ROAD INVESTMENT WITH ROAD PRICING - INVESTMENT CRITERIA AND THE REVENUE/COST ISSUE

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ABSTRACT

The investment criterion with road pricing is derived from a simple aggregate model of a road system. The model treats capacity and standard as joint products. The criterion implies that capacity should be expanded when the congestion component of revenue from road pricing per unit of capacity *plus* benefits of improved standard exceed the cost of adding a unit of capacity. Road pricing based on short run marginal cost will thus not in general provide proper financial incentives for investment. Whether the revenue from road pricing will cover the cost of the road system will in addition to the economies of scale in road construction also depend on the magnitude of the "standard" component. In an urban road system there may also be strong interdependencies between different projects as shown by an example from Oslo. This makes the provision of urban roads unsuitable for decentralized decisionmaking and thus also for a market solution. While road pricing may not provide the proper guidelines for investment envisaged by "standard" theory and we still have a long way to go before we are able to calculate the correct prices to apply, even very crude road pricing schemes can probably improve on the present situation in many urban areas. This is exemplified by estimates from Oslo.

1. INTRODUCTION

The theory of road pricing is well established. The speed-flow relationship for a road link, derived from traffic theory, is usually a starting point. While this "standard" approach highlights the basic principles, it also simplifies to the extent that many important aspects of road pricing may be overlooked. The theory can in principle also be extended to a road network in aggregate. In this case we must interpret changes in the volume of traffic as proportional change in the elements of a vehicle trip matrix and use aggregate measures as average trip time and average trip length for matrix. Again, while this might provide some additional insights both with regard to the impacts of changes in the leel of traffic and with regard to the impacts of different road projects, it also hides some important aspects. In practice, the application of the principle of road pricing to a road network is not without complications. The problems that emerge in application of the theory on the network level, have implications for several issues, including the possible benefits from private ownership and operation of roads. In the following, a road investment criterion with road pricing for a road network in aggregate, is derived. Then some of the problems that emerge in application of the theory to the network level, along with examples from Oslo and their implications, will be discussed.

2. THE COST OF ROAD TRAFFIC

The cost of road traffic consists of three major components, that is:
– The cost of providing and maintaining the infrastructure
– The cost to the users of the system
– The environmental cost caused by the road system and the use of the system

The first component corresponds to the capital- and operating costs of the infrastructure. The second component is the value of travel time and the operating cost of the vehicles using the system. The last component is the cost of noise, air pollution and barrier impact of roads. We might also include the cost of accidents to non-motorized traffic under environmental cost. For a model of road system we here define the following variables:

X = the number of vehicle trips per unit of time

L = the length of the road system in kilometers

$S = q \cdot L$; a variable defining the capacity and standard of the road system (q is average capacity per kilometer of road)

$k = X/S$ is an indicator for the utilization of capacity

In general the variables can be considered as vectors, but to keep the notation simple we use scalars. X should be interpreted as the number of trips in a vehicle trip matrix. A marginal increase in X is the result of a small proportional increase in all the cells of the trip matrix.

The central variable is S. In a road system, the capacity and standard are very often joint products when

road projects are implemented. If an existing road is improved or new road is constructed in order to increase capacity, the standard will usually be improved at the same time. It is not easy to give precise definitions of standard and capacity in road systems. Loosely speaking, it is all the aspects of a road system that influence driving speeds, driving distances and operating costs of vehicles under non-congested driving conditions. While a precise definition of capacity itself is difficult, we can at least relate an increase capacity to the observation that the difference between average trip time in peak and off-peak has decreased, provided average trip time is measured for the same vehicle trip matrices before and after the change in the road system. The only way to have a pure increase in capacity without any standard component is probably to add lanes to existing roads. At the planning stage of a new road link we can - of course- consider a pure expansion of capacity, for example from 4 to 6 lanes. However, the point is that the introduction of a new link by itself will influence the standard of the road system because driving time and/or driving distance between some of the origins and destinations will decrease.

An obvious example of increased standard is the replacement of a signalized intersection by a ramp junction. This will increase the capacity of the junction and the road links approaching the junction. However, in non-congested periods stops will avoid at the junction and this usually means considerable time savings. Replacing a signalized intersection by a roundabout may not make much difference with regard to delays, but off-peak it may approximate the effect of a ramp junction.

On the other hand, if a link in the road system is improved with the primary purpose of improving the standard, the capacity of the system will usually increase at the same time. This is normally the case in rural areas. Depending on the particular change in the road system we are looking at, the relative importance of the standard and the capacity component varies.

Using a single variable to represent both capacity and standard is admittedly not an ideal solution, but we avoid additional variables and functions that are not essential to the argument. Also, any measures or indices we can construct as indicatiors of standard or capacity in road system will probably depend on variables like q and L and be non-decreasing in a variable like S.

We will assume that the cost of the road infrastructure is a function of the length of the system (L), the average capacity per kilometer (q) and the traffic in the system (X). This cost function is defined as:

$$CI = L \cdot f(S,X) \tag{1}$$

The cost to the users of the system is defined as:

$$CU = X \cdot g(S,k) \tag{2}$$

where $g(S,k)$ is average user cost per vehicle trip and is a function of the standard of the road system (S) and the road system (S) and the load on the road system (k).
The environmental cost function is written as:

$$CE = m(X,q,L) \tag{3}$$

The signs of the partial derivatives of these functions are obvious except for $\delta m/\delta q$ (the partial derivative of m with respect to q) and $\delta m/\delta L$ (the partial derivative of m with respect to L). These may depend on the actual projects involved at any time. We have presented these cost functions in their general form, as more detailed description of them is not essential to the argument. We will also assume that L is constant and concentrate on q and X as variables. However, q and L enters nearly symmetrical in the model, so most conclusions with regard to q carries over to L. (In a mroe detailes model we could also replace q by variables that would allow us to distinguish between the number of lanes and capacity per lane.

3. INVESTMENT WITH ROAD PRICING

Ideally the task of a road authority is to choose q (and L) such that the total cost of the system is minimized for any volume of traffic, that is:

$$\text{minimize} \quad C = CI + CU + CE \tag{4}$$

The first order condition of a minimum with respect to q is:

$$\delta C/\delta q = L \cdot \delta f/\delta q + X \cdot \delta g/\delta S \cdot L - L \cdot k^2 \cdot \delta g/\delta k + \delta m/\delta q = 0 \tag{5}$$

274

Equation (5) can be interpreted to say that benefits shall equal the cost for the marginal project, and implicitly determines q as function of X i.e.

$$q = h(X) \qquad (6)$$

This allows us to write the long run marginal cost per vehicle trip as:

$$dC/dX = \delta C/\delta q \cdot dq/dX + \delta C/\delta X \qquad (7)$$

However, from equation (5) $\delta C/\delta q = 0$. Consequently $dC/dX = \delta C/\delta X$. This is a standard result in economic theory: When the infrastructure is optimal, given the volume of traffic, then short and long run marginal cost of increased traffic will coincide. Short run marginal cost in this model is given by:

$$\delta C/\delta X = L \cdot \delta f/\delta X + \delta m/\delta X + g(S,k) + k \cdot (\delta g/\delta k) \qquad (8)$$

Motorists pay their own cost in terms of the time used for the trip and vehicle operating cost, i.e. the average cost $g(S,k)$. Marginal cost pricing implis a price per trip (p) equal to:

$$p = L \cdot \delta f/\delta X + \delta m/\delta X + k \cdot (\delta g/\delta k) \qquad (9)$$

where $k \cdot (\delta g/\delta k)$ is the marginal congestion cost, $\delta m/\delta X$ is the cost of wear and tear on the roads and $\delta m/\delta X$ is the marginal environmental cost. We can solve for $k \cdot (\delta g/\delta k)$ in equation (9) and substitute the expression into (5) to have:

$$X/S.(p - L.\grave{U}f/\grave{U}X - \grave{U}m/\grave{U}X) - X"(\grave{U}g/\grave{U}S) = \grave{U}f/\grave{U}q + \grave{U}m/\grave{U}q \; 1/L \qquad (10)$$

which is the investment criterion with road pricing. In equation (10), $\delta f/\delta q$ is the cost of a marginal increase in capacity per kilometer of road. $-X \cdot (\delta g/\delta S)$ is the benefits due to increased standard. $\delta m/\delta q$ is the environmental cost of a marginal increase in capacity per kilometer of road. The first term on the left hand side $X \cdot (p - \delta f/\delta X - \delta m/\delta X)/S"$ is the revenue from congestion pricing per unit of capacity. Equation (10) can be interpreted in the following way:

When the revenue per unit of capacity from the congestion component of road pricing plus the benefits from improved standard, is equal to the cost of adding an additional unit of capacity (corrected for any environmental impact), then capacity should be increased.

In standard economic theory, the "rules" are that we shall set prices at short run marginal cost and expand capacity when revenue per unit of capacity equals the cost of adding a unit of capacity. The only deviation from standard economic theory is thus that there will be a user cost saving from capacity expansion that is not captured by the revenue from road pricing. This user cost saving is a result of the standard improving component of road investments.

In off-peak periods, the revenue from congestion pricing will be zero or very small, but there may be considerable user cost savings from improved standard. The same will be the case for parts of the road system even in congested periods. Consequently the revenue from road pricing will not be an appropriate measure of benefits.

An interesting issue - both from a theoretical and from a practical point of view - is whether the revenue from "correct" road pricing can provide useful signals as to where and how to invest in an urban road network. In rural areas, the benefits from most road investments can mainly be attributed to improved standard. investments in new roads and road improvements are madel long before traffic volumes reach levels that cause congestion of any important magnitude. This policy also makes sense from an economic point of view when there is an important standard component involved. Due to the fact that capacity and standard in practice appear as joint products, capacity will also increase even if there is no congestion. This is not an original observation. Jansson (1984) is, for example, very clear on this issue.

The point to be emphazised here, is that the standard component in road investment is important even in urban areas with considerable congestion in peak periods.

In addition to the example of intersections mentioned earlier, we may have the case where a new or improved road allows an increase in speed also in off-peak periods or where a new road decreases the distance of driving between different origins and destinations. Two implications follow from these observations:

275

i) Road pricing will - in general - not make cost-benefit analysis of road projects in congested road networks redundant. This would be the case if only capacity is involved and the environmental impact of a road project is included in investment cost as compensation to property owners, because all benefits and costs would then be in financial terms.

ii) Whether marginal cost pricing of road use in urban areas will provide enough revenue to cover the cost of the road system is not only a matter of the economies of scale and invisibilities in the provision of road capacity. It also depends on the magnitude of the "standard" component in benefits. In general no firm conclusion can be drawn on the relative importance of these factors.

Observations i) and ii) have also implications for privatization of the road system. We can not expect that a system with privately owned and operated roads will provide a road system that is optimally designed and where the users of the system are charged the "correct" price, i.e marginal cost. This does not mean that we should not be interested in promoting private operation of roads. It only means that we can not expect - in general - that a private market for provision of roads will give us an "optimum" road system and with "correct" pricing of the road services.

The simple model we presented above allowed some conclusions to be drawn for a road network in general. A model that starts from a stylized speed-flow relationship for single road-link tend to focus on capacity and misses the standard or quality aspect of a road system. It is possible to elaborate more on a model resembling the one above. Instead of minimizing cost, we can maximize social surplus with respect to p and q and thus explicitly introduce the demand side.

However, to really analyze the pricing, investment and revenue issues, we have to use models that treat the netwo4rk explicitly, and not as an aggregate entity.

4. CAN WE APPLY "CORRECT" ROAD PRICING?

It seems to be a common opinion that modern electronic systems may offer the possibility of applying "correct" pricing in urban road systems. There is no doubt that such systems can monitor the vehicles and the traffic flows very accurately. However there is still a long way to go before it is possible to calculate the correct congestion cost that should be charged to vehicles. A congested urban road system is more accurately described as a system of more or less effective bottlenecks where queueing theory in principle applies, than by a system of road links where the speed-flow relationship applies. In reality, the intersections are usually more important than the links as a cause of congestion.

As an example, assume a bottleneck and a sudden increase in the traffic flow approaching the bottleneck. The increase in the flow makes the bottleneck become effective and a queue will be formed. The size of the queue and the average and total delay to vehicles in the queue depend on several parameters. However, the important fact is that the delay a vehicle inflicts on other vehicles in the queue varies considerably. The first vehicles exceeding the capacity inflicts a very high congestion cost on other vehicles. From then on the marginal congestion cost decreases more or less monotonously until the queue dissolves.

It is difficult to use observations from the queue at a bottleneck as basis for congestion pricing even in the simplest of cases. We do not know the marginal congestion cost of the first vehicle in the queue until the queue is dissolved and that may be an hour or more after the first vehicle has left the road system.

Another problem - mainly due to intersections and turning movements - is that a vehicle may inflict considerable delays on vehicles using other links. The complications that arise from this fact is also reflected in the difficulty of modelling assymetric traffic assignment.

Consequently applying congestion pricing - even with the most sophisticated electronic schemes - can only be done in a very rough and approximate way compared to the "correct" pricing. The problem is not one of having the approximate electronic scheme, but rather our ability to model real life traffic systems and from this to infer the correct price to charge. It might take a considerable time and effort before we can assert a "correct" marginal cost. However, the difficulty of charging "correctly" for congestion, is not a serious obstacle to road pricing. A movement of prices in the right direction can improve considerably on the present situation, even if we only end up with another suboptimal situation with regards to efficiency in the traffic system.

5. APPRAISAL OF ROAD PROJECT IN A NETWORK SETTING

Whether we start out from a simple theory of pricing and investment in roads derived from speed - flow relationship for a single link or from a similar exercise generalized for a road network, we reach some conclusions on investment criteria. However, their application to the road network is not without problems. In dealing with road projects in a network setup, one has to realize that there might be a great degree of interdependence between

the benefits of different projects. The main cause of interdependence is the interplay between many bottlenecks and drivers route choice in the system. This has two implications:

i) In general the appraisal of investment projects - especially in congested networks should be based on a comprehensive analysis of different projects and project combinations. The analysis must take into account the impact on the total system.

ii) Making decisions on road investment is not a task suitable for decentralized decision making.

The second point implies that it is difficult to imagine that a road network resembling some kind of an optimum network can arise as a market solution in a competitive market even without any standard component.

Some of the issues raised above can be examplified by the results from two recent studies undertaken in Oslo. One deals with road project appraisal and the other with the costs and benefits of the cordon toll scheme in Oslo.

6. BENEFITS OF ROAD PROJECTS IN OSLO

The cordon toll scheme in Oslo was introduced to raise money for a large scale road investment program for the main roads in the region. The net revenue from the toll scheme shall supplement funds from the central government. With some 70 road projects under consideration and period of implementation that is 15 years, it is worthwhile to investigate the benefits of different project combinations and different alternatives for scheduling the projects within this period (Larsen 1991).

Figure 1 shows the results from the evaluation of two projects when each of them are added separately to the present network and when each of them are added with the other one already in the network. Both projects are now under construction.
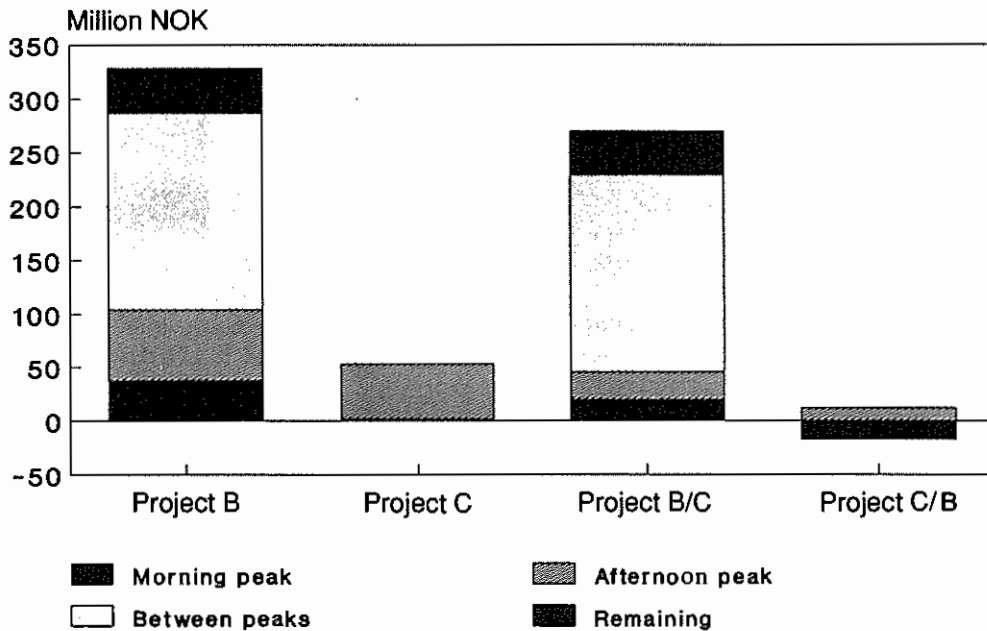

Figure 1: VALUE OF SAVINGS IN TRAVEL TIME AND OPERATING COST OF VEHICLES

277

Project B is a new road link in tunnel. It is an extension of the the main ring road in Oslo. In the context of the discussion presented earlier, this project implies a combination of improved capacity and increased standard. Project C adds an additional outbound lane to the main road going westward from Oslo. The project will not involve any important standard improvement and may be considered as a pure increase in capacity. The benefits in terms of time savings and reduction in operating cost of vehicles have been calculated by assigning 4 fixed car trip matrices, representing different time periods, on the road network according to the user equilibrium principle. Different unit costs were applied for each matrix to take care of differences in the composition of traffic. The benefit for each time period is multiplied by the number of hours the matrix represent on a yearly basis. The distribution of benefits in the different time periods for project B, clearly shows that the "standard component" is quite important in this project. The benefits of project C are confined to the afternoon peak.

If project C is already included in the network, the benefits of project B decrease. On the other hand, if B already is included in the network, the benefits of C become negative. This signals the presence of Braess paradox, which may be a real problem in congested networks (Florian, 1984).

The two projects are clearly interdependent. To some extent they provide additional capacity for the same traffic flows, and in that case we might expect, as the results show, a negative interdependence.

Another example is shown in Table 1. Different combinations of 4 projects along the ring road was analyzed by the same method as in the previous example. There were 16 possible combinations for each matrix, and hence 64 traffic assignments were run. One of the projects was project B in Figure 1. The other three projects replace signalized intersections with ramp junctions. The distribution of benefits to traffic in different time periods was very similar to project B. We have thus another example showing considerable benefits in non-congested periods where marginal cost pricing would yield very small revenue. Table 1 only shows the benefit of the 4 projects when they are added as the first and the last respectively.

Table 1: Annual benefits of four projects when they are added as the first and the last to the present network. (Million NOK)1)

Project	Added first	Added last
SS	75.3	93.2
TU	23.3	49.2
GF (B)	29.6	44.6
NS	12.4	-14.4

1) Value of time savings and savings in vehicle operating cost.

In this case we found a strong positive interdependence between the benefits of three of the projects, while the last project had negative benefits when the other three projects had been included in the network. Thus we have another example of Braess paradox. Both examples above clearly show that decisions on selection and phasing of road projects in an urban system should be centralized, and that there is no reason to expect that a market would provide for the best solution. The case for decentralization and market solutions is strong when it is safe to assume that a major part of the benefits of a projects of a project is captured by the revenue from a project. In a congested road network, a major part of the benefits from a specific project might accrue to traffic in other parts of the system due to the effect on route choice, and may depend crucially on whether or when some other projects are implemented.

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Million NOK
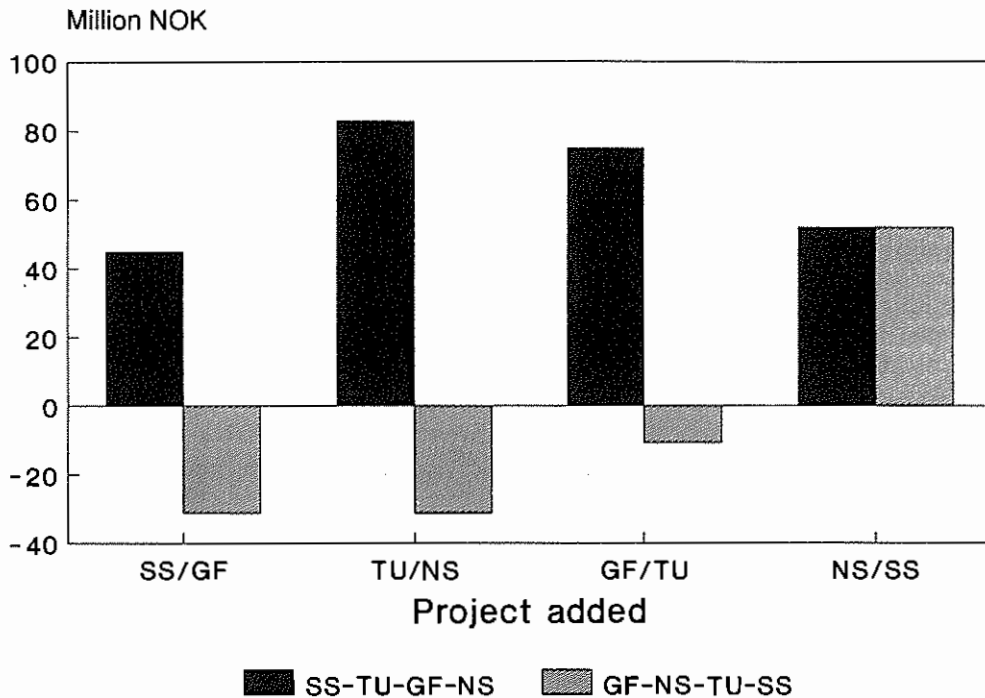
Figure 2:ACCUMULATED ANNUAL NET BENEFITS
- BEST AND WORST SEQUENCE

Figure 2 shows the accumulation of *net* annual benefits with the best and the worst sequence. Taken together Table 1 and Figure 2 clearly indicate the importance of looking at project combinations and sequences and of looking at the total impact on the traffic in the system. The analysis of the investment projects is based on constant vehicle trip matrices. This is a great simplification as any major road project may have long term impacts on mode choice, travel patterns and land use. However, even this simplified approach should capture a major part of the benefits related to time savings and operating cost savings.

7. BENEFITS FROM ROAD PRICING

The conclusion from paragraph 3 was that even a very crude form of road pricing might provide considerable benefits compared to the present situation. A cordon toll is one of the options in this regard. The present cordon toll scheme in Oslo was designed without any consideration being given to the principles of road pricing. The sole purpose of the scheme, at present, is to raise money for the road investment program. The scheme is operated for 24 hours a day around the week. Only inbound traffic is tolled. Seasonal tickets allowing an unlimited number of trips are extensively used and the toll rates do not vary by time of day for those who pay per trip. For the toll ring scheme in Oslo we have attempted to estimate the benefits of the present scheme and for an modified scheme. The modified scheme is still based on a cordon toll for inbound traffic, but the toll rates approximate the average marginal cost for vehicle trips crossing the toll ring (Ramjerdi and Larsen 1991).

It is thus possible to compare the impact of a revenue raising scheme and the impact of modifying this scheme in the direction of road pricing. The modified scheme that we investigated is still a long way from proper

279

road pricing. A cordon toll based on marginal congestion cost implies that the toll is too high for some trips and too low for others. The estimate of average marginal cost is also based on the speed - flow relationship for links in the network. In this study we used variable demand assignment on combined vehicle trip/transit trip matrices. For each cell in the matrices (450 zones) we applied a demand function based on a logit model formulation. An equilibrium solution in this model imply that the actual times that enter in the demand functions corresponds to the actual times for vehicle trips between the different zones. The feedback from driving conditions to demand for vehicle trips is thus taken care of, although in a very simplified way.

On the other hand, there are several effects of a cordon toll or road pricing in general, that the model is unable to capture. Differentiated rates by time of day will have an impact on the timing of trips. There will also be impacts on destination choice. In the long run we may expect greater impacts on travel patterns and land use. There might also be feedbacks that influence the level of service in public transit. One of the potential benefits of sophisticated road pricing, is also improved route choice in the road system. In technical terms this means that the system moves from a user equilibrium to a system optimum. A cordon toll like the one in Oslo has negligible impacts on route choice and thus will not improve on route choice. The results presented in the tables below are thus estimates of short term impacts based on very strict assumptions. However, they are estimates of the impacts that are usually emphasized in the theory of road pricing.

Table 2: Estimated Benefits and Costs of Present Toll Scheme in Oslo. (Mill NOK per year)

	Time savings savings	Operating cost	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

Source: Ramjerdi and Larsen, 1991.

Table 2 shows the estimated benefits of the present system (disregarding environmental impacts). The cost of operating the system is an estimated 96.6 Million NOK per year and the cost of delays at toll gates was roughly estimated to 4.9 Million NOK per year. We see that the net benefits due to time savings and changes in consumer surplus are less then the cost of operating the present scheme. Thus it would not be worthwhile to implement the present scheme only to improve the efficiency in the traffic system. From the decrease in traffic and savings in users' cost it is possible to calculate an average marginal cost for the trips 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 is 35.60 NOK for peak periods, 3.80 NOK for between peaks, and 1.40 NOK for other periods. The cost of financing defined as the social cost per unit of net revenue is 0.158. This figure can be compared to the opportunity cost (or shadow price) of tax revenue. In Norway the opportunity cost might be in the range 0.3-0.4. The present toll scheme should thus be a less costly way of raising revenue than general taxation on the margin.

Table 2 shows the estimated benefits and cost of the improved scheme. We assumed that tolls would only be charged in peak periods because the present gasoline tax in Norway is sufficiently high to cover the marginal cost in off-peak periods.

Table 3: Estimated Benefits and Costs of Improved Toll Scheme in Oslo. (Mill NOK per year)

	Time savings	Operating cost savings	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

Source: Ramjerdi and Larsen, 1991.

The revenue estimated for the modified sheme was 180 Million NOK per year and the annual cost of toll collection of toll collection was estimated at 70 Million NOK per year. The estimates for the modified toll scheme thus suggest that it would have benefits that exceed the costs and would be worthwhile to introduce in order to improve even if it is very crude compared to the road pricing advocated in theory.

As earlier it is possible to calculate the average marginal cost of the trips that switches to public transport. For peak periods this average marginal cost is 29.5 NOK. As expected, this is higher than 25 NOK, the "optimum" toll.

As the benefits of the modified scheme has benefits that exceed the costs, the cost of financing in this alternative is negative as it should be cases if we introduce a price or tax to improve resource allocation. The toll paid by the users is a revenue to the authority collecting the toll and is thus a transfer payment. This transfer payment that is one of the major obstacles to the introduction of road pricing from a political point of view. The revenue in Table 1 is a good estimate of the revenue from the present system and the estimated revenue for the modified scheme is less than one third of the present revenue. The users in aggregate will thus pay fare less with a cordon toll only in the peak periods even with a toll rate that is two and a half time the present toll rate for light vehicles. In principle the net revenue can be distributed in a way that makes everybody better off. The crucial point is probably to use the revenue in way that avoids giving the impression that road pricing is just another increase in taxes. Whether this is best done by using the revenue for some purpose that directly benefits those who pay or by including road pricing in a package that imply reduction in other taxes, will depend on the local circumstances.

8. SOME CONCLUDING REFLECTIONS ON ROAD PRICING AND PRIVATIZATION OF ROADS

Available evidence indicate that there might be considerable benefits to be gained from introducing road pricing in congested cities. However, the standard theory, taking as a starting point the speed - flow relationship provided by traffic theory, is too simple to apply directly to actual road networks. At present we are not able to model traffic flows in congested road networks in a way that allows us calculate the "correct" price to charge. Neither are we able to model the interplay between demand responses and network impacts to the extent that we can have precise estimates of costs and benefits. These are not problems that can be solved by sophisticated electronic schemes for charging the motorists.

Even if "theoretically correct" road pricing is impossible to implement at present, crude road pricing schemes might improve considerably on the present situation in most congested urban areas.

A "simple" theory on road pricing might lead us to believe that we can do away with cost-benefit analysis in the appraisal of road projects and instead rely on revenue from road pricing, cost and profit to provide the correct signals for investments. This is wrong for two reasons:
1) There is an important "standard" component in road investments, even in congested networks. With marginal cost pricing there will be no increase in financial revenue that corresponds to increased standard. Motorists are of course willing to pay for improved road standard in non-congested periods. However, to make them pay, we have to leave marginal cost pricing.
2) In general strong interdependencies may exist among road projects. We have to assess specific road investments from the impacts they have on the total traffic in the network.

To some extent the question of privatization or private provision of roads, is related to these issues. If privatization shall have something to offer when it comes to the road system, it must be based on an assumption that the private sector will do better than the public sector. In general we might argue that the private sector is more efficient than the public sector, and privatization might help us to avoid "overdesigned" roads and provide more efficient maintenance. On the other hand, networks are notoriously difficult to analyze as market phenomenons and there is no priori reason to expect that a market - in general - is better able to handle the pricing and investment decisions related to congested road networks networks than the public sector.

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