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THE ECONOMICS OF URBAN TOLLS: LESSONS FROM THE STOCKHOLM CASE[1]

Pierre Kopp · Rémy Prud'homme[2]

Abstract: The Stockholm toll causes, as predicted by theory, a reduction in traffic, leading to increased speeds, and to time gains for remaining car-users. But this is only the beginning of the evaluation story. One must also estimate: implementation costs, environmental gains, imperfect secondary markets (in public transportation) benefits and costs, as well as public finance costs and benefits. The net outcome appears to be negative, contrary to the outcome of the official estimate. For an urban toll to produce net benefits, it seems that three conditions are required: a relatively high degree of road congestion, a reasonably cheap implementation system, and a relatively low level of public transport congestion.

Key words: Tolls, Stockholm, Cost-benefit analysis, Road congestion, Public transport congenstion.
Jel Classification: H23, H43, D61, D62, R4.

1. Introduction

On January 2006, the municipality of Stockholm introduced a charge or toll to enter the city Center. The concept of urban toll to control congestion has been introduced in the post war period, and is perfectly justified from a theoretical viewpoint. Very few tolls, however, have been introduced. After Singapore in 1975 and London in 2003 (ignoring Norwegian tolls which are primarily financing devices), the Stockholm toll is actually the third real-life congestion toll experiment. As such, it deserves the attention of transport economists. Did it reach its objectives? Does it stand the test of a cost-benefit analysis? What lessons can be learnt from it?

The toll was first introduced as a seven months trial and was later (in January 2007) made permanent. The system has been abundantly described and

[1] This research was made possible by a grant from the research fund (PREDIT) of the French ministry of Transportation. It also benefited from technical assistance from the Swedish Institute for Transport and Communications Analysis (SIKA). The authors are grateful to both entities for their help. They particularly wish to thank Rickard Wall, of SIKA, and Mats Tjernkvist, of Vagverket Konsult, for their kind help. Obviously, our analysis and conclusions do not commit PREDIT or SIKA. The authors are equally indebted to two anonymous referees for very useful comments.

[2] Respectively Professor emeritus, University Paris XII and Professor, University Paris I (Sorbonne)

publicized, and need not be presented here in great details (see www.stockholmsforsoket.se, or Armelius & Hultkrantz 2006). The tolled zone regroups about 400,000 inhabitants, about 20% of the population of the Stockholm agglomeration, and a much smaller part of its area. The toll is a cordon toll: cars entering or leaving the zone pay a charge. The amount of the charge varies with the time of the day. The toll functioned as expected. Traffic was reduced on the radials, and in the city Center. Speeds were increased. Public transport patronage increased.

There is apparently only one attempt to estimate and compare the costs and the benefits of the scheme. It was conducted by Transek (2006), a consulting firm close to the toll organizers, and made public on the official toll site (www.stockholmsforsoket.se). The main author of the Transek study later published an article (Eliasson 2009) that basically utilizes the same methodology and produces fairly similar numbers. These studies (or rather this study) conclude that the benefits of the scheme exceed its costs. By 690 M SEK (about 75 M €) per year, taking into account operating and depreciation costs, according to Transek (2006); by 654 M SEK (about 71 M €) per year, excluding investment costs, according to Eliasson (2009).

Our own, independent, analysis follows a standard cost-benefit approach (Boardman *et al* 2001). The net social benefit (NSB) of a project or a policy is equal to the sum of:

- changes in consumer surplus (ΔCS);
- changes in costs (ΔCO);
- changes in externalities (ΔEX);
- changes in secondary markets (ΔSM);
- changes in government revenues (ΔGR)
-

$$NSB = \Delta CS + \Delta CO + \Delta EX + \Delta SM + \Delta GR$$

We will examine these five components in turn. The most important is expected to be the change in consumer's surplus, the time gained by car users that now drive faster because of the toll (net of the loss of car users evicted by the toll), since is the theoretical rationale of a congestion toll. But we shall see that the other components, which are usually ignored in the standard textbook approach (although generally not in Transek's), are equally important.

II. Consumer Surplus

The Congestion Pricing Model

In the standard case a single homogeneous road or area is considered, and road usage (q) is best described by vehicle density or (as in London) number of vehicle*km. In real life, the homogeneity assumption is questionable. Not all roads at all moments are similar. Introducing a dose of heterogeneity is certainly desirable. This could be done by distinguishing between peak and off-peak periods. In the case of Stockholm, however, it appears that peak and off-peak periods, although different, are not very different. The main divide in the Stockholm case is not by moments of the day but by types of roads.

It therefore seems appropriate to distinguish between radials, and the city Center roads. Traffic on these two types of road are very different: speeds, and parameters of the flow-speed or density-speed relationships differ markedly. But they cannot be analyzed independently of each other. The demand for driving in the Center and the demand for driving on the radials are closely associated. Road usage and congestion on the radials and in the city Center are both affected by the same toll.

To model the Stockholm case, we consider the number of car trips entering into the city (or leaving the city) per day as the key variable (q). These trips pay the toll. In addition, there are trips made within the city without crossing the city border (Q). We shall assume that Q is given, exogeneous. These trips do not pay the toll. There is a demand curve (representing the marginal willingness to pay) for Center-bound trips D(q). There is a marginal supply or cost curve I(q) for these trips, consisting of two components, in addition to a fixed cost (fuel cost, etc.) not affected by the toll:

- a time cost $c_r(q)$ for the time spent on the radial. With t the value of time, S_r the speed on the radial, w the average occupancy of cars and L_r the average length of radial trips affected by congestion, we have:

$$c_r(q) = L_r{}^*w^*t/S_r(q)$$

- a time cost $c_c(q)$ for the time spent in the Center. With t the value of time, S_c the speed on the radial, w the average occupancy of cars, and L_c the average length of trips in the Center, we have:

$$c_c(q) = L_c{}^*w^*t/[S_c(q+Q)]$$

Hence:

$$I(q) = L_r{}^*w^*t/S_r(q) + L_c{}^*w^*t/[S_r(q+Q)]$$

As can be seen on Figure 1, in the absence of toll, the demand curve D(q) and the supply curve I(q) intersect in A, which is the equilibrium point, with X trips on the radials. This situation, however, ignores congestion externalities on both the radials and in the Center. These congestion externalities are equal to I'(q), the derivative of I(q), multiplied by q (for radial road trips, and by q+Q for Center road trips). To take them into account, we must consider the marginal social cost S(q), equal to the individual cost curve I(q) augmented of these externalites:

$$S(q) = I(q) + I'(q)^{\star}q$$

Point B, where the social cost curve intersects the demand curve describes the optimal situation. In B, with q=Y, the social benefits of an additional trip are just equal to the social costs of that trip, and social welfare is maximized. Reducing q from X to Y will improve welfare by ABC, or to put it otherwise, by LGEP-GBA. LGEP is the time gain of the Y people that continue to use their car; GBA is the welfare loss of the X-Y people who abandon their car.

This magnitude, ABC, is what should be defined as congestion costs: what society can gain by moving from the existing situation A to the optimal situation B.

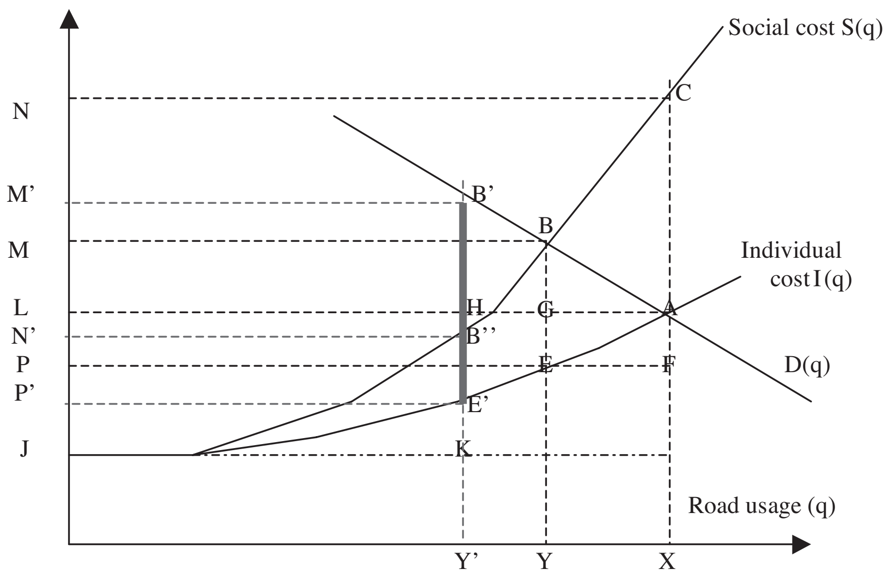

FIGURE 1. Road Congestion with a Congestion Charge.

The simplest and most effective way of reducing car traffic from X to Y is to have a toll equal to BE. Note that the toll should not be AC, the marginal congestion cost in the pre-policy situation, but BE, the marginal congestion cost in the optimal situation. The Stockholm toll certainly reduces road usage. But we cannot know before hand if it reduces it to the socially optimal level. The toll is likely to be lower or higher than the optimal toll. It will reduce road usage to Y', with Y' to the right or to the left of Y. In that case, the potential welfare gain will be reduced (by B'BB''). Finding out whether the toll level is too high or too low (relative to the optimal toll) is an important by-product of our methodology. The use of this simple economic model is a major difference between our approach and that of Transek (2006)-Eliasson (2009). They do not use, and do not need, individual and social cost curves nor a demand curve. They rely upon transport engineering calculations to estimate before toll speeds and after toll speeds, to estimate time gains.

The Stockholm experiment makes it possible to estimate the demand curve D(q). We know one point of this curve, point A. We can know a second point of this curve, point B', the equilibrium situation created by the toll. The quantity of trips entering the city after the toll, Y', is recorded. The average toll can be deducted. It is added to the cost of the trip for q=Y'. Point B' can therefore be determined. Having two points of D(q), it is easy to determine the equation of this demand curve.

Equipped with I(q), S(q) and D(q), we can easily calculate all the magnitudes we are interested in. We can determine point B, the socially optimal situation, with Y the socially optimal number of trips entering the city – what should be the policy goal. We can determine BE the optimal toll, and compare it with B'E' the actual toll, and find out whether the present toll is too low or too high. We can also determine ABC-B'BB''" the social gain generated by the toll. This social gain is also equal to the time gained by non evicted car users, LHE'P' minus the surplus loss of evicted car users HB'A.

In reality, the analysis is more complicated. If, as we believe, part of the decline in traffic is due to causes other than the toll (an increase in fuel prices for instance), then the demand curve shifts leftward, from $D_1(q)$ to $D_2(q)$ – not represented here for the sake of simplicity. We can construct a counterfactual situation, that describes what would have happened in the absence of the toll, in order to study the impact of the toll per se.

Values of Key Parameters

To conduct the analysis, we need numbers on several key magnitudes that describe the Stockholm situation.

Number of trips into the city and out of the city (q). We have data on the number of vehicles entering the city Center, and leaving the city Center, for "spring" 2005, and for May and April 2006, per day per periods of 15 minutes.[1] We are

[1] Calculated from files "mi_tidpunct_medeldygn_betalstation_05_06_Rin.xls" and "mi_tidpunct_medeldygn_betalstation_05_06_Rut.xls" produced by the municipality of Stockholm

interested in the trips affected by the toll. The number of trips during the toll period declined by 82 thousands, a 20% decline.

However, not all of this decline can be attributed to the toll, for at least three reasons. *First*, during the off-toll period, the number of trips could, if anything, have been expected to increase, because the toll should have induced some of the drivers to leave earlier and to come back later; it actually declined by 5.3%, reflecting exogenous forces. *Second*, one such obvious exogenous force is the fuel price increase: during the Spring 2005-Spring 2006 period, gasoline price increased by 1.4 SEK (0.15 €) per litre, a 13% increase. The short-term elasticity of urban travel to fuel prices is known to be around –0.4. Fuels price increases should therefore have led to a 5.2% decline in trips, which is the decline observed for off-toll period trips. *Third*, in October 2006, with the toll not operating, traffic was 6.6% lower than in October 2005. These three numbers do not differ much from each other. To be on the safe side, we shall retain 5%. By contrast, Transek (2006)-Eliasson (2009) ignore these three points, and estimate the effects of non-toll factors to amount to a negligible 1%. In our analysis we will consider that traffic during the toll period was reduced by non-toll forces from 410 thousand to 390 thousand trips per day, then by the toll to the observed 328 thousands trips. This toll-induced decline of 61,000 trips represents -17.7% relative to the counterfactual, and -15.0% relative to the initial situation.

Number of trips within the Center. Trips made within the Center consist of the q trips that enter and leave the city, plus the Q trips that have both their origin and destination within the city (and are toll exempt). Q is difficult to estimate. Our best estimate is based on the 2004 Transport Survey undertaken by Trivector (2005). The number of Center to Center trips represented 25.2% of the number of Periphery to Center (and Center to Periphery) trips. If $Q = 0.252 \star q$, then Q was equal to 133 thousand trips on a 24 hours basis and to 103 thousands trips during the toll-period. As mentioned above, we will assume that Q remains constant. During the toll period, there were 513 thousand trips in 2005, down to 493 thousands trips in 2006 as a result of the toll. It is worth noting that the bulk (about 80 %) of the trips made within the Center are made by incoming and outgoing vehicles.

Length of trips. The Transport Survey indicates the length of Center to Center car trips: 3.7 km. This is slightly longer than the 3.3 km radius of the charged zone. We will assume that 3.7 km is also the average length of trips made in the Center by vehicles coming from outside the Center. It is more difficult to estimate the length of the part of radial trips affected by the charge, the part on which traffic declined and speed increased. According to the Transport Survey, the average length of periphery to Center trips is 17.2

km. Substracting 3.7 km driven within the city, we are left with 13.5 km on radials. However, a substantial part of this mileage is done on non-congested arterial roads not affected by the toll, as a mere look at the maps showing changes in travel time by road sections will show. We will assume that 50% of these 13.5 km drive is affected by the toll, or 6.7 km. This is probably an overestimate.[1]

These estimates make it possible to produce TABLE 1 that shows the amount of traffic affected by the toll, in different ways. The q trips entering and leaving the Center are affected in terms of number and of speed, although the impact of the toll on speed is not the same on the radials and in the Center. The Q trips from Center to Center, that do not pay the toll, are affected in terms of speed.

TABLE 1. Traffic Affected by the Toll, 2005-6.

	Radials	**Center**
2005 (in 1000 trips/day)	410	513
2006 observed (in 1000 trips/day)	328	431
2006 counterfactual (in 1000 trips/day)	390	493
Toll-induced change (in 1000 trips/day)	-62	-62
Length (in km)	6.7	3.7

Sources: see text.

Speed-density relationships coefficients a and b. The relation between speed S and density D, which reflects the physical characteristics of road space, is known to be linear: S = a + b*D (see for instance Newbery 1990). We verified that it is so on Stockholm roads, because we have data on flow and speed for every period of 15 minutes (96 periods) for hundreds of locations and days.

For the *radials*, we obtain the average speed in 2005 during the toll period by dividing the cumulated flows by cumulated densities for a sample of 2,200

[1] Data produced by a transport model suggests a shorter length. Traffic volumes (in vehicle*km) declined in the county by 435 thousand vehicles*km. Substracting the 266 thousand veh*km decline that took place in the charged zone, we are left with a decline of 169 thousand veh*km in the rest of the Stockholm county. Most of that decline took place on the radials. Since traffic on these radials declined by 38 thousand vehicles, this would suggest an average length of about 4.4 km, or 2.2 km per trip. But this number is most probably an underestimate. The decline in traffic on the radials must have been compensated in part by increases in other parts of the country. The decline in traffic volume on the radials would therefore be greater, and so would the average length.

measurements (several points, for several days, for 48 periods of 15 minutes, and for two directions). It is 49.48 km/h – which is an average speed, not an average of speeds. A similar calculation is made for 2006, with an even larger sample. It yields 51.05 km/h. The 2005 speed is generated by a road usage of q=410,000 trips; the 2006 speed by a road usage of q=328,000 trips. We therefore have a_r=57.33 and b_r=0.01915. Speed on the radials is therefore:

$$S_r(q) = 57.33 - 0.01915 * q$$

For *trips in the Center*, we have floating car speed measurements for about 800 trips (2,330 km) in 2005 and 1200 trips (2,570 km) in 2006, which have been designed to constitute representative samples. We calculated average speeds (not averages of speeds), 22.89 km/h in 2005 generated by 410+103 thousand trips, and 26.19 km/h in 2006 generated by 328+103, thousand trips. This yields a_c=43.51, and b_c=0.0402[1]. The speed in the Center is therefore:

$$S_c(q)= 43.51-0.00402 * q$$

Value of time t. The official value of time in Sweden is reported to be 42 SEK (4.6€) per hour for personal trips (including journey to work), that account for 80% of trips, and 190 SEK (20.7€) for business trips. These numbers, however, have to be adjusted. First, they refer to the entire country, not to Stockholm. Values of time are not politically decided: they reflect the users' willingness to pay for time savings. Productivity (output per worker) is reported to be 35% higher in Stockholm; the value of time for business trips should therefore be adjusted by 35%. Disposable income is reported to be 12% higher in Stockholm; the value of time for personal trips should be increased by 12%. Second, the above-mentioned value of time numbers are for 2001. They increase like the GDP growth rate, which has increased about 10% between 2001 and 2006. Taking all this into account produces values of time of 52 SEK per hour for personal trips, of 282 SEK for business trips, and of an average value of time for 2006 of about 98 SEK/hour (10.7 €). This is about equal to the official value for France.

Other parameters. It is generally agreed that there is on average 1.25 person per vehicle in Stockholm: w=1.25. The toll schedule is well known. But not all vehicles entering the city pay the toll. Some are exempt (taxis, trips from the North East crossing the Center, etc.). To determine the effective toll T, we divide toll proceeds by the number of trips. On an average spring 2006

[1] Some people have asked: what happens to Q (=103) in this equation? The density-speed relationships yields S_c=a'-b*(q+Q). But since Q is a constant, this can be re-written S_c=a'-b*q-bQ, or S_c=a-b*q with a=a'-b*Q. Q is not forgotten, it is «incorporated» in the intercept a.

day, with 328 thousand vehicle trips, the toll proceeds were 3.18 M SEK/day. This amounts to 9.7 SEK (1€) per trip on average.[1]

TABLE 2. Value of Relevant Parameters and Magnitudes.

	2005	2006
q = Trips to/from Center, toll-period (in 1000)	410	329
Q = Trips Center to Center, toll-period (1000)	103	103
q+Q = Trips within Center (1000)	513	432
L_c = Length trips within Center (km)	3.7	3.7
L_r = Length trips / congested radials (km)	6.7	6.7
a_r = intercept in speed-q relation on radials	57.33	57.33
b_r = coefficient same relation	-0.0192	-0.0192
a_c = intercept in speed-q relation in Center	43.51	43.51
b_c = coefficient in same relation	-0.0402	-0.0402
t_p= Value of time personal trips (SEK/hr)		52
t_b= Value of time for business trips (SEK/h)		282
t= Average value of time (SEK/h)		98
T = Average toll/trip (SEK/trip)	-	9.7
w = Vehicle occupancy (person/vehicle)	1.25	1.25

Note: SEK = Swedish crown (1 SEK = 0.109 €)

With the values of the main parameters thus identified or estimated, and summarized in TABLE 2, we can now implement our simple theoretical model. We first establish the supply (cost) and demand curves of the model. We then use them to find out whether the actual toll and congestion reductions are optimal or not, and to estimate the associated gains and benefits. We continue with a discussion of these findings.

Changes in consumer surplus

With I(q) the individual cost curve, S(q) the social cost curve, D1(q) the demand in 2005 and D2(q) the demand in 2006 after taking into account the exogenous shift leftwards in the demand curve, the equations of the cost and demand curves are as follows:

$I(q) = 820.75/(57.33-0.0192*q) + 453.25/(43,51-0.0402*q)$

$S(q)= 820.75/(57.33-0.0192*q) + 453.25/(43,51-0.0402*q) + 820.75*0.0192*q/(57.33-0.0192*q)^2 + 453.25*0.0402*(q+103)/(43.51-0.0402*q)^2$

$D_1(q) = 70.19 – 0.0898*q$

$D_2(q) = 83.36 – 0.130*q$

[1] This is less than the 10, 15 or 20 SEK of the formal price because it is an average that takes into account the zero SEK price paid by toll-exempt vehicles.

Table 3 presents the results of this analysis, and throws some light on the anatomy of congestion reduction in Stockholm Center. When the number of trips to/from the Center declines, speeds on both radials and in the Center increase. A 16% decline, such as the one induced by the toll during the toll-period[1], increases speed by 4.5% on the radials and by 10.5% in the Center. This increase in speed in turn reduces the time cost borne by the remaining car users. Simultaneously, it decreases the congestion externality generated by the marginal user. The total social cost (individual cost plus externality) is also reduced, although by smaller percentages.

Table 3. Speeds, Costs, Demand, Time gains and Surplus Losses for Different Road Usage Levels.

	2005 Observed	**2006 Estim.**	**2006 /D1**	**Optimal /D2**	**Optimal**
Road usage q (1000 trips/day)	410	328	389	324	324
Speeds (km/h)					
Speed on radials S_r (km/h)	49.5	51.0	49.9	51.1	51.1
Speed in Center S_c (km/h)	22.9	26.2	23.8	26.3	26.3
Costs & utility (SEK/trip)					
Indiv. cost I	33.4	31.0	32.7	31.0	31.0
Social cost S	48.8	41.5	46.8	41.2	41.2
Toll (effective or optimal)	-	9.7	9.7	10.3	10.3
Time gains & Surplus losses (M SEK/yr)					
Time gain for remaining users	-	238	174	303	183
Surplus loss for evicted users	-	-76	-61	-83	-70
Net gains	-	+163	+113	+220	+113

Source: Authors calculations. *Note*: Time gains and surplus losses under «2006 (observed)» compare the effective situation to the initial 2005 situation; under «2006 (estim)», they compare the effective situation to the (more realistic) counterfactual situation created by an exogneous demand decline of 5%; under «optimal (D1)», they compare the optimal situation ignoring the exogeneous decline to the initial 2005 situation; under «optimal D2» they compare the optimal situation taking into account this decline to the counterfactual situation. M SEK = millions of Swedish crowns. 1 SEK = 0.109 €). Yearly costs or benefits are obtained by multiplying daily costs or benefits by 250 tolled days. The surplus loss for evicted users is equal to [D(q)-(Dq2005 or Dq2006estim)]*(q-q2005 or q2006estim)/2

Relative to the counterfactual (the estimated 2006 road usage in the absence of toll) situation, the 16% decline in road usage creates time gains for the

[1] (328 – 389) / 389 = 15.7%

remaining car users of about 174 M SEK (19 M €) per year. Evicted car users suffer a loss, of about 61 M SEK (6.6 M €). The net gain associated with the toll amounts to 113 M SEK (12 M €). This is the number to be taken into consideration in an evaluation of the toll.

If we ignore the exogeneous demand decline, and attribute all the change to the toll, these gains – and also the losses – are significantly increased, by nearly 40%. This is noteworthy. It means that the 5% exogeneous decline did decrease substantially congestion costs, because of the non-linear cost relationships.

It is also interesting to note that in both cases, the toll level is nearly appropriate, in the sense that it takes road usage (328 thousands) practically to the optimal level (324 thousands). The present toll level is slightly lower than would be desirable, but the net time gains would practically be the same if truly optimal tolls were imposed.

Our estimates of time gains for remaining car users (174 M SEK/year) are three times lower than the estimates of Transek (523 M SEK) and Eliasson (536 M SEK). Since we use similar numbers for the value of time, and similar number of trips, this large discrepancy comes from differences in our respective estimates of time gains. Transek and Eliasson estimates are produced by transport engineering models. Ours are produced by the economic model presented above. It is interesting to calculate the implied demand elasticities attached to these findings. They are presented in Table 4. The implied price elasticity of our time gains estimates is already very high[1], but that of Transek and Eliasson are well beyond anything reasonable. Table 4 also includes the ratio of net road users gains to toll proceeds. As Rothengatter (2003, p. 124) correctly points out: «Tax revenues in the optimal situation exceed external congestion costs by 4 to 9 times. This means that to remove a small welfare loss a large flow of tax revenues has to be generated». Net gains relative to toll proceeds should therefore be in the 11% to 25% range. Our estimates yield a 14% ratio. Transek and Eliasson estimates of time gains imply unlikely ratios much above 50%. We are therefore led to believe that the Transek and Eliasson methodology exaggerates the time gains generated by the toll.

[1] Although it is remarkably close to the -2.02 elasticity of demand relative to the generalised cost for all car trips calculated for London by Transport for London (TFL 2008, p. 5).

Table 4. Implied Elasticities of Traffic, according toVarious Time Gains Estimates.

	P-K	**Transek**	**Eliasson**	**Rothengatter**
Change in user cost	+8.4%	+3.5%	+3.7%	-
Change in traffic	-16%	-20%	-20%	-
Implied price elasticity of demand	-1.9	-6.1	-5.4	-
Ratio of net time gains to toll proceeds	14%	67%	57%	11-25%

Sources and notes: P-K = Prud'homme & Kopp. Transek (2006). Eliasson (2009). Rothengatter (2003). The relative change in user cost is the ratio of (toll paid - value of time gains) / initial trip user cost, taken to be 89.1 SEK per trip; this is calculated for the remaining car users. Net time gains are the time gains of remaining car users minus the welfare loss of evicted car users.

III. Implementation Costs

Operating a toll is not costless. The traditional approach to road pricing usually does not address this cost. For instance, none of the eight articles on "Modelling of Urban Road Pricing and its Implementation" in a special issue of *Transport Policy* (vol. 13, N° 2) seems even to mention it. It may well be that in the future such costs will decrease sharply, but for the time being, they are important and must be investigated.

The cost of the Stockholm toll should in principle be easy to determine because the toll conception, development and implementation has been contracted out by the National Road Administration to IBM, a private company. Only a few elements of the cost have been paid directly by the National Road Administration (some infrastructure investments for 94 M SEK, prosecution costs for 15 M SEK, tax administration expenditures for 24 M SEK) or by the municipality of Stockholm (information costs for 80 M SEK). There are several difficulties, however. The contract with IBM, for 1880 M SEK was for the seven months period of the trial. It included initial investments and operation costs for that period.

It is difficult to know what regular operation costs are and will be. An official estimate of 17.5 M SEK per month is said to include replacement expenditures (it is not easy to understand how replacement expenditures were so high in the first months of operation). Not all operation costs, however, are replacement expenditures. Every day, more than 6,000 "reminders" are sent to people who did not pay, about 100 court appeals are processed, more than 2,000 telephone calls are answered, an unknown (to us) number of cameras or transponders or lasers have to be fixed. All this has a cost, an operation cost. There is a remarkable paucity of information on this cost. We shall assume this unknown "true operation cost" to be 10% of toll proceeds (it is 11% in Oslo), or 6.6 M SEK (0.7 M €) per month.[1]

The difference between the amount paid to IBM during the seven months of the experiment and seven times this monthly operation cost can be assumed to be the investment made by IBM. It is equal to 1880-7*6.6 = 1834 M SEK. To this amount should be added the toll-related additional road expenditure of 94 M SEK.

Investment cost = IBM contract – regular operation costs for 7 months + additional investments

The cost of the Stockholm toll must therefore be estimated on the basis of an investment of 1928 M SEK[2] (210 M €) and of a yearly operation cost of 79 M SEK (12*6.6). The yearly cost, the one that is of interest to us, consists of: operation costs, plus amortization of the capital invested, plus the opportunity cost of this capital, plus the marginal cost of the public funds invested.

Amortization. Over what period should this investment be amortized? It consists of hardware (transponders, cameras, lasers, computers, gantries) that has a relatively short life, and of software (computer programmes, design, knowledge, system manuals) that has also a relatively short life. We tried to find out what Capita, the private company that operates the London toll does. It seems that it initially used a 5 years depreciation period, later changed into a 7 years period. We also asked Vinci, an important French group operating toll facilities in many countries, what their amortization practices – sanctioned by chartered accountants, tax administrations and regulatory agencies in these many countries – are: the answer is 6-7 years. SL, the Stockholm public transport company amortizes its "equipment" over 3-10 years. To be on the safe side, we opted for an 8 years period.

This 8 years amortization period is very different from the 40 years selected by Transek (2006). Transek argues that this period is "common in transport projects". This is true, but unconvincing: transport projects (think of tunnels or rail tracks or bridges) typically include components such as earth removing, concrete, or steel, that have a much longer life than cameras and computers. This difference accounts for a large discrepancy between our estimate and Transek's estimate of implementation cost.

[1] Assuming that each reminder costs 20 SEK (2€) and that each appeal consumes 3 hours (a conservative estimate), this is already 3 M SEK/month.

[2] This may be an underestimate. Some reports put additional charge system costs for the Road Administration (including the investments taken into account here) at 300 M SEK, for the Municipality of Stockholm at 300 M SEK, and for Q-Free the enterprise that provides transponders at 140 M SEK.

Opportunity cost of capital. The opportunity cost of capital – the fact that the public funds invested in the toll would have produced utility had they been invested in other areas, such as research for instance – must be at least 5%.

Marginal cost of public funds. Finally, there is the marginal cost of public funds. This refers to the idea that the taxes that have financed the investment have decreased output by a factor l. In a high tax burden country like Sweden (or France for that matter), it is officially considered to be around 30%. This factor l should be applied to amortization, and to operation costs, but not to the opportunity cost of capital. The calculations are presented in Table 5. they produce a socio-economic cost of the toll system of 512 M SEK (56 M €) per year. Is this high? The main reference available is the London toll system: the cost of the London system is more than twice higher than the cost of the Stockholm system, for a fairly similar output (about 100,000 charges per day).

Table 5. Socio-economic Costs of the Toll System.

	(M SEK)
Investment costs:	
by IBM	*1834*
by NRA	*94*
Total	*1928*
Yearly costs:	
Amortization	241
Oportunity cost of capital	96
Operation costs	79
Marginal cost of public funds	96
Total	512

Sources and notes: See text

iv. Externalities

Less car traffic means less CO2 emissions, less local pollutants emissions and perhaps less accidents. All these reductions imply welfare gains.

CO2

Gains associated with the reduction of CO2 are easiest to estimate. The toll eliminates 60 thousands car trips of 17.2 km between the periphery and the Center per day. It saves 1.03 M vehicle*km/day. This is a serious over evaluation because it assumes that the toll did not induce more or longer trips in the rest of the agglomeration. Assuming an average consumption of 0.1 liters per km – probably another over evaluation – and knowing that 1 liter of fuel consumed produces 2.35 kg of CO2, the toll led to a reduction of 242,000 kg, or 242 tons of CO2 per day. With a price of 25 € (32 US$) per ton, the official French value based on the number produced by a committee chaired by Marcel Boiteux, higher than the value estimated by the International Energy Agency as the average cost of all the investments that would be required to put the globe on a sustainable CO2 path (and much higher than the not too meaningful CO2 market price), this is a gain of 14 M SEK (1.5 M €) per year.

Air pollution

Gains associated with the reduction of local pollutants (NOx, particulates, etc.) are more difficult to estimate. Emissions were reduced like traffic: by about 15%. Air pollution costs were reduced by about this percentage. But we have no estimate of air pollution costs in 2005. We shall use the French official value that estimates the marginal cost of local air pollution created by one vehicle*km driven in "dense urban area"[1] at 0.029 € or 0.26 SEK. The toll induced reduction of 1.03 M vehicle*km is therefore associated with a gain of 67 M SEK (7 M €) per year.[2]

Accidents

The impact of the toll on accidents is twofold. On the one hand, there are less vehicle*km driven, and therefore a lower probability of accidents. This factor would account for a 16% reduction in accidents.

On the other hand, these vehicles are driven at higher speeds, which increases the probability and seriousness of accidents per vehicle*km. The relationship usually accepted, based on a study by Nilsson (2000), is the following. With s1 and s2 the speed in 1 and 2, the number of accidents is multiplied by $(s2/s1)^l$ with l=2 for accidents, l=3 for serious accidents and l=4 for fatalities. The changes in speed arrived at in this study imply for the part of trips on the radials increases of 9% for accidents at large, of 14% for serious accidents and of 19% for fatalities; for the part of trips in the Center, the increases are

[1] Ministère de l'Equipement, *Instruction-cadre relative aux méthodes d'évaluation économique des grands projets d'infrastructures de transport*, 25.3.2004, Annex I p. 5. Dense urban area is defined as an area with a density higher than 420 inhabitants/km2. The density of the Stockholm «metropolitan area» is 498 inh./km2.

[2] The Evaluation report (Stockholmsforsöket 2006 p. 119) values reductions in air pollution emissions at 22 M SEK/year.

respectively 22%, 35% and 49%. To be on the safe side, we shall assume that the impact on accidents in the Center is similar to the impact on radials.

Table 6. Accidents Reduction Gains.

	Casualties	**Serious accidents**	**Minor accidents**
In the county in 2005 (number)	40	804	4086
On roads affected by toll (number)	7.9	158	805
Change due to toll (in %)	+3%	-2%	-7%
Change due to toll (in number)	+0.24	-3.16	-56.3
Unit cost (M SEK)	17.5	3.1	0.175
Toll-induced cost reduction (M SEK)	+4.1	-9.8	-9.9

Notes: Very conservative estimates, that ignore increased accidents in the Center due to increased speeds, and also ignore increased accidents in the rest of the county due to toll-induced increased traffic in the rest of the county.

Overall, accidents at large should have decreased by 7%, serious accidents by 2% and fatalities increased by 3%. These numbers apply to the 2005 traffic affected by the toll on the radials and in the Center. According to the Transport survey, Periphery-Center trips plus Center-Center trips represent, in vehicles*km, slightly less than 20% of Stockholm county trips. We will assume it represents also 20 % of traffic accidents, although this is a gross *overestimate* because average speeds in the county are certainly higher than on the radials and in the Center. We can therefore estimate the number of accidents in 2005, changes in that number due to the toll, and by multiplying by the unit cost, the cost of accidents.

This procedure produces a decrease in accidents costs, i.e. a gain, of 15.6 M SEK (1.7 M €) per year. The increase in the number of casualties, 0.16 casualties per year, is not observable. The estimate by Transek and Eliasson (*ibidem*), 125 M SEK/year is hard to reconcile with the much greater increases in speed calculated by Transek and Eliasson. Such increases should produce an increase in accidents, and accident costs, rather than a decline.

v. Secondary markets: Public Transportation

About half car users evicted out of the roads by the toll shifted to public transportation. Relative to the car market modified by the toll, the Public Transportation (PT) market is a "secondary market". The standard theory of cost-benefit analysis (see for instance Boardman 2001, p. 116) is that what happens on "secondary markets" should be ignored because it is already reflected in the demand curve on the primary market (in our case the demand curve for car trips). There is one important exception to this rule : the presence of market imperfections, such as externalities, or zero marginal costs, on the secondary market. We must therefore examine if there are such market imperfections here.

There are indeed externalities, and more precisely, congestion externalities, in the PT market. Assuming a fixed supply of public transport (just as we assume a fixed supply of road when discussing road congestion), an increase in the number of users will lead to increasing user costs. This increase does not take the form of time lost but of comfort lost. As a matter of fact, one can take the analysis of road congestion and replace "time lost" by "comfort loss", in order to define for public transport an individual cost curve, a social cost curve, a marginal congestion cost which is an externality, and an optimal public transport usage that could be reached thanks to … a public transport congestion toll.

Public Transport Congestion Costs

Unfortunately, it seems that there are few studies of this phenomenon; the paper by Armelius and Hultkrantz (2006) – on the Stockholm case – is a noteworthy exception. In principle therefore, and in the absence of increase in PT supply, we should estimate the increased congestion costs generated by the toll-induced shift in the PT demand, and take this estimate as a cost of the toll.

Are there positive externalities in the form of time gains for PT users, as is often assumed in the literature? Potentially bus users (although not subway and train users, which are more numerous than bus users in Stockholm) could benefit from road congestion reduction and increased traffic speeds, as happened in London. But this appears not to have happened in Stockholm. Stockholmsförsöket (2006, p. 49-50) reports that «*average [bus] speeds throughout most of the trunk road network during the peak morning hour from 7.30-8.30 is unchanged or has improved/deteriorated by a maximum of one km/hour*», and provides a map to that effect. Bus users could also in principle benefit from an increase in bus demand, if such an increase were to result in increased bus frequency that would diminish waiting times (this is the so-called Mohring effect). This did not happen in Stockholm, because bus frequencies on existing buses are reported not to have been modified. Had bus frequencies been modified optimally (at a cost), the public transport congestion cost actually experienced in Stockholm might have been decreased or eliminated. The main public congestion problem in Stockholm, however, is not related to buses, but to subway and trains (which is much more important) characterized by fixed supply.

In reality things are complicated because there was a specific increase in public transport supply in Stockholm. Some 200 buses were added, a few months before the toll experiment started, for service on new lines at peak times. The economic cost of this addition can easily be estimated. The economic gain of this addition, however, is twofold.

First, it mitigates the increase in PT congestion on rail and subway lines and reduces its cost. If the added bus supply were sufficiently large, it could even prevent any increase in PT congestion. This is not what happened in Stockholm, where congestion increased. This "residual" congestion increase cost must therefore be estimated, and added to the increased supply cost.

Second, the PT supply increase was not merely quantitative, but also qualitative. The new bus lines did increase the welfare of some PT users. As a matter of fact, it seems that nearly all of the new bus lines users were previously PT users. They shifted from suburban trains or metro, because the new bus lines are faster. Since they pay the same fare, the time they gain is an increase in their consumer's surplus. It has to be estimated, and deducted from the other items identified.

In spite of this increase in public transport supply, it appears that travel conditions in public transport deteriorated somewhat. Punctuality declined by about 5% in the subway and in commuter rail services (Stockholmsfosöket 2006 p. 51). Cancellations of scheduled subway and commuter trains increased. The proportion of standing passengers increased in the underground (+2 percentage points), in suburban trains (+2 percentage points), in inner city bus services (+ 1 percentage point) but decreased (-1 percentage point) in commuter trains (*ibidem*).[1] Public transport ability to keep on time was also poorer in Spring 2006 than in Spring 2005. Overall, the proportion of public transport passengers who are satisfied decreased from 66% in Spring 2005 to 61% in Spring 2006 (*ibidem*). PT congestion therefore increased, and this increase has a welfare cost. It is difficult to put a money value on these costs. We can offer three – admittedly fragile – estimates.

One is derived from the congestion function proposed by Armelius & Hultkrantz (2006) for Stockholm:

$$T = 8{*}(0.1562+0.0686{*}(n/N)^2)$$

With T = unit cost expressed in hours, n = number of PT trips, and N = total number of trips. An additional 45,000 trips in PT leads to a congestion cost

[1] These (measured) numbers are fairly consistent with the fact that the 33,000 additional trips in PT represent about 2.5% of PT patronage: most of these additional PT travellers are added to the people who travel standing.

increase of 333 M SEK per year. Imputing ¾ of this cost to the toll produces a toll-induced PT congestion cost increase of 250 M SEK (27.3 M €) per year.

The other is derived from the practice of SL, the Stockholm public transport company: if the value of time of people seated in public transport is 1, the value of time of people standing in buses is 2, the value of time of people standing in railways in moderate congestion is 1.5 and in severe congestion is 2. According to the Transport Survey, the average duration of public transport trips is 40 minutes. Assuming that one fourth of this time is access and waiting time, time spent in public transport is on average 30 minutes. The total amount of time spent in public transportation is about 662,000 h per day (1,325 thousands trips of 30 minutes each). A 1.34 percentage point increase[1] in the number of standing travelers represents 8,900 hours of additional standing per day. Valued at 98 SEK per hour, this amounts to 218 M SEK per year. As mentioned before, only three-fourth of this cost, i.e. 168 M SEK (18 M €) per year should be allocated to the toll.[2]

The third is based on an Australian study (the only one of its kind we were able to find) quoted by Litman (2007, p. 11) who writes: "Below a load factor of 80% (80 passengers divided by seats) no crowding cost is incurred. At 100%, crowding increases [unit] costs by 10%. A 160% load factor increases costs by 60%". When crowding is modest, a patronage increase of 25% produces a unit cost increase of 10%: the elasticity of time cost to patronage is 0.4; when crowding increases further this elasticity becomes 0.75. Let us assume that crowding is modest in Stockholm public transport, and retain this 0.4 elasticity. The 33,000 toll-induced additional trips represent a 2.5% increase in patronage, and a 1% increase in unit cost. Multiplied by the 662,000 hours spent daily in public transport valued at 98 SEK/h, this amounts to 162 M SEK per year.

These three estimates are, perhaps by chance, fairly consistent. The first one measures the PT congestion cost generated by the toll. The other two are estimates of the residual congestion cost, after it has been mitigated by the increase in PT supply. They are therefore underestimates of toll-induced PT congestion costs. To be on the safe side, we will nevertheless retain them. We can note that PT increased congestion costs are of the same order of magnitude as car decongestion benefits.

[1] This is the average of changes in the various public transport means (underground, buses, etc.) weighted by the importance of «boardings» on each of these means.

[2] Transek (2006) ignores this cost; Eliasson (2009) writes that: «assuming that the value of time when standing is twice the noram value of travel time, the cost for the increased risk of standing can be estimated to be around 15 M SEK/year», but does not explain how this number is arrived at.

Public Transportation profitability

The increase in the PT profitability is measured by the change of the producer's surplus. It is equal to additional fares minus additional costs associated with toll-induced increased patronage. Additional fares are easy to estimate. The average user fee (total fares divided by number of trips) in 2005 was 12.5 SEK/trip (1.4€). For 33,000 trips/day and 250 tolled days, this is 102 M SEK (11.1 M €) per year**.** Unfortunately, we do not know much about the marginal cost. To be on the safe side, we will assume that the money marginal cost is zero, and that the only marginal costs are in terms of increased congestion. This is an hypothesis extremely favorable to the toll.

If we want to ignore the bus supply component of the package and focus on the toll only, this cost and this gain is all we should consider.[1] If we want to include this component in the evaluation, two additional items must be estimated.

Cost of increase in public transport supply

It is difficult to increase public transport supply in Stockholm, for technical and economic reason. As mentioned above, the only significant increase introduced in conjunction with the toll was the purchase of about 200 buses put on service on 16 suburban lines at peak hours. It is reported that the associated investment (borne by the central government) amounts to 580 M SEK (63 M €), and that associated yearly operation costs amount to 341 M SEK (37 M €). About half of operation costs are covered by subsides (also borne by the central government). Table 7 presents these costs on a yearly basis. The cost of increased bus supply is estimated at 559 M SEK (61 M €) per year.

Table 7. Costs of Increased Public Transport Supply.

	M SEK
Investment costs	*580*
Yearly costs:	
Amortization[a]	106
Opportunity cost of capital[b]	29
Operation costs	341
Marginal cost of public fund[c]	83
Total	559

Notes: [a]over 5 years. [b]5% of investment cost. [c]30% of amortization and (government paid) operation costs

[1] With the marginal cost of public fund associated with the additional subsidy (equal to additional fares) given to SL by the County Coucil.

Increase in consumer's surplus on new bus lines

Most of the new bus lines users are former PT users who find the new service "more convenient", "faster" or "with fewer changes" than the previous one. The data we found on the number of new bus line users, and on their gain, is not very good. On the number of beneficiaries, we have the number of vehicle*km per year (7 M). Assuming an average bus load of 15 person/bus, this is 105 M passengers*km. This number is consistent with another estimate obtained by multiplying the total number of passengers*km by the ratio of new bus lines to total bus lines. Assuming an average trip distance of 17.2 km, we obtain 6.2 M trips/year[1]. The average trip time by PT was 44 minutes. Let us assume that the new bus lines decrease transport time by 15%, or 6.6 minutes/trip – a rather generous assumption. This translates into time savings of 680,000 hours/year. At 92 SEK per hour, the value for all trips, this amounts to 62.6 M SEK/year. At 52 SEK per hour, the more realistic value of time for non business trips only, this amounts to 35.4 M SEK/year. To keep things simple, we shall retain the average of these two estimates: 49 M SEK (5 M €) per year.

VI. Public Finance Impacts

Toll proceeds. The money raised as toll payment, which amounts to 792 M SEK (86 M€) per year, should be ignored. This amount is neither a gain nor a cost. It is a transfer. It is money taken out of the pocket of car users, which obviously decreases their welfare, and welfare in general. But it is money that increases the revenues of public bodies, and that will supposedly be spent usefully (for transportation purposes or for equally desirable different purposes, it does not matters) and will therefore increase welfare by the same amount. The two welfare changes cancel each other. It would be a mistake to count as a benefit the useful actions that will be financed by this payment, while ignoring the cost borne by those who pay the toll. It would equally be a mistake to count as a cost the toll paid by car users while ignoring the welfare benefits the toll payments will finance. Both must be counted, or more simply, ignored.

However, it can be argued that this money, which accrues to the national Treasury, is much less distortionary than ordinary taxes. As a matter of fact, it is not distortionary at all, since it modifies behaviors in a desirable direc-

[1] This means about 25,000 trips per day, quite consistent with the 33,000 additional PT trips generated by the toll.

tion. It is therefore justified to apply the marginal cost of public funds to toll proceeds, and to count 234 M SEK (23 M €) as a social benefit.

Fuel taxes. A similar issue arises with respect to the reduction in fuels taxes brought by the toll. We estimated the fuel consumption reduction to be 103 M liters per year. With taxes of about 7 SEK per liter, this is a tax loss of 70 M SEK per year for the Treasury. Fuels taxes are not distortionary, and they are likely to be replaced by more distortionary taxes. We can therefore apply the marginal cost of public funds to this amount and count 21 M SEK (2 M €) per year as a social cost.

Increased subsidy to SL. The subsidy to SL happens to be about equal to fares paid by users. If fares increased by 102 M SEK, as estimated, the subsidy increased by the same amount. Thirty percent of this subsidy, or 31 M SEK (3 M €) is a social cost.

VII. CONCLUSIONS

We are fully aware of the limits of this analysis. Additional efforts should be made to try and evaluate the cost of a deterioration of service levels in public transportation. One could also try to distinguish between peak and non-peak periods. It would also be important to try to assess the distribution of the various gains and costs amongst different income groups or different geographical areas. It must also be clear that we have only focused on short-terms effects, deliberately ignoring the impacts the toll might have on location patterns. In addition, the analysis is static. The gap we find between costs and gains would be reduced if traffic – and in the absence of a toll, congestion – were to increase, and would one day be reversed. Over time, the value of time would also increase, increasing further this congestion gain. In addition, environmental gains would also increase. So would toll proceeds, and the associated marginal cost of public funds saved. By 2020, the toll would probably be generating social benefits, although much would depend upon the marginal cost of public transportation supply. On the other hand, over a longer time-period, the toll would probably induce some people and enterprises to relocate outside the tolled zone, which might increase transport and transport costs.

In spite of all these shortcomings, our analysis helps answer three important policy questions: is the Stockholm toll welfare increasing? How important are congestion costs? When is a toll justified in practice?

Is the Stockholm toll welfare increasing?

Unfortunately not. TABLE 8 summarizes our findings.

TABLE 8. Toll Induced Socio-economic Costs and Gains.

	M SEK/year	**M €/year**
Consumer surplus:		
Time gain for car users	+174	+19
Surplus loss of evicted car users	-61	-7
Total congestion-related impacts	*+113*	*+12*
Toll implementation cost	-512	-56
Externalities:		
CO2 reduction gain	+14	+1
Air pollution reduction gain	+67[a]	+7
Accidents reduction gain	+16	+2
Total environmental gains	*+97*	*+13*
Secondary markets:		
Cost of increased PT congestion	-168[b]	-18
Increase in SL surplus	+102[c]	+11
Cost of increased public transport supply	-559	-61
Welfare gain of new bus line users	+49	+6
Total impact on public transportation	*-576*	*-62*
Public finance gains and costs:		
MCPF[d] on toll revenues	+234	+26
MCPF on fuel taxes forgone	-21	-2
MCPF on increased PT subsidies	-31	-3
Total impact on public finance	*+182*	*+20*
Total	-186[e] or -698[f]	-20 or -76

Source: See text. *Notes*:[a]Overestimated by ignoring likely toll-induced additional suburban travel; [b]the lowest of two fragile estimates; [c]Overestimated by the amount of an unknown marginal cost or increased patronage; [d]MCPF stands for marginal cost of public funds; [e]Ignoring gains and cost of increased bus supply; [f]Considering increase in bus supply as part of a toll plus bus supply package.

TABLE 8 shows that costs outweight benefits by nearly 190 to 700 M SEK (21 to 76 M €) per year. The first number relates to the toll *stricto sensu*, the second to the toll plus new bus lines package. These numbers are estimates of the yearly socio-economic gains and costs associated with the toll. They tell what a toll like the one introduced in Stockholm would cause in a city like Stockholm on a yearly basis.

There are indeed uncertainties attached to several of the numbers produced. Note, however, that in doubtful cases, we have usually made the choice most favorable to the toll. We therefore probably overestimate the gains of the toll and underestimate its costs. The main lessons of the analysis, however, are largely independent of the precise numbers produced: they relate to the type, nature – and orders of magnitude – of benefits and costs to be considered.

The structure of gains and costs is interesting. Traditional economic analysis focuses nearly exclusively on congestion-related gains, and justifies a toll on the basis of such gains. Yet, as Table 7 shows, these gains and costs are relatively small: a little more than 100 M SEK (12 M €). Four or five other elements often ignored weight as much or more, and determine the economic viability of a toll. (i) One is environmental costs, for about 100 M SEK (11 M €). (ii) A second relates to the implementation costs of the toll system, for about 500 M SEK (56 M €). Economists tend to assume away this "transaction costs", as if imposing a toll was costless: it is not. (iii) A third item, also usually neglected in theoretical analyses, is the cost of increased public transport congestion, partly limited by an hypothetical increase in SL producer surplus. (iv) A fourth is the cost of increasing PT supply incurred to mitigate it, for about 500 M SEK (56 M €). (v) A fifth item is linked to the toll proceeds and to other public finance related impacts. Toll proceeds are in principle neither a gain nor a cost, but assuming they reduce taxes, the marginal cost of public funds forgone is a gain, for more than 200 M SEK (20 M €), partly limited by additional public expenditures.

How important are congestion costs?

One of the main by-products of our analysis is an order of magnitude of congestion costs in Europe. Congestion costs should not be defined as the difference between existing driving times and free-flow driving times. The free-flow driving time (associated with heavy traffic) is an impossible reference situation. What makes sense is to consider the optimal driving time (and the associated optimal traffic) as the reference situation. And to define congestion costs as the difference between existing and optimal driving times, as the avoidable costs, as what can be gained by introducing optimal policies such as an optimal congestion charge.

It happens that the level of the Stockholm congestion charge was about optimal. Congestion was reduced, and was reduced as much as it could and should be reduced. The value of the net time gain estimated is therefore a good measure of congestion costs in Stockholm : about 110 M SEK per year.

This is to be compared with of an estimated GDP of the Stockholm municipality of about 360 G SEK.[1] This produces a congestion cost to GDP ratio

[1] The GDP of the Stockholm county, with 966,000 workers, is 670 G SEK in 2006; the

of 0.03%. With the congestion cost estimate of Transek, which is 4.5 times greater than our estimate (and, to our judgement, vastly exaggerated), this would yield a congestion/GDP ratio of 0.14%. These congestion cost estimates capture the benefits of reducing congestion in the entire tolled zone as well as on all the radials going into the city, that is most of the congestion in the municipality area. Stockholm is certainly the most congested part of Sweden. If congestion costs represent 0.03% of GDP in Stockholm[1] they cannot possibly represent more than 0.02% of GDP in Sweden.[2] We are very far from the congestion/GDP estimates of the European Commission that ranged from 2% to 0.5%. Congestion pricing is highly desirable in theory, but in a country like Sweden, it cannot increase welfare by more than 0.02%.

When is a toll justified?

Our negative conclusion about the social utility of the Stockholm toll does not condemn the concept of urban toll. Our appraisal helps understand the conditions required for an urban toll to be really welfare improving.

A first condition is severity of road congestion. In an urban area with very severe traffic conditions, widespread congestion and very low speeds, the benefits of reducing congestion to its optimal level will be much greater. The comparison of London and Stockholm is illustrative in this regard. The benefits achieved by reducing traffic by about 17% in broadly similar areas are about ten times larger in London than in Stockholm – because London was much more congested than Stockholm, and also because the value of time is higher in London.

A second condition is low implementation costs. Collecting tolls from millions of car drivers (the number in both Stockholm and London is about 40 million operations per year), checking or double-checking, pursuing delinquents, etc. is necessarily costly. Undoubtedly, technical progress and experience will drive these costs down, perhaps rapidly. Already, Stockholm costs are less than half London costs. For the time being, they nevertheless remain high.

A third condition is modest public transport congestion. Evicting car users might be desirable from an environmental and road congestion viewpoint. But some of the evicted car users will shift to public transportation. This will either deteriorate conditions in public transportation or require an increase in public transportation supply (or both, as in the case of Stockholm). The

number of workers in the municipality is 516,000; allocating the GDP pro rata then number of workers produces a GDP of the municipality of 358 G SEK.

[1] 0.14 according to Transek.

[2] 0.1% according to Transek.

cost of these two outcomes – the marginal cost of public transportation – will vary greatly from city to city. The lower they are, the more attractive the toll. These costs happen to be high in the case of Stockholm, although they are probably higher in many other cities.

It appears that these conditions were not fully met in the case of Stockholm. There must be, or there will be in the future, cities where they are met, and where an urban toll would be better justified than in Stockholm today.

To sum up, our main conclusions are: (i) the toll level set in Stockholm was about optimal; (ii) the time gains generated by this optimal toll represent about 0.03% of the GDP of the Stockholm municipality (which is much larger than the tolled zone); (iii) implementation costs, public transport congestion costs, environmental and public finance impacts are each as important or more important than time gains, and (iv) over all the social costs of the Stockholm toll outweight its benefits.

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