THE STOCKHOLM TOLL : AN ECONOMIC EVALUATION[1]

Rémy Prud'homme and Pierre Kopp[2]

January 25, 2007, revised May 23, 2007

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. These gains, calculated to be about +170 M. SEK (+19 M€) per year, appear to be modest, much lower than similar gains estimated in London, because congestion was moderate and reducing it to its optimal level, which is what the toll achieves, does not represent massive time gains. The toll also causes a loss for evicted car-users, for about -60 M. SEK (-7 M €) per year. It also produces environmental benefits, for an estimated +100 M SEK (+11 M€) per year. A major cost is the implementation cost, less than half the cost experienced in London, but nevertheless high at about -500 M SEK (-56 M€) per year. Finally, the toll led to an increase in public transport congestion tentatively estimated to be above -170 M SEK (-18 M€) per year, in spite of a very costly (about -500 M SEK or -61 M€, per year) increase in bus supply that may or may not be counted in an evaluation of the scheme. 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.

[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.

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

I – Introduction

On January 2006, the municipality of Stockholm introduced a charge or toll to enter the city Center. The main purpose of the charge is to reduce congestion on the radials leading to this center, and within it. The toll was a trial, established for a seven months period, to be followed by a referendum on its continuation. Transport economists worldwide are of course very much interested by this experiment, which is accompanied by an important monitoring, data gathering, and evaluation process. This paper, by independent academics, is a modest addition to this on-going evaluation. It is based on a simple model of congestion and congestion pricing (Prud'homme 1999) already used by the authors to evaluate the London congestion charge (Prud'homme & Bocarejo, 2004), and modified to suit the Stockholm case. There is already one (and apparently only one) evaluation, by TRANSEK, a consulting group, which has a quasi official character. Inasmuch as possible we will compare our findings with those of TRANSEK. The interest of the study, however, goes beyond the mere case of Stockholm, since it raises general issues about tolls and tolls evaluation.

The toll system has been abundantly described, and need not be presented here (see www.stockhomsforsoket.se, or Armelius & Hultzkrantz 2006). However, a few words on the transport context, based on a 2004 transport survey, might be useful. *First*, there were about 300,000 periphery-Center trips by car per day (not to be confused with car trips) and 80,000 Center-Center trips, which are potentially directly affected by the toll. They represented about 15% of trips by car in the agglomeration and about 10% of all motorized trips in the agglomeration. *Second*, in terms of modal share, trips by car dominated the picture at the agglomeration level, but public transportation did for Center-related trips, with about 550,000 periphery-Center trips and 200,000 Center-Center trips. *Third*, car trips are (on average) much faster (60%-80% faster) than public transport trips, even in the case of periphery-Center and of Center-Center trips, i.e. of trips affected by the toll. *Fourth*, congestion levels were modest: the average speed of Periphery-Center trips by car was 34 km/h including access times; assuming 5 minutes for access time, this means an average speed of 39 km/h, including stops at traffic lights corresponding to much higher speeds (around 50 km/h) on the radials and much lower speeds (around 23 km/h) in the Center.

The paper examines successively five types of benefits and costs: (i) the gains and costs of decreased road congestion generated by the toll, (ii) the environmental and safety benefits associated with it, (iii) the implementation costs of the toll, (iv) the public transport congestion costs generated by the toll and mitigated by investments in public transportation, and (v) the public finance impacts of the toll. The first category includes the time gains for remaining car users and the surplus loss of evicted car users, that is the classical elements that justify a toll; although it is not the most important in money terms, it requires more effort and more space than the other items.

II – Congestion Reduction Gains and Costs of the Toll

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. Knowledge of road characteristics and of road usage demand makes it possible to determine the optimal road usage, the optimal toll, the social benefits associated with this toll or indeed with any other toll. 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 or 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) as the key variable (q). These trips pay the toll in 2006. 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 τ 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:

$$c_r(q) = L_r*w*\tau/S_r(q)$$

- a time cost $c_c(q)$ for the time spent in the Center. With τ 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:

$$c_c(q) = L_c*w*\tau/[S_c(q+Q)]$$

Hence:

$$I(q) = L_r*w*\tau/S_r(q) + L_c*w*\tau/[S_r(q+Q)]$$

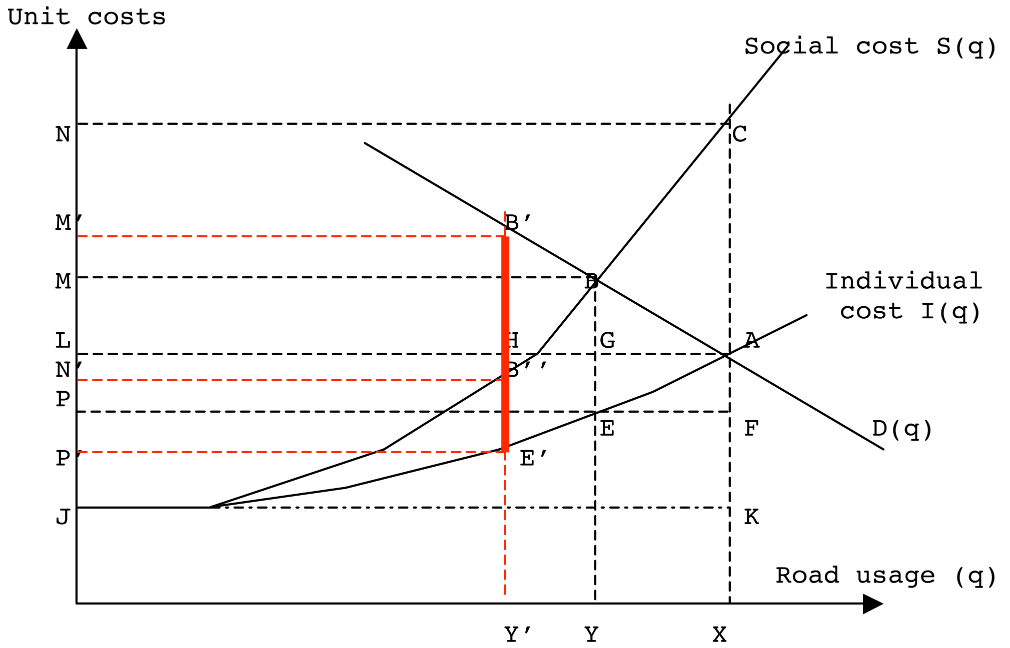
As can be seen on Figure 1, in the absence of toll, the demand curve D(q) and the supply curve I(q) intersect in A, which is the equilibrium point, with X trips on the radials. This situation, however, ignores congestion externalities on both the radials and in the Center. These externalities are equal to 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:

$$S(q) = I(q) + I'(q)*q$$

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 one of the objective of the study.

For the analyst, the beauty of the Stockholm experiment is that it 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, but described in Annex A). 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 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, not affected by the toll (the toll could have been expected to increase traffic during the off-toll period by inciting car users to leave earlier and to come back later) declined by 5.3%, reflecting exogenous forces. *Second*, one such obvious exogenous force is the fuel price increase: during the

[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

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 prices 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%. In our analysis we will consider 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. This is significantly less than the 20 or 25% declines often reported[1], and apparently utilized in the Transek study.

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. 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*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 453 thousands trips in 2006 as a result of the toll. It is worth noting that the bulk (about ¾) 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

[1] The number of vehicle trips per day (529 thousands) sounds rather different from the number of trips from suburb to center and center to suburbs recorded in the 2004 Transport Survey (305 thousands passenger trips, which would imply 243 thousand vehicle trips). The two numbers, however, can be reconciled by taking into consideration three flows : (i) the flow of people going from suburb to suburb through the center, (ii) the flow of goods vehicles and buses (not recorded in a Transport Survey), and (iii) the flow of people going from outside the county to the center (not recorded in a Transport Survey either). The first of these flows, according to the Transport Survey itself (Table 5.6) represents 160 thousands people, or 128 thousand cars. The second flow might represent an additional 20%, or 74 thousand cars. The third flow represents about 10% of all the other flows i.e. 44 thousand cars. This produces 243+160+74+44=521 thousand vehicles.

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

	Radials	Center
2005 (in 1000)	410	531
2006 observed (in 1000)	328	431
2006 counterfactual (in 1000)	390	493
Toll-induced change (in 1000)	-62	-62
Length (in km)	6.7	3.7

Sources : see text.

Speed-density relationships coefficients α and β - The relation between speed S and density D, which reflects the physical characteristics of road space, is known to be

[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 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.

linear: S = α + β*D. It is indeed easy to verify that it is so on Stockholm roads, because we have data on flow and speed for 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 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 α_r=57.33 and β_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 α_c=43.51, and β_c=0.0402[1]. The speed in the Center is therefore:

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

Value of time τ – 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

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

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 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
α_r = intercept in speed-q relation on radials	57.33	57.33
β_r = coefficient same relation	-0.0192	-0.0192
α_c = intercept in speed-q relation in Center	43.51	43.51
β_c = coefficient in same relation	-0.0402	-0.0402
τ_p= Value of time personal trips (SEK/hr)		52
τ_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.

Main Findings

With I(q) the individual cost curve, S(q) the social cost curve, D1(q) the demand in 2005 and D2(q) the demand

[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.

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[1] :

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

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

$$D_1(q) = 70.19 - 0.0898*q$$

$$D_2(q) = 83.36 - 0.130*q$$

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, 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.

[1] See Annex A for the details of the calculation of the demand equations

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

	2005	2006 Observed	2006 Estim.	Optimal /D1	Optimal /D2
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 : Author's calculations. *Note* : Time gains and surplus losses under 200 (observed) compare the effective situation to the initial 2005 situation ; under 2006 (estim) 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 couterfactual situation. M SEK = millions of Swedish crowns. 1 SEK = 0.109 €)

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 remaining car users of about 174 MSEK (19 M€) per year. Evicted car users suffer a loss, of about 61 M SEK (5.3 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 at 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.

Implied Elasticities

Our estimates of the time gains generated by the toll are low. They are particularly low relative to Transek's estimates, as shown in Table 4. How consistent are our estimates (and those of Transek) with what is known of the price-elasticity of the demand for car traffic ?

Table 4 – Time Gains and Surplus Losses, Transek and P-K Estimates

	Transek (M SEK/yr)	P-K (M SEK/yr)
Time gains for remaining car users	+523	+174
Decreased uncertainty	+78	-
Surplus Loss for evicted car users	-13	-61
Total, net gains	+600	113
Toll proceeds	792	792

Note : P-K stands for Prud'homme & Kopp

The large discrepancies shown in Table 4 do not seem to come from different values of time (both analyses use a value close to 100 SEK/h) nor from differences in vehicle*km driven. They come from differences in approaches. Our approach uses a relatively standard economic methodology, that mimics the behavior of car users by means of demand and supply curves. Transek's approach uses transport-engineering techniques to model, in a link-by-link fashion, flows and speeds in the entire county in 2005 and 2006. This makes it possible to capture the rich diversity of reality, including the role of traffic lights (something our simplified economic approach does not do). Physical changes are afterwards translated into economic gains and losses. In short, ours is an economic approach producing speeds and flows as a by-product, whereas Transek's is an engineering approach producing economic gains and losses as a by-product. In principle, both approaches are legitimate. We cannot discuss Transek's model, but we can –and should– compare the economic outcomes of the two approaches with what is known of economic realities.

A toll increases the cost of a trip by the amount of the toll, and decreases this cost by the amount of time gains. It is the difference between the two –the net increase– that induces some car-users to abandon their car. A system in which time gains are as high as toll payments is a logical impossibility (nobody would give up the car, and there would be no time gains). Transek's numbers come close to that situation, as shown in Table 4.

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 estimates imply an unlikely 74%

ratio. If we assume that only non-business users are eliminated by the toll, this increases the value of time for remaining car users (by about 10%), and pushes up our and Tansek's implied ratios by about 10%, making Transeks' outcomes even less plausible.

Table 5 – Ratio of Net Gains to Toll Proceeds

	Net gains/toll proceeds
Rothengatter	11% to 25%
Transek	74%
Prud'homme & Kopp	14%

Time gains, as estimated by Transek and by us can be transformed into time gains per trip, and deducted from the average toll per trip. This net cost increase is related to the average cost of a car trip. Dividing the relative traffic decrease by this relative unit trip cost increase yields an elasticity of traffic demand to price. Welfare losses, as estimated, also imply price elasticities. In the language of Figure 1, the welfare loss of evicted car users is B'AC= (HB'*HA)/2, and the elasticity is (AH/AL)/(HB'/HY'). Table 5 presents the resulting implied elasticities in the "base case" with the average value of time of 98 SEK/h and the average distance of 17.2 km/trip.

Nobody knows for sure the exact price elasticity of the demand for car transportation, which probably varies from place to place and time-to-time, but generally accepted estimates seem to be in -0.4 to -1.2 range[1].

Our estimates imply elasticities that are already on the high side. Two assumptions of the base case, however, can be questioned. First, if one considers that evicted car-users are all non-business trips, with a lower value of time, then the initial cost of a trip will be significantly reduced (by 35%), and so will be elasticities. Second, the cost of trip is calculated on the basis of the average length of periphery-Center trips (17.2 km). Many of these trips are likely to be shorter, therefore cheaper, requiring lower elasticities. As a matter of fact, it is interesting to note that, although

[1] In a survey article Litman (2006) writes : « A typical value is –0.5 (NHI, 1995). Booz, Allen, Hamilton (2003) estimate the generalized cost of travel in the Canberra, Australia region to be –0.87 for peak, -1.18 for off-peak, and –1.02 overall (peak and off-peak combined). Lee (2000) estimates the elasticity of vehicle travel with respect to Total Price (including fuel, vehicle wear and mileage-related ownership costs, tolls, parking fees and travel time, which is equivalent to generalized costs) is –0.5 to –1.0 in the short run, and –1.0 to –2.0 over the long run.

the net loss (toll minus time gains) for car users is nearly similar for all periphery-Center trips, it represents a percentage of the trip cost that decreases rapidly with the length of the trip. This means that people located near the tolled zone are more likely to give up their car than people located far away from the zone. Most elasticity estimates (think of km driven as a function of fuel prices for instance) have been calculated on cases in which the price change impacted equally all users. The elasticities implied by our estimates can therefore be reconciled with commonly accepted values.

Table 6 – Price Elasticities of Traffic Demand Implied by Estimates of Time Gains and Welfare Losses, Base Case

	On time gains		On welfare losses	
	P-K	Transek	P-K	Transek
Toll cost minus time gains[a] (SEK/trip)	8.0	2.4	-	-
Surplus loss implied cost increase (id)	-	-	7.0	1.3
Average initial cost[b] (id)	89.1	89.1	89.1	89.1
Cost increase (%)	9.0%	2.7%	7.9%	1.4%
Demand decrease (%)	–16%	–20%	–16%	–20%
Implied elasticities	–1.8	–7.4	–1.9	–14.3

Source: Author's calculations. *Note*: [a]The time gain utilized includes time gains by Center to Center trips that do not pay the toll and should in principle be excluded. [b]1.5 SEK/km*17.2 km + 1.25 person/car*31min*98/60 SEK/min. P-K stands for Prud'homme & Kopp.

This seems difficult to do with the elasticities implied by Transek's estimates. Not only are the values produced by time gains (-14) and welfare losses (-7) inconsistent with each other, they are well beyond anything reasonable.

III – Environmental Gains

Less car traffic means less CO_2 emissions, less local pollutants emissions and probably less accidents. All these reductions imply welfare gains.

CO2

Gains associated with the reduction of CO_2 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 overevaluation 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 overevaluation– and knowing that 1 liter of fuel consumed produces 2.35 kg of CO_2, 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 (an 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** (7M €) 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 $(s2/s1)^{\lambda}$ with $\lambda=2$ for accidents, $\lambda=3$ for serious accidents and $\lambda=4$ 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 respectively 22%, 35% and 49%. To be on the safe side, we shall assume that the impact on

[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 (Stockholmsförsöket 2006 p. 119) values reductions in air pollution emissions at 22 M SEK/year.

accidents in the Center is similar to the impact on radials.

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.

Table 7 – 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.

This procedures 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. Transek's estimate, 125 M SEK/year (Stockholmsförsöket 2006 p.119) is hard to reconcile with the much greater increases in speed calculated by Transek. Such increases should produce an increase in accidents, and accident costs, rather than a decline.

IV – Toll Implementation Costs

Operating a toll is not costless. The traditional approach to road pricing usually ignores 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 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,

[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 MSEK, for the Municipality of Stockholm at 300 MSEK, and for Q-Free the enterprise that provides transponders at 140 MSEK.

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. 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.

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 λ, which in a high tax burden country like Sweden, can be taken to be around 30%. This factor λ should be applied to amortization, and to operation costs, but not to the opportunity cost of capital. The calculations are presented in Table 8. 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 8 – 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

V –Public Transport Congestion Costs

Some of the car users evicted by the toll are now using public transportation (PT). As mentioned above, the number of car trips declined by 82,000, which means about 102,000 passenger trips. It is estimated that slightly less than half of these trips, that is 45,000 trips are now made by public transport. Since we estimated that about one-quarter of the registered decline in car trips is not attributable to the toll, we shall retain that the toll generated an increase of 33,000 PT trips. How can this be translated in terms of cost-benefit analysis?

Relative to the car market modified by the toll, the PT market is a “secondary market”. One could argue that these modal shifters incur a loss because their travel time has increased substantially (by some 50%), or a gain because they save on car transport expenditures, or that they enjoy a consumer’s surplus (what they are ready to pay is greater than the PT fee they actually pay). 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 for car trips, on the primary market. 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 this is the case.

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 (the individual cost curve plus its derivative multiplied by the number of users), a marginal congestion cost which is an externality, and an optimal public transport usage that should be reached thanks to … a PT congestion toll. 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.

Is there a positive externality 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) could benefit from congestion reduction and increased traffic speeds, as was the case 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.

Is it the case that there is a PT producer's surplus, equal to the additional fares paid by additional users ? The TRANSEK study assumes it. This would be true if no additional costs were incurred by the producer, that is if the marginal cost of PT in Stockholm was zero. This hypothesis, however, is unrealistic. Over the past five years, ridership in SL, the public transport company, has not increased at all, but total costs, in constant prices, have increased significantly (by 29%). This, if anything, would suggest an infinite marginal cost! This is in part explained by the fact that in order to maintain its ridership, SL has increased its supply (expressed in seat-km), and in part because the unit cost of inputs (wages, fuel) has increased faster than average prices. But it is difficult to believe that a company that increases its costs when its customers do not increase, would not have increased its costs (or even not increased them more than usual) when its customers did increase.

In reality things are more complicated because there was a specific increase in PT supply in Stockholm. Some 200 buses were added, a few months before the toll experiment started, for increased service on certain 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 and reduces its cost. If the added PT 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.

Some people believe that an evaluation of the toll should ignore this increase in bus supply. It is true that the two are not necessary linked. On the other hand, it can be argued that the toll and the buses were actually presented as complementary, as a package: all the apologetic literature produced by the Stockholm municipality makes reference to this increase in bus supply. The referendum on the toll was a referendum on the toll plus the new bus lines.

Cost of increased congestion in public transport

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

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.

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

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

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, remarkably 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.

Increase in producer surplus

The increase in producer surplus 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 (63M€), and that associated yearly operation costs amount to 341 M SEK (37 M€). About half of operation costs are covered by

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

subsides (also borne by the central government). Table 9 presents these costs on a yearly basis. The cost of increased bus supply is estimated at **559 M SEK** (61 M€) per year.

Table 9 –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	83
Total	559

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

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 of the Toll

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

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

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 direction. 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 is 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.

VIII - Costs and Gains Compared

Table 9 summarize our findings. It shows that costs outweight benefits by nearly 200 (20 M €) to 700 M SEK (98 M€) per year. The first number relate 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 yearly basis[1]. There are indeed uncertainties attached to many of the numbers produced, because they reflect choices made under insufficient information. Note, however, that in doubtful cases, we have usually made the choice most favorable to the toll. Let us give two examples: because we do not know what evicted car users do when they do not shift to PT, we assume they are not traveling elsewhere by car; because we do not know the marginal cost imposed on the public transport company by additional PT users we ignore it. 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 toll produces two main types of benefits: time savings for those who remain on the roads, for about 110 M SEK (12 M€) per year; and environmental benefits, for about 100 M SEK (11 M€) per year. A striking finding of our analysis is how modest are time savings. In the case of London, a traffic reduction of the same magnitude produced time savings (estimated by a similar methodology) about ten times higher. This merely reflects the fact that road congestion was much more severe in London than in Stockholm. Total benefits of the toll are very real: they amount to more than 200 M SEK per year. But they are to be compared with equally real costs –particularly implementation costs and public transport congestion costs– which turn out to be greater. The net result of the analysis is that the Stockholm toll is uneconomic.

[1] If one is interested only in the gains/costs of operating the toll system, ignoring the sunk investments costs (the question that was asked at the referendum), the system implies a net loss of 145 M SEK/year when the additional bus supply is taken into consideration, and a net gain of 247 M SEK/year if the additional bus supply is ignored, or eliminated.

Table 10 – Toll Induced Socio-economic Costs and Gains

	M SEK/year	M €/year
Congestion-related gains & losses :		
Time gain for car users	+174	+19
Surplus loss of evicted car users	-61	-7
Total congestion-related impacts	*+113*	*+12*
Environmental gains :		
CO2 reduction gain	+14	+1
Air pollution reduction gain	+67[a]	+7
Accidents reduction gain	+16	+2
Total environmental gains	*+97*	*+10*
Toll implementation cost	-512	-56
Toll-induced public transport gains and costs :		
Cost of increased PT congestion	-168[b]	-18
Increase in SL surplus	+102[c]	+11
Total PT congestion costs	*-66*	*-7*
Increased bus supply gains and costs		
Cost of increased public transport supply	-559	-61
Welfare gain of new bus line users	+49	+6
Total	*-510*	*-56*
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 public finance gains and costs	*+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 patrinage ; [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.

The structure of gains and costs is interesting. Traditional economic analysis focuses nearly exclusively on congestion-related gains and costs, and justifies a toll on the basis of these gains and costs. Yet, as Table 10 shows these gains and costs are relatively small: a little more than 100 M SEK (13 M€). Four or five other elements often ignored weight as much or more, and determine the economic viability of a toll. One is environmental costs, for about 100 M SEK (11 M€). 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. The fact that this cost will most probably decline over time with technical progress is one thing; ignoring that it is very high in Stockholm is another thing. A third item, also usually neglected in theoretical analyses, consists of the increase cost of public transport congestion, partly limited by an hypothetical increase in SL producer surplus. A fifth is the cost of increasing PT supply incurred to mitigate it, for about 500 M SEK (56 M€). A fourth item is linked to the toll proceeds and to other public finance related impacts. Toll proceeds are directly neither a gain or 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.

It is possible to allocate spatially these gains and costs. Congestion-related, environmental gains, and time gains for users of the new bus lines accrue to Stockholm residents and enterprises, as well as the cost of increased PT congestion. These gains and costs amount to a gain of about 81 or 130 M SEK (9 or 14 M €): in view of the uncertainties of these estimates, the toll can be considered slightly beneficial for Stockholm. All of the other elements (except for the small gain in CO_2, which benefits mankind at large), are costs for the Swedish central government, and therefore for all Swedish citizens.

VII – Conclusions

Our analysis remains provisional and tentative. Much work remains to be done. Many of the numbers we use, on traffic reductions, on speeds, on public transport supply costs, on accidents costs, etc. are relatively fragile, and will be improved in the future, when all the data collected has been processed. An effort 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 spite of all these shortcomings, our analysis authorizes some conclusions.

The Stockholm toll experiment offers a unique occasion to evaluate an important policy instrument, and one that justly receives a great deal of attention. In theory, a toll is fully justified to reduce road transport externalities in an urban area to an optimal level. The analysis shows that it does so indeed in Stockholm –and that theory is right. Traffic was reduced by the toll, speeds were increased, and time was saved. The analysis also shows that the toll level chosen was about right. More important is the fact that the costs generated by the toll in the case of Stockholm happen to be higher than the time benefits of the toll. Even if we add, on the benefit side, environmental gains, and the marginal cost of public funds on toll proceeds, total costs are definitely higher than benefits. Stockholm –or more precisely Sweden– would have been be much better off –by nearly 200 or 700 M SEK (20 to 100 M€) per year– without the toll.

The September referendum on the toll, which was positive in the Stockholm municipality, has been presented as evidence of popular support of this toll, and of tolls in general. This is not convincing. *First*, the question asked was not whether the toll was a good thing or not, but whether an existing toll, with important investments made, should be continued or not. *Second*, it was made clear that the additional bus service introduced in 2005 would be discontinued in case of a negative answer, a minor form of blackmail. *Third*, the voters were asked to compare the benefits of the scheme continuation, that accrue mostly to them, with the costs, that are borne mostly by Sweden at large; if anything the outcome of such a referendum would show that people are ready to have tolls, provided most associated costs are paid for by someone else. *Finally*, the question was asked to the residents of the Stockholm municipality only, who are a minority (44%) of toll users. Fourteen other municipalities in the county organized votes. Altogether, the popular vote was negative, as shown in Table 11.

Table 11 – Vote Results on Toll Continuation, Stockholm County, 2006

	Yes	No	Total	% Yes
Stockholm municipality	239,000	212,000	451,000	53.0
14 other municipalities	128,000	194,000	322,000	39.8
Sub-total	367,000	406,000	773,000	47.5
Other county municipalities[a]	128,000	134,000	262,000	48.9
Total	495,000	540,000	1,035,000	47.8

Note : [a]Estimated by means of a regression analysis estimating yes in municipality i as a function of left votes in municipality i as follows :

$$Yes_i = 3065 + 0.742\ Left_i \quad (R2=0.75)$$

and No in municipality i as a function of right votes in municipality i as follows :

$$No_i = -436 + 0.823\ Right_i \quad (R2=0.92)$$

Sources : http://val.cscs.se for referendum results in 14 municipalities, and www.scb.se for election results, with Left=s+v+mp and Right=c+fp+m+kd

The present 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. We explored this dynamics in additional work not reported here. 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.

Presently, however, the Stockholm experiment does not appear economically justified, and can be considered as a waste of scarce resources. This negative conclusion does not necessarily condemn the idea 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 15% 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.

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, even in Stockholm, 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 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 happens to be high in the case of Stockholm.

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 to-day.

References

Armelius, Hanna & Lars Hultzenkrantz. 2006. « The politico-economic link between public transport and road pricing : An ex-ante study of the Stockholm road-princing trial ». *Transport Policy*, vol 13, pp. 162-172

Boardman, Antony, et al. 2001. *Cost-Benefit Analysis*. Upper Side River, New Jersey. Prentice Hall. 526p.

Booz Allen Hamilton. 2003. *Transport Demand Elasticities Study.* Canberra Department of Urban Services (www.actpla.act.gov.au/plandev/transport/ACTElasticityStudy_FinalReport.pdf).

Lee, Douglass. 2000. "Demand Elasticities for Highway Travel," *HERS Technical Documents*, FHWA

Litman, Todd. 2006. *Transportation Elasticities How Prices and Other Factors Affect Travel Behavior*. Victoria Transport Policy Institute. 62p. (*www.vtpi.org/elasticities.pdf)*

Litman, Todd. 2007. *Valuing Transit Service Quality Improvements*. Victoria Transport Policy Institute. 34p.(www.vtpi.org/traveltime.pdf)

Nilsson, Goran. 2000. *Hastighetsförandringar och traficsäkerhetseffektur.* Vag-och-transport forkningsinstitutet. 11p. (VTI Nolat 76-2000)

Prud'homme, Rémy & Juan Pablo Bocarejo. 2005. « The London Congestion Charge : A Tentative Economic Appraisal ». *Transport Policy*, vol.12, n° 3, pp. 279-88.

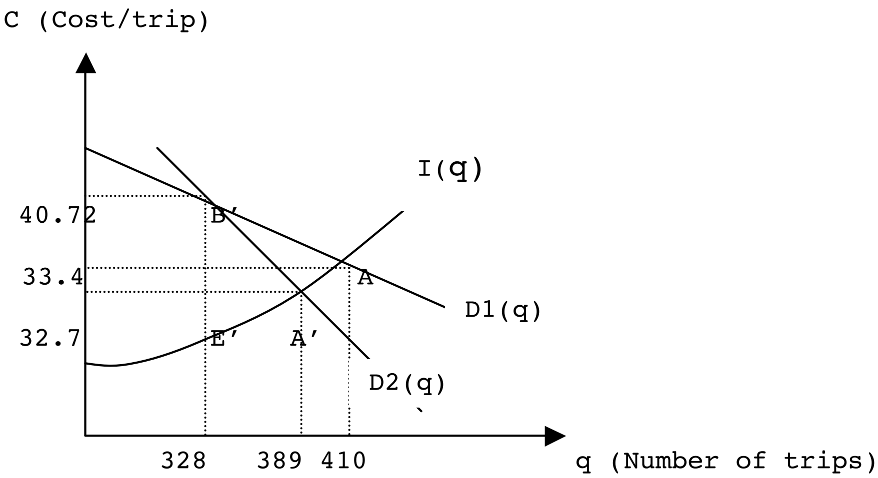
Prud'homme, Rémy. 1999. "Les coûts de la congestion dans la région parisienne". *Revue d'Economie Politique*. 109 (4), Juillet août 1999, pp. 426-441.

Rothengatter, Werner. 2003. How Good is First Best ? Marginal Cost and Other Pricing Principles for User Charging Transport ». *Transport Policy*. 10 :121-130.

Stockholmsförsöket. 2006. *Facts and Results from the Stockholm Trial First version June 2006*. 128p

(56,000 signs)

Annex A – Equations of the demand curves



Point A is the 2005 pre-toll situation, with q=410 and c=I410)=33.36. Point B' is the 2006 post-toll situation, with q=328 and c=I(328)+E'B', with the toll E'B'=9.7, ie with c=40.72

The equation of D1(q), the AB' line is:

$$D1(q) = 70.19 - 0.0898*q$$

Let us assume, as we do, that the demand curve has been shifted leftwards by exogeneous forces (such as higher fuel prices) by 5%. It means that, in the absence of the toll the 2006 situation would have been represented by A', with q=410*0.95=389.5 and c(389.5)=32.73. With the toll the situation is moved to B' as above, with q=328 and c(328)+E'B'=40.72.

The A'B' line is D2(q) the true demand curve to be considered in the analysis of the toll, and its equation is:

$$D2(q) = 83.36 - 0.13*q$$

Annex B – Calculation Sheet for Time Gains[1]

Calculation Sheet for Time Gains

Values of parameters:					
t=Value of time	98	98	98	98	98
w=vehicle occupancy	1,25	1,25	1,25	1,25	1,25
Lr=Length on radials	6,7	6,7	6,7	6,7	6,7
Lr=Length in Center	3,7	3,7	3,7	3,7	3,7
Q=Center to center trips	103	103	103	103	103
α_r	57,33	57,33	57,33	57,33	57,33
br	0,01915	0,01915	0,01915	0,01915	0,01915
ac	43,51	43,51	43,51	43,51	43,51
bc	0,0402	0,0402	0,0402	0,0402	0,0402
T=Average toll	9,7	9,7	9,7	9,7	9,7
Lr*w*t	820,75	820,75	820,75	820,75	820,75
Lc*w*t	453,25	453,25	453,25	453,25	453,25
	Initial	Couterfactual	Effective	optimal/D2	Optima/D1
Values of q:	410	389,5	328	324	324
Values of functions					
Ir(q) on radial	16,588	16,457	16,078	16,054	16,054
Ic(q) in center	16,770	16,273	14,947	14,868	14,868
I(q)	33,358	32,731	31,024	30,922	30,922
Sr(q)	19,220	18,919	18,056	18,002	18,002
Sc(q)	29,565	27,841	23,487	23,240	23,240
S(q)	48,785	46,760	41,543	41,242	41,242
D1(q)	33,357	35,199	40,724	41,084	41,084
D2(q)	30,066	32,731	40,724	41,244	41,244
S(q)-D2(q)	18,719	14,029	0,818	-0,003	-0,003
Sr	49,479	49,871	51,049	51,125	51,125
Sc	22,887	23,712	26,184	26,345	26,345
Externality	15,428	14,029	10,518	10,320	10,320
Toll			9,700	10,323	10,323
S(q)-D1(q)		0,000		0,158	0,158
Values of time gains:					
Effective relative to initial or counterfactual					
On radials	41,84	31,13		32,71	43,28
In Center	196,42	142,96		150,05	260,06
Total time gain	238,26	174,09		182,75	303,34
Surplus loss	75,51	61,45		69,70	83,06
Net gain/loss	162,75	112,64		113,05	220,28

[1] The Excell spread sheet can be found on http://www.pierrekopp.com/etudes.php