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An evaluation of the toll ring in Oslo, Norway

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AN EVALUATION OF THE TOLL RING IN OSLO, NORWAY

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ABSTRACT

This thesis investigates the possible short-run economic gains from implementing a different system of road pricing in Oslo, Norway. Oslo is the largest city in Norway, with a population of 450, 000 inhabitants.

First, the existing cordon toll ring that forces all inbound traffic to pay a flat toll to enter the central business district 24 hours a day is described. Second, the literature on optimal road pricing is investigated. Third, the flat tariff toll system is compared to two differentiated pricing systems that better reflect the costs imposed by drivers on society. When the loss of surplus and gains because of time savings for the pricing systems are compared with revenues collected, it is possible to conclude that more differentiated pricing increase economic welfare. More differentiated prices are also closer to the theoretical solution for optimal road pricing.

CHAPTER 1

1.0 INTRODUCTION.

In Norway the supply of roads is less than the demand for roads, especially in urban areas. This is because roads are mainly financed by government funds, and the government gives rural roads priority over urban roads. The reason for this is that in large parts of the rural districts viable alternatives to road transportation do not exist. The result has been slow development of roads in urban areas. Increasing urbanization is another factor that makes it harder to solve the road capacity problems in the largest cities.

The result is increasing congestion on parts of the road network, with longer travel times and environmental problems as a consequense. In Norway these problems are relatively small compared to the largest cities in Euroupe, Asia and the U.S.A, but it is of interest to investigate if it is possible to use the price mechanism to solve these congestion problems.

This thesis attemps to analyze the short-run impacts of alternative road pricing systems. It will be shown that differentiated tolls by time of day will yield an economic gain to society compared to the present toll scheme where a flat rate toll is collected 24 hours a day. Differentiated tariffs mean that the toll is higher during rush hours when congestion is high, and lower during off-peak hours when congestion is low. Compared to a flat toll, higher tolls during rush hours reduce traffic flows, congestion and driving times and lower tolls during off-peak hours increase traffic flows. The result is more even traffic levels during the day which reduce the total social cost of transportation.

In this thesis the impacts of alternative road pricing systems are determined and evaluated given the existing demand for and supply of roads. This short-run analysis has its limitation. In the long-run, road and public transit improvements financed by tolls and changes in demand will alter the costs and benefits of the alternative road pricing systems. A complete cost-benefit analysis would incorporate these long-run changes, determine net benefits in each time period, and determine the present discounted value of net benefits. Such a long-run analysis is not within the scope of this thesis, but the long-run implications of the short-run results will be explored.

Hau(1991) and Walters(1968) derived the theoretical solutions to the road congestion problem. These authors describe how in theory marginal cost pricing would result in the optimal use of existing roads and an optimal sized road system. In this thesis, the theory of optimal congestion tolls is presented, the practical limitations of the theory are discussed and the impact of a more practical system of differentiated tolls are determined, evaluated, and compared to the impacts of the current flat rate toll system.

The thesis is organized in the following manner: The remainder of this chapter provides background information on the Oslo, Norway toll ring including the rationale for and the structure of the toll ring. Chapter 2 reviews the literature on road pricing. The theoretical solution to marginal cost pricing of existing roads, and optimal road investments are presented and the results of road pricing in Singapore, in the U.S.A. and in Oslo are described. In chapter 3, four scenarios with different road pricing systems are developed, simulated and evaluated. The results indicated that compared with the present pricing system the most differentiated scheme generates the largest total traffic, but with less congestion during the rush hours. A discussion of the distributional effects of the toll ring and its effects on land use and commercial traffic closes the chapter. In chapter 4 the time savings resulting from the toll ring are analyzed. Any increase in road prices will reduce traffic volumes. This reduction harms those who alter the number or times of their trips, reduces travel times which benefits those drivers who do not alter their travel behavior and affects total toll revenue. According to the analysis the present toll scheme collects the most revenue, but the case with the largest differentiation yields the largest social net benefits mainly because of the value of time savings.

The thesis concludes that the results of a pricing system with differentiated tolls by time of day are more desirable than the results of the present pricing system. A differentiated toll system is closer to the theoretical optimal pricing system, and creates more even traffic flows over the day. An additional benefit of a differentiated pricing system is that it reduces the need for increased road capacity.

1.1 Costs to drivers and to society because of the use of vehicles, and the meaning of road pricing.

Drivers should generally face the costs to society resulting from their vehicle use. From an economic point of view, this is necessary for the potential vehicles users to take a "correct" desicion concerning the means of tranportation, the time of travel and the travel route.

The cost components that must be included in calculating the cost of vehicles use include:

Costs to society:	Private costs:
-Wear and tear on roads	-Operating costs of the vehicle included insurance and vehicle taxes
-Travel time for drivers and passengers	-Travel time for driver and passengers

-Risk of accidents for driver and passengers	-Risk of accidents for driver and passengers
-Increased risk of accidents for other traffic	
-Increased operating costs for other traffic	
-Increased travel times for other traffic	
-Increased environmental costs because of pollution	

Some of these costs are borne by the driver, and other costs are borne by the society.

Whether the drivers' private costs reflect the costs to society is dependent on the size and form of the taxes on ownership and usage of the vehicle. Valuation of environmental costs and the cost of traffic accidents is important in determining if the trafficants cover the full cost of using the roads. The taxes that drivers pay should reflect society's judgement of these costs.

Optimal road pricing is a form of taxation where all the external effects of a trip by a vehicle are calculated in monetary terms and presented as a user price. In this thesis this notion is reduced to the external effects drivers impose on each other. A consequence of this is that the user price must vary continually with the traffic level on each road link. Such a system is troublesome and expensive to implement on a real world road network. Alternative systems that could be implemented are effective to a certain degree depending upon the similarity to the optimal system; that is, how differentiated the tariffs are with respect to time.

Implementation of optimal road pricing will yield benefits for society. Some drivers alter the number and/or times of their trips and their loss is less than the time savings gain for the rest of the traffic. Optimal road pricing also produces revenue for the authorities. Since this revenue reflects the users willingness to pay for the roads, it signals whether road improvements are desirable and where they should be mode. Optimal investment strategy implies that the authorities allocate road investments in such a way that at the margin revenues equal the construction costs.

There are also environmental costs to society caused by drivers. Such costs are air and noise pollution that increase with traffic volumes. In the Oslo region these costs have increased over time. These costs should be reduced in the future by road improvements which will include tunnels that will allow through traffic to bypass the central city and roads in areas where population density is lower. These environmental costs are not explicitly included in this thesis.

There are practical problems, in implementing a theoretical optimal road pricing system. In the real world it is difficult to build optimal sized roads because the demand for road capacity fluctuates over the day. In addition, in urban areas travellers have a choice among several modes of transportation. Intermodel choice makes it difficult to make accurate predictions about the impact of road investments on traffic levels.

1.1.1 Background information on the toll ring in Oslo, Norway.

This section provides background information on the Oslo toll ring. First the forces, political and traffic management concerns that led to the toll ring, are discussed. Also, the technical and financial outcomes of the electronic road pricing in Oslo are discussed.

1.1.2 Political and traffic management concerns.

The growth in traffic during the last two decades has led to congestion on the main roads around the largest cities in Norway. In Oslo, the largest city and the capital of Norway, the problem has evolved from congestion during the rush hours to congestion during most of the day. Congestion has worsened local environmental and traffic safety problems. Traffic forecasts indicate that congestion is expected to increase over time. Ambitious plans for urban motorways in Oslo were made thirty years ago. Opposition from politicians and citizens who were concerned about the impact these motorways would have on the urban environment, and the lack of funds for such an extensive road improvements, caused only fragments of these plans to be realized (Stortingsmelding nr.46, 1985-86). Improving the public transport system was the preferred solution to the growing road traffic. Oslo's metro was expanded with funds from the local government. Even though the expansion led to increased travel by public transportation, road traffic still increased. One possible reason for this is that the ticket prices for public transportation increased more than the price on gasoline (Aldrin 1991). Since rural districts are given priority, only limited road funds have been allocated by the national government to Oslo. Therefore, planners had to look at alternative ways of financing road improvements.

For these reasons, a toll ring was introduced to finance the road network in Oslo on February 1, 1990. As an inducement, the national government agreed to increase its funds for road investment in Oslo so that national government funds would approximately match the income from the toll road system. If the new road system was financed only by national governmental funding, it would take 35 years to complete. Toll money in addition to national governmental funds would make it possible to complete 50 new road projects at a cost of NOK 12 billion (USD

1.7 billion) in only 15 years.

User charges for the roads were discussed, beginning in 1980 (Stortingsmelding nr. 46). The local political administration asked planners to develop different financing systems that would achieve two goals. First, raise money for construction of new roads and improvements to old roads, public transportation and some special facilities for pedestrians and bicyclists. Second, restrain traffic during rush hours. The proposed systems were a toll ring, road pricing based on areas (an area lisencing scheme), and higher parking fees. The placement of the toll ring, at the Ringveien, Kirkeveien or the Center ring, see enclosure 1, was also discussed.

Two factors which caused the city government to choose the toll ring option were the proposed tunnel under the city and the estimated cost to business of traffic congestion.
In 1984 a plan for building a tunnel under the city to allow traffic from the west to the north and south to avoid passing through the center of the city was developed. This plan was approved in 1986. The tunnel was to be financed by tolls, but people could avoid paying the toll by driving through the city center. In 1983 the Institute of Transport Economics (Larsen 1985) estimated that businesses in Oslo annually lost NOK 500 million due to traffic congestion on the roads into and out of the city. The city government decided to establish a toll ring in December 1987, and two years and one month later, this toll ring was implemented.

Although the city government decided that the toll ring should be built, it had very little support among the residents of Oslo. Their resistance was based primarily on equity concerns. Many thought it was unequitable that drivers should pay more than they already did, and that some drivers depending on where they lived and worked had to pay while others did not. Variations in the distance from the toll ring to the central business district (CBD) are the reason that people perceive a geographical unfairness according to the survey results by Solheim in 1991.

Many were also concerned about the large investments and the cost of a toll ring system, and they believed that the funds for road improvements should be raised by a larger tax on cars and/or a higher gasoline tax. The opinion polls show that the public opinion of the toll ring is less negative today, but still about one half of the public opposes it (Solheim 1991 and Simonsen 1991).

1.1.3 Structure of the toll ring.

The population of the Oslo-region is approximately 700,000. Oslo is located at the north end of the Oslofjord with large greenbelt areas to the north and the east. Built up areas and roads form three corridors leading to the central parts of Oslo. A total of 19 toll plazas of various sizes form a cordon line cutting across these corridors, and the driver of each vehicle must pay a toll to drive into the city. However, the toll is not collected when vehicles leave the city. The Oslo toll ring is designed so that it is impossible to enter the city without paying the toll. The toll stations are placed from 3 to 8 kilometers outside the center of the city (see enclosure 1). To complete the ring, five local roads have been closed or converted to one way travel to prevent drivers from avoiding the toll.

There are three types of lanes in the toll plazas: manual, automatic, and subscriber's lanes. The drivers pay an attendant in the manual lane or use a coin machine in the automatic lane. Cars in these lanes must stop to pay, reducing the traffic capacity to approximately 400 cars per hour per lane. In the subscription lanes, cars pass at normal speed without stopping, allowing a capacity of 1600 cars per hour: four times that of the manual lanes.

The subscriber system is based on an identification tag mounted on the inside of the vehicle's front windshield. A "reader" mounted over the subscription lane records the tag's identification code. The information is transferred to a computer system which determines the tag's validity. This procedure takes less than 0.4 seconds. If the tag is not valid, or the car has no tag, the driver is informed by a yellow traffic signal and a video-picture is taken of the passing car. To protect the passenger's privacy they are not included in the picture. The owner of the vehicle is then assessed a fine of NOK 250. The number of drivers who try to cross the toll ring without paying is relatively small, 0.1 percent.

The amount of the toll is constant 24 hours a day, 7 days a week. However, drivers who purchase subscriptions receive discounts. The discounts are intended to encourage drivers to utilize "no stop" lanes and thus, reduce or avoid car queues in the manual lanes. When the toll ring was first established, this enticement was important; therefore, drivers received a 25 percent discount from the normal subscription price if they bought annual subscription before January 15, 1990. This campaign was successful and resulted in about 50 percent of all crossings occurring in the "no stop" lanes from the first day. During February 1994, about 64 percent of all traffic through the toll ring used the subscription lanes. This traffic used either season tickets or clipcards. Season tickets allow an unlimited number of crossings during a one month, six month or an annual period. The clipcards allow either 25, 175 or 350 crossings. Each time the vehicle crosses the toll ring its electronic tag is debited. When the vehicle enters the toll station and there are fewer than 10 crossings left on the card, a signal with a white cross informs the driver that it is time to renew the card. The different tariffs are listed in table 1.1.1.

For a commuter who crosses the toll ring once a day for the entire year, the price per crossing with an annual subscription is NOK 7. The more a driver with a subscription crosses the toll ring the cheaper the price per crossing becomes. For example, with a 350 crossings clipcard the price becomes NOK 7.7.

Table 1.1.1: Tariffs for crossing the Oslo toll ring.
Reference: Fjellinjen A/S.

Way of payment	Light vehicles (under 3500 kilos)
Single ticket	11 NOK
One month	260 NOK
Six month	1,400 NOK
Annual	2,600 NOK
Clipcards:	
25	240 NOK
175	1,500 NOK
350	2,700 NOK

July 21, 1994, USD 1 = NOK 6.8. Heavy vehicles (over 3,500 kilos) pay twice as much.

This pricing policy reduces the cost per crossing for frequent users who often are peak hour users. Such a policy is not an optimal road pricing policy. In fact, congestion pricing suggests that those who use the roads at peak hours pay the highest price. Pressure from businesses whose vehicles cross the toll ring many times a day and commuters may have resulted in the choice of a flat tariff.

With respect to traffic congestion and minimization of collection costs, the toll ring has been a success. Except for one toll plaza where the manual lane is overloaded during the tourist season, there have been no traffic problems at the toll plazas.

Today, 19 of the original 50 road projects have been completed. Traffic flow and environmental conditions in the city center have improved as a result of these projects (NILU, 1992). Approximately 30 of the road projects are tunnels which remove cars from the city streets. One of the main projects which has been completed is the Oslo Tunnel, that allows 70,000 cars per weekday to bypass the CBD. This project allowed the City Hall Square to be transformed from a traffic inferno to a public park between the water front and the City Hall. The completed projects increased traffic speeds through Oslo reducing travel times and benefiting drivers.

The new roads have not eliminated the need for an efficient public transportation system. This system needs to be further developed to prevent future road congestion. Therefore, about 20 percent of the income from the toll road system is allocated to improve public transport infrastructure.

1.1.4 Financial outcomes.

In 1993, 207,000 vehicles passed through the toll ring each day, comprising almost 40 percent of all trips in the Oslo region. The revenue from the toll collection is approximately NOK 630 million (90 mill. USD) per year, and operational expenses represent about 11 percent of this total. When all 50 projects are fully financed, and the liabilities and share capital of the company that is in charge of the toll ring are repaid, it is assumed that the toll plazas will be removed, and the company dissolved. Given the experience and revenues so far and the long term budget, the company should be dissolved in 2007.

Conclusion.

The toll ring in Oslo functions well and serves its purpose: to collect revenue for further road building. These revenues have financed new roads and tunnels and increased capacity for public transportation. These investments have already reduced air pollution and traffic congestion in the CBD.

1.2 Attitudes towards the toll ring.

The desicion to build a cordon toll ring to finance road investments in the Oslo region, was made by the local government, but the desicion was opposed by many groups. This section discusses public opinion concerning the toll ring.

Mail surveys were undertaken to investigate the public's opinions about the toll ring both before and after the implementation of the toll ring. About 1,000 persons over 18 years of age, who lived in the Oslo region, were interviewed by telephone about their attitudes concerning the toll ring before and after it was imposed (Solheim 1991). Later two more studies of people's attitudes concerning this issue, were undertaken independently of the first study (Stangeby, April, November 1991). The results of these surveys were similar with about 60 percent reacting negatively to the toll ring in 1990. In the latter studies, the percentage with a negative opinion was a bit lower than in the former studies (See table 1.2.1.). Not only did the share with a negative attitude decline, but also the very negative share decreased by 9 percent.

Surprisingly, the population's opinions did not become more positive after the system was introduced, as happened in Bergen a few years earlier. The reason for this difference could be that people that live near the coast[1] are more accustomed to

Table 1.2.1: Attitudes about the toll ring, 1989 and 1990, in percent. Reference: Solheim 1991.

Attitude	1989		1990	
Very negative	37		28	
Fairly negative	28	65	32	60
Fairly positive	22		28	
Very positive	7	29	6	34
Don't know	6		6	
Total	100		100	

toll-roads because they frequently use bridges and ferries. In the Oslo region, people are not accustomed to user charges for roads, and this lack of familiarity may be the reason for their skepticism. In addition, people are generally skeptical of politicians and their promises, and many doubt that the collected toll revenues will be used for its original purposes or may not value the project financed by toll revenues highly.

The reduction in the negative attitude from 1989 to 1990 was among men, people from 45 to 59 years of age, people with high incomes, and people who lived in Oslo but outside the toll ring.

[1]Bergen is located near the western coast in Norway.

Knowledge about the toll ring seems to have been widespread by the autumn of 1990. Ninety-four percent knew the cost for a single crossing, but only 10 percent knew how much a monthly ticket cost. In 1989 only about one half of the people asked knew the cost of a single crossing.

For the question, "Why the toll ring was built," about two out of three correctly answered that it would help finance further road construction, and about 1 out of 3 that it also was to limit traffic, but this second group decreased from 1989 to 1990 (See table 1.2.2.) The most striking fact was that the group who thought that the money was collected for the government increased from 13 to 24 percent.

Most of the people who were favorable to the toll ring in 1989 believed that it was designed to decrease traffic congestion. This share was lower in 1990 while the group who thought this was a good way to collect money for road projects increased from 30 to 40 percent.

Typical negative opinions were "drivers already pay enough", and "it is an expensive way of collecting money". Many were also negative because they believed that it would create problems with queues. The last reason was hardly mentioned in 1990. In 1989 almost 40 percent thought that the toll ring would cause them to make fewer auto trips and more trips with public transportation. In 1990 this share had declined to under 20 percent. Implications of these responses are that people will change their attitude and eventually view the toll ring as a good thing, and use their

Table 1.2.2: Opinions about why the toll ring is/will be built in Oslo in percent. Reference: Solheim 1991.

Opinions	1989	1990
Money for roads	64	66
Money for "Fjellinjen"[2]	6	8
Constrain traffic	32	23
Environmental use	10	9
Increase public transport	4	8
More money to the Government	13	24
Do not know	3	4
Number of answers	1,015	1,010

(The percentages do not add up to 100 because people could choose more than one answer.)

vehicles more in the future.

In the autumn of 1990, 54 percent of all families with a car bought a subscription card of some kind. The most common purchase was a one year card that 26 percent bought while 5 percent bought 1/2 year cards, and 3 percent one month cards. Employers covered the costs for 43 percent of those who purchased subscription. The share that received support from their employer differed depending on the type of subscription. Fifty percent of those with one year subscriptions were covered, while only 18 percent of one month and six month subscription were paid for by employers.

The share of subscription cards and the share of these cards covered by the employer also increased with the number of cars in the family and with the families' income. Among families with an income of 250,000 NOK and up, 62 percent bought subscription, and

[2]"Fjellinjen" is the name of the tunnel under the city-center of Oslo, from south-west to north.

for 50 percent of the families the cost was covered by their employers. The numbers are similar for families with two or more cars.

Drivers with subscriptions are even more likely to have a negative opinion of the toll-ring (65%) than drivers without them (59%). These results are significant at the 10 percent level. This attitude is independent of whether or not their subscription cards are covered by their firm. There appears to be a general negative attitude towards the toll ring, and this negative attitude is independent of the personal additional costs or of income.

Conclusion.

The opinion surveys indicate that after experiencing the toll ring auto drivers have less negative opinions, but the general attitude is still negative. This negative attitude is distributed equally among income groups. The reason for the general negative attitude is that people probably understand that their gains of the toll ring are less than their costs. In the long-run the benefits for most people will hopefully exceed the costs, and then the public opinion may also change.

CHAPTER 2

2.0 REVIEW OF THE LITERATURE

This chapter begins with an explanation of the theoretical solutions to the optimal road pricing and investment problems based on T. Hau's and A. Walter's work. However, the primary objective of the Oslo toll ring was to collect revenue to finance road improvements in the Oslo region and not to control congestion. Previous investigations of road pricing in Singapore and in the U.S.A, and the experience with the Oslo toll ring are also reviewed in this chapter.

2.1.1. Introduction to road pricing theory.

In this section, the relationship between travel time and the number of vehicles on a road is first discussed. Based on this relationship the optimal toll fee is derived and the use of revenue from such a toll to finance optimal road investments in a road network is described.

Travel time and the number of vehicles on the road are used to determine an optimal toll that varies with respect to time of day. This congestion toll forces drivers to take into consideration the extra travel times they impose to others. The use of congestion tolls to internalize the external costs increases economic welfare.

The costs to society in form of longer travel times caused by congestion can be reduced by investments in road capacity. Optimal congestions tolls not only result in the efficient use of existing roads, but also indicate optimal road investments and provide the revenue required to finance these investments. Walter's "Putty-model" which is used to determine an optimal user fee and road investment for each traffic level is discussed in the last part of this section.

2.1.2 What is road pricing?

Among economists, concerns about optimal user fees for roads have a long tradition. The Norwegian Parliament's recent debates concerning the possibility of using the price mechanism to regulate traffic, rather than only using it to raise revenue for road projects, has made road pricing a household word in Norway.

When road congestion occurs, an additional vehicle imposes additional costs on all in the form of longer travel times. These costs include higher vehicle operating costs primarily gasoline expences and the environmental impacts of additional air and noise pollution.

In principle, optimal road prices should include the costs of all these external effects in a user fee paid by the driver. These costs can be collected in different ways. The advantages and disadvantages of different systems of road pricing are discussed in the following sections.

2.1.3 Marginal cost road pricing.

In a theoretically ideal system of road pricing, the road user pays for all the costs he/she imposes on other drivers. The toll for each road link in the road system must vary continually with traffic on that road. In practice, such an ideal system would be hard to implement. First, it would be difficult to develop computer programs to calculate the ideal prices for a road system where traffic fluctuates. Second, even if this were possible, it would be very expensive to implement such a pricing system. Third, under this system a driver would not know the amount of money he/she had to pay for using a road link until after the costs he/she had imposed on others were calculated. Under such a complex system prices would no longer function as signals to the road users[3].

It is possible to create a system that can overcome the first of these problems, but the other problems remain. At the time this thesis is written, ideal marginal cost road pricing has not been implemented anywhere in the world.

This approach is still of some importance because there exist models that are able to measure traffic volumes within a

[3] When prices for the use of a certain road link increases, it is supposed to prevent congestion on the link. Therefore it is important that users know the price before they use the road.

time period for a given road network. These models assume that all information about travel time and costs for each travel route, are known a priori. Using these models one is able to estimate the social benefits of implementing a toll for road use, (Jean-Hansen, 1991).

In practice one operates with prices, or taxes, that are known in advance. Drivers impose different costs on each other depending upon the time of the day. Therefore, the prices should also vary by time of day. These systems will be effective if they are close to the ideal, this means, they should vary directly with traffic volumes.

It is also possible to differentiate the prices with respect to places in the road network. Higher prices for highly congested places would divert traffic elsewhere improving traffic flows. It is also possible to divide a city area into different zones and vary prices by zone, for example higher prices in the center and lower prices further from the center.

A combination of prices differentiated by time and zone would be similar to an ideal marginal costs pricing system, but would imply large construction costs because collection of revenue would be more difficult.

World-wide experience with advanced road pricing systems is limited and road pricing experience in Norway has been limited to toll rings, a relatively crude form of road pricing. The existing toll rings do not differentiate prices with respect to the amount of traffic. Thus the existing road pricing system provides no differential incentives for users to change their time of travel or choice of route. The impacts of such a flat toll are determined and evaluated in chapter 3.

2.1.4 A theoretical approach.

This section provides a theoretical approach to optimal road pricing in the short run. The use of an uncongested road network is similar to the consumption of a public good. A driver's use of the road network will not have any negative implications for other drivers. The marginal driver will in other words not impose any negative external effects on the other users of the road, and the marginal external costs on society will be close to zero[4].

When congestion occurs on the road network it is a form of external cost. The price of a private good is determined by the critera of demand or willingness to pay and supply. In a road network with congestion, this price includes the extra time the drivers uses because of traffic congestion. The additional time costs imposed on other drivers are not included in a driver's economic costs, and are therefore an external cost. To effectively utilize the existing roads, requires a mechanism that excludes drivers who have a lower willingness to pay than the marginal cost to society. Excluding drivers from the use of the road network may sound harsh, but it need not imply anything more

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[4] The environmental costs caused by increased vehicles use are not mentioned, but increased congestion will lead to increased air and noise pollution.

than car pooling, travelling at a different time of the day, or increased use of public transportation.

In situations with excessive congestion, the marginal costs to society exceed the marginal benefits. Thus even small reductions in traffic imply net social benefits. Excessive congestion, can be looked upon as a market failure were mispricing causes too many drivers to use the road network. Economists argue that the use of roads should be rationed by a price mechanism.

The theoretical analysis begins by postulating a relationship between travel times and the number of vehicles using the roads. Assume that x^0 cars drive on a road per hour. The total travel can be expressed as

$$T(x^0) = X^0\ t(x^0) \qquad \text{(eq.) } 2.3.1$$

Where $t(x)$ describes average time per car and has the number of vehicles as an argument. Further assume that x^0 cars per hour do not lead to any congestion, but when traffic increases beyond x^0, congestion occurs and the average time per car increases. When traffic increases and approaches the road's maximum capacity, $t(x)$ increases further. This means that

$$t'(x) = \text{constant when } x < x^0$$

and

$$t'(x) > 0 \text{ and } t''(x) > 0 \text{ when } x > x^0$$

The extra time that the marginal driver imposes on all drivers is found by differenciating $T(x)$.

$$T'(x) = t(x) + x\,t'(x) \qquad \text{(eq.) } 2.3.2$$

The total marginal cost has two components. The first component is the time the marginal driver uses, and the second component is the extra time the marginal driver imposes on all other drivers. The optimal congestion toll equal the monetary value of the second component, $x\,t'(x)$, for every level of traffic, x. These equations can be converted to cost equations by using as a shadow price a constant value of time for the representative driver. It is then possible to write

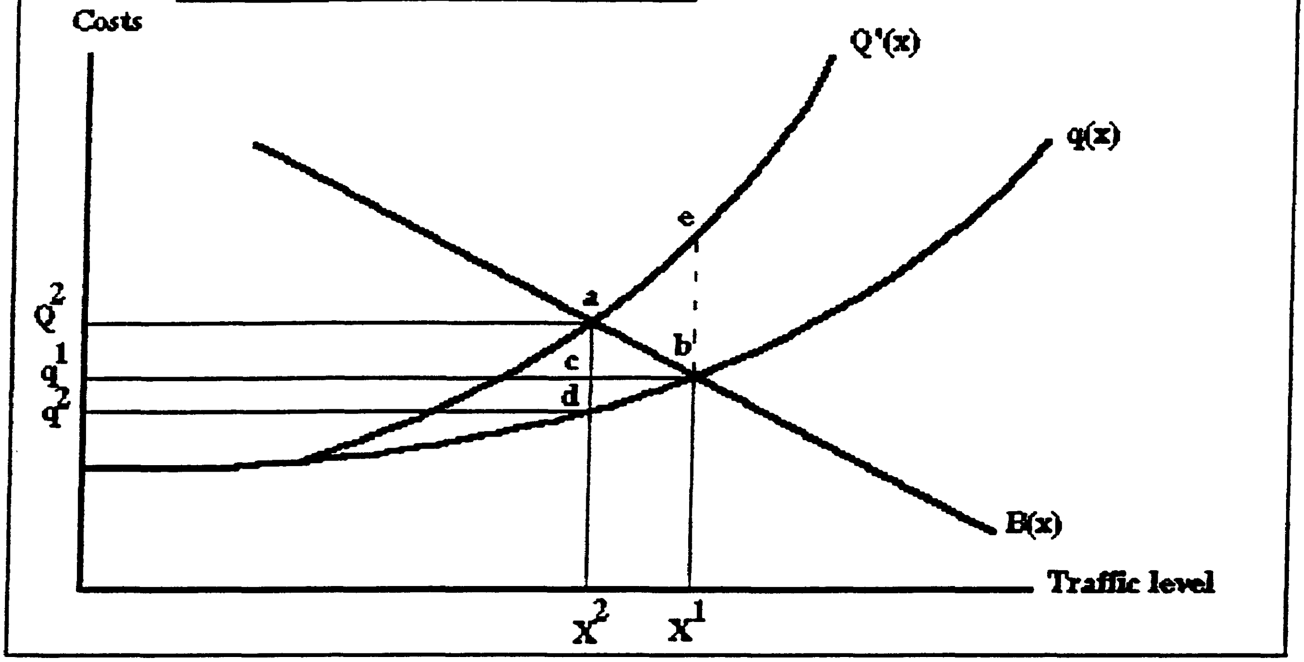
$$q(x) = p\,t(x) \qquad \text{(eq.) } 2.3.3$$

$$Q'(x) = p\,t(x) + p\,t'(x) \qquad \text{(eq.) } 2.3.4$$

where p is a constant shadow price of time, $q(x)$ is average time costs per vehicle and $Q'(x)$ is total marginal time costs. The congestion toll is the difference between the social time cost $Q'(x)$ and the private time cost of another trip. The congestion toll $= p\,x\,t'(x)$ is represented in Illustration 1 by the vertical distance between $Q'(x)$ and $q(x)$.

The demand side is incorporated in this example by determining and aggregating the drivers' individual willingness to pay for their use of the road. The resulting inverse demand function can be written as

Illustration 1. Marginal cost pricing.



$$B = D^{-1}(x) = B(x) \qquad \text{(eq.) 2.3.6}$$

where $B'(x) < 0$. It is now possible to determine the optimal user fee or toll, given the demand. The drivers' private costs are given by $q(x)$. The intersection between $B(X)$ and $q(x)$ where $B(x^1) = q(x^1)$ determines the traffic volume x^1 that exists in the absence of congestion.

Illustration 1 also shows that the implementation of optimal road pricing would reduce the traffic volume from x^1 to x^2. The optimal toll at this traffic volume is

$$Q(x^2) - q(x^2) = p\ x^2\ t'(x^2)$$

This toll implies an economic net benefit to the society because of reduced travel times. A reduction of the traffic volume from

x^1 to x^2 is a potential pareto improvement, because when drivers pay a toll corresponding the costs they impose on other drivers, they are forced to take into consideration the negative external effects they impose on others. In other words, the negative external effects are internalized by the toll.

The economic gain to society caused by optimal road pricing can be calculated in several ways. Two different ways of showing this is in illustration 1, and are based on Johansson and Mattson (1994). If one moves from the optimal solution with traffic level x^2 to the nonoptimal level x^1, the costs, represented by the area x^2aex^1, is larger than the benefits, represented by the smaller area x^2abx^1. This means that the welfare loss by not using an optimal toll is depicted by the area abe. An alternative is to investigate the areas which represents benefits and costs when road pricing is imposed. The costs is the area q^1cdq^2 in addition to x^2cbx^1 and the benefits are the area x^2abx^1. The net benefits are therefore the area q^1cdq^2, that represents the gains in travel times minus the area cab, the loss of surplus because of suppressed trips. Thus there are gains to society from marginal cost road pricing, but drivers are worse off since the gain to travellers because of time savings are less than the tolls they have to pay (q^2Q^2cd).

The public good caused by the congestion toll is reduced congestion in the short run and road improvements in the long run. This theoretical approach is a form of balanced budget incidence, which compares the incidence of the congestion toll, and the resulting public good, reduced congestion. It is argued that the result is a net gain to society.

2.1.5 Road Pricing and Road Investments.

Roads represent a part of society's common resources. Everybody in the society benefits from roads, not only the drivers. The question that arises is who is going to pay for these resources. Roads have certain similarities with public goods, as earlier mentioned. A public good should be provided if it results in gains to society. For example, road improvements provide benefits if these improvements reduce the risks of accidents and wear and tear on cars.

When congestion occurs on roads, it represents a loss to society in form of longer travel time. These costs can be reduced by investments in road capacity. When drivers' private costs differ from the costs to society, and optimal congestion toll are implemented drivers will face the "right" user price, and their willingness to pay will be revealed. Once willingness to pay is known, critera for optimal investment in road improvements can be derived. According to theory the investment critera should be based on marginal not average costs.

Road planners have financial limits on their activities. The road projects are financed by a number of taxes and in the long-run budgets have to balance. There will be competition among profitable projects, and if the government chooses to invest in roads, other public investments must be delayed or reduced. When the road planners decide to build roads, they have to take the users' needs into consideration to determine an optimal stock of roads. This concerns the financing of the road projects and also how to collect the taxes. Which types of taxes are the better for the financing and who shall pay?

Thus, road pricing and road investments are closely linked especially when congestion exist. In the literature these two issues are also linked as the following discussion of Walters and Hau's work indicates.

2.1.6 The Putty model.

Optimal road investment strategy based on marginal cost road pricing can be illustrated with a simple model. Walters (1968) calls this model the Putty model, because it is assumed that the investments are divisible; the roads can be changed marginally. Also constant returns to scale in road building, maintenance and use of the road are assumed to hold. If constant returns to scale in road building and maintenance exists, increases in fixed costs yields a proportional increase in capacity. If constant returns to scale in the use of roads exists, travel time is constant when capacity and traffic are increased by the same percentage. Illustration 2 shows optimal traffic volume on a road given demand. The optimal user price is p*.

Description:

Q'(x): Marginal costs for one trip.

q(x): Generalized costs for one trip.

B: Demand

afc: Average fixed costs

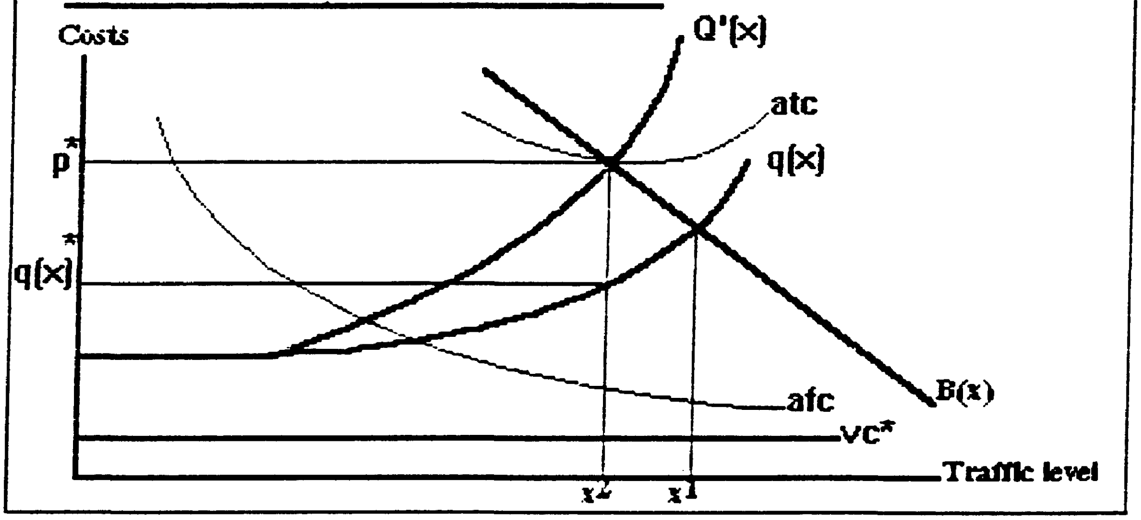
atc: Average total costs

vc: Variable maintenance costs

x*: Optimal traffic

p*: Optimal total price for one trip.

Illustration 2. Optimal investments.



In this model, the user price consists of three different types of costs. First, the driver has to cover his own operating costs of using his/her car. Secondly, the user has to cover his/her share of the variable maintenance costs. Thirdly, the user of the road has to pay a tax that corrects for the negative external effects he/she imposes on other users.

The authorities' fixed costs consist of capital costs, fixed maintenance costs, operating costs and depreciation. The curve atc is the vertical sum of afc, vc and q(x). The figure illustrates an optimal situation in both the long-run and in the short-run. The size of the fixed costs, and therefore the size of the investments is exactly covered by the user fee. The user fee must in the case of optimal investments also cover the authorities variable maintenance costs. The optimal user fee for traffic level x* is therefore :

optimal fee = vc* + p* - q(x)*.

The model's principle conclusion is that the users' willingness to pay determines road capacity. In the short run, the road capacity may not be optimal. If the capacity is too low, the optimal user fee implies profits for the authorities. This is a signal to marginally increase the investment and the fixed costs until these costs are exactly covered by the user fee (Hau 1991).

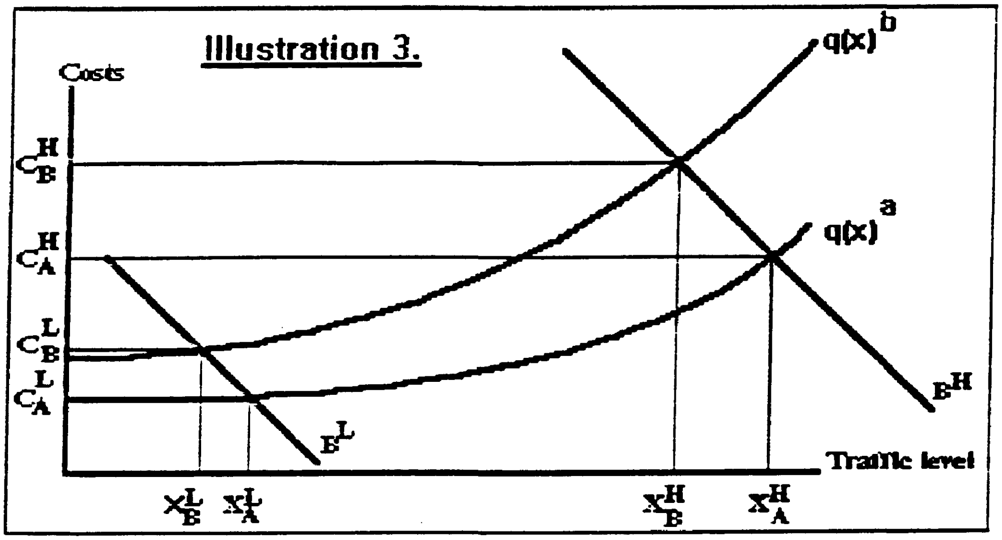
The realism of the Putty model's assumptions are problematic. Investment in and expansion of road capacity is indivisible rather than incremental in nature. Road capacity can be increased by building more and wider lanes. In illustration 3, the impact of a road investment is represented by the shift from average cost curve $q(x)^b$ to $q(x)^a$. The lanes be a certain width to carry traffic and the road has to be finished to be useful. Hau (1991) states that if a road with one lane in each direction is doubled in size, its capacity more than doubles. This indicates increasing returns to scale in road building, at least when one looks at an isolated road.

Another issue that makes optimal investment difficult is that roads to a large degree are non-reversible. At the time of investment, one to a certain extent can choose among different sized roads, but after this choice is mode, one must use the existing road. Uncertain forecasts about future traffic are therefore a problem for the authorities. Changes must be made by new investments. The existing road cannot easily be transformed without significant costs.

The Putty model also assumes constant demand. This assumption is unrealistic, because traffic varies significantly by time of day. Illustration 3 shows the demand in two periods where the demand is high (B^h) and low (B^l).

In illustration 3, the marginal cost curves are not drawn, but one can easily see that the traffic in the low traffic period produces no negative externalities. In the high traffic period, on the contrary, the external costs are large.

In this case, the implementation of perfect road pricing requires that users in the low traffic period not pay for the use of the road (If necessary they would pay the variable maintenance



costs only). The investment costs for increased road capacity are covered by the traffic that is responsible for this cost. If the high traffic periods are short, the revenues from the fees will be relatively low. An optimal investment strategy with revenue from marginal cost road pricing, will therefore have consequences for the speed at which roads are built. However, this capacity restriction is appropriate on economic grounds.

Illustration 3 portrayes another aspect of road investment. Investment in increased capacity will also result in increased road quality. Improved quality includes improvements to existing lanes, such as wider lanes, new lanes, and improvements to entrance and exit lanes. Increased road quality decreases average costs.

Increased road quality is an aspect that is embedded in new roads. Investments in better qualiy roads also increases capacity. In reality there exist small substitution possibilities between these two aspects of road investments. One could say that they were joint products as shown in the illustration. The illustration shows that the average costs are reduced after investments that increase capacity, and also improve road quality.

In the long run, improvements in the road network will cause both the marginal and the average cost curves in illustration 1 to become flatter. If excessive congestion exists initially, the revenues from the congestion tolls are used for road improvements. When the road network is improved congestion will decrease and therefore the toll will decrease. If the demand for roads increases more slowly than road capacity over time drivers will benefit not only from lower tolls, but also from faster travel times. Another way of stating this is that when congestion is reduced the benefits of road pricing are also reduced and the need for large tolls decreases. Eventually the cost curves will become horizontal, and the optimal toll will be zero.

2.1.7 Road investments in urban areas.

Road investments in urban areas have certain problems in addition to those of other road investments. A consequence of this, is that it becomes more difficult to determine if a road project is profitable.

Road investments in city areas are very expensive for a number of reasons. The land values are high in an urban area. The costs will therefore reduce the profitability of road projects. Because of lack of space, investments require expensive solutions such as bridges or tunnels. Another problem is the large variation in the demand for trips in city areas. Urban road are primarily intended to increase capacity not improve standards. Urban road standards are generally good, or at least difficult to improve. The benefits of investments during the low demand periods are therefore low. The main problem is that the capacity is too low during peak periods, and new capacity only has value during these periods. During the rest of the day this capacity is wasted.

The road network is a system of more or less effective bottlenecks. Intersections have a critical impact on driving times. If one removes one bottleneck the queue of cars may only be removed to the next bottleneck without achieving any reduction in travel times.

In urban areas public transportation is a good alternative to private cars. Public transportation routes are well developed compared to rural areas. Increasing the demand for buses and tramways will reduce the need for road investments. If one invests in roads, the use of cars may become attractive for people who earlier used public transportation. If these people change from public transport to private cars, the time savings are harder to calculate and the overcapacity outside the rush hours will become even larger. For this reason transportation planners in urban areas have also included the prices of public transportation when they try to decide on road investments. Larsen (1989) argues that both public transportation and private cars should have differentiated tariffs.

Conclusion.

This section found theoretically optimal user fees for roads. These toll fees which vary with traffic level force drivers to take into consideration the external costs in the form of longer travel times they impose to other drivers. This user fee should be large when congestion is heavy, and small when congestion is light. As congestion toll revenues are used for road improvements, the benefits of tolls decrease and the toll will therefore decrease. Thus in the long-run drivers will benefit from smaller toll fees and faster travel times. However, the complexity of the urban transportation system must be recognized when road improvements are considered.

2.2 Road pricing in practice.

The theoretical solutions to road pricing are discussed in the previous section. This section will investigate road pricing in practice, and how close road pricing in practice has come to the theoretical solutions. In this section, first the Singapore road pricing system is discussed then road pricing in the U.S.A. and in Oslo are rewieved.

2.2.1 The Singapore ALS.

Singapore's ALS was implemented in 1975. Since the Singapore scheme was the first of its kind, a number of unanticipated side effects occurred and the scheme had to be modified to correct these problems. Initially drivers were charged a flat tariff for driving into the CBD (In Singapore called the Restricted Zone, RZ,) during the morning rush hours, between 7:30 and 9:30 in the morning. However, severe congestion problems from 9:30 am to 10:00 am caused the collection period to be extended to 10:15 am. Congestion in the evening became worse than in the morning and collection was extended once again to 4:30 to 6:30 in the afternoon. The tariffs have been changed a number of times, and currently the tariffs are as follows (Wilson, 1988) (In 1992 dollars):

	Daily		Monthly	
Motorcycle	S$ 1	(USD 0.6)	S$ 20	(USD 11.6)
Company cars	S$ 6	(USD 3.5)	S$ 120	(USD 70.0)
Other cars	S$ 3	(USD 1.7)	S$ 60	(USD 35.0)

The ALS has achieved its objective. Holland and Watson (1977) found that the traffic decreased by 44 percent on average, and up to 73 percent during the morning rush. The average speed increased from 20 kilometers per hour (kph) to 33. In 1992, the average speed inside the RZ during rush hours was greater in Singapore than many other large cities (Brian, 1992).

Singapore	33 kph	New York	10 kph
Stockholm	18 kph	Bangkok	10 kph
London	12 kph	Oslo	34 kph

However, it is not clear that benefits of this policy exceed its costs. Even if the Singapore ALS has improved the traffic and environmental situation inside the RZ, changes in travel behavior have caused traffic to increase greatly on peripheral streets. These charges may have offset the advantageous impacts inside the RZ and have caused Singapore to plan an ERP system. In response to the ALS, commuters in Singapore also shifted their travel mode from the auto to public transportation. Since not enough buses were available and planners did not designate enough bus lanes, public transportation travel times increased harming many commuters (Wilson 1986). The rescheduling of trips to before or after the collection period, also led to increased congestion and longer travel times and reduced welfare during these periods. Those who pay the toll are better off only if the time savings are large enough to compensate for the costs of the toll. All in all Wilson estimated that the ALS's effects on drivers were uncertain and that the toll might even have decreased their welfare.

An alternative to road pricing is to create disincentives to auto ownership. This technique has been used in Singapore, and Rex (1994) points out that ALS, together with other restraints on owners of vehicles, may reduce the welfare for Singapore's citizens in the future. Singapore has greatly increased the purchase price of automobiles to reduce the number of cars on the small and densely populated island to a relatively low level. For example, a Mazda 323 with automatic transmission costs USD 63,000 in Singapore, about six times as much as in the U.S.A. This price reflects import duties and extremely high registration fees.

Since the cost of housing is about half that of a car, cars have high status in Singapore, and Rex concludes that the high cost of automobile ownership may cause highly skilled workers to migrate to other countries. A lower tariff rate for the ALS or ERP and especially lowering the purchase price of cars would increase their welfare and prevent people from migrating. While Singapore's policy leads to less congestion, road costs and pollution, the restrictions may be too severe. Rex argues that road congestion in Singapore is exaggerated and states that the city should be compared with large cities such as New York and

Tokyo and must be willing to tolerate a large amount of road congestion. An alternative is little restriction on autos, large investments in roads, and increased congestion and pollution. The economicly efficient solution, according to theory is that the drivers should pay for the full costs of their actions.

In Oslo the congestion is not as heavy as in Singapore and other large cities, and some economists argue (Ramjerdi 1994) that the congestion is so insignificant in Oslo that road pricing is unnecessary. A car is probably not the status symbol that it is in Singapore. The price of a brand new Mazda 323 is about 1/3 that of a medium sized apartment. In this respect, the situation in Oslo is the opposite of the situation in Singapore. In addition, drivers in Oslo partly pay the costs of their use of the roads.

2.2.2 Road pricing experience in the U.S.A.

Tolls for roads and bridges became common in the U.S.A. during the 1950s and 60s, but even if the country started early with this method of financing roads, it did not develop in the same way as it developed in Europe. During the last two decades Europe and the industrialized parts of Asia have been the innovators of new systems of road financing and road pricing. In cities like New York and Los Angeles, which face even worse congestion problems than cities like Rome and London, congestion pricing is still virtually nonexistent.

DeCorla (1994) states that even if there is a growing interest in congestion pricing because of its economic and environmental benefits, it is difficult for the U.S. public to accept this concept. The public views congestion pricing as another tax while only a few commercial road users value the time savings from reduced congestion more than they dread the toll costs. The general public has a difficult time understanding why they now have to pay for what they earlier got for free.

Other American writers (Schriener 1993) believe that the financing of toll-roads is a more important problem in the U.S.A. Private financing seems to be the most common form of financing for this type of road in the U.S.A. However, many states such as Arizona and Virginia do not allow public funds to be mingled with private funds. This policy has made funding of toll roads difficult. Schriener (1993) states that this is the reason why several planned toll-roads were never built in Arizona.

Despite financing problems, a number of large toll-road projects are planned in Orange County, California. One of them, the San Joaquin Transportation Corridor, a 15 mile toll-road, is financed through the sale of bonds. The bonds have been sold to private interests at interest rates of approximately 7.6 percent (Korman 1993). A proposed fee of USD 2 per trip will make one of the most expensive toll roads in the U.S. Construction is expected to begin in 1995 on another 100 percent privately financed toll-road in Orange County. Tolls will be collected on this road for up to 35 years. An electronic road pricing system will be utilized to implement congestion pricing on two express lanes in each direction. This arrangement will hopefully reduce the large traffic jams which occur along this route (Korman 1993).

Orange County can provide an example for other areas that face similar problems (Hartje 1991). The design of the toll plazas is approximately the same as in Oslo, except that one will have a reversible High Occupancy Vehicle (HOV) lane in the median. For the system to work efficiently, AVI tags must be sold to as many vehicles as possible.

If the road projects in Orange County reduce congestion and improve environmental conditions, this example will probably be followed elsewhere the U.S.A. Maybe one will even see a toll ring in cities like New York and Los Angeles some time in future.

Conclusions.

The Singapore toll scheme is similar to the theoretical optimal scheme in that tolls are high during congested periods and no toll is chartered during congested periods. This scheme has reduced traffic during peak hours and improved environmental conditions, but increased traffic on untolled peripheral streets has resulted in increased congestion and environmental problems on those streets. The toll scheme also increased the demand for public transit, but since public transit capacity was limited travel times for many commuters increased. Thus the impact of the toll scheme on economic welfare is unclear.

Large scale toll schemes like the one in Singapore are absent in the U.S.A, but plans are being developed for additional toll roads. On current roads a flat toll is collected to finance the road improvements. True congestion pricing has not yet been implemented in the U.S.A.

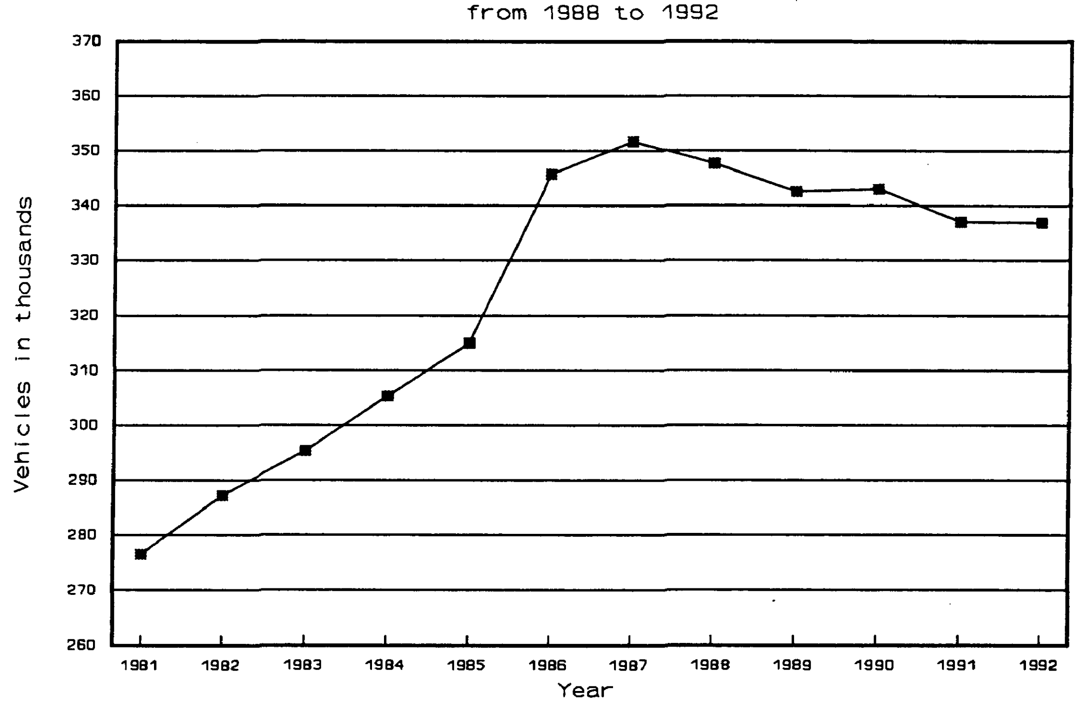
2.3 The Oslo toll scheme.

The Oslo toll scheme's flat toll 24 hours a day is antitheoretical to the theoretical solution to road pricing. The purpose is mainly to collect revenues for further road investments, and in this respect the toll scheme has been a success. A toll system that is closer to optimal road pricing is investigated in chapter 3 and 4. However, this section investigates the impact of the toll ring on travel habits in the Oslo region during the first years of implementation. This section begins by discussing the Oslo region's traffic trends. Then the toll ring's impact on the travel behavior of different groups of drivers is described.

2.3.1 Oslo region traffic trends and the impact of the toll ring on traffic volumes.

Nationwide, the total number of automobiles remained steady at slightly under 2 million from 1988 to 1992, but there were regional differences. The number of vehicles registered in the Oslo region decreased from 1987 to 1992 (Statistisk ordbok 1993), after a rapid increase in the early eighties, as can be seen in Figure 1.

Figure 1: Number of vehicles in the Oslo-region from 1988 to 1992



The number of private cars decreased while buses and trucks increased in number from 1987. At the same time, the region's population increased by about 8000 per year.

Even if the total number of cars decreased after 1987, traffic in the Oslo region did not decrease. Table 2.3.1 which reports the yearly count of cars on three roads leading into Oslo and one road inside the CBD indicates that total traffic on these routes increased from 1988 to 1992. Traffic decreased slightly at Vinterbru and Kringen. It seems peculiar that the traffic increased at Vinterbru from 1989 to 1990 when no improvements were made in road capacity. At Franzefoss where road capacity was increased, there was a large increase in traffic. However, despite the increased traffic significant time savings occurred on route E68. In general, traffic increased in this

Table 2.3.1: Average number, in 1,000, of vehicles per 24 hour in both directions. Reference: Statistical yearbook 1989-1993.

	1988	1989	1990	1991	1992
E6 Vinterbru	31,4	28,6	30,1	30,7	30,3
E68 Franzefoss	23,8	24,5	24,0	25,0	27,0
Rv4 Kringen	8,5	8,7	8,6	8,4	8,3
Oslo W.vn.	15,7	16,0	14,6	14,6	14,7
Total	79,2	77,8	77,3	78,7	80,3

road, except from 1989 to 1990, when the toll ring was implemented.

Traffic declined sharply on the one road located inside the Oslo CBD from 1989 to 1990. This decline reflects a general decrease in traffic inside the CBD which can be attributed to the toll ring and several road projects, among them, the Oslo tunnel, that diverted traffic from the CBD.

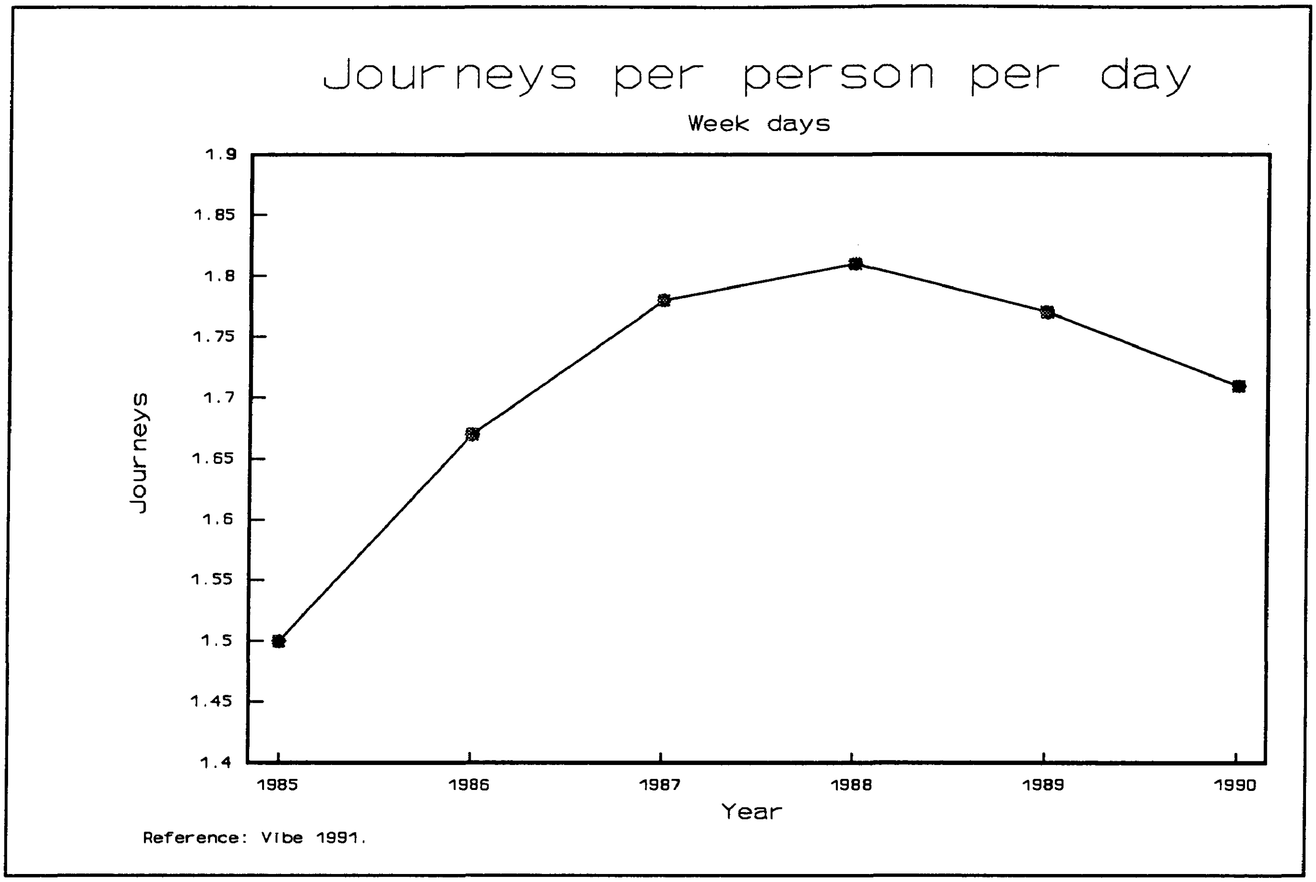
Since traffic increased from 1988 until 1992, at the same time as the number of cars decreased, those people who owned cars must have used them more often. This trend is verified by Vibe's study which found that automobile use in the Oslo region increased from 1985 to 1990 by 0.21 journeys per car per weekday. It is important to determine the causes of these changes.

Figure 2 indicates that the number of journeys increased from 1985 until 1988 and then began to decline. Although, the number of journeys per person per day in 1990 still exceeded the number in 1986. This decline coincides with the decline in total number of cars and the beginning of the general decline in the Norwegian economy. The reduction in the number of weekday journeys from 1989 to 1990 was 3.3 percent.

2.3.2 Change in travel habits on different groups of drivers.

Given the general developments in the Oslo region traffic, changes that occurred from 1989 to 1990 are investigated in more detail, in an attempt to determine the toll ring's impact on people's travel habits.

The following discussion is based on Hjorthol and Larsen's 1991 mail survey of 40,000 randomly chosen people between 13 and 75 years of age in the Oslo-region during the autumns of 1989 and 1990. The survey consisted of a one day travel diary where the respondents answered questions about where they travelled to, from which places, why, and at which times of the day. This



investigation covered every day of the week. To determine which social group the respondents belonged to, questions about income, work, age, sex, car ownership, transportation to and from work, and driver's license were included.

The survey conducted in 1990 was identical to the 1989 one except that questions about the toll ring were included. Fifty-three percent responded in 1989, and 75 percent of this group responded again in 1990. The responses for this group, of approximately 16,000, are reported, and their answers are summarized in the following pages.

The respondents took an average of 2.67 journeys per day in 1989 and 2.37 in 1990. Table 2.3.2 shows that the decrease in journeys, 14.6 percent was the largest for discretionary journeys taken during leisure time. This group includes different kinds of shopping, private visits, errands and recreation.

Table 2.3.2: Number, and shares of journeys in 1989 and 1990, by the purposes of the journey. In percent. Reference: Hjorthol 1991.

Purpose of the journey	1989 Percent	1989 Number per day	1990 Percent	1990 Number per day	Percentage difference-
Discretionary	55	1.45	53	1.24	-14.64
Commuters	37	0.99	39	0.92	- 6.8
In Business	8	0.21	8	0.21	- 0.9
Total	100	2.67	100	2.37	-10.6

The reduction for commuters was 6.8 percent, and the reduction in business trips was only 0.9 percent. These figures may be a bit inaccurate, but the trend seems plausible because leisure trips are more flexible in frequency, timing and destination than the other two groups. If the toll fee is collected for each crossing, depending upon the amount of the fee, it should have a much larger impact on trip frequencies for discretionary trips than on the other groups.

Most of the journeys are taken by car, as a driver or as passengers, but table 2.3.3. reports other types of journeys as well. Both in absolute number and as a percentage, the journeys in cars decreased the most. In 1989, 1.77 journeys were made as a driver or passenger per person per day, but by 1990 this number was 1.52. These numbers are not consistent with the Vibe 1991 investigation, even if Vibe's results are based on weekdays, and the Hjorthol study is based on the entire week; such inconsistencies indicate that the survey results may not

Table 2.3.3: Number of journeys by mode transport.
Reference: Hjorthol 1991.

Way of transport	Percent	1989 number per day	Percent	1990 number per day	percentage difference
Walking/ bicycle	12	0.33	13	0.31	4.9
Public transport	19	0.5	20	0.47	-6.3
Car, driver	56	1.49	55	1.31	11.7
Car,passenger	10	0.28	9	0.21	24.2
other	3	0.07	3	0.06	-5.3
Total	100	2.67	100	2.37	-10.6

be robust. The Hjorthol study shows a decrease in journeys by car of almost 12 percent, and that fifty-five percent of all journeys were auto journeys. Journeys by public transportation also decreased slightly from 0.5 journeys per day in 1989 to 0.47 in 1990, but the share of all journeys by public transportation increased by 1 percent. The share of journeys by bicycle or walking also increased slightly.

Because of these conflicting results, it is necessary to take a closer look at the reliability of the self reported data. It is possible that the decreases in all types of transportation are exaggerated. It is likely that people under reported their use of cars. The large differences between table 2.3.1 (based on actual counts) which shows only a 1 percent decrease and table

2.3.3 which shows a more than 10 percent decrease support this conclusion. Also differences occur in the use of public transportation. In table 2.3.3, a decrease of 0.03 trips per day is reported, but at the same time according to the total revenue from ticket sales for public transportation, which carried people from the outlying regions to the center of the city, increased by 3 percent. Part of this increase is probably due to price increases, but ridership also increased. Manual counts of public transportation use also support this conclusion.

2.3.3 Change in travel habits with respect to subscription and residental location.

An important question is the impact of subscription cards on toll ring crossings. The implementation of the toll ring caused only an income effect for people who purchased subscriptions. The cost of the subscription reduced their disposible income, but the toll ring did not affect their cost for an additional trip. People without subscriptions also experienced an income effect caused by the toll ring, but these users also experienced a substitution effect. The substitution effect will cause them to reduce the number of times they cross the toll ring and will, therefore, change their travel behavior.
Thus we should expect to observe a large reduction in trips that cross the toll ring by those who do not purchase cards, but little or no reduction by those who purchase cards. To answer

this question, the entire group is divided into five sub-groups;

1 - persons without driver's licenses or cars,

2 - persons with a car who did not purchase a subscription

3 - persons with one car who did purchase a subscription

4 - persons with two or more cars who did not purchase a subscription

5 - persons with two or more cars who purchased a subscription for at least one car.

Table 2.3.4 presents the average reduction in the number of journeys by car per person per day for the different groups. Journeys by persons who did not own a car in 1989 are naturally not reported. The table shows that there was no difference in

Table 2.3.4: Reduction in number of car journeys by sub-group. Reference: Hjorthol 1991.

Subgroups	%-diff.89-90	%-decrease
1 car, no subscription	0.18	(12)
1 car, subscription	0.18	(8)
>1 car, no subscription	0.23	(11)
>1 car, subscription	0.21	(8)

the absolute reductions, and the number of car journeys for the different groups, but there was a difference in relative reduction. People with subscriptions decreased their journeys by a smaller percentage (8%) than people without subscriptions (12%). People with subscriptions, purchased them (or got them from their employer) because they used their cars intensively, and they reduced the number of trips much less than the others.

Table 2.3.5 reports the changes from autumn 1989 to autumn 1990 with respect to where their journey originated and where their final destination was, and whether or not they crossed the toll ring.

Table 2.3.5: Share of journeys as a driver in each zone in the Oslo region in 1989 and 1990. Reference: Hjorthol 1991.

Startzone	Final destination			
	Oslo, inside toll ring	Oslo west region	Oslo north region	Oslo south region
Oslo, inside				
1989	43.1	54.4	55.7	48.2
1990	42.1	53.4	52.5	44.5
Oslo, west				
1989	54.6	64.1	71.3	56.1
1990	53.8	65.7	66.3	60.2
Oslo, north				
1989	54.7	69.5	66.0	74.8
1990	52.9	64.7	66.4	71.3
Oslo, south				
1989	47.9	55.7	73.4	60.2
1990	45.0	62.4	68.8	59.9

Within each region the changes are small, but between regions the changes are larger. The largest decrease is for journeys from the regions outside the center of Oslo to destination inside the center city area. The long time period required to travel using public transportation from one subscription area to another, for example from the western region to the northern region reduces the percentage of these trips made by public transit. The fact that one has to change commuter trains discourages many from using public transportation and causes them to use cars instead. The road improvements made after the toll ring was implemented reduced travel times for these journeys, and thus reinforced this tendency. A commuter train trip from the outlying regions to the CBD is fairly fast. This should imply an increase in journeys by public transportation, but this increase has been small, about two percent. The smallest reduction in auto travel occurred in the western region. This region had the smallest decrease in journeys with final destination in the CBD of all regions and journeys inside this region increased by 1.5 percent. It would seem reasonable that the western region was affected the least by the toll ring since it is by far the most affluent of the regions surrounding Oslo.

Table 2.3.6. reports the share of car journeys out of total journeys that crossed the toll ring before and after the toll ring was implemented, by region. The share of journeys by car decreased by 2.6 percent and this decrease is the smallest for the western region. Table 2.3.7 shows the decrease in

Table 2.3.6: Share of journeys that cross the cordon line by car, in percent. Reference: Solland 1991.

	1989	1990	%-difference
West	20.8	20.5	-0.3
North	19.9	18.4	-1.5
South	14.3	13.5	-0.8
Total:	55.0	52.4	-2.6

journeys by car is exactly offset by the increase in journeys by public transportation.

Table 2.3.7: Share of journeys that crosses the cordon line by public transportation, in percent. Reference: Solland 1991.

	1989	1990	%-difference
West	11.3	12.9	1.6
North	10.7	12.1	1.4
South	9.5	9.1	-0.4
Total:	31.5	34.1	2.6

One peculiar item in the last table is that both the journeys by public transportation and the journeys by car from the south decreased (table 2.3.6 and 2.3.8). This region may have been affected more by the toll ring and the economic recession than the other regions.

Data on the share of journeys to work by car that crossed the toll ring, reported in table 2.3.8, indicates that this share was larger in 1990 than in 1989. This supports the hypothesis that leisure travel was affected most by the toll ring.

Table 2.3.8: Share of journeys to work by a car. Reference: Solland 1991.

	1989	1990	%-difference
West	24.2	27.1	2.9
North	25.3	28.2	2.9
South	18.6	18.0	-0.6
Total:	68.1	73.3	5.2

The investigations of people's travel habits before and after the introduction of the toll ring indicate a decline in traffic of about 5-10 percent, but a general decline in the number of cars in the Oslo region after 1987 (figure 1) and the proportion of vehicles registered outside the toll ring reported in table 2.3.9 indicates that the reduction may be overestimated. The decline in the number of cars from 1987 altered the car ownership status of households in the Oslo region. The percentage of households without a car increased, and the percentage of households with one or two cars decreased. During the same period, the number of people employed in the Oslo region decreased[5]. This suggests that the reduction in traffic was not only because of the toll ring, but also because of a general recession in the Norwegian economy. Additional factors besides the toll ring that may have reduced automobile journeys include:

- An approximately 16 percent increase in gasoline prices between autumn 1989 and autumn 1990 that caused a 1.2 percent decline in gasoline sales (Bil og veistatistikk, 1992).
- Reductions in subsidies for car travel. The percentage of car households with a car who had a company car fell from 7.5 in 1989 to 6.9 in 1990, and the percentage with access to free parking at work fell from 56.7 percent in 1989 to 53.7 percent in 1990.

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[5] The unemployment rate for the Oslo region increased 1,6% from 1989 to 1990.

The reduction in car traffic from 1989 to 1990 was 3.3 percent (Vibe 1991) to 14 percent (Hjorthol 1991). Many factors were responsible for this total change. This author estimate that the toll ring is responsible for about 3 percent of this decrease. This low estimate reflects actual traffic counts from 1988 to 1993[6] that are summed up in table 2.3.9 and the impact of the recession.

The counts in table 2.3.9 show a decline in traffic from 1989 to 1990 of 4.9 percent, but the decline had already started in 1988. From 1988 to 1989, the decrease in traffic was 1.3 percent, and there is no reason to believe that this would not have continued from 1989 to 1990. A decrease in employment of 1,6 percent from 1989 to 1990 implies that 11,000 fewer people needed to travel to and from work. If 20 percent of these normally crossed the toll ring, it would mean a decrease in traffic of about one percent. Since the increase in gasoline prices led to

Table 2.3.9: Average traffic that crossed the toll ring per 24 hour period from 1988 to 1993, seven days a week. Reference: See footnote 6.

	1988	1989	1990	1991	1992	1993
West	83,009	83,164	80,851	80,716	81,294	82,584
North	80,712	79,519	74,274	73,402	71,285	72,993
South	55,781	53,979	50,923	50,522	50,828	51,448
Total	219,502	216,662	206,048	204,387	204,420	207,025

[6] Reference: Kristiansen,K. Prosamrapport nr. 28, Oslo 1992, and also unpublished registration of vehicles crossing the toll ring 1991-1993 from A/S Fjellinjen.

a decrease in gasoline sales of 1,2 percent, this change is responsible for another 0,5 percent decrease in traffic. This adds up to about 3.5 percent decrease, but since the economic recession has additional negative impacts on traffic, a three percent decrease caused by the toll ring is the final result.

A toll fee of NOK 11 could be considered fairly high, and one could have expected a larger impact on travel behavior. Yet, as a marginal cost, this fee should be compared with the costs of operating a car. Gasoline cost in October 1990 was more than NOK 7 per liter, and given that journeys that cross the toll ring average 26 kilometers, the gasoline expenses exceeded the toll. In addition, the cost of car ownership in Norway is among the highest in Europe. Given the high fixed car cost in Norway, a higher marginal cost can be justified for using the car. The cost of public transportation is also comparable to the costs of operating a car given public transportation's higher door-to-door time, that includes walking time, waiting time and transfers. These are reasons why the toll ring has not had a larger impact on travel behavior.

An alternative way of financing the road projects in the Oslo region would have been to increase the gasoline tax. Large costs would have been avoided because the toll stations would have been unnecessary. The gasoline tax increase could be structured so that it would collect sufficient revenue to finance the planned road improvements.

The problem would be to set the borders for the increase in the tax. People would travel longer distances to purchase gasoline, and a number of gasoline stations would go bankrupt if the gasoline prices suddenly increased at some stations and not at others. This problem could be dealt with, if the gasoline tax increase were gradually decreased with distance from the city. Due to this problem gasoline tax finance was never given serious consideration for the Oslo region road improvements.

Conclusion.

One of the objectives of the toll ring was to reduce total traffic and, especially, to reduce rush hour traffic. This objective was achieved during the first two years after the toll ring was implemented, but recent counts show that better roads in the future will only cause traffic to increase. This development has already begun, as the volume of traffic crossing the toll ring increased after 1992. These traffic increases are probably a product of changes in the Norwegian economy. Nineteen-nenety three was a relatively good year for Norway with low inflation and a reduction in the unemployment rate. This recovery will probably continue for the next few years. The recovery in combination with population increases in the Oslo region will have a significant impact on traffic. Traffic is estimated to reach its 1988 level by 1997 (Gylt 1991).

The total traffic level decreased in Oslo, and some of these changes can be directly linked to the toll ring. Journeys by vehicle during leisure time decreased more than journeys taken in conjunction with the driver's work. This is because leisure trips are more flexible in frequency and timing than commuter trips and business trips where the vehicle user is more or less dependent on their vehicles.

It is also determined that drivers with subscriptions changed their travel habits less than drivers without subscription, and that drivers from affluent parts of Oslo reduced their driving the least.

CHAPTER 3

3.0 IMPACTS OF ALTERNATIVE TARIFFS.

In this chapter the impact of differentiated tolls on the numbers of trips, on total revenue, and on the amount paid by different categories of drivers are investigated. Also those drivers who benefit from and are harmed by differential tolls are identified. These results are compared with those of the present flat tariff.

In this chapter, the short-run impacts of differentiated tolls are simulated. The long-run effects of changes in road pricing, the road or public transit improvements financed by toll revenues, and changes in population or incomes, are not treated. A complete cost benefit analysis would include all these factors. Including these factors, alters the costs and benefits of the alternative road pricing systems by changing road and public transit cost curves and the demand for roads and public transit. These long-run effects are not within the scope of this thesis. However, the long-run effects of changes in road prices on the demand for roads is approximated by analyzing the impact of increasing the reaction coefficients used in this chapter.
The effects of the cordon toll ring on different income level groups and on land use and commercial traffic are also discussed.

3.1 The Economics behind the Calculations.

The objective of differentiated tariffs is to utilize the existing road system in the most efficient manner. This results from private marginal costs that more closely reflecting social marginal costs. Investigations concerning attitudes indicate that drivers believe they are being treated unfairly if they have to pay the same amount of money to cross the toll ring during rush hours when road space is scarce, or at another time of the day when the traffic is very light (Simonsen 1991). One advantage of a high tariff during rush hours is that even a small decrease in traffic caused by this policy should result in a more even utilization of the road space over the day. The closer convergence of private and social costs is under a differentiated tariff than under a flat tariff is reflected in Illustration 4.

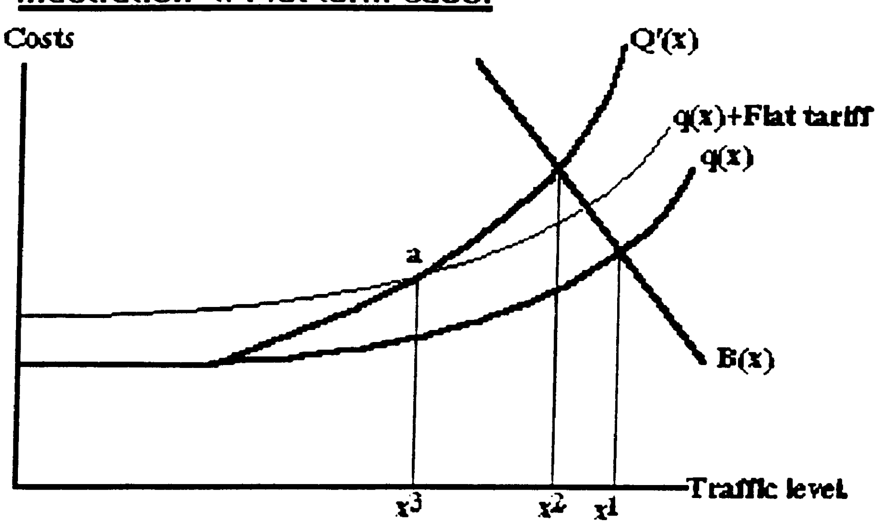

Illustration 4. Flat tariff case.

At point a with traffic level x^3, social costs equal private costs with a flat tariff, but this is the only point where this occurs. When traffic exceeds level a, marginal social cost exceeds private marginal costs, and the toll is too small. If the traffic is lower than level a, private costs are larger than social costs and the toll is too large. Thus, differentiated tolls are more efficient than the present scheme if congestion as described in section 2.1.3 exists.

The optimal solution would be to set the toll at zero when the congestion was lower than traffic level x^3, and then to increase it as traffic increased to reach a maximum when traffic equals x^2 during the rush hours, and then to reduce it as traffic decreased. A problem with this solution is not knowing exactly when to adjust the prices. That is, knowing exactly where one is on the curve. In addition, drivers would not know in advance the cost of crossing the toll ring. In practice the tolls are varied infrequently. In Oslo only one small change has occurred. Nine months after the introduction of the toll ring the single crossing toll was increased by NOK 1. However, the flat tariff system has not been modified. While a system of differentiated tariffs is not marginal cost road pricing, it is closer to it than a flat tariff scheme. The impacts of a differentiated system are simulated in the remainder of this chapter.

3.2 Assumptions, definitions and the model.

In this section the impacts of alternative pricing policies on traffic levels, and on different groups of drivers, and on total revenue are investigated.

It is assumed that all drivers undertake a marginal judgement every time they decide to take a journey, and that they pay each time they pass the toll ring. This is not true, because subscriptions allow drivers to pay the same amount whenever they cross the toll ring once or ten times per day. Subscriptions will be included in the analysis when it is likely that they will have an impact on the conclusions.

A potential traveler faces a number of choices. Whether to undertake the journey or not, at which time of the day to travel at, and what method of transportation to use. The pricing policy that was chosen for the Oslo toll ring affects these choices, and a different price policy will have different effects. For the analysis, drivers are divided into three types: discretionary trips, commuters and business trips.

-Discretionary trips: shopping, visits, errands and recreation.

-Commuters: Trips made to and from work.

-Business trips: The group that take journeys to perform their work such as all sorts of deliveries and services.

The week is divided into;

-rush hours (7-10 a.m.); Weekdays, the evening rush is not included.

-outside rush hours on weekdays.

-weekend; Saturday and Sunday.

Results are presented for four scenarios.

Scenario 1: situation before the implementation of the toll ring.

Scenario 2: the present flat tariff scheme.

Scenario 3 & 4: differentiated tariffs.

In Table 3.2.1, the tariffs by time of day are presented for the four scenarios. A typical trip that crosses the toll ring is about 26 kilometers, and according to A/S Fjellinjen the average cost of a trip is NOK 15.

Table 3.2.1: Toll charges assumed in the following scenarios: (1) The initial situation , (2) Flat toll (3) Differentiated (4) Differentiated.

	Scenarios			
	1	2	3	4
Rush hours	0	11 NOK	20 NOK	30 NOK
Outside rush	0	11 NOK	7 NOK	5 NOK
Weekend	0	11 NOK	9 NOK	4 NOK

July 21, 1994: USD 1 = NOK 6.8.

The charges in scenario 3 and 4 are based on figures mentioned by that participants in recent debates concerning how large the future tolls should be. For example, future toll charges of between NOK 20 and 30 during the rush hours were suggested by Jean-Hansen (1991). The toll charges for the other time periods are more arbitrary, but experts have suggested that they be less than half the rush hour price.

Two parameters which affect the impacts and evaluation of a pricing scheme are the elasticity of demand and the portion of income spent on tariffs. The more elastic a group's demand, the greater the impact of a price change on their behavior and the larger their indirect burden. Since the price elasticity of demand for discretionary trips is much larger than for the other two types of trips, differentiated tariffs, compared with a flat tariff charge will have a larger impact on discretionary trips than the other two types of trips. Thus charges will reduce congestion for discretionary trips, but have little impact on congestion for the other two types of trips. Compared to a flat rate toll, differentiated tolls should collect a smaller share of the total toll revenue from discretionary drivers and a larger share from the other two groups. In addition, the larger the portion of the road users income that is spent on toll, the greater their direct burden as a percentage of income.

It is assumed that the change in traffic volume caused by a NOK 1 change in the tariffs based on the formulas below is 0.06 for discretionary trips, and 0.025 for commuters and 0.01 for businesses (Ramjerdi 1993). These figures are called reaction coefficients and are assumed to hold for all drivers, with or without seasonal passes. This simplification is suggested by Jean-Hansen (1991).

The reaction coefficients are also chosen based the actual reductions in traffic caused by a similar toll scheme in Bergen that was implemented a few years earlier. Gasoline prices increased sligtly, and in approximately the same proportions in both Bergen and Oslo. This factor is included in the coefficients. When estimating the coefficients for the Oslo toll ring, Ramjerdi assumed that the coefficients were slightly smaller, because the Oslo toll ring is more sophisticated than the Bergen toll ring. In Bergen, the toll is collected manually and in Oslo most of the tolls are collected electronically. This reduction in time cost caused smaller reaction coefficients to be chosen.

The reaction coefficients appear in formulas (i) - (iii) below.

Discretionary trips:

(i) X(1,j)= X(1,1)-X(1,1)*0,06*P(j)/P(1)

Commuters:

(ii) X(2,j)= X(2,1)-X(2,1)*0,025*P(j)/P(1)

Business trips:

(iii) X(3,j)= X(3,1)-X(3,1)*0,01*P(j)/P(1),

where :i = 1-3 are 1: Discretionary trips

2: Commuters

3: Business trips

:j = scenarios 1-4.

:T(j)= toll in situation j.

and P(j)= T(j)+15 = Price for one crossing in situation j.

In 1989, on average 216,662 cars per day crossed the toll ring. This includes an average of 108,390 on a Saturday or Sunday and 259,975 on a weekday. On weekdays, 24 percent crossed the ring during the rush hours between 7 and 10 a.m., and 76 percent outside rush hours[8]. This data, when combined with the shares for trip types from the 1991 mail survey (Hjorthol 1991), yields Table 3.2.2.

Table 3.2.2: Shares in percent by type of trip, days of the week, and time of day.

Purpose	Weekdays Rush	Weekdays No rush	Weekends
Discretionary	10.37	41.18	73.13
Commuting	38.58	21.68	12.29
Business	51.05	37.15	14.59
Total	100	100	100

Assuming that the shares did not change, the shares from 1991 are applied to the actual counts from 1989 to determine the number of

[8]These are number of crossings from outside the CBD into the CBD only.

trips by purpose and time period.

To determine if the reaction coefficients are reasonable, the predictions for 1991 based on the 1989 data are compared with the 1991 counts. Although it should take time for people to adjust to the toll ring, most adjustments should have been made by 1991. If these predictions for the flat tariff is accurate, it seems reasonable to use the same procedure to simulate the impacts of differentiated tariffs.

3.3 Base case simulation results.

In this section the base case simulated traffic levels for the four scenarios, by type of trip, and by time of day and week are presented. In section 3.5, a sensitivity analysis of the impact of alternative coefficient values on these results is conducted.

Calculated total traffic per year crossing the toll ring (104 Saturdays and Sundays, and 261 weekdays), is reported in Table 3.3.1.

The accuracy of these numbers can be determined by comparing the simulated and actual traffic volumes. The simulated total traffic per year is 74.5 million vehicles after a period of flat tariffs of NOK 11. In 1991, the actual traffic per year was 74.6 million vehicles. Thus, the simulated values closely approximate the actual values and the estimation procedure appears to be

Table 3.3.1: Total traffic per year crossing the toll ring by scenarios and trip type. Measured in million crossings per year. The numbers in brackets are percentages of the initial scenario.

Type	Scenario 1	2	3	4
Discretionary	31,2(100)	27,9(89.4)	28,0(89.7)	28,5(91.4)
Commuters	18,9(100)	18,1(95.8)	18,1(95.8)	18,0(95.2)
Business	29,0(100)	28,5(98.3)	28,5(98.3)	28,5(98.3)
Total:	79,1(100)	74,5(94.2)	74,6(94.3)	75,0(94.8)

reliable. Thus, is assumed that the reaction coefficients are approximately correct, and even if the actual coefficients differ slightly from the coefficients used in the simulations this should not greatly alter the conclusions.

To further investgate what the results from a toll are between the different trip types, arc elasticities are useful. One will then find which trip type that has the most elastic demand for road use. An arc elasticity can be written as

$$(dX/(X1+X2)/2) \;/\; (dP/(P1+P2)/2) \qquad \text{where}$$

dX is change is traffic from scenario 1 to 2

dP is the change in price (toll) from scenario 1 to 2

X1 is the initial traffic level

X2 is the traffic level for scenario 2

P1 is the initial price (NOK 15)

P2 is the toll in scenario 2 (NOK 11)

The computed elasticities from scenario 1 to 2 are 0.13 for discretionary trips, 0.05 for commuters and 0.02 for businesses. This means that discretionary trips have the most elastic demand for road use and reduce their trips the most when tolls have to be paid, and businesses have the least elastic demand for trips and reduce their trips the least.

Table 3.3.1 indicates that the total number of vehicles that cross the toll ring increases when differentiated tariffs are substituted for the flat tariff. The flat tariff reduces traffic by almost 6 percent, and the most differentiated tariff reduces traffic by only approximately 1 percent. The major difference between flat and differentiated tariffs is their impact on discretionary trips which occur primarily outside the rush hours. The flat tariff reduces these trips by 10.6 percent but the most highly differentiated tariff reduces them by only 8.6 percent.

The impacts of differentiated tariffs by time of day and day of the week can also be determined. The simulated results for these time periods are reported in tables 3.3.2. through 3.3.4.

According to table 3.3.2, a flat tariff reduces rush hour traffic by 3.6 percent, and the differentiated tariffs cause a larger reduction.

Discretionary trips comprise only 10 percent of the total rush hour traffic. The present toll scheme reduces this type of trip by 10.4 percent and the most highly differentiated tariff reduces this type by, 18 percent. Commuters are less willing to reduce their auto trips significantly. People who use cars in their

Table 3.3.2: Traffic by type on a typical weekday during the rush hours, measured in 1000 crossings. The numbers in brackets are percentages of the initial values.

	Scenario			
Type	1	2	3	4
Discretionary	6,4(100)	5,7(89,6)	5,5(86.0)	5,2(82.0)
Commuters	24,0(100)	22,9(95.7)	22,6(94.2)	22,2(92.5)
Business	31,7(100)	31,2(98.3)	31,0(97.7)	30,8(97.0)
Total	62,2(100)	59,9(96.4)	59,1(95.1)	58,3(93.7)

work, the business category, reduced their rush hour trips by only 1.7 percent under the current flat tariff. The most highly differentiated tariff reduces this type of trip by only 3 percent.

During off-peak periods on weekdays road space is no longer a scarce good, the differentiated tariffs are lower than the current flat tariff, and according to Table 3.3.3, the traffic volumes under the differentiated tariffs are greater than the volumes under the flat tariff. The reduction on weekdays during off-peak periods from the initial situation to the present scheme is 6 percent, much larger than the rush hour reductions. The source of this result is that discretionary trips comprise a larger share of total trips during off-peak hours than during the rush hours. With a differentiated tariff, compared to a flat tariff, off-peak traffic increases because more discretionary trips are taken. The changes for the other two trip types are small and reflect the inelastic demand for these trip types.

Table 3.3.3: Traffic by type on a typical weekday <u>during off-peak hours</u>, measured in 1000 crossings. The numbers in brackets are the percentages of the initial values.

	Scenario			
Type	1	2	3	4
Discretionary	81,4(100)	72,9(89.6)	74,2(91.5)	74,8(92.0)
Commuters	43,1(100)	41,2(95.7)	41,5(96.3)	41,7(96.7)
Business	73,1(100)	71,9(98.3)	72,1(98.5)	72,1(98.7)
Total	197,7(100)	185,8(94.0)	187,8(95.0)	188,7(95.5)

On the weekends, the vast majority of trips are discretionary. Seventy-three percent of all car use on the weekends is of this type. Table 3.3.4. reports the simulated weekend traffic.

Table 3.3.4: Traffic of each type on a <u>weekend</u> (Saturday or Sunday), measured in 1000 crossings. The numbers in brackets are the percentages of the initial values.

	Scenario			
Type	1	2	3	4
Discretionary	79,2(100)	71,0(89.6)	71,6(90.4)	73,2(92.4)
Commuters	13,3(100)	12,7(95.7)	12,7(96.0)	12,8(96.8)
Business	15,8(100)	15,5(98.3)	15,5(98.4)	15,6(97.3)
Total	108,3(100)	99,2(91.6)	99,9(92.3)	101,7(93.9)

A flat tariff causes the largest reduction in weekend traffic. The reduction is 8.4 percent, and most of this reduction is discretionary trips. If the tariff is reduced to NOK 4, as in scenario four, the traffic decreases by only 6.1 percent. For weekends, this result is more efficient since traffic volumes for all the weekend simulations are less than the capacity of the roads; therefore, the most efficient weekend tariff is zero.

In this section it has been assumed that subscriptions are not offered. Introducing subscriptions may alter the previous results. The most frequent road users purchase subscriptions, therefore those who make business and commuter trips are more likely to subscribe than those who make discretionary trips. The result of this reduction in average trip cost for commuters and business trips is that the average tariff by trip type in Table 3.4.2 is more equal for the different types of trips. Thus the reductions in commuters and business trips will be smaller than those previously indicated and the impacts of the different pricing systems will be more similar than the following section indicates.

3.4 Total revenue and the distribution of the burden of the toll.

According to Table 3.4.1, the more differentiated the tariffs the lower the revenue from the toll ring. Of course, changing the tariffs could alter this result. Allowing subscription discounts will reduce all the numbers in Table 3.4.1. and 3.4.2, but the overestimates should not alter the relationship between tariffs and revenues and the other conclusions. For example, the simulated total revenue in scenario two with the current flat tariff of NOK 11 per crossing, NOK 820 million, exceeds the current revenue. Because of subscriptions the average payment per crossing was actually NOK 8.4 in 1991, which yielded total revenue of approximately NOK 630 million.

Table 3.4.1: Total revenue in million NOK by scenario and trip type.

Type	Scenario 2	Scenario 3	Scenario 4
Discretionary	307,2 (37.5)	229,8 (30.9)	169,6 (23.3)
Commuters	199,0 (24.3)	205,9 (27.7)	233,7 (32.2)
Business	313,8 (38.3)	308,3 (41.4)	323,2 (44.5)
Total	820,0 (100)	744,0(100)	726,5 (100)

In scenario 3 and 4, a larger share of total revenue will be paid by businesses because these users need to use road capacity during the rush hours, and they are less willing to change their behavior. The opposite pattern is observed for discretionary trips. This groups share is reduced from 37.5 percent under the current system to 23.3 percent in scenario 4. Since commuters are only slightly more willing to alter their behavior than business travelers. This group also pays a larger share of total revenue under differentiated tariffs.

Table 3.4.2. summarizes the average payment by trip types and scenario. There are only small differences from scenario 2 to scenario 3 and 4 for businesses and commuters. For discretionary trips the change is, as expected, much larger.

Table 3.4.2: Average tariffs by trip type and scenario.

Type	Scenario 2	3	4
Discretionary	11	8.21	5.95
Commuters	11	11.38	12.98
Business	11	10.82	11.34

Differentiated tariffs benefit discretionary drivers. Their total payment decreases substantially as does their average price per crossing. Thus, the more highly differentiated the tariffs the smaller the impact on this trip type.

The other two groups pay more than under the present scheme and thus are harmed by differentiated tariffs. Differentiated tariffs redistribute income from commuters and business to discretionary drivers. This is probably a faire distribution. With differentiated tariffs, those who generate the largest external costs also pay the most, assuming that drivers pay the full tariff for each crossing. Allowing subscriptions, will cause the tariff for many discretionary trips to exceed that of many nondiscretionary trips. When subscriptions are allowed, a business vehicle that crosses the ring three times a day with an annual subscription, pays about half the price per crossing of a nonsubscription discretionary trip. This may be a low estimate since a business vehicle may cross many more times a day. To a degree, this also holds for commuters with subscriptions, who also use their cars for discretionary trips in the evenings. Also since subscriptions reduce the cost per trip, the reduction in trips will be smaller when subscriptions are allowed.

According to economic theory, differentiated tariffs should represent an improvement on the present flat tariff scheme, because higher tariffs during rush hours and lower tariffs at other times, are closer to optimal congestion pricing than the present scheme. According to the estimates, differentiated tariffs reduce traffic during the rush hours and increase traffic during off-peak periods. The only problem with differentiation is that it decreases total revenues. When the toll ring was first implemented, flat tariffs probably alleviated implementation problems. Given current technology and subscription levels, the transition to differentiated tariffs would not be difficult.

3.5 Sensitivity analysis.

The results of the simulations depend on the reaction coefficients. In this section, the impacts of varying the coefficients will be investigated for three cases. Case 1 investigates whether small changes in the reaction coefficients have a signigicant impact on the results. Cases 2 and 3 attemt to capture long-run impacts of changes in road prices on the demand for roads. In case 2 all coefficients are increased, and in case 3 the rush hour coefficients are increased, and all the other coefficients are decreased. The cases yield results that are close to the actual traffic volumes.

In case 1 it is assumed that the reaction coefficients decrease with traffic volume. To investigate this possibility the rush hour coefficients for the differentiated pricing scenarios 3 and 4 are increased slightly with the degree of differentiation, and the nonrush coefficients including the weekend coefficients are reduced slightly with the degree of differentiation for discretionary and commuters trips. Because of the small reaction coefficient for business trips these are kept constant. The changes in the coefficients are proportional to the difference between the differentiated tariffs and the flat tariff of scenario 2. This is called case 1.

The decision not to alter the coefficients for scenario 2 is based on the accuracy of the base case simulated traffic levels for scenario 2. The original reactions coefficients for scenario 2 and the revised reaction coefficients for scenario 3 and 4 are reported in Table 3.5.1.

Table 3.5.1: Case 1 reaction coefficients.

	Rush hours			Non rush/weekend		
	Scenario					
Type	2	3	4	2	3	4
Discretionary	.060	.065	.070	.060	.0575	.055
Commuters	.025	.026	.027	.025	.0225	.002
Business	.010	.010	.010	.010	.0100	.010

When one compares the results in Table 3.5.2. with the previous ones (tables 3.3.2-3.3.4), no large changes are observed. Discretionary trips decrease during the rush hours and increase outside the rush hours and on the weekend. The pattern is observed for commuters, but to a lesser degree. The total number of crossings increases, but only by 400,000 in scenario 3, and by less than 300,000 in scenario 4. These changes cause small and insignificant changes in total revenues and in the shares of total revenue paid by the different trip types.

Table 3.5.2. Case 1 results: Traffic in each group per day by times of the week for scenario 3 and 4.

	Rush hours		Outside rush		Weekend	
Scenario	3	4	3	4	3	4
Discretionary	5,5	5,1	74,5	75,4	72,0	73,7
Commuters	22,6	22,1	41,7	42,0	12,8	13,0
Business	31,0	30,8	72,1	72,1	15,5	15,6
Total	59,0	58,0	188,4	189,5	100,3	102,3

The original estimates closely parallel the results for a flat tariff in the short-run, two to three years, and the estimates for the differentiated tariffs may be quite accurate as well[9]. When the reaction coefficients were varied, the resulting changes were inconsequential. These changes in the coefficients seem logical and are suggested by several writers (Ramjerdi,1994).

[9] A sensitivity analysis could be for larger and smaller reaction coefficients, but because of the conducted small impacts found in this section, these analyses are not conducted.

Jean-Hansen (1991) suggests increasing all coefficients to attempt to capture the long-run impacts of changes in road prices on the demand for roads. It is important to note that other long-run changes are implicitly included in this suggestion. Thus in case 2, all coefficients were increased by 50 percent for all scenarios and for all times the day and days of the week. The results of these simulations, reported in Table 3.5.3, indicate that the number of cars crossing the toll ring changes slightly, while revenue is quite stable. A problem with this approach is that it underestimates the number of vehicles that actually crossed the Oslo toll ring. The number of vehicles that crossed the ring was lowest in 1991-1992 and increased the following years. Thus increasing the coefficients by 50 percent to capture long-run adjustments does not appear to be appropriate.

Table 3.5.3: Case 2: results when the coefficients are 50 percent higher.

Total traffic in million cars by scenarios.	2	3	4
All purposes	72,3	73,0	73,0

Total revenue in million NOK by scenarios.	2	3	4
All purposes	795,1	729,2	721,0

To more closely approximate the actual crossings, the above procedure was modified by increasing the rush hour coefficients by 50 percent, and decreasing the off-peak coefficients by 50 percent except for the business group's coefficient which was not changed. These changes, referred to as case 3, will cause a larger reduction in discretionary trips during the rush hours, and an increase in off-peak trips compared to the previous simulations.

The simulation results for case 3 are reported in Table 3.5.4. These results closely parallel the actual traffic levels during the first five years of the toll ring. The number of cars crossing the toll ring is estimated to be about 77 million in 1994, and this simulation yields a slightly lower estimate. With differentiated tariffs, the number of cars decreases slightly and so does revenue.

Table 3.5.4. Case 3 results.

Total traffic in million cars by scenario.	2	3	4
All purposes	76,3	76,3	76,1

Revenue by scenario and trip type.	2	3	4
Discretionary	323,2(38,5)	239,3(31.8)	168,8(23.0)
Commuters	200,6(23.9)	203,7(27.1)	226,2(30.8)
Business	315,1(37.5)	309,1(41,1)	339,1(46.2
Total	838,8(100)	752,1(100)	734,0(100)

As the tariff differentiation increases these changes in the reaction coefficients cause the business trip type to pay more and discretionary and commuters trip type to pay less than was the case for the original estimates found in Table 3.4.1.

3.6. Distributional effects.

The more differentiated the tariffs, the larger the portion of the total revenue paid by high income groups. The higher income groups are willing to pay more because they assign higher values to the trips and receive greater benefits from reduced travel times. For discretionary trips, and to a certain degree also among commuters, the value of time increases with disposable income. In general, wealthier individuals are willing to pay more to use the roads. Thus, when the toll ring was implemented, low income groups reduced their trips more and payed a smaller share of the total revenue than high income groups[10].

The employers of those with high incomes more often than those of others pay their toll ring expenses. It might seem that this is unfair to people with lower incomes, but covering toll ring costs is simply another form of compensation, which in the absence of the toll ring would take some other form. However, those with higher incomes are still charged for their use of the roads.

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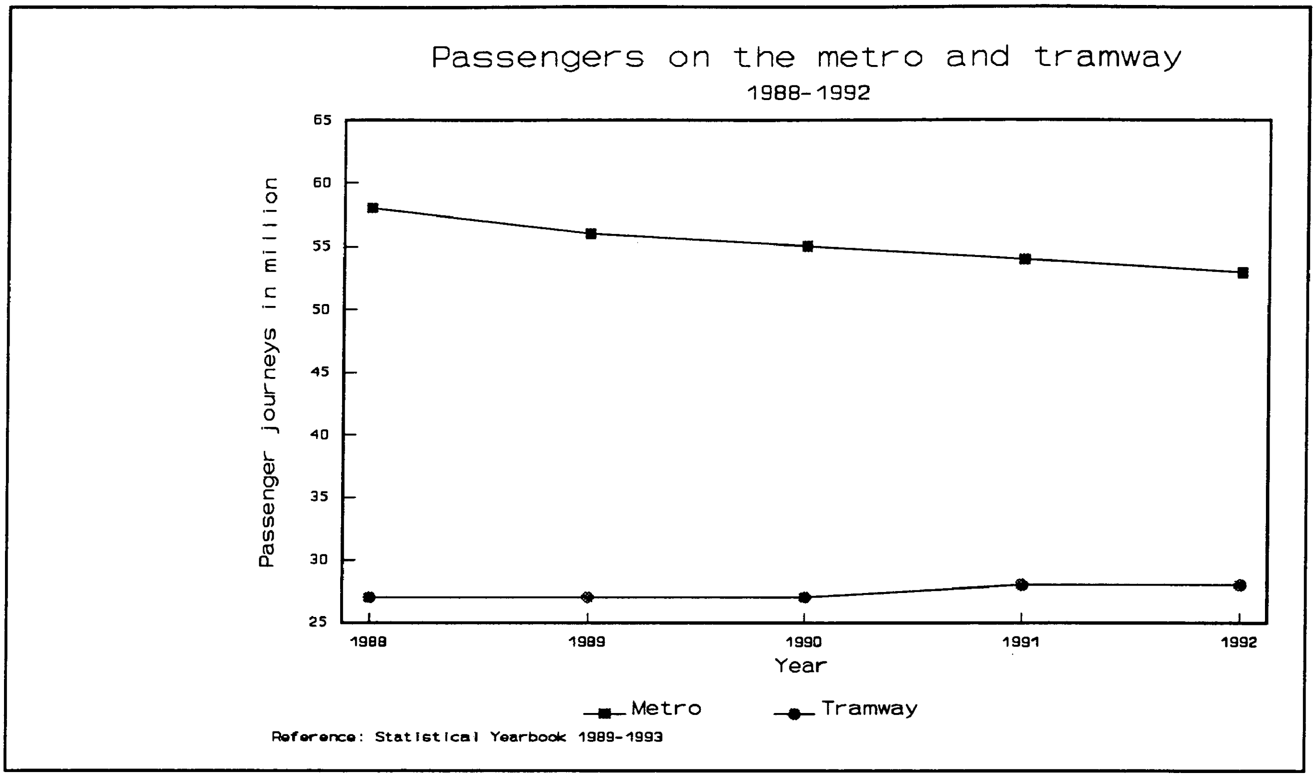
[10] A low income family in is Norway defined as a family with a total income of NOK 100,000 (about USD 14,000) per year, and a high income family has an income above NOK 250,000 (about USD 36,000) per year.

Another generalization is that the more important the journey, the more a person is willing to pay. Therefore, the number of business trips which cross the toll ring was only slightly reduced by the toll ring. However business will benefit from reduced travel time. Thus the net impact on businesses which will ultimately fall on factor owners or consumers is uncertain.

Low income motorists are more likely to switch their travel times when a differentiated toll is charged. This group also is more likely to switch their travel mode from the auto to public transit. The more differentiated the tariffs, the more likely low income individuals are to alter their travel times and modes. This group will be harmed unless alternative transport is improved.

Public transportation is the best alternative to the car, but it does not seem to be a very good alternative for most people. Figure 3 illustrates trends in the use of the metro and the tramway from 1988 to 1989.
The figure shows that the traffic on the metro decreased steadily after 1988 even though the toll ring was implemented in 1990. The metro brings commuters from the near suburbs to the central city. The number of passengers using the tramway increased during this period. The tramway primarily serves the center city. This increase may be the result of reduced traffic in the CBD due to an increase in the number of one way streets and closed streets in the CBD. At the same time, total commuter train ticket sales

Figure 3.



increased slightly from 1989 to 1990[11]. This trend continued in 1991-1992. More frequent commuter trains in the Oslo region should increase the number of passengers in the future as transit ridership is more responsive to service improvements than any other factor (Oslo sporveier 1991). Also, reductions in the high transit fares, should also increase transit ridership[12].

Even if the number of people who transferred from cars to public transportation has not been very large, those who used public transportation before the implementation of the toll ring benefited from more frequent departures and fewer required

[11] The total ticket sales increased by 2-3 percent during this period (Statistical Yearbook 1992).

[12] The fare for a trip from the near suburbs or inside the city was NOK 14 (about USD 2) in 1992.

transfers to other trains. Bus riders have also benefited from improved service. For example, the number of buses in the Oslo region increased by 1200 (18%) from 1989 to 1992.

As we have seen, the road user charges benefit higher income groups because the value they assign to the time saved exceeds their toll expenditures. Low income groups who do not own cars, also benefit from public transportation improvements financed by toll revenues. It is the middle income car owners who are most likely to be harmed by the toll ring. The value that they assign to the time served, is likely to be less than their toll expenditures and they are more likely to change their travel habits.

3.7 Effects on land use and commercial traffic.

The current toll ring has hardly affected the businesses use of vehicles. The previous simulations indicate that differentiated tariffs have a similar small impact. Although in the long-run the toll ring could alter business locations, no clear evidence of such changes has been observed to date in the Oslo region. However, earlier observations from Singapore (Holland 1978) suggest that a small reduction in trade occurred following the introduction of the Area Licensing Scheme. But there were no significant locational changes, and a general recession could have caused the reduction in trade. In Oslo, the opposite effect might have occurred because shops that previously were located on busy streets are now in an area where only pedestrians and business vehicles are allowed. This may have made these stores more accessable for both pedestrians and business vehicles. In addition, more parking lots were built inside and on the outskirts of the CBD.

Some industries will probably change their location in the long run because of the toll ring. In London supermarkets and industrial activities that generate heavy traffic tended to move outside the priced area, and hotels, quality shopping, and some higher value residential uses, moved inside (The chartered Institute of Transport, 1992). Since this pattern of land use already exists in Oslo, the toll ring will probably have only a small impact on land use. Commercial traffic, such as trucks carrying heavy and light goods, and taxies that have to pass the toll ring several times a day, will find it advantageous to buy seasonal passes. However, the benefits of the toll ring for these drivers, which include time savings, more space for loading and unloading, and reduced congestion, may exceed their toll cost. One indicator of this result is that taxable income in the Oslo region increased from 1989 to 1992 even though the Norwegian economy experienced a recession during this period.

3.8 Environmental impacts

The toll ring has reduced environmental problems caused by air and noise pollution from vehicles. This is mainly because of tunnels that divert traffic away from high density residental areas. An investigation coordinated by NILU (1992) measured air and noise pollution in a residental area before and after the construction of a tunnel. The residents clearly benefited from reductions in air and noise pollution.

Total reduction of pollution is a goal in Norway, and a strongly differentiated road pricing tariff scheme would have reduced pollution. The Public Pollution Control (SFT) has estimated that the pollution is five times greater in a queue or a standstill than in a situation with smoothly flowing traffic. Therefore, the society would benefit from differentiated tariffs which reduces car queues during the rush hours even if the overall traffic level increased.

3.9 Conclusions.

Discretionary trips are affected the most by the toll ring, and business trips are the least affected in the short-run. Thus, when differentiated tariffs are imposed, discretionary trips during the rush hours decrease the most, and this group pays the smallest share of total revenue. Discretionary trips pay only 24 percent of the total revenue while the business group pays almost 45 percent. Under the present flat tariff scheme these two groups pay about the same amount.

In the sensitivity analysis, it was first assumed that as the tariffs became more differentiated, the rush hour reaction coefficients increased, and the coefficients for the other time periods decreased. These changes in the coefficients caused only small changes in traffic patterns. Then all the coefficients were increased by 50 percent in an attempt to estimate long-run traffic volumes and total revenue. However, these estimates were too low to be plausible. Finally, to estimate the long-run demand for roads, the rush hour coefficients were increased by 50 percent and the coefficients for the other time periods were decreased by 50 percent. This simulation provided estimates that were by the end of 1994 only slightly low for scenario 2, and can probably be used as well to provide reasonable estimates for differentiated tariffs. Differentiated tariffs will also have an impact on time savings as discussed in the next section.

CHAPTER 4

4.0. WELFARE IMPACTS.

Based on the results from chapter 3, the welfare implications of the scenarios 2, 3 and 4 pricing schemes are investigated in this chapter. Three components will be combined to determine the most efficient pricing scheme; revenue derived from the toll ring, lost surplus due to suppressed trips, and gains from reduced travel times. Simulated revenue from the toll ring was determined in chapter 3 for scenarios 2 through 4. In this chapter the lost surplus due to suppressed trips and the gains from reduced travel times will be calculated for these three scenarios. These three components will be used to determine the most efficient pricing scheme.

4.1.1 Loss of surplus

The following calculations are based on 1989 data because the reductions in traffic due to the toll ring are known, and the previous simulated traffic volumes for the flat tariff were very similar to the actual figures. In 1989, before the toll ring was implemented, 79.1 million vehicles crossed the cordon line. Of these crossings 16.3 million were during the rush hours, 51.5 million were on weekdays during off-peak hours, and 11.3 million were on the weekends.

The average tariff to cross the cordon line for all drivers, regardless of time of day, was NOK 8.4, but NOK 11 is used in these calculations to provide a better comparison with the differentiated tariff scenarios. In table 4.1.1 the loss of surplus is calculated for the different scenarios, for rush hours, weekdays during off-peak hours, and weekends[13].

Table 4.1.1: Loss of surplus by scenarios and time of day. Numbers in million NOK.

	Peak	Off-peak	Weekend	Total
Scenario 2:	6,63	34,10	10,44	51,17
Scenario 3:	8,10	24,23	8,74	41,07
Scenario 4:	9,90	22,72	6,67	39,29

The loss from suppressed trips is the largest for scenario 2 due to a large reduction in off-peak weekday trips caused by the flat tariff of NOK 11. Congestion is low during this period, and it is not efficient to price drivers off the road. Scenario three and four are both more efficient than scenario 2. High tariffs during rush hours cause a small loss of surplus because the demand for trips at this time is the least elastic. Lower tariffs in the other periods reduce the loss from suppressed trips and cause drivers to use the roads when there is little or no congestion.

[13] NOK 11 is used as the price per crossing in scenario 2. The weighted average price per crossing is 9.97 for scenario 3, and 9.69 for scenario 4.

In illustration 1, the lost surplus is represented by the area abd. This area is largest for scenario 2 and is reduced as prices become more differentiated. A more differentiated tariff reduce the lost surplus because drivers pay a toll that is closer to social marginal costs. This requires a higher toll during the rush hours and a smaller toll during hours with little or no congestion.

4.1.2 Time savings.

The time savings on 17 routes to and from the center of Oslo from 1989 to 1992 are measured during the rush hours, 3 hours in the morning and 2 hours in the afternoon. The average speed increased by only 1 kilometers per hour[14], and time saving averaged 1.32 minutes per trip (Prosamrapport nr. 29). The speeds did not increase substantially because of extensive road construction. This construction has caused the speeds to be lower than what can be expected in the future. The small speed increase that is measured during the rush hours is used to calculate the value of the time savings for the rush hours. Half the time savings are assumed to occur on weekdays during off-peak hours and on the weekends. This estimate is based on advice from one of the planners from the Oslo Roadbuilding Association.

This savings is represented by the area q^1cdq^2 in

---

[14] The average speed was 33,8 kilometers per hour (approximately 22 miles per hour) on the average trip of 26 kilometers (approximately 16 miles).

Illustration 1. The actual time savings can be compared with scenario 3 where the simulated reductions in traffic are assumed to yield time savings of 3 minutes during the rush hours and 0.5 minutes on weekdays during off-peak hours and on weekends.
In scenario 4, the simulated reductions in traffic are assumed to yield time savings of 3.5 minutes during the rush hours, and the same time savings as in scenario 3 on weekdays during off-peak hours and on weekends. These numbers are assumptions and may not be accurate, but they are based on the principle that when the congestion is heavy, traffic reductions will yield large time savings, and when congestion is light or insignificant, traffic reductions will yield small time savings.

To estimate total time savings, the traffic that crosses the cordon line in the three scenarios is multiplied by the time savings and the average number of passengers per car that crosses the toll ring, 1.2,(Vibe, 1991), and transformed into saved hours.

Time is valued differently by each group. Time is likely to be more valuable for a delivery man who has to visit a customer before a certain time than for a private visiter late at night. There are also differences in the value of time savings between countries. Cole 1990 estimates the value of time per hour per person for Canadians as follows:

-Discretionary: NOK 118 approximately USD 17

-Commuters : NOK 124 approximately USD 18

-Business : NOK 152 approximately USD 22

These estimates are much higher than those for the U.S.A, Japan, and Norway for discretionary and commuters' trips. Estimates for commuters in the U.S.A, measured in current dollars and expressed in 1990 dollars are USD 8.9 (Chui, M 1987), and for Japan about USD 5.7 (Edwards 1983). The values of time for Norway as calculated in Kjorekostnadsboka 1991 (The Driving Cost Handbook 1991) are as follows:

-Discretionary:	NOK	19.0	approximately	USD	2.7
-Commuters :	NOK	33.8	approximately	USD	4.8
-Business :	NOK	128.5	approximately	USD	18.4

The values for the time savings are reported in Table 4.1.2 for different trip types for scenario 2 through 4. The table shows that the toll ring and the road improvements yield substantial time savings even for small increases in speeds. Among the trip types, it is the business trips that have the largest time savings. This is because the value of time is larger for this group, and because they make over half their trips during the rush hours. The time savings are larger the more differentiated the tariffs. The most substantial difference between the scenarios, is for business trips during the rush hours. A doubling of time savings from scenario 2 to scenario 3 more than doubles the value of the time savings for business travelers. Since the business group has the least elastic demand for road use, a small reduction is traffic during rush hours yields a large time savings for them.

Table 4.1.2: Calculations of time savings by type of trip for days of the week and time of day. Measured in million NOK.

	Scenarios 2	3	4
Peak hours:			
Discretionary:	0,8	1,8	2,1
Commuters :	5,4	12,1	14,0
Business :	27,2	61,0	70,3
Total :	33,4	74,9	86,3
Off-peak hours:			
Discretionary:	5,0	3,8	3,9
Commuters :	4,7	3,6	3,6
Business :	30,5	23,6	23,5
Total :	40,8	31,0	31,0
Weekend:			
Discretionary:	1,9	1,5	1,47
Commuters :	0,6	0,4	0,4
Business :	2,5	1,9	2,0
Total :	5,0	6,8	3,9
Total all scenarios:	78,0	112,8	121,2

The other periods exhibit the opposite pattern. Since the traffic level is lighter during off-peak hours on weekdays and on weekends, the value of time savings are reduced with increasing price differentiation, but only by a small amount. These results can be attributed to light initial traffic levels that are only slightly increased by the lower tariff.

Time delays connected with the collection of money impose costs on the drivers who use the coin automats and the manual lanes. The additional time required in these lanes averages 15 seconds. On February 1, 1992, 39.8 percent used these lanes, and the share for each trip type was different. Of the total 74.5 million trips that crossed the toll ring, 29.1 million were discretionary trips (72 percent manual/coin) 17.8 million commuter trips (31 percent manual/coin) and 27.5 million business trips (11 percent manual/coin). Since the total number of crossings differs little in each scenario, the cost of the delays, reported in Table 4.1.3, is approximately the same for each scenario.

Table 4.1.3: Calculations of time delay by type of trip by day of the week and by time of day. Measured in million NOK.

	Peak hours	Off-peak	Week-end	All week
Discretionary:	0,111	1,365	0,516	2,0
Commuters :	0,317	0,550	0,066	0,9
Business :	0,566	1,272	0,106	1,9
Total	0,995	3,187	0,689	4,9

Most of the costs of delay occur during off-peak hours, and discretionary and business trips carry most of the burden. These costs are a small share of the value of time savings.

4.1.2 Comparison between the scenarios.

Based on the profit and loss account for A/S Fjellinjen, the toll ring has capital costs of NOK 26 million per year and annual operating costs of NOK 70 million. The costs and benefits of the toll ring are summarized in table 4.1.4.

Table 4.1.4: Summary of the evaluation of the scenarios, measured in million NOK.

	Lost surplus	Time savings	Total
Scenario 2:	51,2	78,0	26,8
Scenario 3:	41,1	112,8	71,7
Scenario 4:	39,3	121,2	81,9

Collection costs:

Costs of delays at toll booths	-4,9
Capital costs	-26,0
Operating costs	-70,0
Total	-100,9

Table 4.1.4 indicates that the scenarios with differentiated tolls produce the best results. When scenario 2 and 4 are compared graphically in Illustration 1, the area q^1cdq^2 is approximately 1.5 times larger than the area abc for scenario 2, while in scenario 4 the first area is 3.1 times larger than the second. This means that scenario 4 yields larger benefits to society than the present pricing scheme. The same holds for scenario 3, but to a less degree. In scenario 2 the lost surplus and the value of time savings are equal during off-peak hours on

weekdays and on weekends. For the same time periods, the time savings are larger than the lost surplus for scenario 3 and 4. Also, in scenario 2 only 42 percent of the toll revenue is collected from the rush hour traffic that makes investments in increased road capacity necessary. In comparison, this percentage for scenario 4 is 71 percent.

The present scheme was chosen because collection of revenue is the most important objective of the Oslo toll ring. From Tble 3.4.1, scenario 3 yields 9 percent less revenue than scenario 2, and scenario 4, 11 percent less than scenario 2. When one takes lost surplus, time savings and collection costs into consideration, these numbers shrink to 4.2 and 5.2 percent respectively. The differences between the scenarios are listed in Table 4.1.5.

Table 4.1.5: Comparison between the scenarios.

	Revenue	Lost surplus	Time savings	Collection costs	Total
Scenario 2:	820,0	51,2	78,0	100,9	745,9
Scenario 3:	744,0	41,1	112,8	100,9	714,8
Scenario 4:	726,5	39,3	121,2	100,9	707,5

The scenario with the strongest form of differentiation is preferable from society's point of view. This system yields the least lost surplus, and time savings which are closer to those of optimal road pricing. Revenue decreases, but the reductions in traffic during the rush hours would also reduce the demand for road investments.

From these results, the present flat tariff toll scheme is the least efficient and the strongest differentiated toll scheme is the most efficient. In this analysis, lost surplus and collection costs are real costs to society, and time savings are real gains. Table 4.1.5 shows that when differentiation increases, the real costs to society represented by lost surplus decreases, and real gains to society represented by time savings, increases. This means once again that the stronger the differentiation of tariffs by time of day, the larger the gains to society. The revenue decreases with stronger differentiation, but revenue is not a real cost to society, just a transfer from motorists to the government.

Another way of showing the differences between the scenarios is to compute the welfare cost per NOK of revenue for each scenario. The average welfare costs is computed in Table 4.1.6, and supports the other results in this chapter. The most

Table 4.1.6: Average welfare cost for each scenario.

	Scenario		
	2	3	4
Average welfare cost	0.09	0.04	0.03

differentiated scenario yields the least welfare costs, and a larger gain to society compared to the present flat rate toll scheme.

5.0 CONCLUSIONS.

This thesis establishes that it is possible to design a toll system that is more efficient than the present flat rate toll ring. To achieve this, a system that is closer to the theoretically optimal road pricing system should be employed. A differentiated toll system is more efficient because suppressed trips are reduced. Reduced rush hour traffic volumes results in travel time reductions. The simulated system of differentiated tariffs yields less revenue than the flat rate tariff, but better use of the road network over the day, that is, reduced traffic during the rush hours when congestion occurs and increased traffic on weekdays during off-peak hours and on weekends, when congestion is not present, reduces the need for increased road capacity.

The calculations indicate that improvements in the present Oslo pricing scheme will yield net benefits to society. According to the simulated implementation of differentiated tariffs, moving from scenario 2 to 4 reduces social costs in the Oslo region by about NOK 55 million per year. These numbers may not be exact, but the conclusion is clear; the present flat tariff scheme can easily be improved by introducing differentiated tariffs.

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Appendix 1

EXPLANATIONS TO TABLES IN CHAPTER 3 AND 4:

Tables, chapter 3:

Table 3.3.1 is a summation of tables 3.3.2 through 3.3.4.

Table 3.3.2. Example.

The initial value for rush hours:

```
259,975*0.24(rush)*0.1037(from table 3.2.2) = 6,4
                  *0.3858                   =24,0
                  *0.5105                   =31,7
```

Use formulas i) - iii) in chapter 3 on scenario 2-4.

Example: 6,4-(6.4*0.06(11+15)/15)= 5,7

Table 3.3.3 also uses 259,975 as a base number.
Table 3.3.4. uses 108,390.

Otherwise the calculations are exactly similar to table 3.3.2.

Table 3.4.1.

Example for discretionary trips for scenario 4.

```
 5,2 (from table 3.3.2) *261 (days) *30 (from table 3.2.1) +
74,8 (            3.3.3) *261 (    ) * 5 (               ) +
73,2 (            3.3.4) *104 (    ) * 4 (               ) =169,6
```

Tables, chapter 4:

Table 4.1.1.

Example for scenario 2:

1-(59,9/ 62,2)(from table 3.3.2)*16,3 mill. * 11 NOK		=	6,64
1-(185,8/197,7)(3.3.3)*51,5		=	34,21
1-(99,2/108,3)(3.3.4)*11,3		=	10,47
	Total	=	51,32

Table 4.1.2.

Scenario 2

Peak hours:

	Left in	*(traffic*min./60)	* Table 3.2.2*persons=	
Discr. :	19.0*	(15,7* 1.32/60)	*0.1037*1.2	= 0,816
Comm. :	33.8*		*0.3858	= 5,402
Business :	128.5*		*0.5105	=27,174
		Total		=33,392

Off-peak:

Discr. :	19*	(48,5* 0.67/60)	*0.4118*1.2	=
Comm. :			*0.2168	=
Business:			*0.3715	=
		Total		=40,83

Weekends:

Discr. :	19*	(10,3* 0.67/60)	*0.7313*1.2	=
Comm. :			*0.1229	=
Business:			*0.1459	=
		Total		= 5,086

Table 4.1.3

Peak hours:(	Left in traffic*	Share trip type*	minutes/60)	*Table 3.2.2	*persons=	
Discr. :	19,0*(15,7	*0.72	*0,25/60)	*0.1037	*1.2=	0,111
Comm. :	33,8*(	*0.31	)	*0.3858	=	0,317
Bus. :	128,5*(	*0.11	)	*0.5105	=	0,566
Off-peak:						
Discr. :	(48,5		)	*0.4118	=	1,365
Comm. :	(		)	*0.2168	=	0,550
Bus. :	(		)	*0.3715	=	1,272
Weekends:						
Discr:	(10,3		)	*0.7313	=	0,516
Comm :	(		)	*0.1229	=	0,066
Bus :	(		)	*0.1459	=	0,106

Table 4.1.6.

The average welfare costs = net benefits / revenue

Where net benefits = lost surplus
+ collection costs
- time savings

ENCLOSURE 1.

THE TOLL RING