ROAD PRICING IN URBAN AREAS: A MEANS OF FINANCING INVESTMENT IN TRANSPORT INFRASTRUCTURE OR OF IMPROVING RESOURCE ALLOCATION, THE CASE OF OSLO

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1. INTRODUCTION

Road pricing has been discussed in the context of two objectives- improving resource allocation and financing the expansion of the capacity of the road network. An economically efficient transport policy measure to alleviate congestion and environmental impacts of congestion is to combine a socially "optimal" programme of expansion of the capacity of the road network with a socially "optimal" road pricing scheme.

A growing interest in alternative financing schemes for investment in transport infrastructure is partly due to the fact that different levels of government in Norway as in many other countries face increasing problem in financing these investments.

Already three cities in Norway- Bergen, Oslo and Trondheim- operate cordon tolls where inbound traffic is tolled. The decisions to operate the cordon toll were solely based on the need to supplement grants from the central government to finance major programmes of capacity expansion of the road network.

We focus on Oslo as a case study. The present cordon toll in Oslo is evaluated using a multi-modal, equilibrium model of demand and supply within discrete choice framework. "Cost of financing" through toll revenue, a measure comparable to the opportunity cost of public funds, is calculated for the present scheme. Based on this measure one can concluded that the present system is efficient. An alternative scheme that approximates a "socially optimal" cordon toll scheme is evaluated and compared with the present scheme. The benefits from a road investment programme without toll and with an "optimal" cordon toll

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This paper is an extension of previous works [Ramjerdi & Larsen, (1991) and Larsen, Mathiew & Ramjerdi, (1991)]. The author would like to acknowledge Heinz Spiess for his valuable suggestions on the calculation of the a "socially optimal" toll scheme.

scheme are compared. The benefits from the road investment programme decreases under the "optimal" cordon toll scheme. Finally we present the evaluation of a "socially optimal" road pricing scheme were vehicles pay a fee on every road link of their trip paths. The fee on a link is set equal to the social cost of travel on that link. We present the comparison of this scheme with an "optimal" cordon toll scheme.

2. METHODOLOGY AND ASSUMPTIONS

The general equilibrium effect of a scheme is evaluated using a multi-modal, model of demand and supply within discrete choice framework. In an earlier study (Ramjerdi,1988) such an approach is discussed in detail. However, in this study a simultaneous mode choice and equilibrium assignment model is used. The EMME/2 system has been used for this purpose.

The road network is represented by a network consisting of links and nodes in which travel time on each link is an increasing function of total link flow describing the technology of congestion, i.e. $t= f(V)$, where t is travel time and V is link flow. Car operating cost is proportional to distance travelled over the network. Travel times for public transport are also based on a network representation consisting of bus, street car, underground and, commuter train. Route choices are assumed to be strictly cost minimizing, in other words each trip from origin to destination by car or public transport, uses the minimum generalized cost route, where the generalized cost for cars is a weighted sum of travel time, car operating cost, parking,and toll fee (if the route includes a toll). The generalized cost for public transport is a weighted sum of walking time, waiting time, invehicle time and public transport fare.

In a "socially optimal" road pricing scheme, the social cost of travel on a link is charged on each link. Consequently the generalized cost of travel on a link, expressed in time, will be

$$t= f(V) + V f'(V)$$

A conditional logit model of mode choice for all trip purposes except for business trip was calibrated to apply to the fraction of travellers not captive to the public transport mode. Business travel by car and goods transport are assumed to be inelastic to toll rates within the range considered in this study.

Based on observed travel pattern, demand matrices for car and public transportation for 4 different time periods were estimated. Corresponding networks for these periods were constructed.

As the result of introducing any of the schemes discussed we can expect the following changes in the travel:

- shifts in modes of travel
- shifts in the timing of trips
- changes in the chaining of trips
- changes in destination choices
- changes in demand for travel (ie. trip generation)
- changes in route choices
- long term locational impacts.

In this study we assume that total demand for travel is met by public transport and road network. We have also disregarded the impact of a toll scheme on departure time, trip chaining and destination choice. Locational impacts of the toll scheme or of the road investment programme are disregarded.

We also assume that present excise taxes on gasoline and vehicles in Norway approximate the cost of wear and tear on roads and the environmental cost of a trip. What concerns us here is thus the congestion cost related to travel time and operating cost of vehicles.

Table 1. Unit Costs per Vehicle Hours in NOK

	Travel Time		Operating	No.of Hours
	Business	Other	Cost	Per Year
Peak Periods	166	38	3.25	460
Between Peaks	156	31	3.25	2000
Other Periods	167	27	3.25	4475

Table 1 shows a summary of the unit costs used in this study. The value of travel time in each time period is based on traffic composition during that time period.

The following formula can be used to get an estimate of the changes in user costs (Williams 1976):

$$UC = \sum_{ij} (C^{o}_{ij} - C^{\backslash}_{ij}) * (X^{o}_{ij} + X^{\backslash}_{ij})/2 - \sum_{ij} toll_{ij} * (X^{o}_{ij} - X^{\backslash}_{ij})/2 \quad (2)$$

The term C is the generalized cost of car trips between zone i and j net of toll payment. The first term in Eq (2) is the benefits due to less congestion and the second term is loss of surplus from suppressed trips that can be attributed to the toll. The toll fee paid by the traffic remaining, cancels out with the revenue from the toll and is not a social cost. We can generalize Eq (2) over all the modes considered. In this study we have assumed the generalized cost of travel with public transportation remain constant.

The location of the toll gates in Oslo is shown in Figure 1. Only inbound traffic is tolled. The toll ring is operated on a continuous basis. The fees in 1991 were 10 NOK for cars and vans and 20 NOK for heavy vehicles. Monthly passes were 250 NOK and 500 NOK respectively.

The annual cost of the present cordon toll scheme in Oslo is 96.6 Mill NOK (Ramjerdi & Larsen, 1991). This comprise of annualized capital cost of 26.6 Mill NOK and annual operating cost of 70.0 Mill NOK

The annual cost of the stops at toll gates comprising of cost of delays and additional fuel consumption is of the order of 4.9 mill NOK.

3. EVALUATION OF THE PRESENT CORDON TOLL SCHEME IN OSLO

Table 2 shows a summary of the evaluation of the present toll scheme in Oslo. As presented in this table the costs of the present toll scheme exceeds the benefits, and thus the scheme would not be worthwhile to introduce only for the sake of improving economic efficiency in the traffic system. The net benefits in the peak periods exceeds the net disbenefits in other periods, but not enough to cover the cost of toll collection.

The scheme turns out as an efficient means of raising revenue for road investment, and for this purpose it it is probably cheaper than government funds in Norway. The social cost of the scheme per unit of net revenue is 0.16 compared to marginal (welfare) cost of taxes of 0.2-0.4 for Norway. The (relative) social cost of a toll financing scheme (sc) can be written as:

$$sc = (CC + UC)/(R - CC)$$

where CC is the cost of toll collection, R is toll revenue and UC is users' costs.

From the decrease in traffic and savings in users' cost it is possible to calculate an average marginal cost for the traffic that switches to public transport. This is an average of the marginal cost in the no-toll situation and the marginal cost in the present situation. Average marginal cost (NOK) per trip for peak periods is 35.60, for between peaks is 3.80 and for other periods is 1.40. The marginal cost for tolled trips indicate that improvements are possible, as the marginal cost still exceeds the toll in peak periods and the toll exceeds marginal cost in off-peak periods.

Table 2. Summary of the Evaluation of the Present Scheme (Present Toll Scheme - No Toll)

BENEFITS MILL NOK PER YEAR:

	TIME SAVING	OPERATING COST SAV.	LOSS OF SURPLUS	TOTAL
PEAK PERIODS	42.1	2.4	-6.3	38.3
BETWEEN PEAKS	5.0	0.2	-7.0	-1.7
OTHER PERIODS	5.3	0.4	-20.4	-14.7
TOTAL	52.4	3.0	-33.6	21.9

BENEFITS TO TRAFFIC	21.9
STOPS AT TOLL GATES	-4.9
COST OF TOLL COLLECTION	-96.6
TOTAL	-79.6
COST OF FINANCING (sc):	0.158

4. EVALUATION OF AN "OPTIMAL" CORDON TOLL SCHEME FOR OSLO

In an earlier work (Larsen & Ramjerdi 1990) a cordon toll scheme which approximates an "optimal" scheme is calculated. This study indicates that a toll fee of about 25 NOK enforced on inbound traffic during the peak periods will approximate marginal (external) cost for the traffic concerned. The marginal cost for traffic in the other periods approximate zero. The same study points out to the necessary adjustment in the location of the present cordon toll. This improved location of cordon toll is illustrated by the broken line in Figure 1.

While the present scheme (Table 2) will not satisfy a simple cost/benefit criteria, but will provide low-cost funds, the estimates for an adjusted scheme will be accepted also on a cost/benefit basis. According to our estimates the net financial revenue will decrease from

503.4 Mill NOK per year with the present scheme to 110 Mill NOK per year with an "optimal" cordon toll. However, there will be no social cost that can be attributed to to the net revenue from an "optimal" scheme.

Table 3. Summary of the Evaluation of an "Optimal" Cordon Toll Scheme ("Optimal" Toll - No Toll)

BENEFITS MILL NOK PER YEAR:

	TIME SAVING	OPERATING COST SAV.	LOSS OF SURPLUS	TOTAL
PEAK PERIODS	108.5	6.0	-19.4	95.2
BETWEEN PEAKS	0.0	0.0	0.0	0.0
OTHER PERIODS	0.0	0.0	0.0	0.0
TOTAL	108.5	6.0	-19.4	95.2

BENEFITS TO TRAFFIC	95.2
STOPS AT TOLL GATES	-4.9
COST OF TOLL COLLECTION	-70.0
TOTAL	24.7
ESTIMATED TOLL REVENUE:	180.0

5. EVALUATION OF A ROAD INVESTMENT PROGRAMME FOR OSLO

Table 4 shows the evaluation of a road investment programme. Less then 1/3 of the benefits from the road projects considered in this study is from the traffic in peak periods and thus related to expansion of capacity, the rest might be attributed to improved "standard" of the road system.

A toll fee of 20 NOK enforced on inbound traffic during the peak periods approximate marginal cost in this case. The toll fee is thus lower than the "optimal" toll fee with no road investment. The marginal cost for traffic in other periods approximates zero.

Table 5 shows the summary of the evaluation of road investment projects with an "optimal" cordon toll scheme.

With the investment projects, the marginal cost and thus also the "optimal" toll decreases from approximately 25 NOK to approximately 20 NOK. As expected the benefits from road investments decrease when an "optimal" cordon toll is applied. However, the decrease is only about 10 %.

Table 4. Summary of the Evaluation of a Road Investment Programme (Investment/No Toll - Present System/No Toll)

BENEFITS MILL NOK PER YEAR:

	TIME SAVING	OPERATING COST SAV.	LOSS OF SURPLUS	TOTAL
PEAK PERIODS	73.3	4.3	2.0	79.5
BETWEEN PEAKS	79.7	3.0	0.5	83.3
OTHER PERIODS	59.2	4.6	1.0	64.8
TOTAL	212.2	11.9	3.5	227.6

Table 5. Summary of the Evaluation of an "Optimal" Toll Scheme with a Road Investment Programme ("Optimal" Cordon Toll/Investment - No Toll/Investment)

BENEFITS MILL NOK PER YEAR:

	TIME SAVING	OPERATING COST SAV.	LOSS OF SURPLUS	TOTAL
PEAK PERIODS	71.0	4.0	-15.8	59.2
BETWEEN PEAKS	0.0	0.0	0.0	0.0
OTHER PERIODS	0.0	0.0	0.0	0.0
TOTAL	71.0	4.0	-15.8	59.2

BENEFITS TO TRAFFIC	59.2
STOPS AT TOLL GATES	-.5
COST OF TOLL COLLECTION	-70.0
TOTAL	-11.3
ESTIMATED TOLL REVENUE:	167.0

6. EVALUATION OF A "SOCIALLY OPTIMAL" ROAD PRICING SCHEME FOR OSLO

Table 6 shows a summary of the evaluation of a "socially optimal" road pricing scheme. In a "socially optimal" road pricing scheme, the social cost of travel on a link is charged on each link.

This calculation shows that the total benefit in a "socially optimal" road pricing scheme is 50 percent higher than an "optimal" cordon toll scheme. However the estimated toll revènue decreases from 180 Mill NOK in "optimal" cordon toll scheme to 152 MILL NOK in a "socially optimal" scheme. The revenue is still larger than the benefit. However, the difference between the revenue and benefit is much smaller in a "socially optimal" road pricing scheme than an "optimal" toll scheme. Additional benefit in a "socially optimal" scheme comes from changes in route choice (changes to routes with lower total social costs). The reduced revenue in a "socially optimal" scheme compared to "optimal" cordon toll can also be attributed to this fact. The differences between net benefits and revenues from these two scheme indicate that the distributional effect in a "socially optimal" scheme is less and it is more equitable and hence politically more acceptable.

Table 6.Summary of the Evaluation of a "Socially Optimal" Road Pricing Scheme ("Socially Optimal" Scheme-No Toll)*

BENEFITS MILL NOK PER YEAR:	TIME SAVING	OPERATING COST SAV.	LOSS OF SURPLUS	TOTAL
PEAK PERIODS	162.61	7.62	-19.31	143.31
BETWEEN PEAKS	0.0	0.0	0.0	0.0
OTHER PERIODS	0.0	0.0	0.0	0.0
TOTAL	162.61	7.62	-19.31	143.31
ESTIMATED TOLL REVENUE:		152.08		

*An earlier study (Larsen, Mathieu & Ramjerdi, 1991) shows the estimated time saving and toll revenue differently. The author believes that this difference is due to error in methodology as well as data in the previous calculation.

Average trip length decreases from 15.48 km with out toll to 14.10 km in a "social optimal" road pricing scheme and to 13.81 in an "optimal" cordon toll scheme. This implies that a larger part of long trips in an "optimal" cordon toll are priced out compared to a "social optimal" scheme. In an "optimal" cordon toll scheme, toll fee for a major part of longer round trips is 50 NOK, lager than toll fee based on their social cost. Maximum toll fee in a "socially optimal" scheme for a round trip is 51.7 NOK. There are only 49 round trips with a fee of 50 NOK or larger. The minimum toll fee for a one way trip in the "socially optimal" scheme is -0.04 NOK. This implies that some motorist should be paid for taking a route in a "social optimal" scheme. However, only 38 trips have a negative fee. less than zero. These trips have their origins and destinations in the inner city of Oslo.

Table 7. Average and Standard Deviation of Toll Fee in a "Socially Optimal" Road Pricing Scheme for Different Trip Distance bands (one way trip)

Trip Distance, Km	Average Fee, NOK	SD
0- 2	0.00	0.00
2- 4	0.60	1.05
4- 6	1.63	1.92
6-10	3.52	3.69
10-15	6.06	5.31
15-20	8.17	6.21
20-30	9.12	6.62
30-40	8.93	7.26
40-50	8.42	6.51

Table 7 presents the average and standard deviation of toll fee paid in a "social optimal" scheme for different trip distance bands (one way trip). The standard deviation indicates of the degree of congestion of the different parts of the road network. A comparison of toll fees in a "socially optimal" scheme with that of an "optimal toll" scheme indicates that a "socially optimal" scheme is a more equitable system. This also points to the difficulties in political acceptance of an "optimal" cordon toll scheme. However, with the present technologies, the additional costs of a "socially optimal" road pricing scheme might be difficult to justify based on the additional benefits.

The calculation of toll revenue in the "socially optimal" scheme on links of the road network actually points out the location of some bottlenecks and where investment projects are planned.

6. SUMMARY OF CONCLUSIONS

We presented the evaluation of the present toll scheme in Oslo. The costs of the present toll scheme exceeds the benefits, and thus the scheme would not be worthwhile to introduce only for the sake of improving economic efficiency in the traffic system. However, the scheme turns out as an efficient means of raising revenue for road investment, and for this purpose it it is probably cheaper than government funds in Norway. The social cost of the scheme per unit of net revenue is 0.16 compared to marginal (welfare) cost of taxes of 0.2-0.4.

The evaluation of an alternative scheme that approximates an "optimal" cordon toll scheme was presented and compared with the present scheme. While the present scheme does not satisfy a simple cost/benefit criteria, but will provide low-cost funds, the estimates for an adjusted scheme will be accepted also on a cost/benefit basis. The net financial revenue is estimated to decrease from 503.4 Mill NOK per year with the present scheme to 110 Mill NOK per year with an "optimal" cordon toll. However, there will be no social cost that can be attributed to to the net revenue from an "optimal" scheme.

The benefits from a road investment programme with no toll and with an "optimal" cordon toll scheme were compared. The "optimal" cordon toll under road investment programme decreases from 25 NOK (with out road investment programme) to approximately 20 NOK. The benefits from the road investment programme decreases under an "optimal" toll scheme. However, the decrease is only about 10 %.

Finally we presented the evaluation of a "socially optimal" road pricing scheme and compared it with the "optimal" cordon toll scheme. A "socially optimal" scheme shows 50 percent more net benefit than "optimal" cordon toll scheme. The toll revenue in the "socially optimal" scheme is also less than the "optimal" cordon toll scheme. This should make the "socially optimal" scheme more politically acceptable. In addition, the comparison of toll fees in a "socially optimal" scheme with that of an "optimal toll" scheme indicates that a "socially optimal" scheme is a more equitable system. This points to the difficulties in political acceptance of an "optimal" cordon toll scheme. However, with the present technologies, the additional costs of a "socially optimal" road pricing scheme might be difficult to justify based on the additional benefits.

The calculation of toll revenue in the "socially optimal" scheme on links of the road network actually points out to the location of present bottlenecks and where some of the investment projects are planned.

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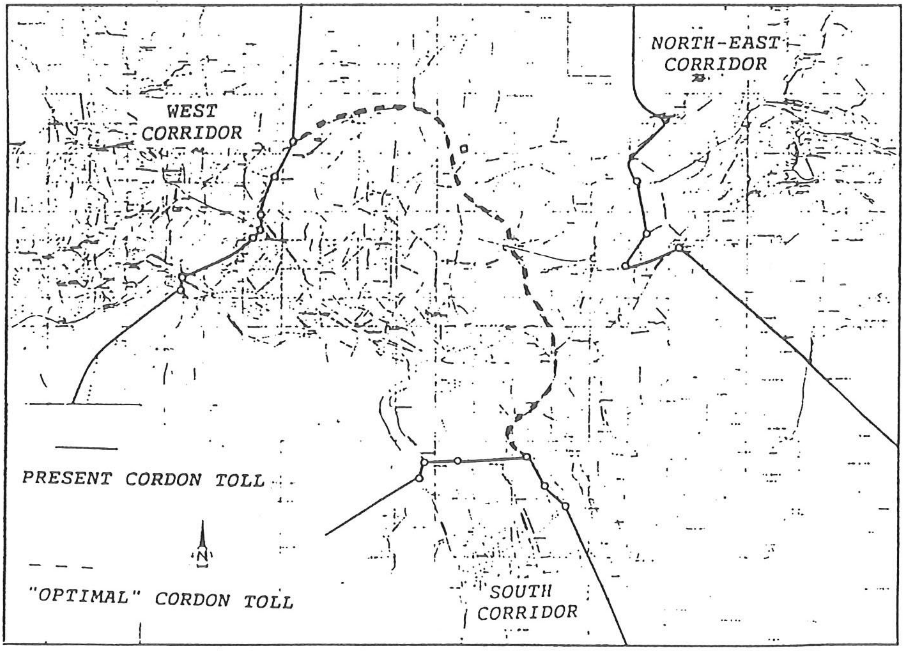

Figure 1. Location of the Cordon Toll in Oslo