of the system (220 mSEK) includes necessary reinvestments and maintenance such as replacement of cameras and other hardware, and also certain additional costs such as moving charging portals when the building of a northern bypass starts in the summer of 2007.

The yearly socioeconomic surplus of 683 mSEK should then be compared to the investment cost. It is not entirely obvious what the ”investment” cost really is. We will take the ”investment” cost to be the entire start-up cost: in other words, not only the costs

[1] Kostnad för att bibehålla samma genomsnittliga komfort i kollektivtrafiken, trots tillkommande resenärer. Beräknad med Banverkets genomsnittliga kostnadssamband (implementerat i SamKalk).

prior to the start of the system, but also the operating costs during 2006 together with certain other additional minor costs, such as those for traffic signals, and the services of the Swedish Enforcement Agency and the Swedish Tax Agency. This start-up cost also includes, in addition to purely technical investments, system development in a wide sense, educating and training staff, testing, public information, etc. Also included are the Swedish Road Administration's costs for closing down the system and evaluating the results during the second half of 2006. This entire initial cost for the system is budgeted at approximately SEK 1.9 billion (of which SEK 1,050 million was incurred prior to the start of operations). A significant part of the costs prior to the start in early 2006 was extensive testing – the system would only be operational for 7 months, making it absolutely necessary that everything worked right from the start. Not all costs incurred during 2006 were ”running” costs: the system was improved in several ways during the spring of 2006. Actual running costs decreased significantly by each month, when it quickly became obvious that things in fact went better than planned: the number of complaints and legal actions were for example considerably lower than what had been anticipated, reducing costs for legal and tax administration. Further, the number of calls to the call center (the single biggest item in running costs) turned out to be around 1/20 than what had been anticipated – around 1500 calls per day instead of 30 000 per day. This meant that the call center was very much oversized, and during the spring, it was downsized – a considerable reduction of running costs. This means that investments costs could probably have been reduced quite substantially if the conditions (and not least the time constraints) had been different. This point may be especially important to note for other cities considering similar schemes.

Assuming an investment cost of 1900 mSEK means that the investment will be recovered in financial terms in around 3,5 years, since the net financial surplus is around 540 mSEK/year. (This excludes the increased net revenue of the transit operator.) In socioeconomic terms, the investment is ”recovered” in a little more than 4 years (assuming the recommended Swedish values for MCPF 1.3 and SPPF 1.23). Tot calculate the net present value of the investment, we need to assume a lifespan. Since reinvestment and maintenance costs are included in the running costs of 220 mSEK/year, a possible lifespan of 20 years seem to be a cautious estimate. The Norwegian systems, for example, have been running for around 15-20 years, and there seems to be no technical reasons for any of them to stop any time soon. This would give a net present value of around 8 billion SEK (assuming the Swedish recommended discount rate of 4% per year, and assuming that all benefits and costs remain constant) and a net present value ratio of 4.3.

The long-term costs and benefits are further discussed in section X.

Data and measurements

Extensive traffic measurements were carried out before and after the charges were put into place, covering both travel times and traffic flows. This data is the basis for most of the effect calculations. The data that we used was collected mainly in April 2005 and April 2006, but many of the measurement points – especially the travel time measurements, which are the most critical – were measured continuously since March

2005 and up to now (through automatic travel time measurement systems). This means that the risk is small for temporary circumstances to affect measurements: most measurements could be checked for consistency against much longer periods.

The number of vehicles per 15 minutes period were registered on 245 links. The measurements covered (for most links) around 10 weekdays, and the average was used. Traffic flows from 189 of these links were then used to calibrate OD-matrices representing the situation ”with” and ”without” the charges (using forecasts for the situation with and without the charges as ”prior” matrices). Assigning these OD-matrices to the network gave the flows on the remaining links. Separate OD matrices were calibrated for different parts of the day, but (as will be explained below) the crucial figure is really only the 24h flow on each link. To obtain this reliably, however, it was necessary to calibrate several OD matrices for the morning peak, afternoon peak etc. The 189 links used for the flow calibration represented around 7% the vehicle kilometers traveled (VKT) in the county, and around 15% of the VKT in the central parts of the county.

Measurements of travel times with/without the charges were used for 867 links. These links represented nearly 40% of the county VKT, and nearly 60% of the VKT in the central parts. The remaining travel times were calculated based on traffic flows, using the volume/delay-functions previously developed for Stockholm. When total time gains had been calculated, the measured travel times turned out to represent 80% of the total time gains.

Consumer surplus

The consumer surplus *W* from the congestion charges is evaluated using rule-of-a-half. It is calculated linkwise, not per OD-pair: This makes it a lot easier to use measurements in the calculations, since flows and travel times per link are readily available, whereas travel times and flows per OD-pair is not (they are possible to calculate in principle, but it is a major task and not necessary ayway).

$$W = \tfrac{1}{2}\Sigma_{lr}(T^0_{lr}+T^1_{lr})(\theta^0_{lr}t^0_{lr} - \theta^1_{lr}t^1_{lr} - c_{lr})$$

Here, l denotes link, r time period (the day is divided into 15-min intervals), T_{lr} the number of vehicles passing link l during time period r, t_{lr} the travel time on link l during time period r and c_{lr} the congestion charge on link l during time period r. Index 0 and 1 denote the situation with/without charges, and θ_{lr} denotes the value of travel time per vehicle on link l during time period r. The sum is taken across all links and 15 minutes periods. We assume that the monetary travel cost on each link is unchanged by the charges, apart from the charges themselves; i.e., fuel costs etc. are unchanged. Hence, the only monetary cost that enters the expression for *W* is the congestion charge[2].

[2] It may be superfluous to point this out, but since the question almost invariably arises, we do it anyway: only such “sub-markets” or “alternatives” (combinations of e.g. mode, departure time, destination etc.) where travel costs or times change enter the consumer surplus calculation. This means that travel times and costs of other alternatives than car trips do not enter the formula, since these are assumed to remain unchanged by the congestion charges (costs for increased congestion in the public transport system is discussed below).

In our calculations, we simplify the formula by assuming that the values of time θ^0_{lr} and θ^1_{lr} are independent of link and time period, and equal with and without the charges. This assumption is due to lack of data (mostly[3]); there are very few links where we have data on the mix of vehicle types (private cars vs. distribution vehicles). Note that assuming that the value of time per link is unchanged by the charges will in general underestimate the consumer surplus, since it is those travellers with the highest value of time that will remain on the road.

The consumer surplus W can be separated into three parts to to facilitate computation and explanation to laymen.

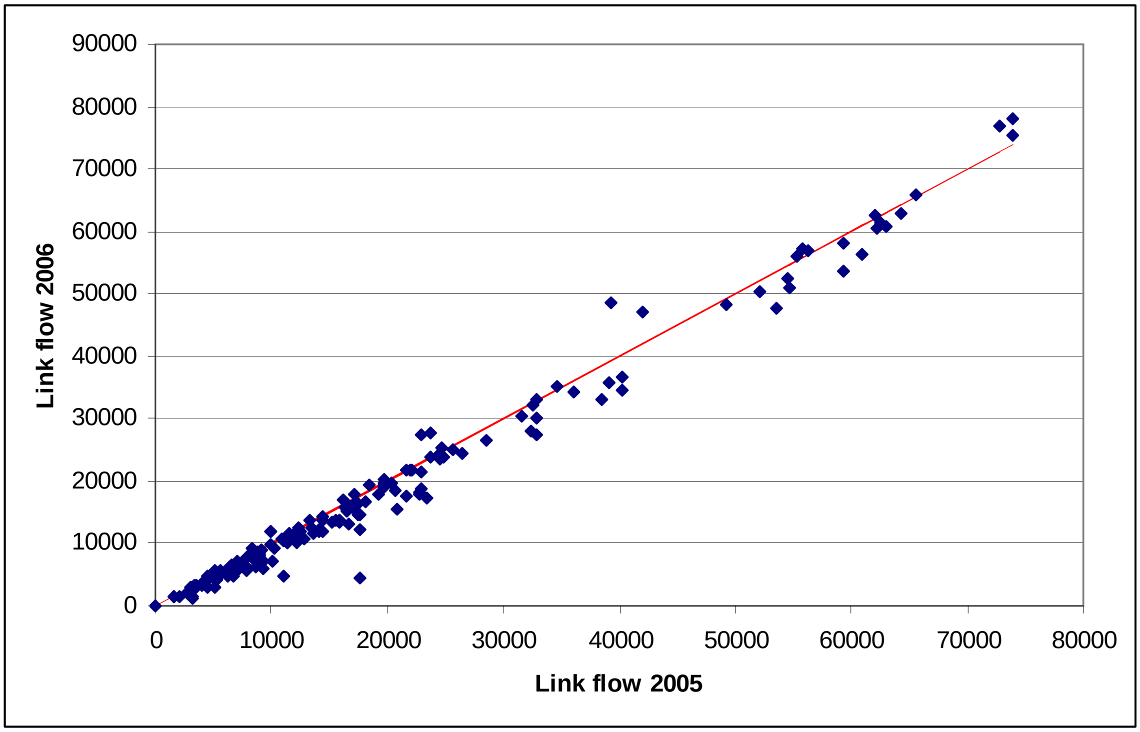
$$W = - \Sigma_{lr}T^1_{lr}c_{lr} + \Sigma_{lr}T^1_{lr}\theta(t^0_{lr} - t^1_{lr}) - \Sigma_{lr}½(T^0_{lr} - T^1_{lr})(c_{lr} - \theta t^0_{lr} + \theta t^1_{lr})$$

The first term is the revenues from the system, which are readily available. The second term is the value of the time gains with the charges in place. The third term may be called ”adjustment costs”: it is the loss for travellers ”leaving the roads” (or adjusting their behaviour in other ways).

Calculating link flows

As explained above, traffic measurements on 189 links were used to calibrate OD matrices for the situations with and without the charges, which then gave 24h link flows for each link in the county. The figure below shows measured flows in 2005 and 2006. The red line is a 45 degrees line: dots above it are flows that increased, dots below it are flows that decreased. Note that a few of the highest flows increased somewhat: these are flows on the Essinge ring road, the only bypass around the charged area, which was not charged.

[3] There are ways wher it would be possible to calculate these values of time approximately, using the travel surveys (covering private trips) made before and during the trial, and using the preciously few surveys of distribution traffic. Time did not allow this, however, and it is not vertain that it would even work in practice: the best way would seem to try to calibrate a multi-class OD matrix using these surveys, which is difficult at best. Moreover, the quality and size of these surveys are much lower than that of the traffic counts.



To obtain link flow per 15 minute time period, we constructed "flow profiles" describing the percentage of the 24h flow traversing the link during each 15 minutes period. After quite a bit of experimentation, we used 12 types of such flow profiles – different depending on the flow on the link (less or more than 25 000 veh/day), geography (inner suburb, outer suburb, city centre) and whether the flow was "morning peaked", "afternoon peaked" or "equally peaked". The figure below shows examples of the flow profiles.

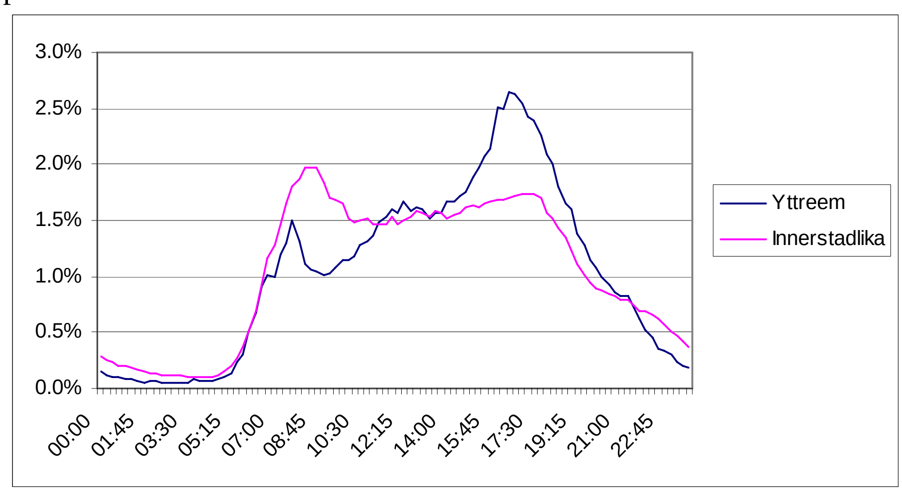


Figure 1. Flow profiles: "Yttreem" means "Outer suburb, afternoon peak". "Innerstadlika" means "City centre, equally peaked".

Using these profiles and the measured and calculated link flows, respectively, we calculated the link flow per 15 minutes time period for each link in the county with and without the charges.

Calculating link travel times

Travel times were calculated using the same logic. For 867 links, true, measured travel times with/without charges were used. For the remaining links, travel times for the morning and afternoon peaks were calculated using volume-delay functions, based on calculated link flows with/without the charges. The figure below shows travel time measurements for mornng and afternoon peaks. A few outliers can be seen: these stem from floating car measurements with very high day-to-day variability and too few measurement days, and were not used. Most of the data come from automatic travel time measurement, and were averaged over several weeks each year, giving very reliable point estimates of the average travel time per 15 minutes period.

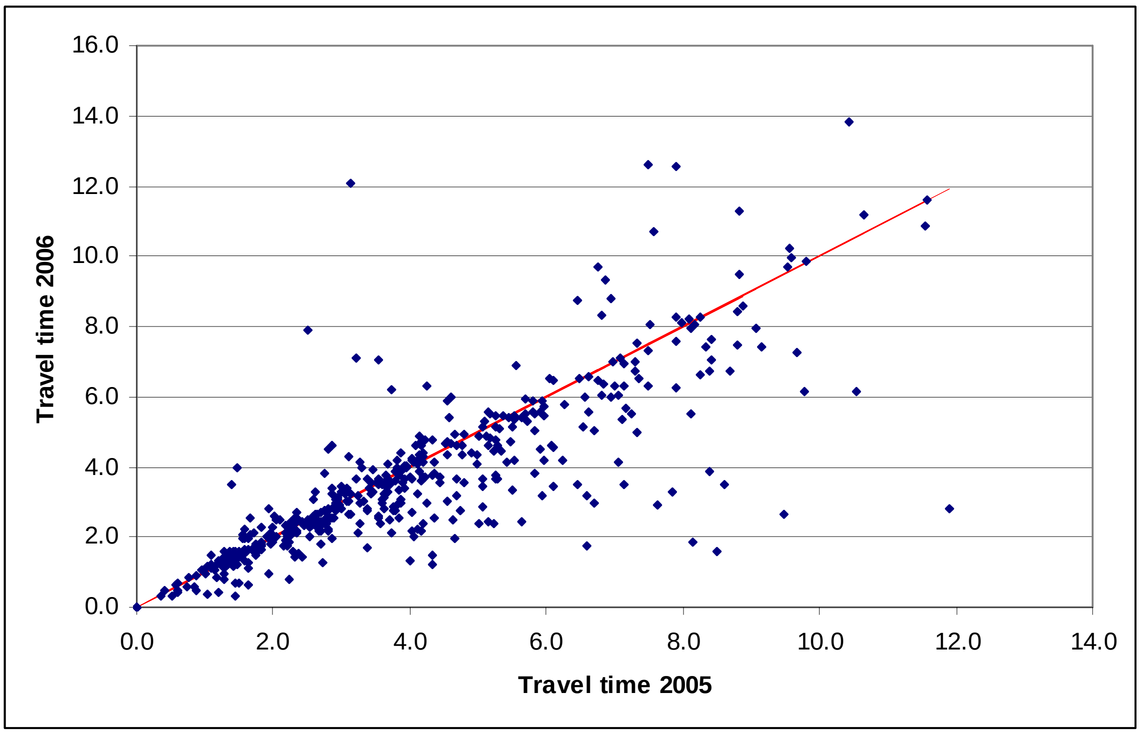
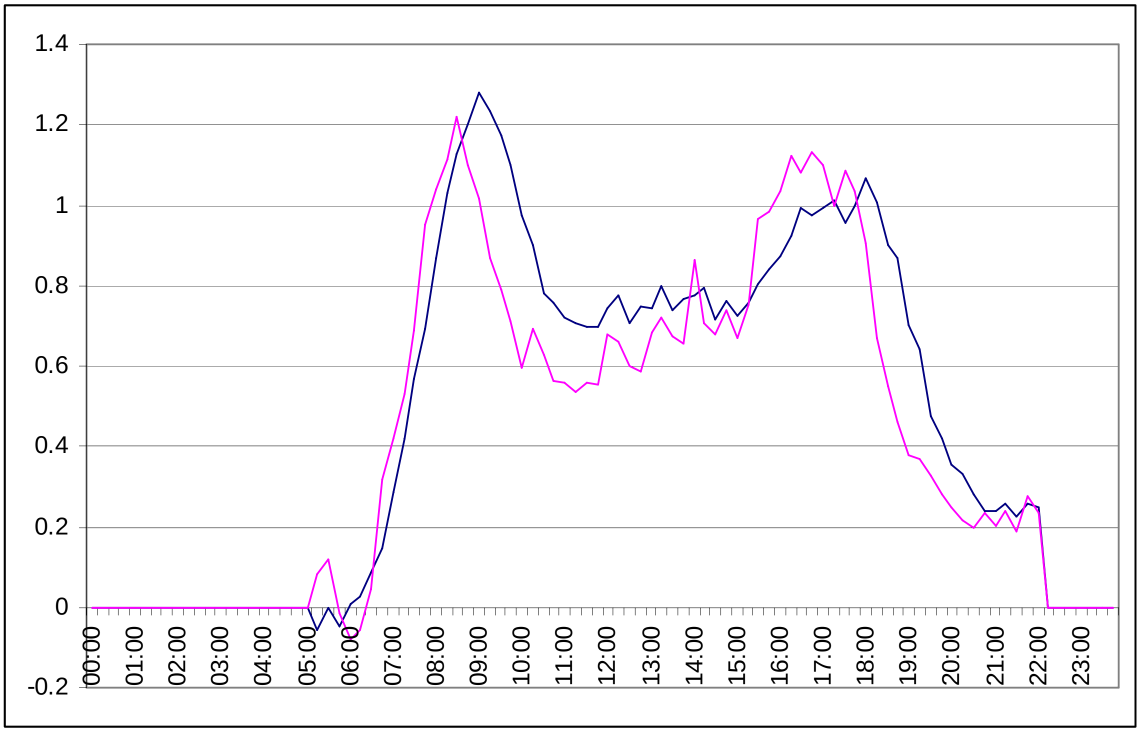


Figure 2. Measured afternoon peak and morning peak travel times 2005 and 2005.

To obtain travel times for each 15 minutes period, "travel time variation profiles" were constructed, giving the delay per 15 minutes period (additional travel time in percent compared to free flow travel time), relative to measured peak travel times. The average travel time during the morning peak (7.00-9.00) was taken to be "100% delay", and the travel time for other periods from 5 am to 12.30 am was expressed relative to this. Hence, the worst quarters (around 8.30) have delays above "100%". Afternoon travel times were constructed in the same way, with delays expressed as fractions of the average afternoon peak travel time. Examples of these "travel time profiles" are given below.



The value of time per vehicle

The table below shows how the value of time per vehicle was calculated. The values of time were taken from recommended Swedish values, except the value for private car trips which were taken from a stated preference study of Stockholm car drivers conducted by Transek in 2003. The recommended Swedish value of time for private trips is only 42 SEK/h, but several studies have shown that the value of time for car drivers in Stockholm is considerably higher, due to e.g. higher incomes, higher share of working trips and self-selection (those with the highest value of time choose car over public transport).

The shares of private trips, business trips and distribution traffic were taken from travel surveys, as was the number of persons per vehicle.

Value of time, private trips	65 SEK/h
Travellers per vehicle	1,26 persons
Value of time, business trips	190 SEK/h
Value of time, distribution traffic	190 SEK/h
Value of time for goods transport (added to VoT for distribution traffic)	10 SE/h
Share of business trips	20%
Share of distribution traffic	16%
Average value of time per vehicle	**122 SEK/h**

Valuing reliability

The unreliability of travel times in congested areas is a big problem. During the last couple of years, quite a lot of research has been dedicated to trying to incorporate this phenomenon in CBA. Most likely, travel time reliability is about to be included in the Swedish recommendations for how CBA should be carried out. Hence, it was decided that this factor should be included in the CBA for the congestion tax – especially since reducing travel time variability could be anticipated to be one of major benefits of the congestion tax.

Travel time variability was valued as 0.9*(value of time)*(standard deviation of travel time), following Eliasson (2003). Newly developed methodology was used to calculate the effects on travel time variability from measured travel times, using the following formula:

$$\sigma = t \exp\left(\alpha_\tau + \beta \frac{t}{T} + \gamma \left(\frac{t}{T} \right)^3 \right)$$

where σ is the standard deviation of travel time, *t* is link travel time, T free-flow travel time on the link and α, β and γ are parameters (α=-0.4, β=1.23 and γ=-0.036). The development of this formula is described in Eliasson (2006).

Clearly, it would have been even better to *measure* travel time variability rather than calculating it using observed link travel times and the formula above. The data allows us to do this, but (so far) there has not been time for this. However, calculations (by Henrik Edwards at the National Road Administration) using a subset of the data seem to indicate that the magnitude of this benefit is about right.

Consumer surplus - results

Using link flows and link travel times and the formulas above, we end up with the following results:

million SEK per year	**Benefit/loss**
Shorter travel times	496
More reliable travel times	78
Adjustment costs (Loss for evicted car drivers and gain for new car drivers)	-68
Paid congestion charges	-763
Consumer surplus, total	***-257***

Adjustment costs are calculated to be -68 mSEK/year. Paid charges amount to 763 mSEK/year (this is a forecast based on actual revenues in April 2006).

The map and the table below show where the time gains occur and to what extent they are calculated using measured travel times (as opposed fo calculations using volume-delay functions).

Colour	Area	Time gain (mSEK/year)	% of total time gain	% that stem from travel time measurements
black	Outer northern suburbs	25	5%	69%
red	Inner northern suburbs	17	3%	89%
light green	Lidingö island	0	0%	NA
dark blue	Northern city centre	185	35%	74%
light blue	Southern city centre	128	24%	90%
brown	Inner southern suburbs	20	4%	84%
yellow	Outer southern suburbs	31	6%	71%
red dash	Essinge bypass, Southern link	-21	-4%	100%
purple	Söderort-Nacka	53	10%	93%
dark green	Västerort-Solna-Sundbyberg	57	11%	98%
	SUM	**496**		**82%**

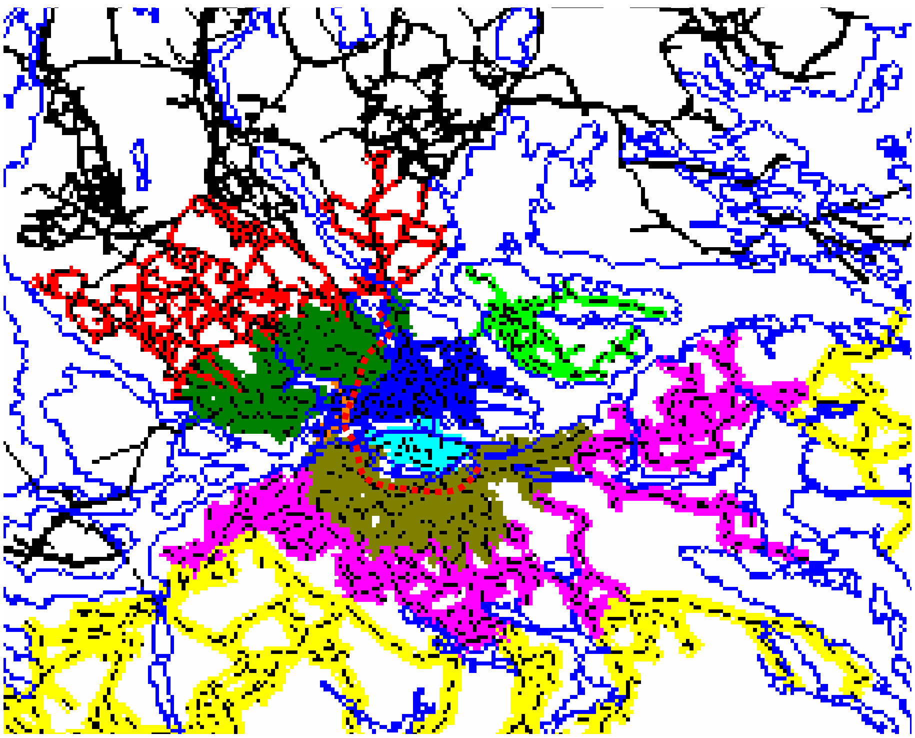


Figure 3. The county network divided into areas. The charged area consists of the light blue and dark blue areas (the city centre). The picture is cropped; the county is about twice a big as the part shown in the picture. (The blue lines are water.)

80% of the time gains are made up of measured travel times, while the rest are calculated using volume-delay functions. A little more than 60% of the time gains arise in the city centre and its immediate vicinity (links crossing the cordon). On the Essinge bypass and the ”Southern link” (an east-west tunnel south of the city centre attached to the Essinge bypass), traffic increased somewhat due to the charges, yielding a time loss of 21 mSEK/year.

Traffic safety and environmental effects

Less greenhouse gas emissions	64
Health and environmental effects	22
Increased traffic safety	125
Other effects, total	***211***

CO_2 and other greenhouse gases

The decline in traffic as a consequence of congestion charging is estimated to reduce emissions of greenhouse gases from traffic in Stockholm County by 2.7% (42.5 ktons). This estimation is based on the matrix calibration against link counts. With the recommended Swedish valuation of 1.5 SEK/kg, this constitutes a benefit of 64 mSEK/year.

Other emissions

Other emissions are estimated to decrease between 1.4% and 2.8% in the county. In the densely populated city centre, the decrease is estimated to be between 10% and 14%. The estimated effect for the county comes from the matrix calibration based on link counts. The estimated effect on the city centre comes from a statistical method (developed and applied by Pontus Matstoms at VTI), where links were sampled randomly and the vehicle kilometers travelled were calculated based on counts from these links.

The recommended Swedish valuations of emissions other than CO_2 also take into account the number of people affected etc. Using recommended valuations and calculation procedures, we end up with a benefit of 22 mSEK/year. Part of this benefit are health effects: the reduced emissions are estimated to 5 life-years saved per year (for Stockholm County as a whole)[4]. The other part of this benefit is reduced pollution and environmental damage.

Traffic safety

Effects on traffic safety were calculated using traffic safety relationships developed by the National Road Administration (as implemented in the Swedish CBA tool ”SamKalk”). Traffic effects were obtained using the calibrated OD matrices.

The reduction in traffic was estimated to lead to a 3.6% reduction of the number of traffic accidents. The number of people killed and severely injured on the roads is expected to decrease by approximately 15 per year, while the number of people slightly injured is expected to fall by just over 50 per year. This translates to a benefit of 125 mSEK/year, using recommended Swedish valuations.

[4] Several recent medical studies indicate that this effect might be much higher – recent figures indicate that the number of life-years saved could be 60 times as high (see Aga et al., 2003 for an overview of the field).

Public costs and revenues

The table below shows public costs and revenues (i.e. producer surplus for different parts of the public sector).

Paid congestion charges	763
Operational costs for charging system (incl. reinvestment and maintenance)	-220
Increased public transit revenues	184
Necessary increase in public transport capacity	-64
Decreased revenues from fuel taxes	-53
Decreased road maintenance costs	1
Public costs and revenues, total	***611***
Marginal cost of public funds, shadow price of public funds	***118***

Congestion charging costs and revenues

”Paid congestion charges”, 763 mSEK/year, is of course the same amount that showed up as a negative item under ”consumer surplus”.

The estimation of yearly operational costs (220 mSEK) is made by the National Road Administration, which is responsible for the system. This cost also includes necessary reinvestments and maintenance such as replacement of cameras and other hardware, and also certain additional costs such as moving charging portals when the building of a northern bypass starts in the summer of 2007.

As a comparison, the Oslo system (which is about the same size in terms on number of passages) has an operational cost of about 150 mSEK/year (and has been running for around 15 years). Compared to the Oslo system, the Stockholm system is less ”labour intensive”: there are no manual payment booths, for example. On the other hand, the payment system is more heavily regulated by legislation, since the charge is a tax (not a ”fee”) from a legal point of view, making it a bit harder to choose really cost-effective payment systems. Moreover, the ”Lidingö exemption” – that vehicles travelling through the charged area between the island of Lidingö and the rest of the county are exempted from charge – makes it necessary to identify basically 100% of the vehicles, in order not to miss an ”Lidingö exemption-vehicle”. The cost estimation from the Road Administration is, in our view, more likely to be a little high than to be too low.

The producer surplus for the transit operator consists of increased fare revenues (184 mSEK/year) minus costs for providing additional capacity to the new passengers. The increased fare revenues were calculated using the current average fare per passenger times the increase in ridership measured by the Stockholm Public Transport Authority.

The cost for additional capacity has been calculated to be 64 mSEK/year, using standard methods developed by the National Rail Administration. Clearly, such average calculation methods need not apply to the particular situation in Stockholm. An alternative method would be to assume no new capacity, and instead try to quantify the increased congestion for transit passengers (higher risk for having to stand etc.). During the Stockholm trial, additional capacity was provided primarily through more train departures and longer trains. The cost for the extra train services was 63 mSEK/year. This did not quite manage to avoid an increase in the share of standing passengers, however. Assuming that the value of travel time when standing is twice the normal value of travel time, the cost for increased risk of standing can be estimated to be around 15 mSEK/year. According to this calculation, the cost for accomodating the additional transit passengers would be around 78 mSEK/year. This, however, is the short-run cost: in the long run, the cost for additional train services is likely to decrease somewhat. The difference between the 64 mSEK/year we arrive at using the Rail Administration's method and the 78 mSEK/year we arrive at using the transit operator's costs plus the increase in "standing costs" is fairly negligible compared to other uncertainties in the CBA.

Decreased revenues from fuel taxes (-53 mSEK/year) was calculated based on the estimated decrease in vehicle kilometers travelled. The (negligible) decreased road maintenance cost (1 mSEK/year) was calculated using methods recommended by the National Road Administration.

Short term vs. long term effects

The present analysis is based upon the assumption that the effects seen between spring 2005 and spring 2006 are in fact the long-run effects of the congestion charges. Clearly, this need not be true: First, there may be other factors affecting traffic between the two years. Second, long-term (several years) effects may be different than short-term (one year) effects. Third, traffic growth is likely to change the effects. Below, we discuss these issues one at a time.

Has traffic been affected by factors other than the charges?

Traffic volumes across the cordon (i.e., to and from the city centre) increased at the same pace as the traffic in the county as a whole from the early 1970's (when regular measurements started) up until the early 1990's, where traffic across the cordon stopped growing. Traffic in the rest of the county, however, continued growing at the same pace, as did the number of transit trips across the cordon. The most likely explanation of this sudden end to traffic growth is simply that the road capacity was reached.

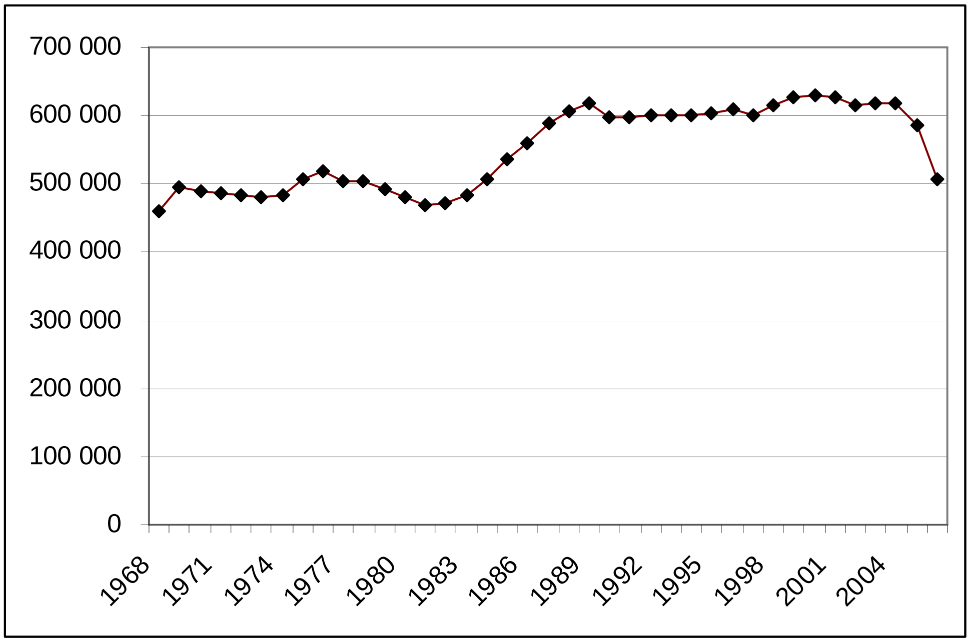


Figure 4. Traffic across the cordon 1968-2006. Between 2004 and 2005, the southern bypass was opened. Between 2005 and 2006, congestion charges were introduced. (The figures have been adjusted for a change in the cordon definition 1991.)

A time series analysis was conducted on this data, analysing the effects on the traffic across the cordon from a number of explanatory variables. The most important factors turned out to be fuel price, number of employed and car ownership. Using the results from the analysis, the combined impacted from these factors was calculated to be a traffic decrease of less than 1%. We concluded that the effects of other factors than the congestion charge were likely to be very small compared to the effect of the charges. This conclusion is also supported by the fact that the traffic variations the last 15 years have been so small, despite significant changes in employment levels, fuel prices etc. over these years.

Difference between long-term and short-term effects

There are two reasons why the long-term effects could be *smaller* than the short-term effects. First, there is the ”acclimatisation” effect: after a while, people might get used to the charge, and consider it less when making their travel choices. This could be especially important if it is, at first, a little difficult to pay the charge – and the extra ”cost” of actually making the payment might decrease with time. Second, the freed-up road space could be filled up with *other* traffic than the one which left the roads because of the charges. Such traffic could either be travellers with higher values of time, or travellers making car trips not crossing the cordon. In fact, the latter effect was visible during the trial: there were e.g. signs in one of the travel surveys that both the number of car trips outside and within the cordon increased somewhat, and that these trips to a larger extent were made during rush hours (there was less reason to avoid rush hours, since congestion had decreased so much).

There are also a number of reasons why the long-term effects could be *larger* than the short-term effects. Several long-term choices, such as choices of workplace, car ownership and residence, will not be affected in the short run – especially not considering that the charges were not permanent – but are likely to be affected in the long run. The fact that this was only a ”trial” might also mean that people decided to ”wait it out”, not thinking it was worthwhile to change their travel habits when it was just half a year.

All in all, we are inclined to believe that long-term effects are most likely to be similar to the short-term effects, but more likely to be larger than to be smaller. This is because it seems that the ”transient” effects seem to have faded out already during the trial: the percentage decrease in traffic across the cordon stayed virtually unchanged after the first one or two months. Meanwhile, the long-term effects on choice of workplace, residence etc. most likely do exist – even if they may be small compared to the immediate effects on mode and route choice, for example. Another reason for this view is that long-term effects in London seem to remain similar to the short-term effects: before the charge was increased (in July 2005), the traffic reduction had remained stable at around 18% for nearly 2.5 year. Even if there is no conclusive evidence, it seems very unlikely that long-term effects will be so different from the short-term effects that this significantly alters the conclusion of the CBA.

Effects of traffic growth

As shown above, the traffic across the cordon essentially stopped growing around 15 years, contrary to the traffic in the rest of the country which continued to grow. It could be logical to believe that the current traffic decrease will, at least partially and gradually, will be used up by new traffic. It is not obvious whether this means that future *benefits* will decrease or increase. What makes the issue complicated are non-linearities and network effects. In a simple aggregated analysis, it is easy to show that an increase in underlying demand (moving the demand curve ”outwards”), benefits will grow at a slightly higher pace (due to the non-linearity in the cost function) than the underlying demand. However, it is not clear that this is always true in more complicated networks. Despite of this, it seems likely that benefits will tend to grow at about the same pace in underlying demand, which in turn is expected to grow at about 1,5% per year. If we assume that benefits will grow at the same pace, this would mean that the net present value increases from 9.7 billion SEK to 11.4 billion SEK (assuming a lifetime of 20 years and a discount rate of 4%).

Conclusions

Even if it is well established that congestion pricing will yield a social surplus, it is not evident neither that it will be enough to cover investment and operational costs, nor that a *real* congestion pricing system, will all its practical and political limitations, will be socially profitable.

Our analysis shows that the Stockholm system yields a large social surplus, well enough to cover both investment and operational costs. The value of the time gains compared to the paid charges is remarkably high compared to most theoretical examples. This seems to depend on that such examples neglect network effects – for example, that many travellers not paying the charge will benefit from decreased congestion, and that bottleneck effects may lead to reduced congestion far away from the charged area.

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