Road Pricing and Toll Financing

with Examples from Oslo and Stockholm

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Introduction to the Thesis

The five essays of this volume comprise my doctoral thesis at the Royal Institute of Technology, Department of Infrastructure and Planning. The topic of the thesis is road pricing and toll financing in urban areas, with examples from Oslo and Stockholm. The traditional response to congestion has been to increase capacity. When confronted by latent demand, however, increased capacity is quickly depleted, leading to renewed congestion and further deterioration of the environment. The prohibitive costs of the provision of additional capacity in urban areas and financial constraints at the different levels of government have revived the interest in road pricing and toll financing in urban areas.

Road pricing requires road users to pay for their marginal social cost. If congestion is the only cause of externalities, then they should pay for the congestion they cause other users. In the short-run, road pricing reduces congestion to an optimal level. The theory suggests that, under certain assumptions, road pricing generates sufficient revenues to optimally expand the capacity to meet future demand (in the long-run). These assumptions - perfect competition, no economies of scale, and a specified income distribution - are not quite met in reality. A further issue about road pricing concerns those who are adversely affected by it. Road users are already paying for roads through road user taxes, which are regressive. Road pricing should at least reduce these taxes. Furthermore, it should make it possible to compensate for adverse effects, but not in a manner that compromises the purpose of road pricing.

Road users adjust their behaviour through a number of choices in response to changes in transportation infrastructure and services and the pricing of the facilities. The aggregate of their responses determines the "optimal price", a key issue in road pricing. However, as easy as it sounds, this is a difficult task. Small (1992, p. 154) explains that there are "strong interactive feedbacks between supply and demand for transportation: demand depends on service levels and prices, while costs and service quality in turn depend crucially on demand through highway congestion and through waiting time for transit vehicles". In spite of the complexity of the subject, it has been necessary to use simplified models. Even so, rigorous theory is necessary if conceptual errors are to be avoided. This thesis comprises the application of a series of simplified models for the evaluation of the impacts of road pricing and toll financing in urban areas.

Overview of the Essays

In *essay no. 1, Road Pricing and Toll Financing in Urban Areas,* I have tried to present some important economic concepts that have a bearing on the provision of roads and pricing, including the efficient pricing and investment rules and the second-best rules. On the impacts of road pricing Newbery (1994, p. 396-97) states "If road users paid the true social cost of transport, perhaps urban geography, commuting patterns, and even the size of towns would be radically different from the present". Evaluations of some of these impacts are extremely difficult since they are caused by shifts throughout the economy that cause adjustments in land values and wages. The implementation of a transport policy such as road pricing and toll financing in urban areas requires public and political support. Issues related to the competing objectives of road pricing are also discussed.

In *essay no. 2, Cost-Benefit Analysis, Users' Benefits and Distributional Consequences of a Toll Scheme for Stockholm,* alternative specifications of disaggregate logit models of mode choice are formulated and tested on commuting data for Stockholm. The main conclusions of this study are: (1) the marginal utility of income is not significantly different for different income groups. This implies that there is no income effect, and consequently the different measures of consumer surplus should coincide; (2) however, the value of travel time saving increases with income due to the higher marginal utility of time among high income groups.

The implications of alternative model specifications are demonstrated by calculating the benefits to different income groups from a transport policy, in this case, a toll scheme. A mode choice model specification which is linear in cost and time results in a larger benefit (smaller loss) for low income groups and for female workers, while a model specification that captures the variation in the value of time with income results in a larger benefit (smaller loss) for high income groups and for male workers.

In *essay no. 3, Road Pricing in Urban Areas: Financing Investment in Transport Infrastructure and Improving Resource Allocation, the Case of Oslo,* a theoretical framework for the evaluation of road projects financed through road pricing is presented. This would allow for the incorporation of the marginal cost of public funds in the evaluations. The standard approach often assumes that the marginal cost of public funds through general taxation, MCF^p, is equal to one.

For this purpose we first analyse the Ramsey problem for a congested road. This analysis shows that the feasible toll for financing a road project can deviate by a positive amount from the optimal toll. The optimal toll is defined as the difference between the social marginal cost and private marginal cost of the use of the facility. The deviation of the feasible toll from the optimal toll increases with the constraint on the budget.

Furthermore, the deviation increases with an increase in the marginal cost of public funds through toll and an increase in (the absolute value of) the price elasticity of demand. Then we investigate the feasible toll on a congested road by taking account of MCF^p. The analysis shows that the solution to this problem is identical to the solution of the Ramsey problem when the constraint on deficit is set such that the Lagrangian multiplier with respect to budget constraint, λ, to be equal to $MCF^p - 1$.

With a multi-modal equilibrium model of demand and supply within a discrete choice framework, alternative schemes for Oslo are evaluated. These schemes include the present toll ring, a "socially optimal" cordon toll and a "socially optimal" road pricing scheme, where vehicles pay a fee on every link of their route. The fee on a link covers the difference between the private marginal cost and the social cost of travel on that link. Other schemes that are evaluated are a road investment package, with no tolls, with the present toll scheme and with a "socially optimal" cordon toll scheme. The comparison of these schemes suggests that a socially optimal road pricing scheme reduces the benefits from the investment package.

Marginal costs of public funds through alternative toll schemes, MCF^t, are estimated. These estimates are compared with MCF^p in Norway. This comparison suggests that the cost of financing road projects with tolls, is much lower than the cost of financing them through public funds. Furthermore, MCF^t for the "socially optimal" cordon toll and for the "socially optimal" road pricing schemes are likely to be less than one.

In *essay no 4, An Evaluation of the Impact of the Oslo Toll Scheme on Travel Behaviour*, short-term impacts of the Oslo toll scheme on tour frequency, trip chaining and mode choice are evaluated. Two alternative models are estimated to evaluate the impact of the cordon toll on tour frequency and trip generation. These are a linear regression model, used for tour frequency, and a recursive model structure to describe work trip generation, discretionary trip generation and tour frequency.

Mode choice models using data from 1989 before the introduction of the scheme show larger utilities for modes "car driver" and "car passenger" for the group with seasonal pass in 1990. The examination of different mode choice models indicates that the marginal toll cost for those with a seasonal pass should be set equal to zero. Furthermore, the utility of the mode car increases once a seasonal pass is obtained. These results suggest that the scheme for toll payment, consisting of seasonal passes and a single pass, is an example of a non-uniform price structure known as a two-part tariff. Hence, it is necessary to estimate a two-level structured logit model, with the choice of the type of pass at one level and the choice of mode at another. The model structure (not presented in the essay) suggests that the choice of mode is higher up in the hierarchy among the choices. Yet the data lack some key variables needed to explain the choice of the type of toll payment. In addition, the first year of the opening of the toll ring was not a normal year because of the introductory prices on seasonal passes and the high percentage of yearly passes that where paid for by employers.

The mode choice models indicate higher implicit values of time for the users with seasonal passes. One implication is that the measure of users' benefits from a toll scheme for the group with seasonal passes should be higher than the rest.

A logit model for the choice of seasonal pass points to a higher car mobility among the group with seasonal passes. A variable, "Payment by Company", is used for the estimation of this model. However, that this variable does not explain the choice of toll payment type.

In summary, the findings of this study suggest that the impact of the toll scheme is more significant at the level of mode choice for travel purpose work, while the impact for discretionary travel seems to be more significant at the level of trip generation.

This study provides additional evidence of the importance of the effects of parking fees on travel behaviour. The tour frequency models show that free parking at work positively influences the demand for car travel. Furthermore, the explicit inclusion of parking costs in the mode choice models suggests that mode choice is affected more by an increase in parking costs than by a similar increase in running costs.

In *essay no. 5, An Evaluation of the Impact of the Oslo Toll Scheme on Destination Choices and House Prices,* the impacts of the Oslo toll scheme on destination choices and house prices are assessed. The changes in destination choices for compulsory travel such as work and education could be traced to changes in home and work location patterns. These are usually considered to be long-term effects. The toll fee is not high enough to compensate for the transaction cost connected with changes of work or home locations. However, those who are in the process of making a change in home or work locations may consider the location of the cordon toll as a factor. The changes in home and work location patterns do not seem to have been significantly affected by the toll ring during its first year of operation.

The second part of this essay traces the impacts of the toll scheme on destination choices of discretionary trips such as shopping, private business and recreation. The toll scheme seems to have had an impact on these destination choices. The impact seems greatest in the vicinity of the cordon toll scheme and decreases with distance from the cordon toll; in other words, there has been a border effect.

The evaluation of the impact of the toll scheme on housing prices produces a similar pattern. Even though the toll scheme (separated from all other influencing factors such as the Oslo package) has little impact on house prices, the evaluation indicates the distributional impacts of the toll scheme.

Some Qualifications

In addition to the usual qualifications, a major additional qualification of the last two essays is related to the quality of the data used to evaluate the impacts of the Oslo toll ring. Hau (1992, p. 28) suggests "even with poor data, one could make some progress in empirical work". This has been my hypothesis and hope. The experience from Oslo should help others to design better studies in connection with the evaluation of the impacts of such schemes.

For the evaluation of the impacts of the toll scheme a research programme was designed which began in 1989 before the scheme was introduced (see essay no. 4 for a description of the programme). The components of the research programme suggest that the main focus was on the evaluation of the impacts of the toll scheme on travel behaviour. The research programme also included a survey of public attitudes towards the toll scheme. An important qualification of this research programme was the failure to specify the scope of the expected impacts, both short- and long-term, including those on travel behaviour. A clear definition of the scope of the research programme and a clear proposal of how to evaluate these impacts were also lacking.

The most important element of this research programme was a two-wave panel study. A one-day travel diary was used in this study and was conducted by mail. The panel consists of about 13,500 respondents who took part in both waves, before and after the introduction of the toll scheme. The response rate in the panel was very low (see essay no. 5). The quality of the data in a mail survey is usually inferior to the data acquired by other methods, such as telephone or home interviews. A major fault with a mail-back survey is the higher incidence of underreporting of shorter trips compared with the results from other methods. Consequently, even though a mail survey was used in both waves, the method of the survey produces some error in evaluating the relative changes, especially when it is expected that a toll scheme could induce some longer trips by car to be replaced with shorter trips by car or some other mode.

A mail survey cannot in any case consist of a very long questionnaire. There is always a trade-off between the length of the questionnaire on one hand and the response rate and the quality of the data on the other hand. As a result, some important questions about the socio-economic data of the respondents and their households were omitted, and the travel diary was limited to the reporting of nine trips. Some of the omitted data are quite relevant to the evaluation of the impacts of the toll scheme. Some of the missing data are quite obvious, such as data on the type of seasonal pass and the type of payments, while others are not as obvious. In Oslo inbound traffic is tolled round the clock, every day of the year. Hence, the toll scheme could have resulted in some trips being tolled-off and some rescheduling among the remaining trips, leading to peak contracting (the reverse of peak spreading). There are some important missing data needed for the estimation of the rescheduling costs.

Attrition and underreporting are common phenomena in panel data. Both of these phenomena lead to a decline in observed mobility. The low response rate points to attrition in the panel. Different evidence suggests attrition and underreporting in the panel study of 1989-1990 (see essays no. 4 and 5). Even though it is relatively simple to correct for attrition, it is almost impossible to correct for underreporting. These problems were ignored in the design of the panel study, and it was not possible to investigate further into the causes of attrition and especially underreporting. In this particular case, where attrition and underreporting cannot be accounted for, a before-and-after travel survey would have been much more useful.

The introduction of the Oslo toll ring in February 1990 coincided with other external factors that influenced traffic. Different evidence suggests that the recession in the Oslo region during the whole period of 1989-1990 had a major impact on travel demand. Among other external factors were the opening of the Oslo tunnel, a major project financed by the toll revenue, and an increase in the price of gasoline of about 16 percent (in real terms).

The research programme included some before-and-after studies for the evaluation of certain specific effects on facilities. These were: the electronic registration of cars crossing the cordon toll, the registration of public transportation ticket sales, and the manual registration of car occupancy at the cordon toll, before-and-after study. Even though these studies were carefully designed to allow for seasonal effects, the extent of other external effects, particularly the effects of the recession on traffic, made it very difficult to isolate the impacts of the toll scheme. This should not be totally unexpected. Yet these studies are still quite relevant for the task of confirming the estimated impacts through travel diaries.

The Design of a Research Programme, an Afterthought

While I agree with Timothy Hau that "even with poor data, one could make some progress in empirical work", personal experience has taught me that an initial investment in the quality of the data spares much time and frustration, in addition to its importance for empirical research.

The starting point of a research programme for the evaluation of the impacts of a road pricing scheme must be the specification of the scope of the expected short- and long-term impacts. These should include impacts on alternative modes, specific facilities, travel behaviour, land use, and the environment and distributional impacts with respect to specific groups by socio-economic characteristics and locations. The Committee Report and Recommendations (1994) by the Committee for Study on Urban Transportation Congestion Pricing, appointed by the National Research Council, U.S.A., provides an outline of the scope of the impacts of a road pricing scheme and a guideline for research. The scope of the impacts of a road pricing scheme is indeed large. A second step would be an identification of the priorities and a clear definition of the scope of the research programme. Finally, the research programme should address how to approach the assessment of these impacts with clear proposals based on sound methodologies.

The incidence of a cordon toll scheme falls disproportionally on businesses and households that are located close to the cordon. In the case of Oslo, the relatively small amount of the toll fee and the location of the toll ring have reduced these adverse effects. Nevertheless, the evaluation of these impacts is quite important and needs to be addressed in a research programme of this sort.

Some of the impacts of a road pricing scheme may occur long before its implementation. Evidence suggests that land values could adjust to anticipated improvements in transportation (McDonald and Osuji, 1995). A toll ring with a high enough toll fee could induce a similar effect. The experience with toll rings in Norway suggests that some initial changes in travel behaviour due to the introduction of a road pricing scheme are modified shortly thereafter (Wærsted, 1992). Hence, it is also important to address the time dimension of the expected impacts of a road pricing scheme in a research programme.

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Essay no. one

Road Pricing and Toll Financing in Urban Areas

1.1 Introduction

Urban areas are experiencing congestion in their transport networks as well as air and noise pollution that threaten the physical environment and their inhabitants. Transport and land use development in urban areas have been costly in terms of the consumption of natural resources and energy. At the same time, urban governments are facing increasing difficulties in financing the infrastructure necessary to support economic development.

The emerging support for road pricing in urban areas is linked to the diversity of problems that urban areas are facing and the different interest groups that view road pricing as a solution to the problems as they see them. Hence, support for road pricing often seems related to conflicting interests in road pricing. Meanwhile, the development of new technologies has made more complex pricing schedules possible so that the dreams of transport economists are being fulfilled[1]. The large amount of literature devoted to this subject in recent years is indeed a testimony to this fact[2]. The number of cities throughout the world that are considering road pricing is on the rise.

In Norway the toll financing of roads and bridges has a history that goes back almost 60 years. Since 1986, with the opening of cordon toll schemes in Bergen, Oslo and Trondheim, there has been a major shift in the location of toll financed projects from the countryside to urban areas[3].

Norway has one of the highest gasoline taxes in Europe. The price of gasoline in Norway is 8.42 NOK/litre for lead free 98 octane (of which 5.41 NOK/litre is tax) and 8.72 NOK/litre for leaded 98 octane (of which 6.24 NOK/litre is tax)[4]. Car ownership is also among the most expensive in Europe. This is due to different taxes that are levied on car ownership.

The high costs of car ownership and car use have not hindered the increase in road traffic, especially in the larger urban areas such as Oslo. Traffic congestion has become a major problem. With increased concern about the environment, there has been a search for remedies. Among the

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[1] For an overview of the available technologies and their performance, see Hau (1992b) and Pietrzyk (1994).

[2] Some recent excellent reviews are by Small et al., (1989), Small (1992a), Hau (1992a), Flowerdew (1993), Mohring (1994), Johansson and Mattsson (1995a) and Gomez-Ibanez and Small (1995).

[3] Toll revenues are estimated at NOK 1.5 billion, while proceeds from all other taxes levied on car use and car ownership will amount to NOK 30.0 billion in 1995. Toll revenues that contribute to the financing of road projects are estimated at NOK 1.2 billion. The total operating, maintenance, administration and capital costs of roads are estimated at NOK 16.1 billion in 1995.

[4] $1.00 = NOK 6.16

measures that have been proposed to reverse the situation are increases in public transport subsidies, further increases in taxes related to car ownership and car use, restrictions on parking in the central city and the use of the newly introduced toll ring for congestion pricing.

To understand road pricing as a transport policy and likewise the scope of its impacts on an urban area, numerous factors must be considered concurrently. The purpose of this paper is merely to touch upon some of them, so as to hopefully shed light on the complexities of the issues involved in making a road pricing scheme fly.

Examining the complexities of demand and supply and the complexities of the interaction of supply and demand in transport with spatial dimensions, Small (1992a, p. 155) points out that the optimal pricing models should be regarded as building blocks of a larger unified model of urban transportation. He also warns that such a unified model may give results quite unlike those arising from models of individual components. One purpose for such a model would be to investigate "what a fully efficient transportation system would look like". Congestion in most cities is underpriced and time-invariant. Parking fees are heavily subsidised. Other external costs, such as noise and air pollution and the risk of accidents, are not totally internalised. Public transit operation requires subsidies, but operators tend to respond inefficiently to subsidy programmes.

The unified model that Small envisages seems to be much removed from the present, but even with such a model at hand I would tend to agree with Sandmo. In the context of environmental externalities, Sandmo (1994, p. 11) states that "Implementing optimal taxes is a daunting task. I do not myself believe that the theory of optimal taxation should be seen as a set of cookbook formulae where you simply have to plug in some numbers taken from econometric studies to get the answers to tax policy problems. Instead it should be seen as a guide to clear and consistent thinking about the issues and as a guide for empirical research, since theory may often lead one to become aware of important connections and parameters which practitioners have tended to neglect. It is often helpful to think about tax reform rather than tax design".

Strotz (1965, p. 380), who in his Urban Transportation Parables addresses optimal pricing and investment rules in a variety of situations, states a similar view. "It is unfortunate, and it may seem self-deprecating, to approach one’s work in a manner described above. However, much of economic theory is of this sort. We construct funny little kites, each illustrating some basic principle of aerodynamics, but we don’t expect any of these kites to really fly. This may be still good heuristics for the practical designer."

What follows in the next three sections are parables: parables that might provide a better insight for the practical designer and illustrate the scope of the impacts of a road pricing scheme in an urban area. Then we shall focus on the impacts of a road pricing scheme and discuss the contending objectives of road pricing and the question of toll revenues.

1.2 Provision and Financing of Roads

A central distinction in transport analysis is the difference between public and private goods, especially the provision of these goods. David Hume (1739) argued that tasks that were not profitable for a single individual to perform, could nevertheless be profitable for the society as a whole. About a hundred years later Dupuit, a French engineer and economist, developed the basis for economic evaluation of public provision by introducing a measure of consumer surplus, and the basis for marginal cost pricing (Dupuit, 1844; 1849). Dupuit used bridges as an example of public works.

The theoretical basis for just financing (taxation and pricing) was developed without considering the expenditure side of the fiscal process. In 1920 Pigou discussed the optimal supply of public goods based on marginal utility theory and proposed the rule that marginal benefit should equal marginal cost at the optimum. Knight (1924) discussed the absence of property rights as a main cause of market failure in providing public goods when externalities were at hand.

Ramsey (1927) formulated a second-best rule for the optimal taxation of commodities with independent demand, subject to a revenue constraint. This rule resulted in the inverse elasticity formula that has been used extensively in the pricing of transport services.

In these works there was no precise definition of public versus private goods. As a result, the authors were unclear about how to measure marginal benefits of goods that have no market price. The effects of taxation on efficiency and distribution were not yet strongly emphasised (Sandmo, 1987).

1.2.1 Road as a Public Good

According to Sandmo (1987), the work by Samuelson (1954; 1955) on the theory of public goods was a major breakthrough in the theory of public finance and was important to the normative theory of public expenditure.

The first problem was to analytically define goods that are consumed collectively and to make a meaningful distinction between individual and total consumption. Public goods are nonrivalrous in consumption. This means that the same unit of the good can be consumed by many individuals, and the availability to one does not diminish the availability to others. A non-rival good can be made available to all relevant individuals at no extra cost.

The use of an uncongested road can be said to be non-rival. When congestion occurs, non-rivalry ceases. A fee on an uncongested road would be non-optimal, for it would reduce the use of the road without providing any benefits to other road users. Non-excludability is another characteristic that is related to public goods. Once the good is supplied to some individuals, it is impossible or costly to prevent others from benefiting from it.

In the case of non-rivalry in consumption neo-classical economic theory suggests that the private sector would not provide the optimum quantity of public goods and services. Roads, for instance, should therefore be provided by the public sector and financed through public funds, taking the social costs of public funds into consideration.

1.2.2 Externalities

For some goods the consumption or production by one agent has indirect effects, i.e., not acting through the price system, on the consumption or production activities of others. These effects are referred to as externalities. Congestion and pollution are the most common examples of externalities in transport. Congestion (and pollution) result from the non-excludability property of roads or the absence of property rights.

Externalities result in a divergence between social and private marginal costs, and an inefficient allocation of resources follows. Taxes, so called Pigovian taxes, can be used to correct for this divergence. The lack of property rights is associated with market failure. Privately owned roads combined with competition in the provision of roads will lead to a Pareto optimal usage if there are no economies of scale (Knight, 1924). Publicly owned roads with free access and road usage by travellers will lead to overuse when traffic becomes congested.

Externalities can also be positive. Improvements in public transport services, such as an increase in the frequency of departures can result in benefits to all travellers (Mohring, 1972). The positive externalities should be corrected for by subsidies determined in a way that accounts for the marginal cost of public funds.

1.2.3 Cost of Financing and Taxation of Externalities

When taxation does not disturb the efficiency properties of the price mechanism, the optimality rule applies, i.e., to attain optimal resource allocation, the marginal benefit should be equal to the marginal cost. In practice however, this is seldom the case. If taxes are distortionary, then the marginal social cost of producing public goods should include a cost that is equal to the loss in efficiency caused by the tax in question. Pigou was aware of this fact.

There is, however, a complication when the demand for a private good depends on the supply of a public good. Assume that the gasoline tax is raised to finance improvements in the road network. This will have two effects. An increase in the tax rate will lower the demand for gasoline and travel (according to Pigou). The increase in the supply of roads (the public good) can increase the demand for travel and hence increase gasoline sales. In this case the social marginal cost of the public good may actually lower the pure resource cost. The effect of the supply of the public good counteracts the effect of the tax. The tax on gasoline is distortionary because it lowers the demand for gasoline. Yet the supply of the public good can pull the taxed good back towards its first best optimal level. In this case it could even lower the economic production cost of the road network (Atkinson and Stern, 1974).

A distortionary tax means that additional public revenue raised by increasing the present tax rates will generate a social cost in terms of reduced efficiency in the economy at large. The cost to consumers per unit of revenue, including extra costs from reduced efficiency, is called the marginal cost of public funds. When a tax system has no distortions, the marginal cost of public funds would be exactly one.

Taxation to counteract negative external effects by correcting for inefficiencies in the competitive allocation of resources, i.e., Pigovian taxes, can have a social cost of public funds that is less than one. This has given rise to suggestions that this kind of taxation not only corrects for inefficiencies, but could also replace other taxes that are distortionary. In other words, such taxes could yield a "double dividend" (Bovenberg and de Mooij, 1994). Sandmo (1994), however, warns that a Pigovian tax higher that the first best level may not be efficient.

The problem of choosing optimal tax rates in the presence of externalities subject to a revenue requirement takes the form of a weighted average of a Ramsey-type pricing and a Pigovian term. The tightness of the constraints on the government budget, i.e. the marginal cost of public funds, determines the weights (Sandmo, 1994). However, in a world of second-best, where information problems or political concerns prevent the tax authorities from levying taxes on the correct tax bases, it is also possible to tax and subsidise related goods (Sandmo, 1976).

The taxation of externalities and the decisions concerning public expenditures must, in the absence of a lump-sum transfer of revenue, be designed to take equity as well as efficiency into consideration. The incidence of the tax burden should be analysed together with the benefits from improvements.

1.3 Efficient Pricing and Investment Rules

Economists are concerned with two types of efficiencies: technical efficiency within a firm and efficiency in allocation. Technical efficiency concerns the effective use of input combinations and production technology by a firm in producing its output. Efficiency in allocation concerns the firm's appropriate level of output to satisfy society's demand within resource and technological constraints (Howitt, 1993).

Efficiency in allocation, by maximising the difference between social benefits and resource costs, specifies rules for pricing and provides guidelines for investment in new capacity. Efficiency in allocation requires that prices be set at marginal costs, because marginal cost relates the benefits from the consumption of a good or service to the cost of providing it.

In order to consume public goods an individual often requires inputs of private goods. A trip as a final product is produced by an individual by means of inputs of private and public goods. Travelling on a road network is not possible without expenditures on a car, gasoline, and the traveller's time with an opportunity cost. In this case it can be assumed that the final good, a trip, a private good as such, is produced by an individual by means of inputs of private and public goods (Sandmo, 1987).

Based on economic efficiency, the charge for making a trip should be equal to the total social costs so that the benefits from making it are at least as large as its total social costs. The first question is to identify the marginal social costs of a particular trip. The second step is to determine whether road users should pay additional taxes above those dictated by their marginal social costs in order to cover the whole cost of the highway system, and to what extent they should pay to meet the revenue constraints confronting the government (Newbery, 1994a).

1.3.1 Pricing and Investment Rules

The development of pricing and investment rules has its origins in the writings of Pigou (1920), Knight (1924) and Hotelling (1938). It has traditionally focused on urban road networks with congestion. Beckman et al. (1956) contributed by noting that at equilibrium every user chooses a route that minimises her own cost, but she does not bear the full cost of her choice. They recommend marginal cost pricing in congested road networks in order to minimise the total cost of the system [5]. Short-run marginal cost

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[5] Beckman et al., (1956) recommend using the collected revenue to lower gasoline taxes or in some way benefit all road users.

pricing was applied to peak-period congestion on roads by Walters (1961)[6] using cost functions and by Strotz (1965) using utility functions.

Mohring and Harwitz (1962) were the first to determine optimal pricing and investment rules in a long-run framework. They were the first to point out that the financial viability of a public infrastructure under optimal pricing and investment depends upon its cost function. Optimal pricing and investment problems have been extended and refined to account for road networks, variations in traffic flow, demand uncertainty, lumpy investment and so on [7]. Examples of these works are Vickrey (1963; 1969), Johnson (1964), Strotz (1965), Mohring (1970), Kraus, Mohring and Pinfold (1976), Keeler and Small (1977), Bruzelius (1978) and d'Ouville and McDonald (1990a). Newbery (1988) and Small et al. (1989) expand the Mohring and Harwitz model by relaxing the assumption of infinitely durable pavement and by explicitly treating the wear and tear on the pavement as an external cost.

Cost functions produce the rules for optimal pricing and investment. For a given production technology and supply relations for inputs, i.e., prices, a cost function for a producer, specifies the minimum cost of producing specified outputs irrespective of the prices of those outputs. Cost functions are defined for the short- and long-run. The short-run is usually defined for a fixed capacity of infrastructure or capital. The long-run refers to a time period during which all inputs could change.

1.3.2 Short-Run Cost Functions and Pricing

By including user time directly as a cost, the congestion technology becomes an integral part of the cost function. The theory on congestion technology dates back to Wardrop (1952) and Beckman et al., (1956) and it has since been a subject of numerous empirical and theoretical studies. Small (1992a) provides an illuminating review and discussion of this subject.

The standard steady-state model of congestion technology results in travel time cost as the average cost of congestion. In the presence of severe congestion, however, travellers will substitute some schedule delay for travel time in equilibrium. This subject was first addressed and modelled by Vickrey (1969). Models of scheduled delay have been further developed by Small (1982) and Arnott et al. (1990). These models deal with trip scheduling endogenously. Empirical studies suggest that this cost, like travel-time costs, is substantial (Small, 1992a).

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[6] Walters (1961) suggests turning over the toll revenue to the local authorities "to spend as they think fit".

[7] See Mohring (1994) and Winston (1985) for excellent surveys.

In addition to travel time and scheduled delay, which are borne primarily by the travellers, other components of the short-run variable cost are: running costs (fuel, oil, tires, maintenance), vehicle capital costs, costs of accidents, parking costs, costs to local government of providing highway-related services, environmental externalities, such as air pollution and noise, and road-maintenance costs (Small et al., 1989). Some of these, such as running costs and vehicle capital costs, are borne by users, while others are social costs.

Optimality requires that a fee covers the difference between the short-run social marginal cost, SRSMC, and the short-run private marginal cost that is borne by the travellers, SRPMC. SRSMC includes the additional costs an extra vehicle imposes on other vehicles and the road authorities through congestion, scheduled delays and wear and tear on pavement. SRSMC should also include other external costs from the use of a facility, such as those imposed on users and non-users of a facility through noise and air pollution and the increased risk of accident. In the absence of externalities other than congestion, the entire short-run private marginal cost is borne by the traveller, and the required charge is SRSMC - SRPMC. When other externalities are present, the optimal fee should cover these additional externality costs as well (Small 1992a; May 1992). Figure 1.1 graphically shows the principles of marginal cost pricing and the determination of an optimal toll[8].

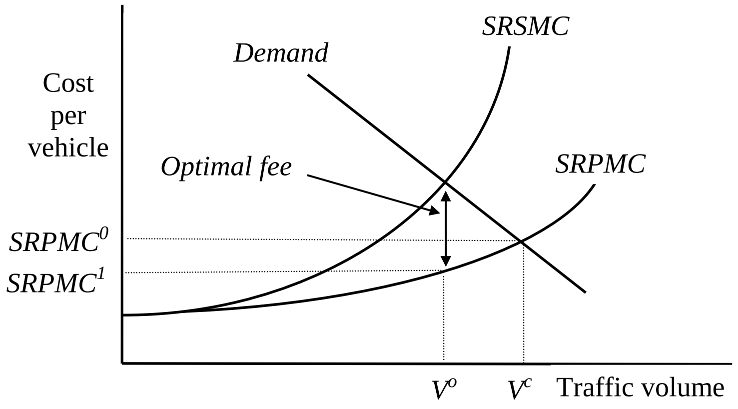

Figure 1.1 Optimal toll.

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[8] For a review of different approaches for the calculation of a Pareto optimal distribution of traffic and a pricing mechanism that guarantees equilibrium, see Johansson and Mattsson (1995b), Smith et al. (1995).

1.3.3 Long-Run Cost Functions and Investment Rules

The comparison of SRSMC with the long-run social marginal cost, LRSMC, provides a guideline for efficient investment in new capacity. The LRSMC includes the costs of expanding the capacity of the facility. Long-run costs are approximated by the sum of short-run cost functions and a cost function for the capital costs of road building. Long-run cost functions reveal the nature of long-run returns to scale[9]. Long-run cost functions also determine the necessary size of road capacity for an efficient accommodation of a given amount and time distribution of traffic.

Capital costs of roads vary with terrain, degree of urbanisation, ease of access to construction site, difficulties of grading, extent of demolition, and land prices (Small, 1992a). It is common to approximate the market prices for the social cost of land, since it is difficult to evaluate it. Distortions in the market prices are caused by different forms of taxation and externalities such as congestion. These factors seem to have effects which counteract each other (Vickrey, 1963; Arnott and MacKinnon, 1978; Kraus, 1981b).

As Howitt (1993) points out, there is a trade-off between SRSMC and LRSMC. The additional traffic on a facility can be accommodated by changing SRSMC and avoiding the expansion of capacity or by increasing the capacity and hence changing LRSMC. Investment is optimal if the SRSMC, and thus the prices, equals the LRSMC. When there are constant returns to scale, the revenue from marginal cost pricing covers the operating and investment costs. Other conditions need to be satisfied in order to recover the total cost. One condition is that the capacity of the facility should be optimal or near optimal. Another condition is that no external benefits or costs other than congestion and wear and tear on the facility should be present. With increasing or decreasing returns to scale, the revenues from marginal cost pricing fall short of or exceed total costs respectively (Newbery, 1988; Small et al., 1989).

These conditions are usually not met in the real world. The provision of transportation infrastructure involves significant indivisibilities (Neutze, 1966; Kraus, 1981b; Starkie, 1982). In addition, the capacity cannot be adjusted rapidly enough to keep pace with changing demand. However, the problem of non-optimal capacity is often less serious than it might seem, even for long-lived infrastructures such as roads (Howitt, 1993).

Evidence supports the existence of economies of scale in the long-run costs of provision of rural roads and of constant or near constant economies of scale in urban freeway and urban road networks (Strotz, 1965; Vickrey, 1969; Keeler and Small, 1977; Kraus, 1981a; Jansson, 1994). Large fixed

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[9] Return to scale with respect to capacity is defined as the ratio of average to marginal cost of capacity and is equal to the inverse of the elasticity of capital cost with respect to capacity.

costs due to indivisibilities, economies of scale in construction, fixed land requirements, and efficiencies in multi-lane traffic flow can cause increasing returns to scale. Increased costs of intersections, especially in urban areas, and rising supply prices of urban land lead to decreasing returns to scale (Small, 1992a; Hau, 1992a). However, most studies suggest that urban rail transit shows increasing returns to scale (Meyer et al., 1965).

By separating car and truck traffic, the optimal pricing and investment on capacity and road thickness within a multi-product framework has been analysed by Newbery (1988) and Small et al., (1989). Their analysis suggests near constant economies of scope and multi-product economies of scale in the provision of roads.

Externalities such as noise, air pollution and community disruptions can justify prices above the transportation firm’s costs. These external costs seem small compared with costs of supplies (Small, 1992a; Newbery, 1988). However, as Howitt (1993) points out, in some built-up areas the environmental and community opposition to infrastructure expansion can be so strong that it becomes politically impossible to expand the capacity. Jansson (1995) describes a case study illustrating this point.

1.4 Second-best Pricing and Investment Rules

The optimal pricing and investment rules that have been discussed above are often referred to as the first-best rules. The necessary conditions for first-best rules are in fact never met in reality because of the presence of economies and diseconomies of scale and price distortions in competing modes. Other examples are political concerns or cases where it is expensive or difficult to obtain information to enforce the first-best rule. Attempts have been made to derive second-best pricing and investment rules under these conditions. The derivations of these second-best rules have often proven to be more complex.

1.4.1 Second-best Rules, Roads

In the absence of congestion, improvements that increase free-flow speeds or improve safety should be financed through public funds. Highway investments in rural areas, and even in the suburban areas, fall into this category. When there are increasing returns to scale, public subsidies are necessary to cover the provision of optimal capacity. With tight constraints on the government budget, i.e. the marginal cost of public funds, it is possible to consider a Ramsey pricing solution.

Different taxes that are levied on car ownership and car use, such as first and annual registration fees and fuel taxes, contribute to the costs of operation and maintenance, the capital costs of roads and the general tax revenue. Fuel taxes (and to some extent taxes on car ownership) can internalise some environmental externalities, such as air pollution, noise and accidents, but they are ineffective in responding to the causes of congestion.

The second-best rule for highway capacity investment has been examined in the absence of congestion pricing (see, for example, Wilson, 1985; d'Ouville and McDonald, 1990b). Small's (1992a) analysis suggests that it is optimal to underinvest in capacity relative to the first-best rule, because underinvestment closes the gap between the cost of travel and its shadow price. However, this second-best rule is based on an underpriced traffic volume. Small concludes that by making allowances for a traffic volume that is higher than in the first-best situation, the second-best rule can result in a capacity that may be smaller or larger than in the first-best case. Henderson (1992) examines the second best-rule by addressing peak shifting due to trip scheduling and concludes that the optimal capacity in the absence of the first-best rule for pricing should be smaller than in the first-best case.

Peak shifting, often referred to as "the law of highway congestion", was formulated by Down (1962) and is referred to as latent demand by Small et al., (1989). Small et al., define latent demand as the potential demand for peak-period travel diverted to alternative periods, routes, modes and workplace locations or deterred by congestion itself.

1.4.2 First and Second-best Rules, Parking

Small (1992a) suggests that parking is a significant part of the social cost of trips in large urban areas and, like other economists, recommends marginal cost pricing or average cost pricing. Economists have long argued that underpriced or free parking produces inefficiencies by allocating too much space for parking facilities. Moreover, underpriced or free parking contributes to the congestion externalities. The search for an on-street or off-street parking place adds to congestion, and on-street parking interacts negatively with the traffic flow. Various empirical studies of mode choice provide evidence that an increase in parking fee has a larger effect on choice than a similar increase in running costs (Gillen, 1977; Willson, 1992).

Parking as a complement to road use has been suggested as a second-best solution to road pricing (see, for example, Gomez-Ibanez and Fauth, 1980; Jansson and Swahn, 1987; Hau, 1990). Nevertheless, theoretical approaches to this issue have only come recently and are indeed few.

Glazer and Niskanen (1992), by focusing on through-traffic, i.e. those who can choose the length of time they park, show that an increase in hourly parking fees, by inducing shorter stays at a space, can increase the turnover of occupants of a given space. Hence an increase in parking fees per unit of time has a negative effect on the contribution of through traffic to congestion.

Focusing on commuters, Arnott et al. (1991) include parking with a spatial property, i.e. the number of parking spaces is given as a function of distance from the city centre, where all commuters are employed, in a model of congestion that deals with scheduled delay endogenously (see Arnott et al., 1990). In this manner they address the impacts of parking costs measured in time and money on the decisions of commuters regarding departure time and parking location. They evaluate three types of optimal pricing schemes: a time-varying congestion pricing scheme, a location-dependent parking pricing scheme and a joint congestion pricing and location-dependent parking pricing scheme. Their analysis shows that an optimal location-dependent parking pricing scheme is at least as efficient as a time-varying congestion pricing scheme, with the joint scheme achieving a full optimum. Furthermore, they suggest that an optimal location-dependent parking policy will have less adverse distributional impacts than a congestion pricing scheme. Taking account of the shortcomings of their model when addressing important features of parking in the real world, they recommend that the results should be evaluated as a second-best solution.

1.4.3 Second-best Rules, Public Transportation

Second-best pricing policy in public transportation has been justified on two main grounds: price distortions in competing modes and significant economies of scale. The application of Ramsey-type pricing has a long tradition in scheduled modes, especially for rail. Winston (1985, p. 81) warns, "Ramsey pricing is plagued by equity problems". Turvey (1971) shows how the second-best price of a mode can deviate from its marginal cost when the prices in competing modes deviate from their marginal costs[10].

Returns to scale in public transport have been the subject of numerous studies and much debate. See Berechman (1993) for a review of the issues involved in this debate. An important reason for increasing returns to scale is the inclusion of users’ time, i.e., waiting time (Mohring, 1972) and walking time (Nash, 1988), as an input factor in the production of public transport.

The two main concerns about the provision of subsidies to public transport are the opportunity cost of public funds and distortions in the firm’s choices of technology. Public transport subsidies are associated with rules that should be structured so as not to inhibit technical efficiency. Like any other public subsidies, they are difficult to administer without undermining incentives for technical efficiency. When rules allow capital, but not operating costs subsidies, there has been a tendency to use a higher ratio of capital to other inputs than that which is technically efficient. Small (1992a,

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[10] Described by Winston (1985).

p. 130) recognises another form of capital bias in the choice among various types of transit and states that authorities "built capital intensive rail systems in locations where corridor volumes do not appear to justify them".

1.5 Impacts of Road Pricing

Newbery (1994a, p. 396) summarises the impacts of a road pricing scheme by stating that "road users should pay the marginal social cost of using the road network if they are to be induced to make the right decision about whether (and by which means) to take a particular journey, and more generally, to ensure that they make the correct allocative decisions between transport and other activities. If road users paid the true social cost of transport, perhaps urban geography, commuting patterns, and even the size of towns would be radically different from the present".

1.5.1 Distributional Impacts

Economic theory suggests that in the taxation of externalities in the absence of lump-sum transfers of revenues, the public expenditure must be designed with a view not only to efficiency, but also to equity considerations. Consequently, the incidence of the tax burden and the benefits from improvements should be analysed together.

On the equity considerations of a Pigovian tax Baumol and Oates (1988, p. 237) suggest that "somewhat paradoxically, a move to a state of Pareto optimality may not itself be a Paretian movement" and to illustrate their point they use congestion pricing as an example. They observe that in this case, "every driver is both a generator of these externalities and a victim of the same externalities produced by other drivers". They suggest that "optimality requires the imposition upon each driver a toll equal to the marginal social damage resulting from his presence, *with no compensation to him for the damage he suffers from the presence of the others*". In this case a Pigovian tax will result in a total loss of welfare to the road users, while maximising the social benefits.

Figure 1.2 illustrates this point. The optimal toll fee is the difference between the short-run social marginal cost, SRSMC, and the short-run private marginal cost, SRPMC. The optimal toll reduces the traffic volume from the competitive level, V^c, to an optimal level, V^o. Compared with the optimal level of traffic, the competitive level of traffic involves a net loss equal to the shaded area $ae^c f$. A driver pays an optimal toll fee equal to $c^o b$ which is greater than her saving that is equal to $c^o c^c$.

The result seems paradoxical since a move to a Pareto Optimum appears to hurt all drivers. However, as Baumol and Oates (1988) point out, this is not so. The proceeds from the Pigovian tax will add to the private consumption of other persons through different channels in the economy. However, if the road users do not share the proceeds, they will suffer a welfare loss.

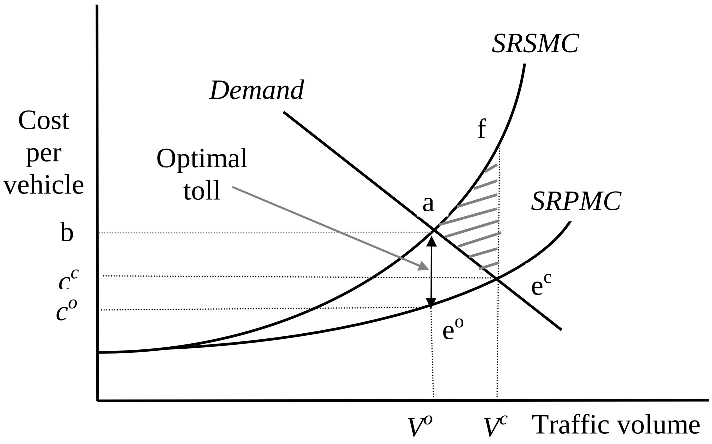

Figure 1.2 Congestion pricing and equity considerations.

Equity considerations pertaining to a congestion pricing scheme have been the focus of theoretical and empirical studies (Vickrey 1955; 1968; Small 1983). Most of these studies indicate the regressiveness of this type of scheme. The incidence of the tax burden among income groups depends on the level of the toll; the higher the toll the greater the differences will be.

Equity considerations could also include geographical incidence. One argument against cordon schemes has been that short distance journeys would bear most of the burden and that the incidence of such schemes falls disproportionately on businesses and households that are located close to the cordon. Another concern is the equity within population subgroups, e.g. a concern for those who do not have any possibilities of switching to alternative modes because of unavailability or other restrictions.

The economic evaluation of equity considerations depends on both the relative propensity of various income groups to travel and the disposition of benefits from toll revenues. Small (1992b) acknowledges that ultimately the burden of congestion pricing will be shifted throughout the economy by price adjustments that will alter land values and wages. Nevertheless, he approaches the equity considerations by identifying the direct impacts of a congestion pricing scheme. He categorises the four outcomes of a pricing scheme as: (a) the actual payment, (b) the inconvenience to those who change behaviour, (c) the benefits to travellers who encounter less congestion, and (d) the benefits from the uses of the revenues.

In theory the actual toll payment, category (a), should be equal to the benefits from the uses of the toll revenue, category (d)[11]. In theory an optimal congestion pricing schedule maximises the difference between (c) and (b). Hence, as long as the benefits from the toll revenue remain where the tolls are collected, there will be an aggregate positive net benefit. The remaining task is to evaluate the distribution of the incidence of the tax burden by category (b) and (c) and to devise a package so that the benefits from improvements address the distributional impacts.

There has been a number of studies aimed at identifying the incidence of congestion tolls and devising a package for addressing the equity considerations (see, for example, Goodwin, 1989; Gomez-Ibanez, 1992; and Giuliano, 1994). Yet the focus of other studies has been on devising a scheme that would minimise the distributional impacts (see, for example, Chen and Bernstein, 1995; Daganzo, 1995).

1.5.2 Impacts on Travel Behaviour

The demand for travel originates from the needs of individuals to participate in activities such as work, education, shopping and recreation, which, among other attributes, have a spatial dimension. Travel demand is determined by the choices of individuals regarding the locations of home and work and car ownership, and likewise the decisions of whether or not to travel, when to travel, what destinations, which mode of travel, and whether to chain trips into one integrated travel route or tour. Income, employment, household type, age and sex are some of the important factors that influence the demand for travel at an individual level. The supply of transport through the provision of accessibility, i.e. the availability of alternative transport facilities, the travel costs of different modes and the quality of the transport services such as travel time, speed, comfort and convenience, will in turn determines the individual's travel.

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[11] He also warns that "This assumption is overly optimistic if the revenue from congestion pricing is in fact spent unwisely, whereas it is overly pessimistic to the extent that the revenue replaces inefficient taxes or facilitates worthwhile expenditures that are currently foregone for lack of funds. Both of these effects occur in different areas of government operation" (Small, 1992b, p. 361).

The impacts of a road pricing or congestion pricing scheme on travel behaviour occur through relative changes in the time distribution of generalised costs of alternative modes. The generalised cost of travel is defined as the sum of all monetary costs and time costs (where time costs are converted into monetary costs by the value of time). In this manner a road pricing scheme will affect all consequential choices of travel. The impact of a pricing scheme on the different levels of choices depends on the purpose of travel and differs among individuals with different socio-economic characteristics. The adjustments of different levels of choices in response to a pricing scheme take time. The degree of flexibility in making these adjustments determines whether they are short-run or long-run impacts. In the following discussion some of these impacts are summarised.

Timing of tours: Tolls and congestion fees will increase the monetary costs of travel and induce a reduction in travel time. Both factors, the reduction in travel time and the increase in the monetary costs of travel, will induce some persons to adjust their travelling schedule so as to benefit from a more desirable departure time or reduced travel time, or it may induce them to avoid paying a toll or to pay a lower toll when the toll level is differentiated.

Tour frequency and trip chaining: A toll fee can decrease the frequency of discretionary trips, such as shopping or recreation, which can be expected to be more price-sensitive than compulsory trips, such as work and business. At the same time it is possible that a larger number of the discretionary trips will be chained together or chained with compulsory trips. This will lead to a greater reduction in the number of discretionary tours as compared to compulsory tours and an increase in the number of trips that are linked together to make a tour.

Mode choice: By changing the relative generalised costs of travel by alternative modes, a toll fee will affect the mode choice.

Destination choice: The changes in the relative cost of travel to alternative destinations will cause a shift in the destination choice. Since there is a larger degree of flexibility of destination choice among discretionary trips, it is reasonable to expect larger shifts in the destinations connected with this type of travel in the short run. A congestion pricing scheme that is approximated by a cordon toll could cause destinations close to the cordon to become less attractive. One would also expect an increase in the average trip length by car, while the total number of car-kilometres is decreasing, because shorter trips will be affected more than longer trips.

Route choice: The change in the overall demand for travel by car will decrease the degree of congestion in the network and produce a new equilibrium with a different route choice pattern. If the pricing scheme is implemented in the form of a cordon toll, some motorists can be expected to make detours to avoid toll payment.

Car ownership: The demand for a car is connected to the utility associated with its use. One would expect some reduction in car ownership to follow a congestion pricing scheme.

1.5.3 Impacts on Land Use

Johansson and Mattsson (1995b) illustrate with a stylised model how the introduction of a toll brings about a relocation in space. However, there is no compelling evidence indicating whether a congestion pricing scheme will induce centralisation or decentralisation (Deakin, 1994). Land use activities are affected by accessibility and by the quality of the environment. A congestion pricing scheme is bound to change both of these factors. The evaluation of the impacts becomes more difficult because it depends very much on how the toll revenues are used, e.g., to improve transport facilities or to reduce present distortionary taxes levied on car use and car ownership. Congestion pricing might induce some people to choose a closer work location or to relocate in order to economise on transportation costs, thereby producing a second wave of changes in travel behaviour.

In an ex ante analysis for Stockholm, Johansson and Mattsson (1995c) examine a cordon toll scheme, the revenues of which are spent on investments in transportation infrastructure. Their analysis shows that the combined effects of the toll scheme and the investment policy give rise to a decentralisation of housing and work place.

1.5.4 Other Impacts

A congestion pricing scheme will lead to improvements in air quality and reduce energy consumption. These impacts stem from the reduction in car travel as well as improvements in traffic flow.

Impacts on commercial traffic are another example of the broad range of impacts of a congestion pricing scheme.

1.6 Competing Objectives and Toll Revenues

The growing interest in road pricing in urban areas is a response to a variety of problems that urban areas are confronting. Most urban governments are facing financial restrictions when it comes to financing the necessary infrastructure to alleviate congestion in their road networks and meet the expected demand. The support group with this view regards road pricing in the traditional sense, i.e., a market based solution that provides revenue for capacity expansion.

An alternative view is that providing more capacity induces more car traffic, which in turn will result in more travel and hence in more congestion that will further deteriorate the environment and increase energy consumption. The support group with this view regards road pricing as a means of curtailing car traffic rather than a means of achieving a socially optimal investment in roads. Their objective for road pricing is to restore the market for public transport, and they advocate the use of toll revenues to provide for public transport subsidies and support slow mode facilities. Yet another support group for road pricing with similar views is the environmentalists who advocate a policy based on principles of sustainable economy and/or ecology (Giuliano, 1992).

Yet the grounds for opposition to road pricing are diverse[12]. Much opposition comes from those who believe that road pricing will add to the present road user taxes and hence become an additional source of revenue for the government. This seems to be the main objection to the toll scheme in Oslo (see footnote no. 13). Other grounds for opposition to road pricing include distributional effects, adverse impacts on businesses, and concern about the protection of privacy with electronic road pricing. Gomez-Ibanez and Small (1995, p. 62) argue that road pricing is perceived as a drastic change compared with the present arrangement. "People do not understand its rationale, they do not trust the technology and institutions to work correctly, they fear unanticipated side effects such as traffic spillovers, and they suspect that some individuals will pay heavy costs while the gains, if any, will be reaped by others".

1.6.1 Market-based Supporters

The supporters of market-based solutions to transport problems view road pricing as the proper device to create a market for transport services by setting the correct scarcity price on the use of road space. Furthermore, the optimal supply of infrastructure will be determined by the revealed demand through the willingness to pay for transport use. The necessary condition if revenues from road pricing are to cover the maintenance and capital costs of optimal expansion of the road network is constant returns to expanding road capacity, a condition that seems to be satisfied in urban areas (Small et al., 1989; Newbery, 1994b).

A market-based solution requires that road pricing replace existing taxes and charges on road users. Other taxes related to non-congestion externalities and taxes to generate revenues according to the constraints of the government budget should be levied on road users after calculating the revealed demand with congestion pricing. Furthermore, they hold the view

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[12] See Giuliano (1992) for a complete list.

that correct pricing will reduce the overall level of socially justified public transport subsidies (Newbery, 1994b).

Most advocates of a market-based solution do not support the privatisation of roads. The ground for their objections is the existence of natural monopoly elements in roads (see Small, 1992a; Hau, 1992a; Newbery, 1994b). An additional complication is associated with the "road network as a network". Investments or charges in part of the network will affect the traffic volumes and profitability of other parts of the network (Newbery, 1994b). These circumstances provide additional grounds for heavy regulations that will reduce the profitability of privately operated roads in urban areas, a problem for which Walters (1987) does not seem to have a good solution.

1.6.2 Environmentalists and Public Transport Supporters

Environmentalists hold the view that the true value of environmental services - local, regional and global - is not reflected in the prices of transport. These prices should include costs related to noise, vibration, accident risk, local air pollution from both primary and secondary pollutants such as ozone, regional and atmospheric pollution, community disruptions, visual intrusion and scenic values, water pollution, loss of wildlife, and the depletion of natural resources. Wider concern for the global environment and future generations has linked principles of sustainable economy and/or ecology to transport. The environmentalists advocate demand constraints, so their support for road pricing is not aimed at achieving a socially optimal expansion of highway capacity, as implied by congestion pricing.

Public transport supporters believe that the market share for public transport has been eroded because of price distortions in the competing mode, i.e. the car. For this group road pricing has a double dividend: it sets the correct price for car use, and it provides the means for subsidies to public transport.

1.6.3 Toll Revenue

Giuliano (1994, p. 349) states, "Implementation of congestion pricing in any circumstance where congestion is extensive will lead to a political mixed blessing: a large amount of toll revenue".

The competing objectives of road pricing suggest a compromise in the redistribution of the benefits among interest groups. Goodwin (1989) suggests that the benefits of road pricing - the release of a certain amount of road space and the toll revenue - should be allocated to (three) different defined purposes, including the environment and public transport. Goodwin (1995, p.151) suggests that the actual proportions in the rule of three "can be negotiated and will be different in different towns". A recent survey conducted in England shows that public support for road pricing increases when road pricing is packaged as part of an integrated transport policy with explicit proposals for using the revenues (Jones, 1991).

Hau (1995, p. 59) argues that toll revenues should be "indirectly channelled back to travellers through reduced transportation-related taxes, so-called road user charges, or improved public services" in order to gain public support. This view is shared by other economists. The use of the toll revenue is the key issue in the design of a road pricing package that meets economic criteria.

Small (1992b) proposes a package of revenue uses that would be a "Pareto improvement" and would potentially gain political support for a scenario where roads are publicly owned and financed. His approach to the design of the package was described earlier under distributional impacts. He identifies the distributional burden of a road pricing scheme to address public support and identifies the demands of different interest groups on such a scheme. The main elements of the package are: reductions in distortionary taxes that are directly linked to the provision of transport services, improvements in roads, public transportation and transportation services in business centres, and an employee commuting allowance. The only element that is not directly associated with transport is the employee commuting allowance. Note that Strotz’s (1965, p. 380) analysis of the first-best rules for pricing and investment proposes a subsidy for each work trip, regardless of the distance travelled, "where there are external economics to the concentration of production activity (seventh parable)".

1.7 Some Implications for Practical Application

Different taxes that are levied on car ownership and car use have contributed to the costs of operation and maintenance, the capital costs of roads and the general tax revenue. The conventional response to congestion has been the expansion of capacity but these expansion have been rapidly absorbed by the latent demand. There is concern that this remedy has further deteriorated the urban environment in particular and environment in general, and it has adversely affected the market for public transportation. Meanwhile, different levels of government have increasing problems providing the necessary infrastructure to support economic development. The recent interest in road pricing in urban areas has been a response to the limited resources available for the expansion of capacity and/or to the inefficiencies in the provision of urban transportation.

Fuel taxes (and to some extent differentiated taxes on car ownership) can to a large extent internalise some environmental externalities such as air pollution, noise and accidents. Nevertheless, these taxes are ineffective in responding to the causes of congestion. Hence, congestion in most urban areas has remained underpriced and time-invariant. The inefficiencies of urban transportation are not confined to the pricing and provision of roads. Parking fees are heavily subsidised by employers, businesses and local governments. Public transport operation requires subsidies, especially when the competing mode, the car, is not priced correctly. Yet subsidies have been costly due to the opportunity cost of public funds, and the response to subsidy programmes has been inefficient. Other externalities, such as noise and air pollution and risks of accidents, are not totally internalised. The main advantage of congestion pricing is that it tackles several of the inefficiencies in urban transportation while generating revenues for the provision of transport infrastructure.

By filling the gap between the private marginal and social marginal costs of road users, congestion pricing reduces congestion to an optimal level. The theory suggests that congestion pricing, under certain assumptions, generates sufficient revenues to optimally expand the capacity to meet future demand (in the long-run). Evidence suggests that these conditions are nearly satisfied in large urban areas. In addition, congestion pricing should reduce the size of the necessary road infrastructure and the necessary subsidies to public transportation, while improving the environment.

The theory also suggests that congestion pricing, by correcting for inefficiencies in the competitive allocation of resources, has a much lower social cost of public funds than those from taxes that are distortionary. Hence, by taking account of the incidence of the costs and benefits of congestion pricing, it should be possible to make everyone better off.

Still, congestion pricing in an urban area requires public and political support that does not seem to make its implementation as easy as toll financing schemes[13]. One main important reason for this is related to the

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[13] The public support for the "Oslo package" has increased from 29 percent in 1989 before the introduction of the toll ring to 41 percent in 1994 (PROSAM, 1994). Most elements of the package, mainly a package of road investment programme, were in place in 1994. The support among those who had to cross the cordon toll between home and work increased from 23 percent in 1989 to 38 percent in 1994. The grounds for supporting the package have shifted from "a measure to decrease car traffic" to "a measure to increase road capacity". The main objection to the package in 1989 was that it was an additional means of charging road users. The percentage of respondents who held this view

perception of road pricing as a drastic change from the present system. It would call for an incremental solution without compromising the strategy. The successful implementation of the electronic toll rings in the three largest Norwegian cities should make it possible to introduce the necessary modifications so that the schemes can be used for congestion pricing. If congestion pricing had been an objective, the design of the schemes would have been different. If that were the case, it is not clear whether the implementation would have gone as smoothly (Ramjerdi, 1994).

Another reason is related to the competing objectives of congestion pricing among different groups of supporters. It should be possible to design a package of congestion pricing and revenue disposition that will facilitate the necessary political compromises. Furthermore, the public opposes congestion pricing because of its distributional impacts, and it is considered regressive. Road users are already paying for roads through road user taxes that are regressive. Road pricing should at least reduce these taxes. It should also make it possible to compensate for the adverse effects, but not in a manner that compromises the purpose of road pricing.

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decreased from 57 percent in 1989 to 48 percent in 1994. This examination of public attitudes suggests that political support for the "Oslo package" was more important than public support.

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Essay no. two

Cost-Benefit Analysis, Users' Benefit and Distributional Consequences of a Toll Scheme for Stockholm

2.1 Introduction

A demand model should allow for both the prediction of the quantity consumed after a change in the price of a good or service has been introduced and for an evaluation of the users' benefits or loss from that change. In the context of transportation the role of a budget constraint at the mode choice level has not been emphasised because of an individual's transportation expenditures are negligible compared to his or her income. If income effects are negligible, different measures of users' benefits coincide; if not, the "correct" measure should be used. More recently there has been an increasing interest in re-examining the income effect at the mode choice level, and if there are any income effects, to develop methodologies for the measurement of the correct users' benefits.

One objective of this work is to evaluate the role of income effects at the mode choice level for Stockholm, and to determine the consequences on the measures of users' benefits. Another objective of this work is to investigate alternative functional forms for the specification of utility and their effects on the subjective value of time. For this purpose travel-to-work data will be used. The main reason for the focus on travel to work is that one can assume a fixed origin and destination as well as a frequency for this travel purpose. Hence, the travel demand can be adequately represented by a mode choice model. For other purposes, such as shopping, one can expect a change in destination and frequency. Results, i.e. alternative mode choice models, will be used in the evaluation of users' benefits from a toll scheme in Stockholm.

The organisation of this paper is as follows. Section 2 summarises different measures of users' benefits and then describes a methodology for the detection of income effects at the mode choice level in section 3. The data is described in section 4 and the application of the methodology to the data is presented in section 5. In section 6 an alternative approach for the specification of a mode choice model is presented and applied to the data for Stockholm. Section 7 presents the application of two alternative mode choice models in the evaluation of users' benefits from a toll scheme in Stockholm. Finally section 8 covers our conclusions.

2.2 Measures of Users' Benefits, a Brief Review

When the income effect is ignored in the specification of utility in the mode choice, the resulting demand model represents both the market demand and compensated demand. In this case all three measures of users' benefits, which will be explained briefly later, coincide. Therefore, introducing income creates some ambiguity in the welfare analysis which naturally depends upon how the preferences are captured in a demand model.

As Williams (1976) points out, evaluation measures and demand models have been developed separately and with little regard to the consistency between them. The rule-of-a-half is still the standard practice in the calculation of users' benefits in transportation projects. This measure has been derived in a manner analogous to the Marshallian measure of consumer surplus that is defined as the difference between the sum people would be prepared to pay and the sum they have to pay for a quantity of goods. As Williams warns, this measure, i.e., rule-of-a-half, is not a correct measure of the welfare change in the classical sense. This formulation implies negligible income effects.

Consumer surplus is a widely used tool in applied welfare economics. The basic idea is to evaluate the value to the consumer measured by his willingness to pay accompanying a change in the price of a good. Because price changes affect consumers' welfare, an evaluation of this effect is often the key input to public policy decisions. Even though the consumer surplus is quite a controversial concept, it is widely used and there is a substantial agreement on the correct quantities to be measured. The measure is the amount the consumer would pay or need to be paid to be just as well off after the price change as he was before the price change, or the Hicksian compensation variation measure. An alternative measure that takes ex post price change utility as the basis of compensation is Hicksian equivalent variation measure (Hausman, 1981). The primary condition for the Marshallian measure of consumer surplus to correspond to the Hicksian measures is to have a constant marginal utility of income.

Jara-Diaz and Farah (1988) provide a review of the relation between utility, demand and the various measures of consumer surplus. A summary of this review will be presented here, since it will introduce some of the concepts used in this work.

They start with a model of consumer behaviour where an individual maximises her utility and its solution is as follows

$$\begin{array}{lll} \text{Maximise:} & U(X) & \text{Solution: } X = X^{*}(P, I) \text{ demand functions} \\ \text{Subject to:} & PX^{T} \leq I & \text{Optimum: } U[X^{*}(P, I)] = V(P, I) \text{ indirect utility function} \\ & X \geq 0 & \end{array} \qquad (1)$$

where X is the vector of goods and services consumed during a period, $U(X)$ is the utility function, P is the vector of prices for goods and services and I is income. The dual of the maximisation problem above and its solution is as follows

Minimise: PX^T Solution: $X = X^c(P, U')$ compensated demand
Subject to: $U(X) \geq U'$ Optimum: $P[X^c(P,U')]^T = e(P, U')$ expenditure function
$X \geq 0$ (2)

If the set of prices changes from P^0 to P^1, the bundle of goods consumed will change from X^0 to X^1 and the level of utility from U_0 to U_1 .

The definition of the compensation variation, *CV*, results in the following

$$U_0 = V(P^0, I) = V(P^1, I - CV) \tag{3}$$

Taking the inverse in (3) and using expenditure functions we obtain

$$CV = e(P^0, U_0) - e(P^1, U_0)$$

or

$$CV = -\int_{p^0}^{P^1} \sum_i X_i^c(P, U_0) dP_i \tag{4}$$

The definition of the equivalent variation, *EV*, leads to

$$U_1 = V(P^1, I) = V(P^0, I + EV) \tag{5}$$

Taking the inverse in (5) and using expenditure functions we get

$$EV = e(P^0, U_1) - e(P^1, U_1)$$

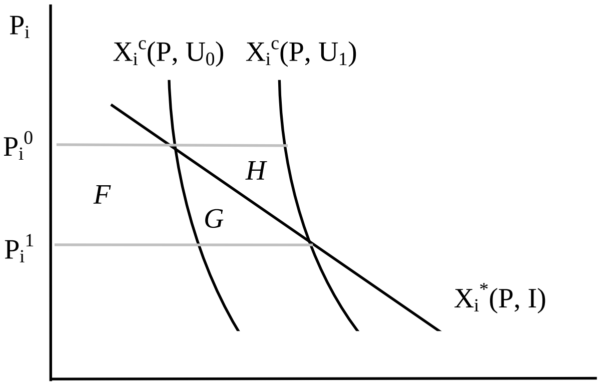
or

$$EV = -\int_{p^0}^{P^1} \sum_i X_i^c(P, U_1) dP_i \tag{6}$$

The definition of the Marshallian measure of consumer surplus leads to

$$\Delta MCS = -\int_{p^0}^{P^1} \sum_i X_i^*(P, I) dP_i \tag{7}$$

Figure 2.1 illustrates different measures of the consumer surplus.



EV = F + G + H; CV = F; Δ MCS = F + G

Figure 2.1 Different measures of consumer surplus (Adapted from Jara-Diaz and Farah, 1988)

Even though disaggregate demand models have long been popular, especially in transportation, the use of methods of applied economics in discrete choice situations is relatively new (for example, Williams, 1977; McFadden, 1975; Small and Rosen, 1981). Because of the emergence of the importance of discrete choice demand models in the evaluation of the impacts of governmental programs on welfare, there has been a renewed interest in the application of the conventional cost-benefit analysis to such models (for example, Small, 1983; Hau, 1985 and 1987; Jara-Diaz and Videla, 1987).

Jara-Diaz and Videla (1987 and 1990) compare more strict measures of users' benefits that have been derived for mode choice models. These are; the expected net maximum utility (Williams, 1977), the social indirect utility function (McFadden, 1981), and the direct integration of the expected demand (Small and Rosen, 1981). They summarise that these three approaches provide a logit formulation of the mode choice when the random component is assumed to be Gumbel probability distributed, and furthermore the different measures of the users’ benefits coincide and are given by

$$UB = \frac{N}{\mu} \ln \sum_i \exp V_i \tag{8}$$

where N is the number of individuals in the population and μ is the marginal utility of income and V_i is the conditional indirect utility function for mode i. As Jara-Diaz and Videla point out both McFadden and Small and Rosen assume a marginal utility of income that is independent of both prices and qualities of modes, and a negligible income effect (i.e., individual choices do not depend on income). Both assumptions follow from the specification of the indirect utility function (McFadden, 1981). If the income effect should be included in the specification of the indirect utility function as such and not as a proxy to other variables (for example Swait and Ben-Akiva, 1987), the marginal utility of income will not be independent of prices and qualities of modes. With this formulation the different measures of users' benefits do not coincide and hence a Hicksian measure is called for. Jara-Diaz and Videla (1987 and 1990) propose a number of approaches to tackle the complications that arise in the calculation of this measure. For example one approach they recommend is similar to that of Williams' (1977), except that they minimise expenditure rather than maximise net utility.

2.3 Detection of Income Effects, Mode Choice

Jara-Diaz and Videla (1989) provide a theoretical framework for the detection of income effect in mode choice. In this paper we summarise their main conclusions and refer the readers to the paper for details.

Assume that the utility function for an individual is defined by $U(X, Q_j)$, where X is a vector of continuous goods (excluding travel) with an associated price vector P and Q_j is a vector of attributes of travel by mode j, among J available alternative modes of travel with price c_j. If the individual has an income I she will choose X and j such that

$$\underset{\substack{X \in x \\ j \in \{1,\ldots,J\}}}{Max} \{U(X, Q_j) | PX^T + c_j \leq I\}$$

or

$$\underset{J \in \{1,\ldots,J\}}{Max} \{\underset{X \in x}{Max}[U(X, Q_j) | PX^T \leq I - c_j]\} \tag{9}$$

Suppose that the utility, $U(X, Q_j)$, is separable in X and Q_j, i.e., the level of satisfaction attained from consuming a bundle X is independent of the modal characteristics. Then the utility function can be written as

$$U(X, Q_j) = U_1(X) + U_2(Q_j) \tag{10}$$

Substituting for $U(X, Q_j)$ from (10) into (9) we obtain

$$\underset{J \in \{1,\ldots,J\}}{Max} \{\underset{X \in x}{Max}[U_1(X, Q_j) | PX^T \leq I - c_j] + U_2(Q_j)\} \tag{11}$$

The optimisation problem (11) produces a set of functions $X^*(P, I - c_j)$ that generates the conditional indirect utility function V_j

$$V_j = V_1(P, I - c_j) + U_2(Q_j) \tag{12}$$

A second order Taylor expansion of V_1 in $I - c_j$ around (P, I) provides

$$V_j = V_1(P,I) - \mu(P,I)c_j + \frac{1}{2}\frac{\partial\mu}{\partial I}c_j^2 + U_2(Q_j) \tag{13}$$

where μ is the marginal utility of income.

Relation (13) shows that the linear-in-cost version of V_j implicitly assumes that the marginal utility of income μ is independent of income.

An additional money unit is more valuable for people with less income, i.e., μ should decrease with individual income. However, as Jara-Diaz (1989) points out, a higher-order behaviour of μ can not be known a priori. Therefore to test for the presence of income effects a second-order expansion is assumed sufficient.

Jara-Diaz and Videla (1989) suggest a specification to test the presence of income effects in mode choice. They propose a more flexible model specification such as

$$V_j = A_j + \alpha c_j + 1/2\, \beta c_j^2 + U_2(Q_j) \tag{14}$$

Hence the value of marginal utility of income is

$$\mu_i = \partial V_i / \partial I = -\alpha - \beta c_i \tag{15}$$

The conditional version of Roy's identity in discrete choice, i.e., $\partial V_j / \partial I = -\partial V / \partial c_j$ is used for this derivation (McFadden, 1981).

The following properties are constructed:

Within an income class, the perceived marginal utility of money should be greater for those who choose cheaper modes, i.e., $\partial\mu(c_j, I) / \partial c_j < 0$, or

$$\partial\mu_j / \partial c_j = -\beta < 0 \quad \text{or} \quad \beta > 0 \tag{16}$$

This effect should diminish with I across income groups, i.e., $\partial\mu^2(c_j, I) / \partial I \partial c_j < 0$, or $\partial\beta(I) / \partial I < 0$ and hence

$$\beta(I_j) > \beta(I_k) \quad I_k > I_j \tag{17}$$

μ_j should be positive, i.e.

$$- \alpha - \beta c_j > 0 \tag{18}$$

The above property combined with (16) results in

$$\alpha < 0 \tag{19}$$

Finally, as stated earlier, an additional money unit is more valuable for people with less income, i.e., $\partial\mu(c_j, I) / \partial I < 0$. Hence, across income groups

$$\mu(I_i) > \mu(I_k) \quad for \quad I_k > I_i \tag{20}$$

2.4 Description of Data

The Stockholm Travel Study of 1986/1987 is the main data source for this study. The data is described for example by Algers and Widlert (1992). The data for this study consists of the travel purpose work and are based on 1408 observations.

Table 2.1 describes the average gross personal income for indicated income brackets and their observed frequencies. Average disposable personal income and gross personal income for workers in the indicated gross personal income ranges are presented in the same table. Table 2.1 shows that there is a strong correlation between personal income and household income. Workers with low personal incomes have on the average low household income. Disposable personal income has a more even distribution than gross personal income due to the progressive taxation system in Sweden. For conversion of gross personal income to disposable personal income Taxeringsstatistiska Undersökningar (1987) was used.

Table 2.2 presents the socio-economic characteristics of the respondents along with their frequency of mode choice in three income strata, low- (gross personal income, GPI, in SEK 1000, 0 < GPI ≤95), medium-(95 < GPI ≤ 130), and high- income (130 < GPI). As shown in this table, the percentage of female and part time workers decreases as income increases, while car ownership increases with income. Because of a larger proportion of part time workers in the low income stratum, one can deduce that the differences between wage rate of low- and high- income strata should not be as large as their income differences. The frequency of choice of slow mode (walk and bicycle) and public transportation is higher among the low income group, while the choice for car mode increases with income.

Table 2.3 presents the average network data for a round trip to work by car, public transportation and slow mode for different income strata. The network data have been simulated by the *EMME/2* system, a software that includes equilibrium assignment models for car and public transport. The outlay for a round trip to work by public transport based on the average monthly pass in 1986 and 1987 is SEK 9.0. Variable car cost is based on distance and an average cost per kilometre. The calculation of variable car cost takes account of those who have claimed deduction for this cost for income taxation. In 1986-87 it was not possible to claim a deduction for cost of commuting with public transport since it was lower than the minimum amount for tax deduction for this purpose. We bring the following two points to the attention.

- Distance to work increases with increase in income.
- Total car cost for mode choice car decreases with income mainly due to tax deduction for commuting cost by car.
- Average car speed is higher for those who have chosen car as compared to other modes.

Table 2.1 Different measures of average income (1986-87).

Gross personal income range 10,000 SEK/year	No. of observation w.r.t. gross personal income	Average income, 1000 SEK/year		
		Gross personal income	Gross household income	Disposable personal income
0 - 2	10	11.1	76.2	9.9
2 - 4	26	30.5	134.0	24.3
4 - 6	54	48.7	156.2	37.1
6 - 8	123	69.3	156.6	50.9
8 - 10	242	89.9	170.6	63.8
10 - 12	261	106.6	198.7	73.6
12 - 14	218	125.4	229.0	85.2
14 - 16	126	147.2	239.0	98.7
16 - 18	64	166.7	258.7	110.3
18 - 20	46	184.8	286.1	120.1
20 - 22	43	204.8	297.7	130.2
22 - 24	20	226.9	342.2	139.5
24 - 26	15	246.5	353.8	146.9
26 - 28	8	266.9	336.3	154.4
28 - 30	7	288.1	452.3	163.2
30 - 32	7	300.0	380.3	168.0
32 - 34	3	321.7	401.0	176.3
34 - 36	1	350.0	415.0	186.4
36 - 38	3	365.3	482.0	191.4
38 - 40	1	396.0	481.0	200.9
40 -over	11	467.0	483.9	220.9

Table 2.2 Mode choice and socio-economic characteristics (1986-87).

	Low	Medium	High
	0<GPI≤95	95<GPI≤130	GPI>130
Sample size	372	481	378
Gross personal income [a]	69.7	109.4	185.7
Disposable personal income	50.8	75.4	115.6
Gross household income	154.2	207.0	277.0
Female workers, percentage	76	50	22
Part time workers, percentage	46	9	4
Access to car, percentage	68	77	100
Frequency of mode choice, %:			
chosen mode: car	30	44	64
chosen mode: transit	47	43	29
chosen mode: slow	23	13	7

[a] All incomes are in 1000 SEK/year, in current prices.

Table 2.3 Network data for a round trip by alternative modes (1986-87).

	0<GPI≤95	95<GPI≤130	GPI>130
For those with access to car:			
parking cost, SEK	3.1	2.3	3.6
car variable cost, SEK	12.2	10.5	8.6
total car cost, SEK	15.2	12.8	12.2
car distance, km	21.1	24.7	28.8
car time, minutes	42.8	48.3	58.3
average speed, car, km/h	30.0	30.7	29.7
in vehicle time public transport, minutes	38.8	44.5	53.9
wait time public transport, minutes	15.0	18.8	19.3
walk time public transport, minutes	18.4	21.1	22.6
Chosen mode: Car			
parking cost, SEK	1.6	2.2	1.7
car variable cost, SEK	12.1	7.8	6.3
total car cost, SEK	13.7	10.0	7.9
car distance, km	23.3	25.7	30.4
car in vehicle time, minutes	44.3	47.6	58.1
average speed, car, km/h	31.5	32.4	31.4
in vehicle time public transport, minutes	44.4	47.9	58.7
wait time public transport, minutes	18.1	22.5	21.6
walk time public transport, minutes	21.1	22.4	23.3

Table 2.3 (continued) Network data for a round trip by alternative modes.

	0<GPI≤95	95<GPI≤130	GPI>130
Chosen mode: PublicTrans./access to car:			
parking cost, SEK	6.6	3.2	10.0
car variable cost, SEK	18.3	16.3	17.2
total car cost, SEK	24.8	19.5	27.2
car distance, km	29.4	28.5	30.9
car time, minutes	60.7	59.5	70.0
average speed, car, km/h	29.0	28.7	26.5
in vehicle time public transport, minutes	53.1	49.3	52.2
wait time public transport, minutes	18.3	16.5	16.5
walk time public transport, minutes	19.6	20.3	22.9
Chosen mode: Slow/Access to car:			
parking cost, SEK	0.6	0.4	2.3
car variable cost, SEK	3.2	5.6	3.9
total car cost, SEK	3.8	6.0	6.2
car distance, km	4.8	9.3	10.4
car time, minutes	13.2	24.0	28.7
average speed, car, km/h	21.8	23.2	21.7
in vehicle time public transport, minutes	7.1	19.8	20.1
wait time public transport, minutes	4.5	10.4	8.9
walk time public transport, minutes	11.4	18.0	16.1

2.5 Application

The preceding theoretical framework will be applied to the commuting data for Stockholm that was described above. To establish a reference for discussion we first estimate a simple mode choice model which is linear in cost and time, for travel to work. The estimation is based on three modes: car, public transportation and slow mode (walk, bicycle). Very few socio-economic variables are used in this model specification. It should be pointed out that almost all who had chosen public transportation for commuting had used a monthly pass, and therefore they had a constant public transportation cost. Hence the cost for public transportation will not affect the estimation. We assume that the cost coefficients for the cost variables are equal. In table 2.4, model A presents the result of the estimation[1]. This model yields a

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[1] This model structure and an initial estimation of the coefficients were provided by Staffan Algers. The observations with a personal income of zero are excluded, i.e., we have excluded "work" trips for respondents who did not have paid work.

marginal utility of income ($\mu_i = -\partial V_i / \partial c_i$) of 0.03351 and a subjective value of time of 19.3 SEK/hr for travellers by the modes car and public transport.

The first step in the detection of income effects as presented earlier is to test for the significance of β in relation (14). This was done by adding the variable $(cost)^2$ in the specification of the linear in cost and time model. In table 2.4, model B shows the results. The coefficient for $(cost)^2$, β, is both significant (t-value = 3.0) and has the right sign (positive). This implies that the marginal utility of income can depend on income and as explained earlier we should expect β to be a function of income. Hence income stratification seems necessary. Separate models for different income strata are estimated. Table 2.5 shows the results.

The results that are presented in table 2.5 show that coefficients α, the coefficient for cost, and β, the coefficient for $(cost)^2$, for the three separate models have the correct signs. Even though β for the high income group is significantly lower than those for other income groups, β for the low-income group is slightly lower than β for medium income group. Nevertheless, α increases with income. It is possible to calculate μ for each income stratum and the corresponding t-values from the variance-covariance matrix of the coefficients, as shown in table 2.6.

The calculation of μ is based on the average costs of travel by car and public transport for the given income stratum and the mode share in that income stratum. Note that the value of μ for the high income stratum is almost equal to μ calculated from the simple mode choice model and that μ for the low income stratum is almost twice as large as that for the high income group.

For the test on the difference between μ_i and μ_k, the t-statistic can be formulated as

$$ts = (\mu_i - \mu_k) / [Var(\mu_i, \mu_k)]^{1/2} = (\mu_i - \mu_k)/[(\mu_i/t_i)^2 + (\mu_k/t_k)^2]^{1/2} \qquad (21)$$

where ts_i is the t-statistics from table 2.6. The results are presented in table 2.7. Based on the t-statistics one cannot reject that the μ_i's are equal.

We can rewrite equation (14) to calculate the subjective value of time and its t-statistics for different income groups as

$$V_j = A_j + \alpha c_j + 1/2\beta c_j^2 + \gamma T_j + \bar{U}_2 (Q_j) \qquad (22)$$

The subjective value of time, svt_i, will be

$$svt_j = \frac{\partial V_j / \partial T_j}{\partial V_j / \partial c_j} = \frac{\gamma}{\alpha + \beta C_j} \qquad (23)$$

and the t-statistics for svt_i will be

$$ts_j = \gamma / [Var(\gamma) + svt_j^2 Var(\alpha) + c_j^2 svt_j^2 Var(\beta) - 2svt_j Cov(\gamma, \alpha) - 2c_j svt_j Cov(\gamma, \beta) - 2c_j svt_j^2 Cov(\alpha, \beta)]^{1/2} \tag{24}$$

Table 2.4 A simple logit model for mode choice (A), and a simple logit model with a quadratic cost term (B).

Variable [a]	Parameter (t-value) Model A	Parameter (t-value) Model B
Constant for public transport	-.6058 (1.9)	
Constant for slow mode	.9221(2.1)	.7696 (1.8)
In vehicle travel time, car and public trans.	-.01076 (2.1)	-.01109 (2.2)
Total cost, driving and parking, car	-.03351(5.7)	-.06679 (5.1)
Total cost squared, car	-	.5495E-3 (3.0)
Dummy = 1 if car used during work, car	2.132 (9.2)	2.070 (8.9)
Dummy = 1 if destination in inner city, car	-.6126 (2.9)	-.5411 (2.5)
Car competition[b], car	-.3785 (3.0)	-.3879 (3.1)
Walking and waiting time, public trans.	-.02360 (3.9)	-.02328 (3.8)
Dummy = 1 for intra-zonal trip, public trans.	-1.266 (2.0)	-1.074 (1.7)
Dummy = 1 for intra-zonal trip, slow mode	.5752 (1.4)	.6825 (1.6)
Distance ≤ 4 km, slow mode	-.3649 (5.6)	-.3748 (5.7
Distance > 4 km, slow mode	-.3411 (6.2)	-.3444 (6.2)
Sample size:	1231	1231
Log likelihood:		
zero coefficients	-1255.89	-1255.89
with constants only	-1110.94	-1110.94
final value	-682.25	-678.24
ρ2 w.r.t. zero	0.4568	0.4600
ρ2 w.r.t. constants	0.3859	0.3895

[a] All times are in minutes and all costs are in SEK (1986-87 price level).

[b] Car competition is defined as the number of cars divided by the number of adults with driving licence in a household.

Table 2.5 Simple logit models for mode choice with a quadratic cost term for different income strata.

Alternatives: 1 Car 2 Public transport 3 Slow mode Variable[a]	0<GPI≤95 (t-values)	95<GPI≤130 (t-values)	130<GPI (t-values)
Constant, 2	.3587 (0.6)	-.9109 (1.9)	-2.419 (3.7)
Constant, 3	1.047 (1,4)	.4224 (0.6)	1.021 (1.0)
In vehicle time 1, 2	-.2576E-2(0.3)	-.5302E-2(0.7)	-.04211 (3.7)
Total cost, 1	-.09403 (2.9)	-.07482 (3.6)	-.03847 (1.5)
Total cost squared, 1	.6352E-3 (1.4)	.8570E-3 (2.9)	.5186E-4 (0.1)
Dummy, car use at work, 1	3.20 (4.1)	2.059 (4.7)	1.813 (5.1)
Dummy, dest. in inner city, 1	.08185 (0.2)	-.7322 (2.3)	-.5782 (1.5)
Car competition, 1	-.1455 (0.6)	-.4211 (2.2)	-.7314 (2.8)
Walk and wait time, 2	-.04436 (3.5)	-.02245 (2.5)	-.9346E-2 (0.9)
Dummy, intra-zonal trip, 2	-1.399 (1.6)	-1.649 (1.4)	-
Dummy, intra-zonal trip, 3	.9021 (1.3)	.5868 (0.9)	.1589 (0.1)
Dist <4 km, 3	-.2807 (2.7)	-.3121 (3.1)	-.7054 (4.5)
Dist >4 km, 3	-.4606 (3.4)	-.3277 (4.0)	-.2926 (3.2)
Sample size:	372	481	378
Log likelihood:			
initial value	-363.68	-489.51	-402.71
constant only	-352.10	-428.98	-294.01
final value	-211.73	-276.39	-168.54
ρ^2 w.r.t. zero	.4178	.4354	.5815
ρ^2 w.r.t. cons.	.3987	.3557	.4268

[a] All times are in minutes and all costs are in SEK.

Table 2.6 Marginal utility of income for different income groups.

Income group	$\mu(c_j)$	$\overline{c}_j$	$\mu(\overline{c}_j)$	(t-value)
0 < GPI ≤ 95	.09043-.001270C_j	10.8	.07671	(1.80)
95 < GPI ≤ 130	.07482-.001714C_j	9.5	.05854	(2.26)
130 < GPI	.03847-.000104C_j	8.3	.03761	(1.13)

Table 2.7 Test on the difference of the marginal utility of income.

Income Group	$\mu(\overline{c}_j)$ - $\mu(\overline{c}_k)$	t-statistics
Low, Medium	.01817	0.62
Low, High	.03856	1.07

Table 2.8 shows the subjective values of time for different income groups. The expected subjective values of time for the low and medium income strata are very low if indeed they should be reasonably proportional to the wage rate. As discussed earlier the differences between the average disposable income across income strata are larger than the wage rate differences because of the larger number of the part time workers in the lower income strata. The t-statistics for the subjective values of time, *svt*, are low.

Table 2.8 Estimated subjective value of time.

Income group	*svt*, SEK/h	t-statistics
$0 < I \leq 95$	2.0	.072
$95 < I \leq 130$	5.4	.061
$130 < I$	67.2	.035

2.6 An Alternative Approach

Train and McFadden (1978) provide a rigorous theoretical treatment of how income and price should be included in the specification of the utility functions for a discrete choice model. They propose a model for the journey to work in which an individual chooses between the consumption of goods and the available time for leisure, subject to both income and time availability. By assuming different functional forms for the direct utility function (a Cobb-Douglas utility function $AX^{1-\varphi} L^{\varphi}$, where X is goods and L is leisure for different values of φ) they investigate the requirements for the way in which price and income should be incorporated in the indirect utility function. They suggest the inclusion of a variable that represents the modal cost (price) divided by the individual wage rate in the specification of the utility in disaggregate demand modelling. Formally the problem is stated as follows

$$\begin{aligned}
&\text{Maximise} && U(X, L) = AX^{1-\varphi} L^{\varphi} \\
&\text{subject to} && X + Bc_i = wW + E \\
& && W + Bt_i + L = T \qquad (25)
\end{aligned}$$

where w is the wage rate, W is the working time in period T, c_i and t_i are the cost and time of travel by the mode i per trip, E is the unearned income, B is the number of trips in period T.

Using W as a decision variable that depends on c_i and t_i, problem (25) results in the following conditional indirect utility function

$$V(c_i, t_i) = A(1 - \beta)^{1-\varphi} \beta^{\varphi} [w^{-\varphi}(E - Bc_i) + w^{1-\varphi} (T - Bt_i)] \qquad (26)$$

Hence $V(c_i,, t_i)$ can be written as

$$\begin{aligned} &V(c_i, t_i) = - K_1(w^{-\varphi}c_i - w^{1-\varphi}t_i) + K_0 && \text{for } 0 < \varphi < 1, \\ &V(c_i, t_i) = - K_1(c_i /w - T_i) + K_0 && \text{for } \varphi \to 1, \\ &V(c_i, t_i) = - K_1(c_i - w\, T_i) + K_0 && \text{for } \varphi \to 0. \qquad (27) \end{aligned}$$

where K_1 and K_2 are constants, i.e., $V(c_i, t_i)$ is not influenced by them.

More recently Jara-Diaz and Videla (1987) re-examine the approach by Train and McFadden with a fixed income, and propose to replace the wage rate by the expenditure rate. They define the expenditure rate as the amount an individual earns per unit of available time, i.e., $I/(T-W)$. Furthermore they suggest that the usual linear specification of representative utility that results from the Train and McFadden approach is inadequate.

By assuming fixed working hours, the constraints of the problem (25) can be used to replace X and L in the objective function, $U(X, L)$, and to obtain the conditional indirect utility function, since W is not any more a decision variable. Hence the conditional indirect utility function can be written as

$$V(X, L) = A\, (I - Bc_i)^{\,1-\varphi}\, (T - W - Bt_i)^{\varphi} \qquad (28)$$

Note that E has been omitted and $I = wW$. A second order Taylor expansion of $V(X, L)$ around $(I, T\text{-}W)$ gives the following result

$$\begin{aligned} V &\approx V(I, T-W) - \frac{\partial V}{\partial X} Bc_i - \frac{\partial V}{\partial L} Bt_i + \frac{\partial^2 V}{\partial X \partial L} B^2 c_i t_i \\ &+ \frac{1}{2}\frac{\partial^2 V}{\partial X^2} B^2 c_i^{\,2} + \frac{1}{2}\frac{\partial^2 V}{\partial L^2} B^2 t_i^{\,2} \end{aligned} \qquad (29)$$

Using Cobb-Douglas form

$$\begin{aligned} V \approx\; & A\{I^{1-\phi}(T-W)^{\varphi} - (1-\varphi)(\frac{T-W}{I})^{\phi} Bc_i - \varphi(\frac{I}{T-W})^{1-\varphi} Bt_i \\ & +\varphi(1-\varphi)\frac{(T-W)^{\varphi-1}}{I^{\varphi}} B^2 c_i t_i - \varphi(1-\varphi)(\frac{T-W}{I})^{\varphi} \frac{1}{2I} B^2 c_i^{\,2} \\ & -\varphi(1-\varphi)(\frac{I}{T-W})^{1-\varphi} \frac{1}{2(T-W)} B^2 t_i^{\,2}\} \end{aligned} \qquad (30)$$

Assume $g = I/(T\text{-}W)$. Then (30) can be rewritten as follows

$$V_i = -(\frac{c_i}{g}) - \frac{\varphi}{1-\varphi} t_i + \varphi \frac{Bc_i}{I} t_i - \frac{\varphi}{2} \frac{Bc_i}{I} \frac{c_i}{g} - \frac{\varphi}{2} \frac{Bt_i}{(T-W)} t_i$$

or

$$V_i = -c_i - \frac{\varphi}{1-\varphi} t_i g + \varphi \frac{Bc_i}{I} t_i g - \frac{\varphi}{2} \frac{Bc_i}{I} c_i - \frac{\varphi}{2} \frac{Bt_i}{(T-W)} t_i g \qquad (31)$$

Jara-Diaz and Videla suggest a simpler version of V_i , by excluding the last two terms in relation (31) as

$$V_i = -c_i - \frac{\beta}{1-\beta} t_i g + \beta \frac{Bc_i}{I} t_i g \qquad (32)$$

It is possible to derive relation (32) by an alternative approach (see Jara-Diaz and Farah, 1987). Note that the first order Taylor expansion of $U(X, L)$ around $(I, T\text{-}W)$ produce a specification for V_i that is similar to (27), however the wage rate is replaced by $g=I/(T\text{-}W)$ (Jara-Diaz and Farah, 1987). The above formulations by Train and McFadden and by Jara-Diaz and Farah are results from a more general approach formulated by Small (1992).

Since in the Stockholm data, W, the working hours in period T, is not available, it will be assumed that $I/(T\text{-}W)$ is proportional to income, I. This assumption might not be as restrictive for Sweden. It is possible to assume that most full time workers have fixed working hours. Furthermore, most part time workers work part time since they have to take part in additional productive activities outside the market (with no wage). By assuming that the additional non-paid productive activities that the part time workers engage in is equal to the difference between their working hours and the full time workers', $I/(T\text{-}W)$ will be proportional to income, I. In that case (31) and (32) can be written as

$$V_j = A_j + \alpha c_j + \beta I t_j + \Phi t_j c_j - \sigma c_j^2/I - \gamma t_j^2 I \qquad (33)$$

$$V_j = A_j + \alpha c_j + \beta t_j I + \Phi t_j c_j \qquad (34)$$

It was not possible to estimate the full model, presented by relation (33), because of the collinearity of the variables. In table 2.9, model A is the result based on the simpler version that is specified by relation (34). Note that all coefficients have significant t-statistics and all signs are correct. In this study we assume that the walk and the wait times in connection with public transportation mode will be weighted by a factor of two compared to the in-vehicle time. A further step is to assume that coefficients for t_iI and t_jc_j are equal. This results in model B that is also displayed in table 2.9.

Based on the model specification presented in (34) the marginal utility of income, μ, and the subjective value of time can be estimated. Table 2.10

shows these results. The expected values of marginal utility of income for different income strata are in fact very close to that which follows from the linear in cost and time model (0.03351) and do not vary between income groups, i.e., there is in fact no income effect at the level of mode choice. The expected subjective values of time from this model specification are within a reasonable range, however, they are different from the expected subjective value of time from the simple mode choice model that is linear in cost and time (19.7 SEK/ hr). The main advantage of formulation of V_j by (34) has been that it captures the effect of income on the subjective value of time that influences the evaluation of a transportation project which will be illustrated later.

Table 2.9 An alternative mode choice model.

Alternatives: 1 Car 2 Public transport 3 Slow mode Variable [a]	Parameter (t-value) Model A	Parameter (t-value) Model B
Constant 2	-1.173(3.8)	-.6155(2.1)
Constant 3	-.2059(0.6)	-.5260(1.9)
Total cost, 1,2	-.04454(2.9)	-.06356(4.9)
Time*Income, 1	-.5213E-3(7.4)	-
Time*Income, 1, 2, 3	-	-.2462E-3(11.8)
Time*Cost, 1	.2940E-3(1.8)	-
Time*Cost, 1, 2	-	.3488E-3(2.4)
Dummy = 1 if car used during work, 1	2.238(9.0)	1.908(8.1)
Dummy =1 if destin. in inner city, 1	-.01324(0.1)	-.5708(2.9)
Car competition, 1	-.4050(3.2)	-.4237(3.3)
Time*Income, 2	-.3056E-3(7.3)	-
Time*Cost, 2	.7332E-3(2.5)	-
Dummy = 1 for intra-zonal trip, 2	-.7242(1.2)	-1.391(2.3)
Dummy = 1 for intra-zonal trip, 3	1.510(3.9)	1.533(4.3)
Time*Income, 3	-.3679E-3(11.2)	-
Sample size:	1231	1231
Log likelihood:		
zero coefficients		-1255.89
with constants only	-1110.94	-1110.94
final value	-687.26	-717.34
ρ2 w.r.t. zero	0.4528	0.4288
ρ2 w.r.t. constants	0.3814	0.3543

[a] All times are in minutes and all costs are in SEK.

Table 2.10 Marginal utilities of income and subjective values of time.

Income group	$\bar{I}_j$ [a]	$\bar{c}_j$ [b]	$\bar{\mu}_j$ [c]	svt [d]
0 < GPI ≤ 95	50.8	8.33	.03386	17.0
95 < GPI ≤ 130	75.4	8.24	.03253	29.1
130 < GPI	115.7	7.67	.03484	44.4

[a] Average disposable personal income of a stratum in 1000 SEK/year.

[b] Average cost is based on average cost of all modes for a stratum and the corresponding mode share.

[c] Expected marginal utility if income.

[d] Expected subjective value of time in SEK/hour.

In summary, there is no reason to believe that an income effect is present at the level of mode choice. However, the mode choice model presented by (34) results in a subjective value of time that increases with income. That implies that the marginal utility of time increases with income since the marginal utility of income does not change with income. Consequently, the two models, the linear in cost and time mode choice model and the model presented by (34), are expected to produce different results when applied for the evaluation of a transport policy.

2.7 Users' Benefits from a Toll Ring in Stockholm

In the absence of an income effect, different measures of user's benefits coincide and relation (8) can be used to calculate the users' benefits. Two alternative models will be used for the evaluation of a toll scheme in Stockholm. The first one is a linear in cost and time mode choice model, described in table 2.4 as model A. Model A results in a constant value of time that does not change with income. The other one, model B, is a mode choice model that captures the variation of subjective value of time with income, as described in table 2.10. However, both models produce similar constant marginal utility of incomes, i.e., no income effect.

The initial intention was to equilibrate the disaggregate demand model and a parallel supply model through the use of the *EMME/2* system. This approach was used in an earlier study for the evaluation of a toll scheme for Stockholm (Ramjerdi, 1988). This evaluation was based on travel demand for peak periods. Based on the results from this study and other similar evaluations (Regionplan 90, 1989), costs and network data of the different modes are simulated for a situation where a toll scheme is implemented. The following summarises the assumptions made.

- Car cost to inner city will be affected by a toll price of SEK 20 per passenger equivalent to SEK 25 per car.
- Car in vehicle time to inner city will be reduced to 82% of previous level.
- Car in vehicle time to other destinations will be reduced to 90 % of previous level.
- In vehicle public transport time to inner city will be reduced to 90 % of previous level.
- In vehicle public transport time to other relations will be reduced to 95% of previous level.

In the calculation of the users' benefits we assume the marginal utility of income to be 0.03351. Table 2.11 shows the comparison of users' benefits for different socio-economic groups from a toll scheme in Stockholm for the mode choice models A and B.

Implied assumptions in the calculation of users' benefits are:

- travel to work is during peak periods.
- both models lead to similar reduction of traffic as the result of the implementation of a cordon toll policy.

The two models produce different overall evaluation of a toll scheme. The total benefit (loss) that follows from the mode choice model A (for the total sample of 1279 commuters) is -498.3 SEK/day. The use of model B shows a benefit of 372.6 SEK/day. It is assume that one commutes 5 days a week, 45 weeks a year and that one makes one round trip per day for commuting.

Table 2.11 shows that the two models give different results for different socio-economic groups. Model A shows larger benefit (smaller loss) for low income groups and for female workers, while model B shows a larger benefit (smaller loss) for high income groups and for male workers. The loss for those commuting to the inner city is less with model B than model A because of the higher subjective value of time for this group when model A is used for the calculation of users' benefits.

This calculation is subject to some qualifications. Among these is the assumption that the alternative demand models and the parallel supply model that simulate a toll scheme produce similar equilibria. However, despite this, it was possible to highlight the differences in the overall benefits as well as the distributional impacts with the alternative demand models.

Table 2.11 Users' benefits from a toll scheme in Stockholm.

Group	Cases	Benefit in SEK per commuter per round trip	Benefit in SEK for total per day	Benefit in SEK per commuter per year
Mode choice model A:				
Low Income	420	.100	41.9	22.4
Medium Income	481	-.162	-77.8	-36.4
High Income	378	-1.223	-462.4	-275.2
Female	583	-.120	-69.8	-26.9
Male	696	-.616	-428.5	-138.5
To Inner city	356	-3.733	-1329.1	-840.0
Others	923	.900	830.8	202.5
Mode choice model B:				
Low Income	420	-.016	-6.6	-3.5
Medium Income	481	.106	51.1	23.9
High Income	378	.868	328.1	195.3
Female	583	-.042	-24.5	-9.5
Male	696	.571	397.1	128.4
To Inner city	356	-2.969	-1057.0	-668.0
Others	923	1.549	1429.6	348.5

2.8 Summary and Conclusions

This study examines alternative mode choice model specifications and their implications for users' benefits from a transportation policy, namely a toll scheme for Stockholm. For this purpose a mode choice model for travel purpose work that is linear with respect to cost and time was estimated.

For the detection of income effects at the mode choice level a methodology developed by Jara-Diaz and Videla (1989) was applied to the data. The results so derived did not allow one to conclude that there is an income effect at the mode choice level for travel to work in Stockholm. An alternative model specification was developed. This model specification gave a marginal utility of income that did not change with income, i.e. there was no income effect present at the mode choice level. Hence, the different measures of users' benefits coincide. However, the alternative model specification resulted in a subjective value of time that increased with income.

The alternative model specification was used for the evaluation of a toll scheme for Stockholm, and the results were compared with those produced by a model that was linear in cost and time. These models give very different results for the different socio-economic groups affected by a toll scheme.

This study shows the importance of the model specification for both the evaluation of demand and the evaluation of the users' benefits from a transportation policy. A mode choice model that captures the effect of income on the subjective value of time, produces users' benefits that can be very different from those produced by a simple mode choice model (linear in cost and time) especially for different socio-economic groups.

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Essay no. three

Road Pricing in Urban Areas: Financing Investment in Transport Infrastructure and Improving Resource Allocation: The Case of Oslo

3.1 Introduction

Road pricing has been discussed in the context of two objectives: improving resource allocation and financing the expansion of the capacity of the road network[1]. An economically efficient transport policy, aimed at the alleviation of congestion and the environmental impacts of road traffic, should combine a socially "optimal" programme of expansion of the capacity of the road network with a socially "optimal" road pricing scheme.

Financing transport infrastructure by means of toll revenues in the traditional sense has a history that dates back almost 60 years in Norway. Since 1986, when toll rings were implemented in the three largest cities in Norway, Bergen, Oslo and Trondheim, there has been a dramatic shift in the location of toll financed projects from the countryside to urban areas. Meanwhile, the contribution from toll financing schemes (toll income plus loans) to the total funds for transport infrastructure has increased from 4-5 percent to 24 percent in 1993.

The growing interest in alternative financing schemes has been a response to the limited available public funds to cope with increasing problems in financing road investments at the different levels of government in Norway as in many other countries[2]. The grants from the central government that supplement toll revenues have been an additional incentive to local politicians in the larger urban areas to initiate toll financing of road projects.

In introducing the cordon toll schemes in the three largest cities in Norway the primary objective has been to raise funds for investments in road infrastructure. There is no direct connection between the location of the toll rings and the road projects that are financed by the toll revenues. Consequently, these toll schemes do not reduce the use of the road projects being financed in this way relative to the rest of the road network. This is an obvious advantage of these schemes over conventional toll financing, where the toll is linked directly to the use of a road project, especially in urban areas.

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[1] Essay number one presents a discussion of the alternative use of revenues from road pricing. The use of revenues from road pricing can be justified for improvements in alternative modes such as public transport and slow mode facilities.

[2] One example is Tromsø in the far north of Norway, the only city in Norway that has introduced a local gasoline tax. Additional grants from the central government supplement the revenue from the local gasoline tax for investment in road infrastructure.

This paper is structured as follows. First a theoretical framework for the evaluation of road projects financed through road pricing is presented. This theoretical framework allows for the incorporation of the marginal cost of public funds in the evaluation of a road project.

Focusing on Oslo as a case study, alternative schemes are then evaluated using a multi-modal, equilibrium model of demand and supply within the discrete choice framework. These schemes include the present cordon toll, an alternative cordon toll that approximates a "socially optimal" toll scheme and a "socially optimal" road pricing scheme where vehicles pay a fee on every link of their route. The fee on each link is set so that it covers the difference between the social marginal cost and the private marginal cost of travel on the link[3]. Other alternatives that are evaluated are a road investment package: i.e. without any toll, with the present toll scheme and with a "socially optimal" cordon toll scheme.

Marginal costs of public funds for alternative toll schemes, as a form of taxation, are estimated. These measures are compared with the marginal cost of public funds through general taxation in Norway.

3.2 Road Pricing and Distortionary Taxes

The main objectives of road pricing have been to improve resource allocation and to finance the expansion of the capacity of the road network. In the context of improving resource allocation, road pricing reduces congestion to an optimal level by charging the users the difference between the private marginal costs and the social marginal costs of the road use. The economic theory suggests that congestion pricing generates sufficient revenues to expand the capacity optimally to meet future demand (in the long-run) when constant returns to scale in the provision of the capacity hold. In addition, congestion pricing reduces the size of the necessary road infrastructure. When there are economies of scale, toll revenues will not be sufficient to recover the capital cost of the road infrastructure[4]. This implies that the facility should be financed partially through public funds and by accounting for the marginal cost of public funds.

In the context of financing the expansion of the capacity of the road network, road pricing is a form of taxation levied on the users and the tax revenue is directly linked to road improvements. Based on the criterion of economic efficiency, the primary purpose of road pricing, as a form of

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[3] This scheme is only a theoretical simulation and is not possible to introduce with the available technologies.

[4] See essay number 1 for a more general discussion on this subject.

taxation, is to raise revenues without changing behaviour[5]. However, the economic theory suggests that a fee on an uncongested road would be non-optimal since it reduces the use of the road without any benefits to other road users (i.e., when congestion alone is the source of externalities). In addition there is a cost related to the toll collection.

If a road facility is to be financed through toll revenues, a toll should be introduced only after the facility starts to become congested. In this case, i.e., when there is no congestion, roads should be financed from the general revenue taxation and again by taking the marginal cost of public funds into consideration.

3.2.1 Distortionary Taxes and the Marginal Cost of Public Funds

Based on economic efficiency, a tax system which produces deadweight losses is called a distortionary tax system. Lump-sum taxes were the classical solution to the problem[6]. However, as Sandmo (1976) suggests, lump-sum taxation is a bad suggestion from a descriptive and normative point of view.

A distortionary tax means that an additional public revenue, raised by increasing the present tax rate, will inflict a social cost on the economy in terms of reduced efficiency. The costs to consumers, including extra costs in terms of reduced efficiency, per unit of revenue is called the shadow price of public funds or the marginal cost of public funds *MCF*. When a tax system has no distortions *MCF* would be exactly 1.0. Traditionally, economists have assumed *MCF* to be greater than one. However, as Ballard and Fullerton (1992) point out, the marginal cost of public funds differs among tax instruments and for different public expenditures and it can take a value less than one. Furthermore, welfare can be increased by a reform that raises one tax and lowers another. The marginal cost of public funds can be used to analyse the composition of a tax system as well as the overall level of taxation.

In general, public funds can be raised either through increased taxation of incomes or through increased taxation on goods and services. The calculations of the marginal cost of public funds have been based on partial-equilibrium analysis or general-equilibrium analysis. The latter is used for the calculation of the overall distortionary effect of a tax instrument, among other taxes, which could produce compounding or offsetting effects.

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[5] However, there will be changes in behaviour through income effects.

[6] For a review of the literature on this subject see Sandmo (1976), Ballard and Fullerton (1992) and Vennemo (1992).

Dodgson and Topham (1987) show that the partial-equilibrium marginal cost of public funds through increased taxation of incomes is equal to

$$MCF = \frac{1}{1 - \frac{\varepsilon_s t}{w}} \qquad (1)$$

where ε_s is the post-tax wage elasticity of supply of labour and t/w is tax as a proportion of post-tax wage. The underlying assumption in relation (1) is that the income tax is levied at a constant rate on all incomes. The calculation of the marginal cost of public funds through increased taxation of income becomes complicated by the different marginal tax rates and exemptions from income tax. Different studies point to a partial-equilibrium estimate of the marginal cost of public funds through increased taxation of income of about 1.20 for the United States and England (Topham, 1984).

The general-equilibrium estimates of *MCF* have generally been much higher than the partial-equilibrium estimates, as high as 1.56 (Ballard et al., 1985). An estimate of *MCF* for Norway is about 1.80-1.90 (Vennemo, 1992).

A tax (except for a lump-sum tax) levied on the output of a good produces a deadweight loss. Hence a tax t_1, per unit of good X will produce a deadweight loss which is measured by the shaded triangular area *abc* in figure 3.1. The additional total cost to the consumers, including the additional deadweight loss, to raise the tax revenue by one unit is the marginal cost of public funds. A tax increase of Δt from t_1 to t_2, changes the price of good X from p_1 to p_2 and the demand by Δx, from x_1 to x_2. If the change in tax is such that $\Delta x = 1$, then $\Delta t = \left|\partial p / \partial x\right|$. The additional tax revenue, $|mtr|$, is equal to area p_1p_2de - *bfec*, or $\left|\partial p / \partial x\right| x - t$. The additional tax revenue is equal to area *jikn* in the middle section of figure 3.1. The additional deadweight loss is equal to area *bfdc* and is equal to $t\Delta x = t$. Note that area *bfdc* is equal to area *ilmk*. Hence the partial-equilibrium marginal cost of public funds through increased taxation of goods and services is equal to

$$MCF = \frac{|mtr| + t}{|mtr|} = \frac{\left|\frac{\partial p}{\partial x}\right| x - t + t}{\left|\frac{\partial p}{\partial x}\right| x - t} = \frac{1}{1 + \frac{\varepsilon t}{p}} \qquad (2)$$

or

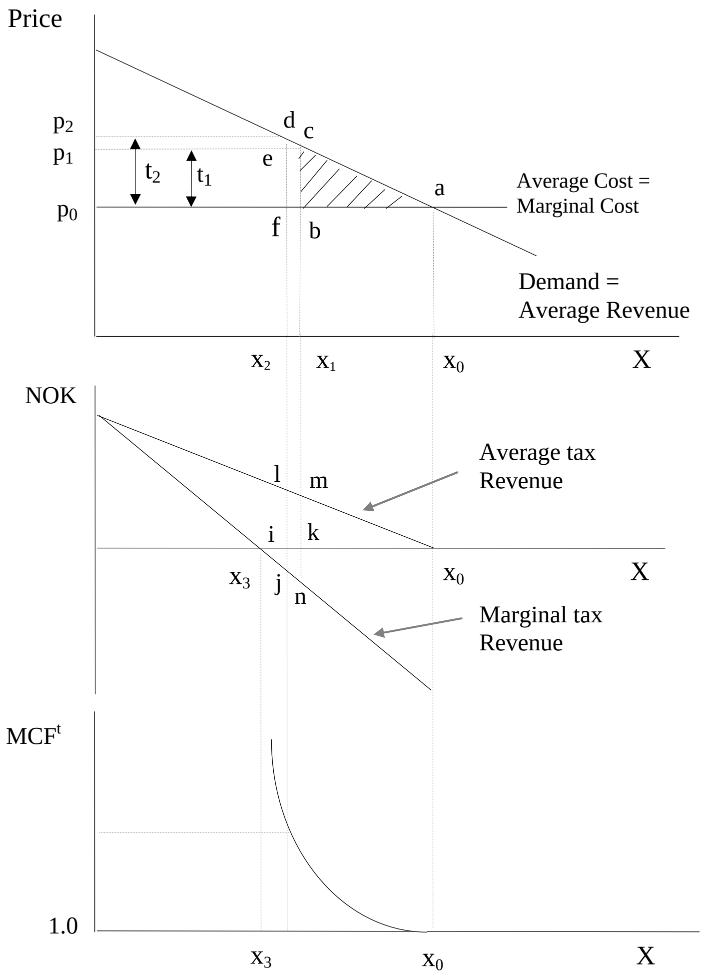

Figure 3.1 The cost of public funds through taxation of goods and services (Adapted from Dodgson and Topham, 1987).

$$\frac{t}{p} = \frac{MCF - 1}{MCF} \cdot \frac{1}{-\varepsilon} \tag{2a}$$

where ε is the own-price elasticity of demand for the taxed good, *t* is the tax per unit of output, *p* is the unit price (including tax) and *t/p* is the initial tax rate. The middle section of figure 3.1 demonstrates the relationship between |mtr|+t and |mtr| and the bottom section shows how the marginal cost of public funds varies between 1 and ∝. Relation (2) shows that *MCF* exceeds one and it increases with an increase in the initial tax rate and with an increase in price elasticity[7]. This formula assumes that the tax proceeds (such as through provision of public goods) do not alter the demand for the taxed good (Dodgson and Topham, 1987).

Ballard and Fullerton (1992) provide examples of the interactions between the public expenditure and the taxed goods and suggest how this interaction could raise or lower the marginal cost of public funds. An example that they provide is when the provision of roads is a complement to the private purchase of gasoline and the taxed good is gasoline. In this case the provision of roads will increase revenues from gasoline tax, and hence reduce the marginal cost of public funds for any tax used to finance roads.

Taxation to counteract negative external effects, i.e., Pigovian taxes, by correcting for inefficiencies in the competitive allocation of resources, can have a social cost of public funds that is less than one, i.e., much lower than the social cost of public funds through general revenue taxation (Sandmo, 1976).

3.3 Benefit-Cost Analysis and the Marginal Cost of Public Funds

Consider that the short-run private marginal cost (average cost) for the use of a road is given by $c(V;V_K)$, where V is the traffic flow and V_K is the capacity. Consider $p=D(V)$ as the inverse demand function where p stands for the generalised cost of travel including a toll fee π. Note that in the following V is the decision variable and π will be endogenously determined. We will first derive the partial-equilibrium marginal cost of public funds through tolls on a congested road.

A toll π_1 will produce a deadweight loss which is measured by the shaded area *abc* in figure 3.2. The additional total cost to the travellers to raise the toll revenue by one unit is the marginal cost of public funds through toll, MCF^t. A toll increase $\Delta\pi$ from π_1 to π_2 increases the generalised cost of travel from p_1 to p_2, decreases the private marginal cost of travel from c_1 to c_2 and the demand from V_1 to V_2. If the change in toll is such that $\Delta V = 1$, then $\Delta p = |\partial p/\partial V|$ and $\Delta c = \partial c/\partial V$. The additional toll revenue $|mtr|$ is equal to the area $p_1p_2de + c_1c_2fh - ecbh$ or equal to $-V\cdot\partial p/\partial V + V\cdot\partial c/\partial V - \pi$. The additional deadweight loss is equal to area *fbcd* that is equal to $\pi\Delta V = \pi$. Meanwhile there will be a decrease in the users' costs that is equal to area fbc_1c_2 that is equal to $V\cdot\partial c/\partial V$. Hence the partial-equilibrium marginal cost of public funds through increased toll is equal to

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[7] The uncompensated demand curve can be used for the derivation of *MCF* (see Dodgson and Topham, 1987).

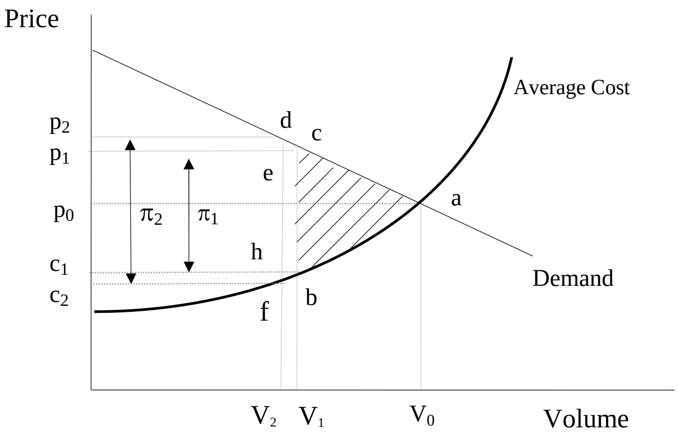

Figure 3.2 The cost of public funds through tolls.

$$MCF^t = \frac{|mtr| + \pi - V\dfrac{\partial c}{\partial V}}{|mtr|} = \frac{-V\dfrac{\partial p}{\partial V} + V\dfrac{\partial c}{\partial V} - \pi + \pi - V\dfrac{\partial c}{\partial V}}{-V\dfrac{\partial p}{\partial V} + V\dfrac{\partial c}{\partial V} - \pi} = \frac{-V\dfrac{\partial p}{\partial V}}{-\pi - V\dfrac{\partial \pi}{\partial V}} \qquad (3)$$

Assume that the provision of the road costs $K(V_K)$. The benefits from the road project is given by

$$B = \int_0^V D(V')dV' \qquad (4)$$

The total cost of the project is

$$C = Vc(V;V_K) + K(V_K) \qquad (5)$$

By assuming a constant capacity in the short-run (5) can be rewritten as

$$C = Vc(V) + K \qquad (5a)$$

Problem 1

Suppose that a highway authority is facing a budget constraint that its deficit (capacity cost less than toll revenues) should be less than a specified amount Φ. Then this problem can be formulated as a Ramsey pricing problem as:

$$\max_{V} \quad \Psi = B - C = \int_0^V D(V')dV' - Vc(V) - K$$

subject to

$$K - \pi V \leq \Phi \tag{6}$$

The Lagrangian function for the above problem is

$$\int_0^V D(V')dV' - Vc(V) - K + \lambda\left[\Phi - K + \pi V\right] \tag{7}$$

where λ is the Lagrangian multiplier with respect to the budget constraint. Taking the partial derivative with respect to *V*, we obtain the first-order condition as follow

$$p - (c + V\frac{\partial c}{\partial V}) + \lambda(\pi + V\frac{\partial \pi}{\partial V}) = 0 \tag{7a}$$

Relation (7a) can be rewritten as

$$p - c - V\frac{\partial c}{\partial V} = \lambda(-\pi - V\frac{\partial \pi}{\partial V}) \cdot \frac{p}{p} \cdot (-V\frac{\partial p}{\partial V}) \Big/ (-V\frac{\partial p}{\partial V}) \tag{7b}$$

By comparing $(-V\frac{\partial p}{\partial V}) \Big/ (-\pi - V\frac{\partial \pi}{\partial V})$ with (3) we can rewrite (7b) as

$$\pi - V\frac{\partial c}{\partial V} = \frac{\lambda}{MCF^t} \cdot \frac{p}{-\varepsilon} \tag{8}$$

where MCF^t is the marginal cost of public funds through tolls and ε is the price elasticity of demand. Assume there is no constraint on the budget, i.e., λ = 0. Then the optimal toll is

$$\pi^o = V\frac{\partial c}{\partial V} \tag{9}$$

Hence with no constraint on the budget, the optimal toll, π^o, is the difference between the social marginal and private marginal cost. By replacing for $V \cdot \partial c / \partial V$ in relation (8) from (9) we get

$$\pi - \pi^o = \frac{\lambda}{MCF^t} \cdot \frac{p}{-\varepsilon} \tag{10}$$

Relation (10) implies that with a constraint on the budget the feasible toll can deviate from the optimal toll, π^o, by a positive amount that increases with an increase in λ, i.e., with the constraint on the deficit. Furthermore, the deviation from π^o decreases with an increase in MCF^t and an increase in (the absolute value of) the price elasticity of demand.

Note that when there is no congestion $\pi^o = 0$. Hence the feasible toll is given by the right side of relation (10) and can be rewritten as

$$\pi = \frac{\lambda}{MCF^t} \cdot \frac{p}{-\varepsilon} \tag{11}$$

In this case, with no constraint on the highway budget then $\pi = 0$.

Problem 2

Suppose that the highway authority, by covering part of the cost of the project through toll revenues, takes the marginal cost of public funds through general taxation, MCF^p, into consideration. Then the total cost of the project can be written as

$$\Omega = [K - \pi V] \cdot MCF^p + \pi V \tag{12}$$

Hence the total cost is

$$C = V \cdot c(V) + [K - \pi V] \cdot MCF^p + \pi V \tag{13}$$

Then the problem of the maximisation of the total benefits, given by relation (4) minus the total cost, given by relation (13), is the following

$$\max_V \ \Psi = \int_0^V D(V')dV' - Vc(V) - \left[K - \pi V\right] MCF^p - \pi V$$

or

$$\max_V \ \Psi = \int_0^V D(V')dV' - Vc(V) + \pi V(MCF^p - 1) - K \cdot MCF^p \tag{14}$$

The first-order condition of the maximisation problem stated by relation (14) is:

$$p-(c+V\frac{\partial c}{\partial V})+(MCF^{p}-1)\cdot(\pi+V\frac{\partial \pi}{\partial V})=0 \tag{15}$$

Relation (15) can be rewritten as

$$\pi-V\frac{\partial c}{\partial V}=(MCF^{p}-1)\cdot(-\pi-V\frac{\partial \pi}{\partial V})\cdot\frac{p}{p}\cdot(-V\frac{\partial p}{\partial V})\Big/(-V\frac{\partial p}{\partial V}) \tag{15a}$$

By comparing $(-V\frac{\partial p}{\partial V})\Big/(-\pi-V\frac{\partial \pi}{\partial V})$ with (3) we can rewrite (15a) as

$$\pi-V\frac{\partial c}{\partial V}=\frac{MCF^{p}-1}{MCF^{t}}\cdot\frac{p}{-\varepsilon} \tag{16}$$

where MCF^{t} is the marginal cost of public funds through tolls and ε is the price elasticity of demand. When the marginal cost of public funds through general taxation is equal to one, then the optimal toll is

$$\pi^{o}=V\frac{\partial c}{\partial V} \tag{17}$$

Hence the optimal toll, π^{o}, is the difference between the social marginal and the private marginal cost. By replacing for $V\cdot\partial c/\partial V$ from (17) in relation (16) we get

$$\pi-\pi^{o}=\frac{MCF^{p}-1}{MCF^{t}}\cdot\frac{p}{-\varepsilon} \tag{18}$$

Relation (18) implies that the feasible toll in this case can deviate from the optimal toll, π^{o}, by a positive amount that increases with an increase in MCF^{p}. Furthermore, the deviation decreases with an increase in MCF^{t} and an increase in (the absolute value of) the price elasticity of demand.

Note that when there is no congestion $\pi^{o}=0$. Hence the feasible toll is given by the right side of relation (18) as

$$\pi = \frac{MCF^p - 1}{MCF^t} \cdot \frac{p}{-\varepsilon} \qquad (19)$$

In this case when MCF^p is equal to one then $\pi = 0$.

Relation (18) can be compared with relation (10). This comparison shows that the solution to this problem is identical with the solution to problem 1 when the constraint on deficit is set such that the Lagrangian multiplier on the constraint on deficit, λ, to be equal to $MCF^p - 1$.

3.4 The Marginal Cost of Public Funds through Road Tolls

The marginal cost of public funds through a toll scheme, i.e., when travel is taxed through a toll, can be approximated as

$$MCF^t = (\Delta CS)/(\Delta TR - \Delta C^t) \qquad (20)$$

where ΔCS is the change in the total cost for the users, ΔTR,. is the change in the toll revenues and ΔC^t is the change in the cost of toll collection, when the toll fee changes by a small amount $\Delta\pi$. The toll revenues net of the cost of toll collection will be used in this calculation, since the purpose is to compare MCF^t with MCF^p. It is possible to ignore the additional costs of administration associated with public funds[8].

At a network level, the changes in the total costs to users induced by introduction of a toll scheme will be approximated by the rule-of-half as follows (Williams, 1977):

$$\Delta CS = \sum_{ij} (c_{ij}^t + \Delta\pi - c_{ij}^o) \cdot (V_{ij}^0 + V_{ij}^t)/2$$

$$= \Delta\pi \sum_{ij} V_{ij}^t + \Delta\pi \sum_{ij} (V_{ij}^0 - V_{ij}^t)/2 + \sum_{ij} (c_{ij}^t - c_{ij}^o) \cdot (V_{ij}^t + V_{ij}^o)/2 \qquad (21)$$

or

$$\Delta CS = \Delta TR + \Delta DWL - \Delta UB^t \qquad (22)$$

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[8] It should be pointed out that the resource costs required for assessing, collecting and paying the taxes is not incorporated in the general equilibrium analysis of marginal cost of public funds. The incorporation of these costs in the general equilibrium analysis of *MFC* is a difficult task (Sandmo, 1976).

where c_{ij}^{o} and c_{ij}^{t} are generalised costs of travel by car net of toll payment and V_{ij}^{o} and V_{ij}^{t} are the number of car trips between zone *i* and *j* before and after the change in the toll fee by $\Delta\pi$[9]. The first term in (21) is the change in the toll revenues collected from the tolled trips ΔTR, the second term is the change in the deadweight loss ΔDWL^{t}, i.e., from the trips that are tolled-off, and the third term is the increase in the users' benefits induced by the change in the generalised cost of travel ΔUB. Note that these three terms are comparable with the three terms in the nominator of relation (3). The toll revenue is not considered as a social cost since it is a transfer from the private consumers to the government. By replacing for ΔCS from (22) in (20), it follows

$$MCF^{t} = 1 + (\Delta C^{t} - \Delta UB + \Delta DWL^{t}) / (\Delta TR - \Delta C^{t}) \qquad (23)$$

In the absence of congestion, the changes in users' benefits, ΔUB, is equal to zero. Hence, the marginal cost of public funds through toll, MCF^{t}, should always be greater than one when there is no congestion. However, ΔUB up to certain level of the toll fee has a positive value (i.e., a benefit) when there is congestion. Hence, when $(\Delta C^{t} - \Delta UB + \Delta DWL^{t}) \leq 0$, MCF^{t} will be less than one. In other words, a toll as a Pigovian tax improves the competitive allocation of resources when there is congestion and for such a tax, the marginal cost of public funds can be less than one (Ballard and Fullerton, 1992).

This condition is probably satisfied in many urban areas with extensive congestion in their road networks and the present cost of toll collection. However, road pricing introduces a main concern about distributional effects. For discussions on this subject see Hau (1992; 1995), Small (1992b) and Essay no. one.

The comparison of MCF^{t} from (23) with the marginal cost of public funds, MCF^{p}, should provide a measure for evaluating whether a road project should be financed through toll revenues. MCF^{p} has been estimated to be between 1.4 to 1.8 for Norway (Vennemo, 1992).

The benefits from investments in road capacity will usually decrease with the introduction of road pricing. However, revenues from a proper road pricing scheme should provide some relevant information about the optimal investment in the road capacity in the long run. With a number of assumptions, the solution to the problem of optimal pricing and investment is

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[9] Equation 21 can generalised over all the modes of transport. It is assumed that the introduction of a toll does not change the generalised cost of travel with other modes. It is also assumed that other costs, e.g., related to environmental externalities, remain the same.

to invest in additional capacity to the point where the revenue per unit of capacity is equal to the cost of adding the additional unit of capacity (Keeler and Small, 1977). These assumptions, mainly related to economies of scales and indivisiblities, might not be as restrictive in an urban area[10].

3.5 Evaluations of Alternative Schemes for Oslo

The Oslo toll ring was opened in 1990 as a financing scheme. Figure 3.3 shows the location of the toll ring and toll stations in the Oslo region. The inbound traffic is tolled all day round, every day of the year. The toll fee in 1990 was NOK 10 (approximately US $ 1.6 in 1990 exchange rate) for light vehicles and twice as much for heavy vehicles. Seasonal passes for light vehicles were NOK 220 for one month, NOK 1200 for 6 months and NOK 2200 for one year. The number of tolled vehicles on an average day was 68,000 (252 days per year). For information on the design and the operation of the scheme, see Wærstad (1992), Ramjerdi (1994) and Gomez-Ibanez and Small (1994).

A/S Fjellinjen, the corporation responsible for the toll collection and the financial operation of the Oslo scheme, estimated the toll revenue for 1991 at NOK 600 million. The estimated cost of operation in 1991 was NOK 70 million. Investments, including the construction of toll stations and equipment; hardware and software for the electronic payment system, add up to NOK 255 million. With the start-up cost, estimated at NOK 5 million, the total capital cost of the Oslo cordon toll will amount to NOK 260 million. With a 7 percent real interest rate (the official rate for the calculation of present value of public projects in Norway), and depreciation period of 15 years the total annual cost of the Oslo toll ring is as follows

Annual capital cost:	NOK 27 million
Annual operating cost:	NOK 70 million
Total annual cost:	NOK 97 million

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[10] See Small (1992a) and Hau (1992) for an introduction to the issues related to this subject.

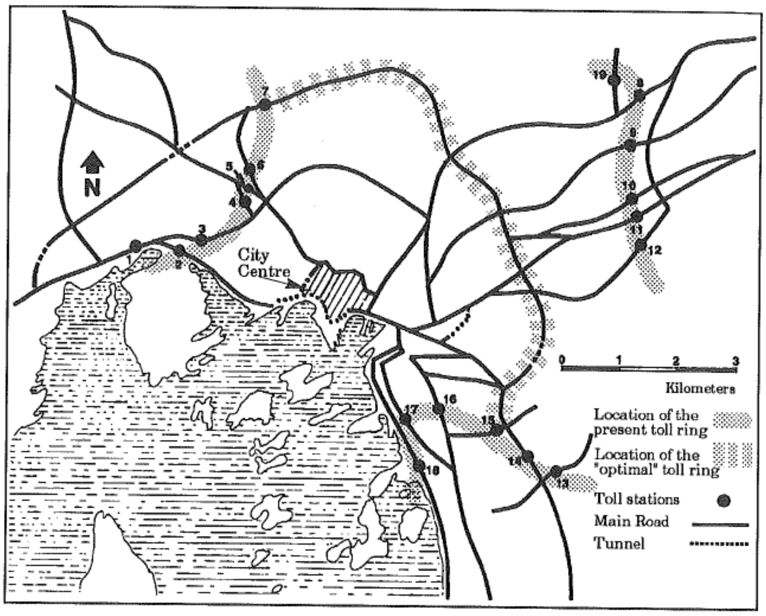

Figure 3.3 Location of the present and an "optimal" toll ring in Oslo.

3.5.1 Methodology and Assumptions

A partial equilibrium effect of a road pricing scheme is evaluated using a multi-modal model of demand and supply within a discrete choice framework. In an earlier study (Ramjerdi, 1988) such an approach was presented in detail. However, in this study a simultaneous mode choice and equilibrium assignment model is used. An implementation for the Oslo region of the traffic analysis system *EMME/2* has been used for this purpose.

Demand matrices for car and public transportation for different time periods were estimated based on observed travel pattern. Corresponding networks for these periods were constructed. The Oslo region is represented by a system of 461 zones. The road network consists of about 4650 links and 1615 regular nodes[11]. The public transport network consists of 162 transit lines and 6262 transit segments.

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[11] Centriods are not included among these nodes.

The road network in the region is represented by a network consisting of links on which the travel costs or times are increasing functions of link flows that describes technologies of congestion on the links. The travel cost on link l is given by $c_l(V_l)$ where V_l is the traffic volume on link l. The operating cost of car is assumed to be proportional to the travel distance. Travel times for public transport are also based on a network representation consisting of bus, street car, underground and commuter train. Route choice is assumed to be strictly cost minimising. In other words, each trip by car or public transport uses the minimum generalised cost route from an origin to a destination. The generalised cost for car includes travel time and toll cost (if the route includes a toll)[12]. The generalised cost for public transport is a weighted sum of walking time, waiting time, in-vehicle time and public transport fare.

In a "socially optimal" road pricing scheme, the social cost of travel on a link will be charged on each link[13]. The social cost of travel on a link, l, can be defined by the marginal link cost function as

$$c_l^M(V_l) = c_l(V_l) + V_l \frac{\partial c_l(V_l)}{\partial V_l} \tag{24}$$

For the calculation of a "socially optimal" road pricing scheme, conical congestion functions were estimated to approximate the piecewise linear congestion functions used for Oslo. The properties of a conical congestion function satisfy the necessary requirements of well behaved congestion and marginal cost functions (Spiess, 1990).

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

It is assumed that the total demand for travel will be met by the supply of public transport and roads. The impacts of a toll scheme or of a road investment package on departure time, trip chaining and destination choice as well as locational impacts are disregarded.

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[12] It is possible to include the variable car cost on the link in the generalised car cost. In this calculation we have assumed that the differences between the variable car costs on alternative routes from an origin to a destination are negligible.

[13] For a review of literature on the technology of congestion and the principles of congestion pricing see Small (1992a), Hau (1992) and Johansson and Mattsson, (1995).

It is also assumed that present taxes which are levied on fuel and vehicles in Norway approximate the road damage and the environmental costs of the road traffic. The evaluations will be limited to time and operating costs of vehicles.

Table 3.1 shows a summary of the unit costs used in this study. The value of travel time in each time period is based on the traffic composition during that time period.

Table 3.1 Unit costs per vehicle hour in NOK[a].

	No. of hours per year	Operating cost	Travel time cost	
			Business	Other
Peak Periods	460	3.25	166	38
Between Peaks	2000	3.25	156	31
Other Periods	4475	3.25	167	27

[a] NOK 10 = US $ 1.6 in 1990

The total annual costs of stops at toll stations, including the costs of additional fuel consumption (about NOK 0.4 million) and delays (about NOK 4.4 million) is estimated to be about NOK 4.8 million[14].

The evaluations of alternative schemes for Oslo will be presented in the following sections. These are partial evaluations relevant in the context of this study. The reference for these evaluations is the present transport network without a toll scheme.

3.5.2 Evaluation of the Present Oslo Toll Scheme

Table 3.2 shows a summary of the evaluation of the present toll scheme with the present transport network in Oslo. The change in users' benefits is largest during the peak periods, since the scheme reduces congestion (NOK 44.5 million per year) and it exceeds by far the change in the deadweight loss (NOK 6.3 million per year). The change in deadweight loss is by far larger than the changes in users' benefits during other periods. However, as table 3.2 shows, the net benefit of the present toll scheme is negative (i.e., a net cost of about NOK 80 million per year). Hence the scheme cannot be justified on the basis of improving the economic efficiency.

Relation (23) can be used to calculate the marginal cost for public funds of the present toll scheme. We assume that the present toll fee (NOK 10) to be relatively small[15]. Then it is possible to approximate (23) by

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[14] Based on the estimate of the annual trips that go through manual stations with an average delay of about 15 seconds for the toll payment, an average car occupancy of 1.3 and a value of time of NOK 30/hour.

$$MCF^t = 1 + (C^t - \Delta UB + \Delta DWL^t) / (TR - C^t) \qquad (25)$$

MCF^t, the marginal cost of public funds for the present toll scheme based on relation (25) is about 1.16. A correct estimate should be slightly higher. Anyway, it is less than the marginal cost of public funds, MCF^p, that in Norway is about 1.6. Note that the calculation of MCF^t was based on the present road network without the road investment package. Since $MCF^t < MCF^p$, the toll as a tax, can replace other taxes that are more distortionary.

Table 3.2 Summary of evaluation: the present Oslo toll scheme.

	Peak periods	Between peaks	Other periods	Total
Reduction in trips (millions/year):				
business	0	0	0	0
others	1.25	1.39	4.07	6.71
Users' benefits (NOK millions/year):				
time savings	42.1	5.0	5.3	52.4
operating cost savings	2.4	0.2	0.4	3.0
total	44.5	5.2	5.7	55.4
Deadweight loss (NOK millions/year)	6.3	7.0	20.4	33.6
Summary (NOK millions/year):				
Users' benefits, ΔUB				55.4
Deadweight loss, ΔDWL^t				33.6
Time savings net of deadweight loss				18.8
Total benefits, $\Delta UB - \Delta DWL^t$				21.8
Cost of stops at toll stations, ΔUC^t				4.8
Cost of toll collection, C^t				96.6
Net benefit, $\Delta UB - \Delta UC^t - \Delta DWL^t - C^t$				-79.6
Toll revenues, TR				600.0
Net toll revenues, $TR - C^t$				503.4
Marginal cost of public funds, MCF^t				1.16

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[15] This might not be a wrong assumption since the impact of the present toll scheme on travel behaviour seems to be relatively small.

It is possible to calculate an average marginal cost for the tolled-off trips from the time savings and the reduction in number of trips by car. The average marginal cost per trip for the peak periods is NOK 33.7, for between peaks it is NOK 3.6 and for other periods it is NOK 1.3. With economic efficiency as a criterion, it is possible to modify the present toll scheme, since the marginal cost during the peak periods exceeds the present toll fee and during other periods are less than the present toll fee.

3.5.3 Evaluation of an "Optimal" Cordon Toll Scheme

In an earlier work (Larsen and Ramjerdi, 1990) a cordon toll scheme that approximates an "optimal" scheme was studied. This study suggests that the inbound traffic should be tolled only during the peak periods in an "optimal" cordon toll scheme. The toll fee that approximates the marginal cost of traffic during the peak periods is about NOK 25 and during other periods about zero. This study suggests an alternative location for the "optimal" toll ring as illustrated in figure 3.3.

Table 3.3 shows a summary of the evaluation of an "optimal" cordon toll scheme. This scheme produces a net benefit of about NOK 24 million per year and the annual toll revenue net of the cost of toll collection is about NOK 110 million.

The average marginal cost of public funds for the "optimal" cordon toll scheme, MCF^t, based on relation (25), is about 0.8. However, a toll fee of NOK 25 cannot be considered to be a small change. Yet, for the calculation of MCF^t according to relation (23) one needs to address the marginal change in the cost of toll collection ΔC^t. After the introduction of a toll scheme, a marginal change in the level of the toll fee produces negligible change in the cost of toll collection. MCF^t, approximated by (25), for an increase in the toll fee from zero to NOK 10 is about 1.5. We assume that the increase in the cost of toll collection to be negligible for an increase in the toll fee from NOK 10 to NOK 25. In this case MCF^t based on relation (23) is close to zero.

This illustrates that the cost of toll collection produces a complication in the calculation of MCF^t. However, alternative approximations of MCF^t point to a value of less than one. This is an example of the taxation of externalities, in this case congestion, for which the marginal cost of public funds is less than one. (Ballard and Fullerton, 1992).

Table 3.3 Summary of evaluation: an "optimal" toll ring.

	Peak periods	Between peaks	Other periods	Total
Reduction in trips (millions/year):				
business	0.0	0	0	0.0
others	3.38	0	0	3.38
Users' benefits (NOK millions/year):				
time savings	108.5	0	0	108.5
operating cost savings	6.0	0	0	6.0
total	114.5	0	0	114.5
Deadweight loss (NOK millions/year)	19.4	0	0	19.4
Summary (NOK millions/year):				
Users benefits, ΔUB				114.5
Deadweight loss, ΔDWL^t				19.4
Time savings net of deadweight loss				89.1
Total benefits, $\Delta UB - \Delta DWL^t$				95.1
Cost of stops at toll stations, ΔUC^t				1.1
Cost of toll collection, C^t				70.0
Net benefit, $\Delta UB - \Delta UC^t - \Delta DWL^t - C^t$				24.0
Toll revenues, TR				180.0
Net toll revenues, $TR - C^t$				110.0
Marginal cost of public funds, MCF^t				≤ 1.0

In an "optimal" cordon toll scheme the traffic is tolled only during the peak periods. The marginal cost of toll collection for extending the scheme to charge the traffic during the uncongested periods is about NOK 27 million per year (the difference between the costs of toll collection in the present scheme and the "optimal" cordon toll scheme). Assume that a toll fee of NOK 10 during the uncongested periods produces a comparable reduction in traffic to that of the present scheme and results in an additional revenue of NOK 200 million per year. Then an estimate of MVF^t for the uncongested periods is $[1+(27-10.9+27.49/200] = 1.2$. Assume that the total cost of a round trip including time cost and toll is about NOK 30 and the price elasticity of demand is -1.2. Then relation (19) gives an estimate of a "feasible toll during the uncongested periods of about NOK 10 if we assume a value of 1.5 for MCF^p. Observe that for this calculation we have used very conservative figures for toll revenues generated during the uncongested periods, the total cost of a trip, toll elasticity of demand and the marginal cost of public funds in Norway. Otherwise a feasible toll during the uncongested periods would have been greater than NOK 10.

The average marginal cost for the tolled-off trips (time savings/reduction in number of trips by car) is NOK 32.1 which is higher than the optimal toll fee of NOK 25.

3.5.4 Evaluation of a "Socially Optimal" Road Pricing Scheme

Table 3.4 shows a summary of the evaluation of a "socially optimal" road pricing scheme. In a "socially optimal" road pricing scheme the social cost of travel is charged on each link during the peak periods. The social cost of travel during other periods is assumed to be zero.

This calculation shows that the total annual benefits in a "socially optimal" road pricing scheme is about NOK 151 million and is about the same size as the toll revenues. Note that the benefits from time savings net of the deadweight loss is about NOK 143 million, which is less than the toll revenue.

In the "optimal" cordon toll scheme, the toll fee for a round trip with two toll crossings is NOK 25 and for a round trip with four toll crossings is NOK 50. The toll fee for some of trips are greater than their social costs. The maximum toll fee in a "socially optimal" scheme for a round trip is NOK 51.7. There are only 49 round trips with a fee of NOK 50 or larger.

Table 3.4 Summary of evaluation: "socially optimal" road pricing scheme.

Users' benefits, ΔUB, (NOK millions/year):	
time savings	162.6
operating cost savings	7.6
total	170.2
Deadweight loss, ΔDWL^t, (NOK millions/year)	19.3
Time savings net of deadweight loss, (NOK millions/year)	143.3
Total benefits, ΔUB- ΔDWL^t, (NOK millions/year)	150.9
Toll revenues, TR, (NOK millions/year)	152.1

Table 3.5 shows the average toll fee for a one way trip by trip length in a "socially optimal" scheme. The standard deviation is a measure of the variation of the degree of congestion in different parts of the road network. A comparison of the toll fees in a "socially optimal" scheme with that of an "optimal toll" scheme indicates that a "socially optimal" scheme is a more equitable scheme.

The estimates of the toll revenues on the links of the road network point to the locations of some the of bottlenecks in Oslo and where some of the investment projects are located.

Table 3.5 Average toll fee for different trip distances (one way trip).

Trip distance, km	Average toll fee, NOK	Standard deviation
0- 2	0.00	0.00
2- 4	0.60	1.05
4- 6	1.63	1.92
6-10	3.52	3.69
10-15	6.06	5.31
15-20	8.17	6.21
20-30	9.12	6.62
30-40	8.93	7.26
40-50	8.42	6.51

3.5.5 Evaluation of a Road Investment Package

Table 3.6 shows the evaluation of a road investment package. About one third of the total benefits from the investment package is related to the benefits to the traffic in the peak periods and is thus related to the expansion of capacity. The rest is related to the benefits to the traffic in other periods, when there is little congestion on the road network and thus related to improved "standard" of the road network such as improvements in the free flow speeds and additions of links that have decreased travel distances.

The road investment package in this exercise includes a large part of the Oslo package. Yet, the results from this calculation should be interpreted in the context of this study and not as an evaluation of the Oslo package. Furthermore we assume that this investment package is to be financed solely by the toll revenues.

Table 3.6 Summary of the evaluation of a road investment package.

	Peak periods	Between peaks	Other periods	Total
Reduction in trips (millions/year):				
business	0	0	0	0
others	-0.343	-0.106	-0.197	-0.646
Users' benefits, ΔUB, (NOK millions):				
time savings	73.3	79.7	59.2	212.2
operating cost savings	4.2	3.0	4.6	11.8
total	77.5	82.7	63.8	224.0
Deadweight loss (NOK millions/year)	-2.0	-0.5	-1.0	-3.5
Summary (NOK millions/year):				
Users' benefits, ΔUB				224.0
Deadweight loss, ΔDWL^t				-3.5
Time savings net of deadweight loss				215.7
Total benefits, ΔUB- ΔDWL^t				227.5

3.5.6 Evaluation of the Investment Package with the Present Toll Scheme

Table 3.7 shows the evaluation of the road investment package with the present toll scheme. The net annual benefit of the road investment package decreases from NOK 228 (see table 3.6) million to about NOK 136 million when evaluated with the present toll scheme. The cost of toll collection explains the main part of the difference. However, with the road investment package, the net annual toll revenue increases from NOK 500 million (see table 3.2) to NOK 513 million, or by about 3 percent.

The marginal cost of public funds for the present toll scheme with the investment package, MCF^t, based on relation (25) is 0.74, i.e., less than one.

The average marginal cost for the tolled-off trips can be calculated based on the changes in time savings and the reduction in number of trips by car from the scenario that consists of the investment package to the scenario that consists of the investment package with the present toll scheme (the differences in the values shown in tables 3.6 and 3.7). The average marginal cost per trip for the peak periods is NOK 28.8, for between peaks NOK 2.4 and for other periods NOK 1.0. The average marginal costs of the tolled-off trips with an investment package are smaller than those that are based on the present network. The comparison of these values with the toll fee (NOK 10) suggests that it is possible to modify the toll scheme, since the marginal cost during peak periods exceeds the toll fee and during other periods are less than the toll fee.

Table 3.7 Summary of evaluation: the investment package with the present Oslo toll scheme.

	Peak periods	Between peaks	Other periods	Total
Reduction in trips (millions/year):				
business	0	0	0	0
others	0.807	1.185	3.709	5.701
Users' benefits (NOK millions/year):				
time savings	106.5	82.8	63.3	252.6
operating cost savings	6.1	3.1	4.9	14.1
total	112.6	85.9	68.2	266.7
Deadweight loss (NOK millions/year)	3.8	6.4	18.6	28.8
Summary(NOK millions/year):				
Users' benefits, ΔUB				266.7
Deadweight loss, ΔDWL^t				28.8
Time savings net of deadweight loss				223.8
Total benefits, $\Delta UB - \Delta DWL^t$				237.9
Cost of stops at toll stations, ΔUC^t				5.4
Cost of toll collection, C^t				96.6
Net benefit, $\Delta \mathrm{UB} - \Delta UC^t - \Delta DWL^t - C^t$				135.9
Toll revenues, TR				610.0
Net toll revenues, $TR - C^t$				513.4
Marginal cost of public funds, MCF^t				0.74

3.5.7 Evaluation of the Investment Package with an Optimal Cordon Toll Scheme

A toll fee of NOK 20 enforced on inbound traffic during the peak periods approximates the marginal cost of travel with the road investment package. The toll fee is thus lower than the "optimal" toll fee with present road network (NOK 25). The marginal cost for the traffic in other periods is approximately zero. We assume that no further adjustment in the location of the optimal toll ring is necessary (see figure 3.3).

Table 3.8 shows the summary of the evaluation of the road investment package with an "optimal" cordon toll scheme. The net annual benefit of the road investment package decreases from NOK 228 million (see table 3.6) to about NOK 215 million when evaluated with the present toll scheme. However, with the road investment package, the net annual toll revenue decreases by about 16 percent, from NOK 513 million (see table 3.7) to NOK 93 million.

The total annual benefits (ΔUB - ΔDWL^t) of the investment package (compared with the present network), are NOK 228 million (see table 3.6). The total annual benefits of the road investment package with an "optimal" cordon toll scheme compared with the present network with an "optimal" cordon toll is NOK 190 million (the difference in the values shown in tables 3.8 and 3.3). Hence, the total benefits of the investment package decreases by about 16 percent with an "optimal" cordon toll scheme.

The average marginal cost for the tolled-off trips can be calculated based on the changes in time savings and the reduction in number of trips by car from the scenario that includes the investment package to the scenario that includes the investment package and the "optimal" toll scheme (the differences in the values shown in tables 3.6 and 3.8). The average marginal cost for the tolled-off trips (time savings/reduction in number of trips by car) is NOK 25.9 which is higher than the "optimal" toll fee of NOK 20.

Table 3.8 Summary of evaluation: the road investment package with an "optimal" toll ring.

	Peak periods	Between peaks	Other periods	Total
Reduction in trips (millions/year):				
business	0	0	0	0
others	2.746	-0.106	-0.197	2.443
Users' benefits, (NOK millions/year):				
time savings	144.3	79.7	59.2	283.2
operating cost savings	8.2	3.0	4.6	15.8
total	152.5	82.7	63.8	299.0
Deadweight loss, (NOK millions/year)	15.3	0.5	-1.0	13.8
Summary (NOK millions/year):				
Users' benefits, ΔUB				299.0
Deadweight loss, ΔDWL^t				13.8
Time savings net of deadweight loss				269.4
Total benefits, ΔUB- ΔDWL^t				285.2
Cost of stops at toll stations, ΔUC^t				0.5
Cost of toll collection, C^t				70.0
Net benefit, $\Delta UB - \Delta UC^t - \Delta DWL^t - C^t$				214.7
Toll revenues, TR				167.0
Net toll revenues, $TR - C^t$				93.0

3.6 Summary and Conclusions

In this paper we have developed a theoretical framework for the incorporation of the marginal cost of public funds in the evaluation of road projects that are financed through road pricing. The standard approach often assumes that the marginal cost of public funds through general taxation is equal to one.

For this purpose we first analysed the Ramsey problem for a road in the presence of congestion. We showed that the feasible toll with a constraint on the budget deviates by a positive amount from the "optimal toll", defined as the difference between the social marginal and the private marginal cost. The deviation of the feasible toll from the "optimal toll" increases with the constraint on the budget. Furthermore, the deviation decreases with an increase in the marginal cost of public funds through toll, MCF^t, and an increase in (the absolute value of) the price elasticity of demand. When there is no congestion, the "optimal toll" is equal to zero. In this case too the toll on the facility will increase with the constraint on the budget and decrease with MCF^t and the absolute value of price elasticity of demand.

Then we investigated the toll that is feasible to set on a congested road by taking into account the marginal cost of public funds through general taxation. We showed that the solution to this problem is identical to the solution to the Ramsey problem when the constraint on deficit is set such that the Lagrangian multiplier with respect to budget constraint, λ, to be equal to $MCF^p - 1$, where MCF^p is the marginal cost of public funds through general taxation.

Then with focus on Oslo as a case study alternative road pricing schemes were evaluated. Table 3.9 shows a summary of the schemes that we studied for this purpose. The present transport network is used as a reference. These schemes are the following:

- The present transport network with the present toll scheme
- The present transport network with an "optimal" cordon toll scheme
- The present transport network with a "socially optimal" road pricing scheme
- A road investment package without a toll scheme
- A road investment package with the present toll scheme
- A road investment package with an "optimal" cordon toll scheme

The present scheme, with a net annual benefit of NOK -80 million (i.e., a net cost), raises a net annual revenue of about NOK 500 million at a marginal cost of public funds, MCF^t, of about 1.2. The MCF^t in this case is less than the marginal cost of public funds, MCF^p, which is about 1.6 in

Norway. Since the calculation of MCF^t was independent of the investment package, it can be concluded that the cost of funding of any public project through toll revenues is less than through public funds that is generated through general taxation. Yet, according to a benefit-cost analysis the scheme should be rejected. Since the toll revenue from the present Oslo scheme is tied to a road investment package, the Oslo toll scheme should be evaluated with the investment package.

The road investment package with the present toll scheme has a net annual benefit of NOK 136 million and raises a net annual revenue of about NOK 513 million at a marginal cost of public funds, MCF^t, of about 0.74.

If the investment package is to be introduced evenly over the life of the present toll scheme, then the present cordon toll scheme has an average net annual benefit of NOK 28 million and raises an average net annual revenue of about NOK 506 million at a marginal cost of public funds, MCF^t, of about 0.95, slightly less than one. This example shows how the interactions between the public expenditure (road investment package) and the taxed goods (car trips through tolls) can decrease the marginal cost of public funds through tolls (Ballard and Fullerton, 1992). This calculation is based on the assumption that the investment package is financed solely through toll revenues.

Table 3.9 Summary of the evaluation of the alternative schemes for Oslo[a].

	Present network			Road investment package		
	Present toll	Optimal cordon toll	Optimal road pricing	No toll	Present toll	Optimal cordon toll
Users' benefits, ΔUB						
Time savings	52.4	108.5	162.6	212.2	252.6	283.2
Operating cost savings	3.0	6.0	7.6	11.8	14.1	15.8
Total	55.4	114.5	170.2	224.0	266.7	299.0
Deadweight loss, ΔDWL^t	33.6	19.4	19.3	-3.5	28.8	13.8
Time savings net of deadweight loss	18.8	89.1	143.3	215.7	223.8	269.4
Total benefits, ΔUB- ΔDWL^t	21.8	95.1	150.9	227.5	237.9	285.2
Cost of stops at toll stations, ΔUC^t	4.8	1.1	na		5.4	0.5
Cost of toll collection, C^t	96.6	70.0	na		96.6	70.0
Net benefit, ΔUB - ΔUC^t - ΔDWL^t - C^t	-79.6	24.0	na	227.5	135.9	214.7
Toll revenues, TR	600.0	180.0	152.1		610.0	167.0
Net toll revenues, TR - C^t	503.4	110.0	na		513.4	93.0
Marginal cost of public funds, MCF^t	1.16	≤ 1.0	na		0.74	≤1.0

[a] All benefits and costs in NOK millions/year.

An alternative cordon toll scheme that approximates a "socially optimal" toll scheme was evaluated and compared with the present scheme. A cordon toll is a very crude approach to road pricing under any condition. With an appropriate location of the cordon toll and correct toll fees, a large part of the benefits expected from a more advanced pricing scheme could be realised. However, a "socially" optimal scheme is more equitable than an "optimal" toll scheme.

The total annual benefits from the "optimal" cordon toll scheme with the present network are estimated at about NOK 95 million, compared with about NOK 22 million for the present scheme and NOK 151 million for a "socially optimal" road pricing scheme. In a "socially optimal" road pricing scheme, the social cost of travel is charged on each link.

An "optimal" cordon toll scheme with the present road network has a net annual benefit of NOK 24 million and raises a net annual revenue of about NOK 110 million. Because of the cost of toll collection it is difficult to calculate a value for MCF^t, yet it can be expected to have a value of less than one. If indeed $MCF^t \leq 1.0$, this would be an example of a taxation of externalities, in this case congestion, that can produce a value of the marginal cost of public funds of less than one (Ballard and Fullerton, 1992).

The total annual benefits from a "socially optimal" road pricing scheme with the present network are 50 percent higher than the benefits from an "optimal" cordon toll scheme. However, the estimated annual toll revenues decrease from NOK 180 million in an "optimal" cordon toll scheme to NOK 152 million in a "socially optimal" scheme. MCF^t for this scheme should be less than MCF^t for an "optimal" cordon toll scheme.

In a "socially optimal" road pricing scheme, the benefits from the time savings net of deadweight loss (about NOK 143 million/year) are less than the toll revenues. However, the difference between the toll revenues and the benefits from the time savings net of deadweight loss is much smaller in a "socially optimal" road pricing scheme than in an "optimal" cordon toll scheme. This suggests that the distributional effects of a "socially optimal" scheme are less than those of an "optimal" cordon toll scheme and hence should be politically more acceptable. However, this scheme is only a theoretical simulation at present and cannot be realised with current technologies.

In the "socially optimal" road pricing scheme, the estimates of toll revenues on the links indicate the locations of some the bottlenecks in the road network in Oslo and are closely linked to the locations of the planned investment projects.

Some of the benefits from the investment package are linked to the expansion of capacity. However, two thirds of the total benefits are related to the non-congested periods, i.e., as a result of the increases in free-flow speeds or improvements that have decreased travel distances.

The total benefits from a road investment package decrease under an "optimal" toll scheme, but the decrease is only about 16 %. The toll fee in the "optimal" cordon toll scheme together with the investment package decreases from about NOK 25 (without the investment package) to about NOK 20.

Acknowledgements

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Essay no. four

An Evaluation of the Impact of the Oslo Toll Scheme on Travel Behaviour

4.1 Introduction

The Oslo cordon toll scheme was introduced in February 1990 as a financing scheme. Consequently the scheme was designed in such a way that it would minimise the impacts on traffic.

The introduction of the scheme coincided with other factors that had an impact on the supply of transport and demand for travel.

On the supply side, there was an increase in the price of gasoline of about 16 percent (in real terms). In addition, the opening of the Oslo tunnel, a main element of a package of road projects financed by the toll revenue, coincided with the introduction of the Oslo cordon toll scheme.

The recession in Norway and in particular in the Oslo/Akershus region that began around 1987 had a major impact on travel demand during the whole period of 1989-1990.

In this paper we will first present a brief description of the Oslo toll scheme and a summary of the changes in other factors that seem to have influenced travel behaviour. Then we will focus on a two-wave panel study conducted in connection with the opening of Oslo toll scheme. This study provides the main data for the evaluation of the impacts of the Oslo scheme on travel behaviour. We will focus on the short-term impact of the Oslo toll scheme on tour frequency, trip chaining and mode choice, while controlling for other influencing factors. We will also briefly address the other impacts of the Oslo cordon toll, mainly related to trip scheduling, route and destination choice. The long-term impacts of these choices as well as impacts attributed to changes in car ownership or home and work locations are not addressed. The evaluation is subject to numerous qualifications, including the use of the panel data in cross-sectional models.

4.2 The Oslo Cordon Toll Scheme

The population in the Oslo region is about 700,000. The greenbelt areas in the North and the East of Oslo combined with the Oslo fjord result in three corridors leading to the central parts of Oslo. The cordon toll which was introduced on 1 February 1990, consists of 19 toll stations located 3 to 8 km from the city centre. Over 54 percent of the work locations in the Oslo/Akershus region were reported to be inside the cordon toll area, compared with about 28 percent of home locations. The home and work locations outside the cordon area are almost equally distributed among the three corridors. Figure 4.1 shows the distribution of the home and work location in the Oslo/Akershus region in relation to the location of the cordon toll.

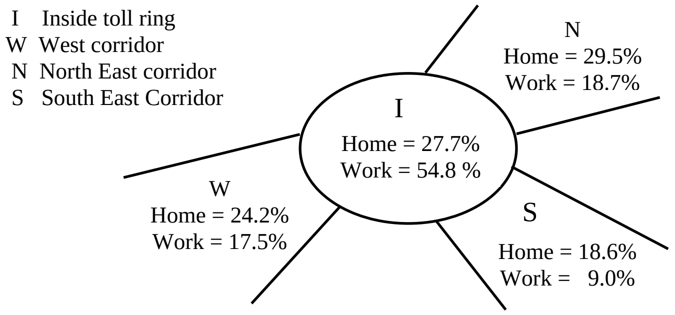

Figure 4.1 Distribution of home and work locations in the Oslo region.

The electronic payment system became operational on 1 December 1990. The design of the scheme, with regard to the location of the toll stations as well as the toll fees, was not based on the principles of road pricing. The location of the toll stations is mainly the outcome of different practical considerations and political negotiations. Toll fees are not differentiated by time of day and seasonal passes are still used extensively.

Inbound traffic is tolled all day round, every day of the year. It amounts to approximately 208,000 vehicles on an average day (about 260,000 vehicles per day during a working day).

The toll fee in 1990 was NOK 10 (approximately US$ 1.6 in 1990 exchange rates) for light vehicles and twice as much for heavy vehicles. Seasonal passes for light vehicles were NOK 220 for one month, NOK 1200 for 6 months and NOK 2200 for one year. The average hourly earnings of an adult worker in the same year in Oslo were about NOK 105 (excluding payments for holidays). The system has now been extended to allow for a number of prepaid passes during an unlimited time. The intention is to totally replace seasonal passes with prepaid passes.

In 1990, 57.5 percent of car traffic crossing the cordon line had a seasonal pass (Statistisk årbok for Oslo, 1991).The corresponding figure in 1991 was about 50.9 percent. About 70 percent of the subscribers in 1990 chose a one year subscription. Close to 60 percent of the subscribers had their employers pay for the toll (Wærsted, 1992).

The higher level of subscriptions in 1990 can be explained by a 20 percent opening discount on subscriptions. Furthermore, the prices of seasonal passes increased by about 14 percent in 1991.

The net revenue of the toll scheme is used for financing a large package of transportation infrastructure projects in the Oslo/Akershus region. The main focus of this package is on increases in road capacity. About 20 percent of the net revenue of the toll scheme is earmarked for improvements in public transportation infrastructure. The remaining revenue, supplemented by approximately equal funds from the central government, is being used to finances 50 new road projects.

About 30 of these road projects are tunnels that divert traffic from city streets. About 17 of the 50 road projects have already been completed. The Oslo tunnel, financed by the toll revenue, was opened two weeks before the opening of the Oslo cordon toll scheme.

For more information on the design, the operation and the evaluation of the Oslo cordon toll scheme, see Wærsted (1992) and Ramjerdi (1992).

4.3 Panel Study of 1989-1990

To evaluate the impact of the cordon toll scheme in the Oslo region a research programme started in 1989, before the introduction of the scheme. For more information on the design of this programme and its different components, see Solheim (1992). In summary, this programme included the following studies:

- Electronic registration of cars crossing the cordon toll (March 89-June 90).
- Registration of public transportation ticket sales (1985-1990).
- Public attitude towards the cordon toll scheme, before and after introduction.
- Manual registration of car occupancy at the cordon toll, before and after study.
- A series of studies addressing particular local issues, such as monitoring traffic on local streets and in a neighbourhood near the cordon toll, before and after introduction.
- The panel study of 1989-1990.

In the two-wave panel study of 1989-1990 a mail survey was conducted. The questionnaire consisted of two parts. The first part covered individual and household data. In the second part, the respondents were requested to fill in a one day travel diary.

The first wave of the panel study took place in October-November of 1989, before the introduction of the toll scheme. The second wave of the panel study took place in October-November of 1990, after the introduction of the toll scheme. The panel consisted of 13,555 respondents who took part in both waves. For more information on this study, see Hjorthol and Larsen (1991).

Different evidence point to attrition and underreporting in the panel study of 1989-1990. Both these phenomena lead to a decline in observed mobility. These phenomena are common in panel data. The Dutch Mobility Panel showed a similar declining mobility trend (Kitamura and Bovy 1987; Wissen and Meurs 1990; Meurs and Ridder 1992). In the following we point out to some of this evidence.

- In the first wave, the response rate was 47 percent. In the second wave, the response rate of the respondents of the first wave was 76 percent.
- The percentage of respondents who had reported no travel in 1990 was 25.5 percent, compared with 20.6 percent in 1989.
- The decrease in the reported work trips from 1989 to 1990 is 9.07 percent. However the reported decrease in work trips cannot be explained by changes in employment. The reported increase in unemployment was 1.62 percent in this period. There was no significant change in the percentage of respondents with full time work (about 81 percent) or working hours' arrangements (fixed, flexible and shift working hours' arrangements).
- The examination of the reported trips for education purposes indicates that underreporting was not as serious for this travel category. The reported reduction in trips for education purposes was 6.3 percent from 1989 to 1990, while the number of students in the panel decreased by 4.3 percent.
- The decrease in the reported business trips was 4.4 percent from 1989 to 1990. However, the number of business trips of the respondents who had reported up to 3 business trips did not change in this period.
- The reported decrease in discretionary trips was 13.3 percent for recreation, 16.5 percent for shopping/personal business and 23.2 percent for social visit, from 1989 to 1990. The characteristics of these trips suggest that underreporting should be at least similar to the underreporting for work purpose travel.

Other evidence on underreporting in the panel is revealed by the reported changes in the shares of each mode of transport. Table 4.1 shows the reported shares of each mode of transport for the trips, in 1989 and 1990.

- Table 4.1 suggests a decrease in car occupancy from 1989 to 1990. However, the decrease in the number of the reported trips by the car passenger mode cannot be supported by other studies. Gylt (1991) does not report any significant change in the occupancy of the cars that cross the cordon toll line from 1989 to 1990 based on the manual count of car occupancy at different check points on the cordon toll line. The Oslo/Akershus Travel Study of 1990-1991 points to a possible increase in car occupancy, during the period of April 1990 to April 1991 (Vibe, 1991). This evidence points to a large degree of underreporting of trips by the mode of car passengers.
- Table 4.1 shows about a 6 percent decrease in trips by public transportation from 1989 to 1990. The reported decrease cannot be supported by other studies. Nordheim and Sælensminde (1991) conclude that the change in the number of trips by public transportation was small (0-3 percent increase) from 1989 to 1990. Their conclusion is based on an analysis of the ticket sales in the region. Vibe (1991) concludes that there was not any significant change in trips by public

transportation during the period of April 1990 to April 1991. Furthermore, there is no evidence to support the reported decrease in the walk and bike modes of travel.
- The characteristics of trips by the car driver mode suggest at least similar underreporting as for travel by public transportation, or about 5 percent decrease in car travel in the Oslo/Akershus region in this period.

In the period of 1989 to 1990 there were some significant changes in other factors that had an effect on travel demand, in particular on the demand for car travel. Therefore, the changes in travel behaviour in this period are only partly due to the introduction of the Oslo toll scheme.

With some qualifications, the panel data are used as cross-sectional data for the assessment of the impact of the cordon toll scheme on tour frequency, trip chaining and mode choice that will be presented later.

Table 4.1 Reported shares of mode of transport for trips, 1989-1990.

Mode of Transport	1989 (share, %)	1990 (share, %)	Change, %
Car Driver, total	20209 (55.9)	17910 (55.4)	-11.9
Car Driver, without pass [a]	20209	11581	
Car Driver, with pass	-	6229	
Car Passenger	3777 (10.5)	2860 (8.9)	-24.3
Public Transportation	7110 (19.7)	6700 (20.4)	-5.8
Walk & Bike	4703 (13.0)	4488 (14.0)	-4.6
Total (including taxi)	36136	32134	-11.1

[a] Seasonal pass for crossing the cordon toll

4.4 Changes in the Oslo/Akershus Region, 1989-1990

The recession in Norway began around 1987 and has continued since. Different evidence suggests that the Oslo region has been hit harder than the rest of the country. One set of evidence is data on gasoline sales.

Figure 4.2 shows the trends in the annual growth of gasoline sales in Norway and in the Oslo/Akershus region. Since 1987, the annual growth rate in gasoline sales in the Oslo/Akershus region has been negative, while at the national level the annual growth rate in gasoline sales was negative only after 1990. The gasoline sales in the Oslo/Akershus decreased by about 1.2 percent from 1989 to 1990.

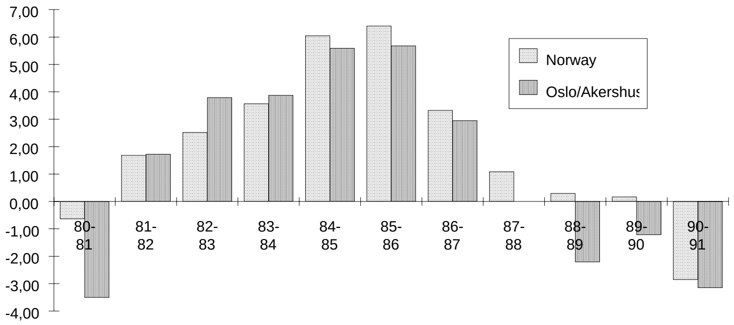

Figure 4.2 Trends in annual growth rates of gasoline sales in Norway and in the Oslo/Akershus region Source: Bil og vei statistikk 1992).

Figure 4.3 shows the trends in unemployment rates in Oslo, Akershus and Norway. Since 1987, unemployment has increased more in Oslo than in Akershus or nationally.

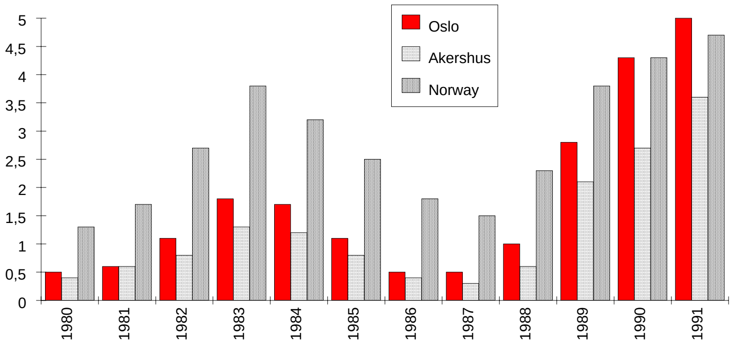

Figure 4.3 Trends in unemployment rates in Oslo, Akershus and Norway (Source: Statistisk årbok for Oslo, 1991).

Another set of evidence on the economic changes in the Oslo region is the trend in the growth of car ownership. Figure 4.4 shows the trend in annual growth rate in the ownership of private cars in Oslo, which has been negative since 1987.

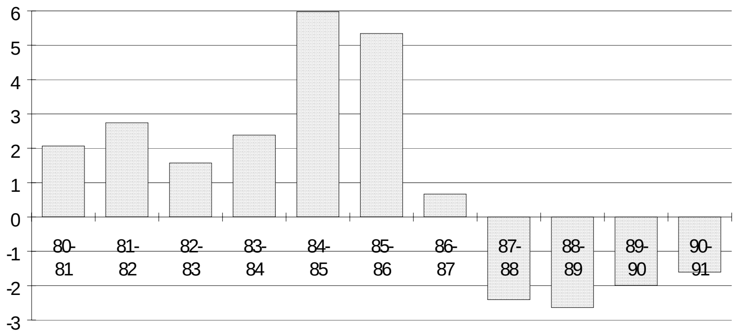

Figure 4.4 Trend in the annual growth rate in the ownership of private cars in Oslo (Source: Statistisk årbok for Oslo, 1992).

The following is a summary of the changes in factors that might have affected travel behaviour and demand for travel from 1989 to 1990.

- The increase in unemployment from 1989 to 1990 was about 1.6 percent.
- There were shifts in the car ownership status of the households in the Oslo/ Akershus region. The percentage of households with no car increased, while the percentage of the households with one or two cars decreased.
- There were significant reductions in subsidies for car travel. The percentage of the car owner households with a company car was 7.5 in 1989 and 6.9 in 1990. In 1989, about 56.1 percent of the respondents had access to a free parking place at work, compared with 53.7 percent in 1990. In 1989, 9.1 percent of the respondents had a fixed car allowance, compared with 8.2 percent in 1990.
- The increase in gasoline price between October-December of 1989 and October-December of 1990 was about 16 percent (in real terms), while the increase in public transportation prices in the same period was 1 to 2 percent.

4.5 Changes in Travel Behaviour, 1989-1990

As the result of the introduction of the toll scheme, coinciding with the recession, one can expect changes in travel behaviour. These changes can be mainly related to:

- tour frequency and trip chaining,
- mode choice,
- destination choice,

- route choice,
- timing of trips.

The reported impact of the Oslo scheme on car traffic crossing the cordon toll in its first year of operation has ranged from insignificant (Wærstad, 1992) to about 10 percent (Solheim, 1992). Our estimate is around a 5 percent decrease in car travel in this period. Part of this reduction could be explained by the recession. However, there seems to be a stronger consensus that the scheme did not have a significant impact neither on other modes of travel nor on car occupancy.

The impacts of the toll scheme on tour frequency, trip chaining and mode choice, while controlling for other influencing factors, will be presented in more detail. We will also briefly address the other impacts of the Oslo cordon toll, mainly related to trip scheduling, route and destination choice.

The toll fee in Oslo is not differentiated by the time of day. However, some peak shifting seems to have occurred from 1989 to 1990. In this case some shifts in trip timing could have occurred due to the suppressed demand during the peak periods. The resulting effect seems to have been a reduction of the length of the peak periods (the reverse of peak spreading), however small. Different evidence in the Oslo/Akershus region suggests that indeed this phenomenon might have occurred.

There is no evidence indicating a relationship between changes in home and work location and the introduction of the cordon toll scheme. Hence, we could not conclude that there were changes related to the cordon toll in destination choices for commuting, business and education travel. These are usually long-term changes. However, we could detect some shifts in destination choices, for discretionary travel purposes, from 1989 to 1990 as a result of the toll scheme and more so as a result of the recession.

According to our assessment of the decrease in travel demand in the period of 1989 to 1990, the most significant change in route choice in the Oslo/Akershus region has been due to the changes in the road network, rather than the decrease in the degree of congestion of the network. Hence, it would be safe to conclude that there were no significant changes in route choice because of the introduction of the cordon toll scheme.

4.5.1 Tour and Trip Chaining

Trips can be categorised as compulsory trips (such as those for work and education) and discretionary trips (such as those for shopping and recreation). There is a larger degree of flexibility in the frequency, timing and destinations associated with discretionary trips.

If the toll fee is to be collected for each cordon crossing, depending on the amount of the fee, it will have a much higher impact on trip frequencies of the discretionary trips than the compulsory trips. At the same time we expect a larger number of the discretionary trips to be chained together or chained with compulsory trips. In summary we expect to observe changes at the following levels:

- A larger reduction of discretionary tours compared with compulsory tours.
- An increase in the number of trips that are linked together to make a tour.

A tour is defined as the trips forming one integrated travel route from home to home. As we described earlier, the use of seasonal passes in 1990 was quite extensive. Given the extensive use of seasonal passes and the low level of toll fee for a single pass, the incentives for changes in travel behaviour were not large.

The average number of trips per car tour, for tours that reported crossing the cordon toll, was 2.74 in 1989 and 2.71 in 1990. The reduction is similar to tours that did not cross the cordon toll (2.39 compared with 2.33). The decrease can be explained by the (relatively) larger reduction of the reported discretionary trips and tours compared with compulsory trips and tours from 1989 to 1990. Economic factors as well as underreporting can explain the decrease in the average number of trips per tour rather than the introduction of the cordon toll fee.

The relative reduction of reported tours that crossed the cordon toll line was 5.7 percent over all modes, 6.6 percent for car driver mode and 4.7 for modes other than car from 1989 to 1990. If attrition and underreporting as well as changes in travel pattern due to the economic recession over the region were symmetrical, then a reduction of about 6 to 7 percent in car traffic could have been due to the cordon toll scheme. Because of the land use pattern, the composition of traffic by purpose cannot be the same over the region. Underreporting is more likely for discretionary trips than for compulsory trips and the economic factors do not affect all travel purposes equally. Furthermore, as we pointed out earlier, the implied reduction of tours by modes other than car cannot be supported by other studies (Gylt, 1991; Nordheim and Sælensminde, 1991).

To evaluate the impact of the toll fee on car tour frequency, alternative models were tested. A linear regression model could best capture the impact of the toll. Table 4.2 shows the results of the estimation. The R-squared values are usually low in tour frequency models. The R-squared value of 0.34 for the car tour frequency model is relatively high.

The coefficient for cordon toll fee in the car tour frequency model is significant. Two crossings over the cordon toll line in 1990 is equivalent to NOK 10 for those without seasonal pass and about NOK 8 for those with seasonal pass and NOK 0 in 1989.

From of the results presented in table 4.2, the decrease in the car traffic that could be attributed to the cordon toll fee alone is about 3.6 percent (i.e., with no change in the other factors that enter the linear regression model). The toll fee elasticity, based on the average number of tours and the average number of toll crossings reported by respondents, is -0.026.

Table 4.2 Car tour frequency, ordinary least square estimates.

Deletion method:	Pairwise	Valid cases:	25878
R-squared:	0.337	Rbar-squared:	0.337
Std error of est:	0.615	R-squared (uncentered):	0.565

Variable[a]	Estimate	Standard Error	2-tailed t-value	Prob	Standard Estimate	Cor.w/D Var.
Constant	0.1077	0.0123	8.73	0.000	-----	-----
Female	-0.0705	0.0082	-8.62	0.000	-0.045	-0.1515
Age < 18	-0.2720	0.0167	-16.26	0.000	-0.091	-0.1647
30 < Age < 45	0.0747	0.0088	8.48	0.000	0.047	0.1607
No. of Cars	0.0569	0.0037	15.33	0.000	0.082	0.1714
Child 0-6	0.0282	0.0074	3.80	0.000	0.022	0.1034
Household Size	0.0303	0.0038	8.03	0.000	0.051	0.1016
House Work	0.0873	0.0161	5.42	0.000	0.029	-0.0163
Income (NOK 1000)	0.0002	0.0000	5.25	0.000	0.029	0.1534
Company Car	0.0503	0.0166	3.04	0.002	0.016	0.1411
Free Parking	0.2829	0.0085	33.25	0.000	0.181	0.3206
Inner City	0.3039	0.0046	65.68	0.000	0.445	0.5093
Toll	-0.0144	0.0064	-2.26	0.024	-0.015	0.3196

ANALYSIS OF VARIANCE TABLE

Source	Variation	d.f.	Mean Square
MODEL	4985.73	12	415.478
RESIDUAL	9793.23	25865	0.379
TOTAL	14779.0	25877	0.571

F(12,25865): 1097.323 Probability of F: 0.000

[a] The definition of variables is as follows; *Female* = 1 if the tour is made by a female & = 0 otherwise, *Age < 18* = 1 if the tour is made by a person less than age of 18 &= 0 otherwise, *30< Age < 45* = 1 if the tour is made by a person of age 30-45 & = 0 otherwise, *No. of Cars* = number of cars in the household, *Child 0-6* = number of the children of age 0-6 in the household, *Household Size* = household size, *House Work* = 1 if occupation is house work &= 0 otherwise, *Income (NOK 1000)* = gross annual household income in NOK 1000, *Company Car* = 1 if the household has access to a company car & = 0 otherwise, *Free Parking* = 1 if the tour is made by one with a free parking place available at work & = 0 otherwise, *Inner City* = 1 if the main destination of the tour is the inner city of Oslo & = 0 otherwise and *Toll* = NOK 5 for each time a tour crosses the cordon toll line for one without a seasonal pass compared with about NOK 4 for those with seasonal passes in 1990 and 0 in 1989.

The result of the estimation shows the importance of access to a "free parking place at work" in the generation of car tours. The parking fee in the inner city of Oslo in 1990 was about 40 NOK/day and 15 NOK/hr. A free parking place at work should be much more highly valued by the employees than the market price of a parking space since it reduces search and walking time along with offering comfort, reliability and convenience.

The impact of the toll fee on trip generation and trip chaining is evaluated by a recursive structure which is used to describe the trip generation of work and discretionary trips (shopping, personal business, social visit and recreation) and the number of trip chains (tours). Business trips were excluded from the analysis.

In the system of trip generation models a recursive relation is assumed among discretionary and compulsory trips. The number of discretionary trips is expressed as a function of compulsory trips (work trips in this case). The advantage of this approach is that the interdependence and the internal relations among trips are captured. For more detail on these types of models see Goulias and Kitamura (1989). The structure of the model, as shown in figure 4.5, captures the relation among trips by purpose and tour.

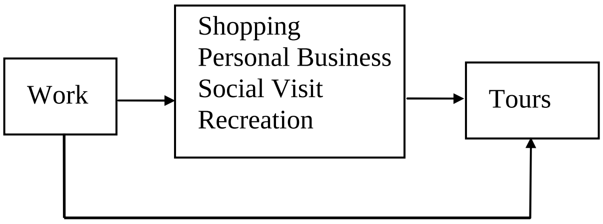

Figure 4.5 Recursive structure of trip generation by trip purpose and tours.

The number of tours is modelled as a linear function of the number of trips by purpose. The coefficient of each trip variable in the model indicates the average number of tours that is generated per trip.

We use the example constructed by Goulias and Kitamura. Suppose a respondent had reported only one tour, home-work-home, a one-stop tour. Then

$$\text{(No. of tours)} = \beta_1 \text{ (No. of work trips)}$$

In this case $\beta_1 = 1$. Suppose, the respondent had reported another tour, home-shopping-shopping-home, a two-stop tour. Then

$$\text{(No. of tours)} = \beta_1 \text{ (No. of work trips)} + \beta_2 \text{ (No. of shopping trips)}$$

In this case $\beta_1 = 1$ and $\beta_2 = 0.5$. Trips that tend to be combined into multi-stop tours will have lower coefficients, and the trips that tend to be pursued in one-stop tours will have a coefficient closer to one, which is the upper bound.

A trip generation model for the work trip will be in the following general form:

$$Y_i = \beta' X_i + \varepsilon_i$$

where Y_i is the number of trips reported by the respondent i, the β's are coefficients, X_i is a vector of explanatory variables and ε_i is a random error term.

The trip generation model for the discretionary trips will be in the following form:

$$Z_i = \gamma' X_i + \alpha Y_i + \varepsilon_i$$

The tour model then will be:

$$C_i = \mu + \lambda Y_i + \delta Z_i + \varepsilon_i$$

where μ should be equal to zero. There cannot be a tour without a trip. In the estimation of these models μ should be constrained to zero. However, in the estimation of the models, presented in table 4.3, this condition was not set. As can be seen from this table the estimates of the constant term (μ) are close to zero. This table shows the two stage least square estimates of the coefficients.

Equation 1 in table 4.3 shows the estimates of the coefficients of variables that described the work trip generation best. All signs of the coefficients seem correct.

The estimate of the coefficient for toll fee is very close to zero and not significant. We could conclude that the toll fee, introduced in 1990, did not have much impact on the work trip at the level of trip generation.

Equation 2 shows the estimates of the coefficients of variables that described discretionary trip generation best. Again all the coefficients have the expected sign. The coefficient for work trip is around 1.2 in this model. Corresponding to each work trip there is on average 1.2 discretionary trips (not including the effects of the other variables of the model and the constant term).

The estimate of the coefficient for toll cost is significant and has the right sign. We can conclude that the toll fee, imposed in 1990, had some impact at the level of trip generation for discretionary trips, however small.

Equation 3 shows the estimates of the coefficients for work trip and discretionary trip in the tour frequency model. The size of the estimate of the coefficient for work trips is larger than the coefficient for the discretionary trips.

The impact of the toll on car tours from the recursive model shown in table 4.3 is about the same (about 3.5 percent) as that from model presented in table 4.2. The toll fee elasticity (of tour frequency) based on average the number of work and discretionary trips, tours and the average number of toll crossings reported by respondents is around -0.038.

Table 4.3 Recursive model for car trip generation and car tour frequency.

Variable [a]	Estimate	Standard Error	t-value	Prob >|t|
Equation 1 *- Dependent variable WORK TRIP by car*				
Constant	-0.0835	0.0118	-7.11	0.000
Female	-0.0609	0.0081	-7.50	0.000
30<Age<45	0.0039	0.0090	0.43	0.664
No. of Cars	0.0306	0.0034	8.90	0.000
Child 0-6	-0.0336	0.0112	-2.99	0.003
Flex Time	0.3539	0.0323	10.96	0.000
Shift Time	1.4382	0.1807	7.96	0.000
Company Car	0.2329	0.0186	12.50	0.000
Free Parking	0.1257	0.0141	8.89	0.000
Inner City	0.1496	0.0043	35.12	0.000
Toll	0.0021	0.0058	0.37	0.714
Equation 2 *- Dependent variable DISCRETIONARY TRIPS by car*				
Constant	-0.2442	0.0391	-6.25	0.000
Work Trip	1.1980	0.0870	13.78	0.000
Age <18	-0.7147	0.0718	-9.96	0.000
45<Age<65	-0.1506	0.0153	-9.88	0.000
Public Trans. Pass	0.1149	0.0264	4.35	0.000
Household Size	0.0528	0.0064	8.22	0.000
Not Working	0.6306	0.0552	11.43	0.000
House Work	0.2268	0.0327	6.93	0.000
Income(NOK 1000)	0.0004	0.0001	7.72	0.000
Inner City	0.1412	0.0150	9.39	0.000
Toll	-0.0340	0.0107	-3.17	0.002
Equation 3 *- Dependent variable TOUR by car*				
CONSTANT	0.0611	0.0043	14.07	0.000
WORK TRIP	0.7649	0.0169	45.37	0.000
DESCR. TRIP	0.6206	0.0112	55.52	0.000

[a] The definitions of some of the variables are the same as in table 4.2. The definition of the additional variables as follows; *Flex Time* = 1 if the work trip is made by one with a flexible working hours' arrangement & = 0 otherwise, *Shift Time* = 1 if the work trip is made by a shift time worker & = 0 otherwise, *Public Trans.Pass* = 1 if one has a seasonal pass for public transportation & = 0 otherwise and *Not Working* = 1 if one is not employed & 0 otherwise.

4.5.2 Choice of Seasonal Pass for Toll Payment

We described the alternative options for toll payment during the first year of the operation of the Oslo toll scheme earlier. The options were either to subscribe to the system with the purchase of a seasonal pass that would allow the subscribers to pass through the cordon toll an unlimited number of times during the subscription period or to pay for the toll manually each time.

The motivation for deciding to purchase a seasonal pass for cordon toll should be connected to the cost of seasonal pass compared with a single pass. That depends on expected use of the system. The expected use would depend both on one’s home and work location in relation to the cordon toll and one’s degree of mobility. Additional factors could be the perceived comfort and convenience and time saving associated with the use of a seasonal pass. However, the marginal toll cost for vehicles with a seasonal pass is zero.

One main obstacle in calculating the toll price elasticity of mode choice is connected to the alternative toll payment arrangement. The choice of a public transportation pass, with a seasonal pass in the choice set, is another similar situation. The expected frequency of public transportation use during a time period influences the choice of the mode of the payment. Once a seasonal pass is acquired, the marginal cost of public transportation is zero. In travel demand modelling, however, the tradition has been to set the marginal cost equal to the average cost per pass, for those with seasonal pass.

The panel survey of 1989-1990 does not allow for the differentiation of alternative types of seasonal passes or the actual cost of the pass to a respondent's household. In addition, there is no information on a respondent's household except for the household size, the number of people in different age categories and the household income.

Based on a sub-sample of employed respondents who had a car in their household, a logit model for the choice of seasonal pass was estimated. Table 4.4 shows the estimation results.

The variables that explain the choice of a seasonal pass produce the expected results. Those with seasonal pass for toll payment seem to have higher car mobility. In addition, we could expect a higher value of travel time among those with a seasonal pass for toll payment, connected to marginal utilities of time, income or both.

The number of cars in the household, household income, the number of toll crossings between the respondent’s home and work location, and whether the payment for seasonal pass is made by the "company", all have a strong positive relationship with the choice of seasonal pass. A higher percentage of female workers reported seasonal passes in their household than male workers (37 compared with 32). In this case, the dummy variable "female" should be interpreted as more than one employed in the household.

Table 4.4 Logit model for the choice of seasonal pass.

Sample size:	2694	
No. of cases with no seasonal pass (alt. 1):	1775	(66%)
No. of cases with seasonal pass (alt. 2):	919	(34%)
Final log-likelihood:	-1376.1	
Rho-squared (0):	0.263	
Rho-squared (C):	0.204	
Variable (alternative) [a]	**Coefficient**	(t-statistics)
Constant (alt.2)	-3.633	(17.6)
Female (alt.2)	0.604	(6.2)
Age-40 (alt.2)	-0.019	(2.9)
No. of cars (alt.2)	0.761	(9.7)
Child 0-6 (alt.2)	-0.297	(3.2)
Income in NOK 100,000 (alt.2)	0.214	(5.2)
Payment by Company (alt.2)	3.278	(11.4)
Free parking at work (alt.2)	0.429	(4.5)
Home-Work distance > 30 km (alt.2)	-0.864	(5.0)
No. of toll crossings (alt.2)	1.261	(14.3)

[a] The definition of variables are as follows; *Female* = 1 if the respondent is a female & = 0 otherwise, *Age -40* = age of the respondent minus 40 if age more than 40 & = 0 other wise, *No. of Cars* = number of cars in the household, *Child 0-6* = number of the children of age 0-6 in the household, *Income in NOK 100,000* = gross annual household income in NOK 100,000, *Payment by Company* = 1 if the seasonal pass for toll is paid by the employer & = 0 otherwise, *Free Parking* = 1 if the respondent has a free parking place available at work & = 0 otherwise, *Home-Work distance >30 km* = 1 if the distance between home and work location is more than 30 km & = 0 otherwise and *No. of toll crossings* = the number of cordon toll lone crossings between home and work location.

4.5.3 Mode Choice

Mode shares of trips in 1989 and 1990 are shown in table 4.1. Altogether there were 15,089 tours reported in 1989 and 13593 tours reported in 1990. Mode shares of tours are similar to that of trips.

To get an indication of the stability in the mode choice the respondents who belonged to a car owner household and had identified the same home and work location (or school location) in 1989 and 1990 were selected. This group had reported 2,650 tours of two trips having the same paths in 1989 as in 1990. There were altogether 497 switches between modes car driver, car passenger, public transportation and walk and bike.

Table 4.5 shows these switches. The largest groups are those who did not switch modes. This evidence could suggest stability in mode choice. In that case a cross-sectional model might lead to an overestimation of the impact of the toll, at least it's short-term impact. The results presented here are based on cross-sectional models.

Table 4.5 Switches in mode of transport, 1989-1990.

Mode	Car Driver, 90	Car Pass., 90	Public Trans., 90	Walk & Bike, 90
Car Driver, 89	1083	27	55	51
Car Passenger, 89	54	105	24	35
Public Transport, 89	70	31	634	35
Walk & Bike, 89	64	24	27	331

For mode choice, we have confined our analysis to tours of only 2 trips, between car driver, car passenger, public transportation and walk and bike. The majority of reported tours are in this category. The respondents who link more than two trips into a tour are more likely to have a higher utility for the use of the car and hence should have a lower toll elasticity. Thus, in this manner, the elasticities should be an upper bound. The results for mode choice for work purpose travel will be presented first.

Table 4.6 shows the results from logit models using data from 1989, before the introduction of the cordon toll scheme, and using data from 1990, after the introduction of the cordon toll scheme. These models have the same specifications. All level-of-service variables have a significant effect with the expected signs. Very few socio-economic variables with significant effect that are intuitively acceptable were included in the models.

Model 1 is the result of estimations using data from 1989 for two groups; the group without and the group with seasonal pass for toll payment in 1990, respectively. The results of the estimation (not shown here) from separate models for these two groups, show a higher implicit value of travel for the group with a seasonal pass, than for those without seasonal pass for toll payment.

The respondents who chose a seasonal pass for toll payment in 1990 had significantly higher utilities for car driver and car passenger modes in 1989. This is reflected by the estimate of the coefficient for the dummy variable "seasonal pass".

Model 2 was estimated using the data from 1990 for those without a seasonal pass for toll payment. The toll fee per cordon crossing is set to NOK 5. All variables, including the toll cost, have a significant effect and the expected signs.

Model 3 is based on data from 1990 and for those with seasonal pass for toll. Here, toll fee per cordon crossing is set to NOK 3.9. This is an approximate figure, based on the distribution of the seasonal pass types (monthly, half-year and yearly), the average number of cordon toll crossings during the subscription period, and the opening discounts.

The coefficient for toll cost in model 3 is positive. However, this variable is proportional to the number of toll crossings. Thus the positive sign could be explained as the extra utility of the car mode in tours that cross the cordon toll, for those with seasonal pass.

Model 4 is the result of the estimation using the whole sample from 1990. In this model the toll cost per cordon crossing for the group without a seasonal pass is set to NOK 5.0 and for the group with seasonal pass it is set NOK 0. Different measures such as the "Rho-Squared" statistics, the implicit value of times and the estimates of different coefficients show that this model is better than a model where toll cost for those with seasonal pass is set to NOK 3.9.

The estimates of the parameters of the models using data from 1989 should have been similar to those of the corresponding models using data from 1990. With the assumption that the correct values of the parameters are identical, a "logit scaling technique" could be used to determine if the variances of the residual error of the utility functions of the two waves are significantly different. In addition, the use of this technique allows for efficient and unbiased estimates of the model parameters. For more detail about this technique see Bradley and Daly (1992).

Table 4.7 shows the results from the logit models using the pooled data from the two periods and applying a scaling technique. Model specifications are the same as those shown in table 4.6. The toll cost per cordon crossing for those with seasonal pass is assumed to be zero.

The scale factors of wave 1 relative to wave 2 are significantly different from 1. One explanation for the significance of the ratio of the error variances is the use of network data for the level-of-service variables in the models.

Table 4.6 Logit models for mode choice, travel purpose work.

Model	***1, 89*** ***all***	***2, 90*** ***no pass***	***3, 90*** ***pass***	***4, 90*** ***all***
Sample size	3246	2035	901	2936
Final Likelihood	-4111.6	-1331.0	-581.9	-1935.5
"Rho-Sq." w.r.t. 0	.474	.478	.503	.480
"Rho-Sq." w.r.t. C	.309	.312	.252	.322
Variable [a]		***Coefficient (t-statistics)***		
Car Driver				
Car availability	1.710 (8.9)	1.115 (4.6)	2.644 (7.0)	1.556 (7.7)
Seasonal pass	1.260 (11.1)	-	-	1.061 (7.8)
In vehicle time, min	-0.0296 (8.1)	-0.0363 (6.1)	-0.0228 (3.3)	-0.0297 (6.9)
Toll cost, NOK	0.0	-0.0723 (4.7)	0.0310 (1.3)	-0.0865 (6.1)
Parking cost, NOK	-0.0451 (13.7)	-0.0327 (7.6)	-0.0386 (6.5)	-0.0344 (10.1)
Running cost, NOK	-0.0405 (6.9)	-0.0453 (4.9)	-0.0274 (3.3)	-0.0338 (5.7)
Car passenger				
Constant	-3.048 (11.3)	-3.576 (8.8)	-2.387 (5.0)	-3.787 (12.2)
Seasonal pass	1.535 (8.8)	-	-	1.535 (8.8)
Female	2.031 (10.2)	1.710 (5.4)	2.728 (7.7)	2.157 (9.3)
In vehicle time, min	-0.0477 (8.6)	-0.0670 (6.7)	-0.0329 (3.9)	-0.0485 (7.9)
Public Transport				
Constant,	1.084 (4.8)	0.6040 (2.0)	-0.4087 (0.8)	0.6077 (2.5)
Female	0.9010 (8.7)	0.6827 (5.3)	1.579 (6.9)	0.8865 (8.0)
In vehicle time, min	-0.0077 (2.4)	-0.0080 (1.9)	-0.0040 (0.7)	-0.0060 (1.8)
Walk time, min	-0.0189 (4.7)	-0.0260 (5.2)	-0.0152 (1.8)	-0.0232 (5.4)
Wait time, min	-0.0506 (5.0)	-0.0530 (4.0)	-0.0318 (1.3)	-0.0468 (4.1)
No. of transfers	-0.2082 (3.8)	-0.2335 (3.2)	-0.0574 (0.5)	-0.1835 (3.0)
Cost, NOK	-0.0405 (6.9)	-0.0453 (4.9)	-0.0254 (3.1)	-0.0338 (5.7)
Walk & Bike				
Constant	1.138 (4.2)	0.7023 (2.3)	0.0409 (0.1)	0.8972 (3.3)
Dist.<4 km, one way	-0.1523 (3.7)	-0.1778 (3.9)	0.0824 (0.9)	-0.1234 (3.0)
Dist. >4 km, one way	-0.2429 (14.4)	-0.2574 (13.0)	-0.1562 (4.9)	-0.2292 (13.8)
Value of Time, in vehicle, NOK/hr				
Car Driver	44	48	50	53
Public Transport	12	11	10	11

[a] The definitions of some of the variables that need clarification are as follows; *Car availability* = number of cars owned per adult over age 18 in the household (with a maximum value of 1.0 and minimum of zero if the respondent did not have driving licence), *Seasonal pass* = 1 if respondent has a car with a seasonal pass in his/her household in 1990 & = 0 otherwise, *Female* = 1 if the respondent is a female & = 0 otherwise, *Dist.<4 km. one way* = one way distance in km if distance is less than or equal to 4 km & 0 otherwise, *Dist.>4 km. one way* = one way distance in km if distance is greater than 4 km & 0 otherwise and *Toll* = NOK 5 for each time a tour crosses the cordon toll line for one without a seasonal pass compared with about NOK 3.9 for those with seasonal passes in 1990 and 0 in 1989. Times and costs in these models are for a tour.

Table 4.7 Logit models for mode choice, pooled data, travel purpose work.

Model	***5, pooled no pass***	***6, pooled pass***	***7, pooled all***
Sample size	4334	1872	6206
Final Likelihood	-5837.4	-2460.0	-8332.8
"Rho-Sq." w.r.t. 0	.306	.339	.313
Variable [a]	***Coefficient (t-statistics)***		
Car Driver			
Car availability	1.312 (3.8)	2.484 (9.2)	1.635 (11.7)
Seasonal pass, 89	-	-	0.8259 (6.8)
Seasonal pass, 90	-	-	1.7070 (9.9)
In vehicle time, min	-0.0398 (10.7)	-0.0239 (4.7)	-0.0342 (12.2)
Toll cost, NOK	-0.0346 (2.8)	-	-0.0419 (3.3)
Parking cost, NOK	-0.0524 (14.3)	-0.0647 (12.9)	-0.0591 (18.9)
Running cost, NOK	-0.0409 (6.8)	-0.0271 (4.4)	-0.0334 (7.8)
Car passenger			
Constant	-3.240 (12.4)	-2.484 (7.3)	-3.491 (16.2)
Seasonal pass, 89	-	-	1.580 (9.2)
Seasonal pass, 90	-	-	2.262 (11.3)
Female	1.706 (8.5)	2.5730 (10.5)	2.113 (13.1)
In vehicle time, min	-0.0613 (9.9)	-0.0345 (5.6)	-0.0487 (11.6)
Public Transport			
Constant,	0.8811 (4.4)	-0.0990 (0.3)	0.9134 (5.4)
Female	0.6586 (7.3)	1.456 (9.1)	0.8556 (10.8)
In vehicle time, min	-0.0071 (2.4)	-0.0064 (1.4)	-0.0059 (2.4)
Walk time, min	-0.0250 (7.3)	-0.0158 (2.5)	-0.0231 (7.6)
Wait time, min	-0.0575 (6.4)	-0.0412 (2.6)	-0.0533 (6.8)
No. of transfers	-0.2400 (4.9)	-0.1688 (2.2)	-0.2253 (5.4)
Cost, NOK	-0.0409 (6.8)	-0.0271 (4.4)	-0.0334 (7.8)
Walk & Bike			
Constant	0.8458 (3.8)	0.3943 (0.9)	1.056 (5.4)
Dist.<4 km, one way	-0.1805 (5.5)	0.0517 (0.7)	-0.1366 (4.5)
Dist. >4 km, one way	-0.2579 (18.1)	-0.1908 (7.6)	-0.2433 (19.4)
Scale, wave 1 / wave 2 (t-stat. w.r.t. 1)	0.9668 (66.0)	1.003 (30.5)	0.9150 (38.2)
Value of Time, in vehicle, NOK/hr			
Car Driver	58	53	61
Public Transport	10	14	11

[a] See table 4.6 for the definition of variables.

For public transportation, level-of-service variables were assumed to be the same in 1989 and 1990. For the car mode, travel times and distances were taken from network data for the two periods. For this purpose, car demand matrices for four different time periods were adjusted using the panel, the total sample in 1989 for car matrices in 1989 and the total sample in 1990 for car matrices in 1990. Earlier we suggested attrition and underreporting in the panel that had produced a much larger decrease in car mobility than the actual decrease. The result is an underestimation of car travel times in 1990 that was different in different time periods. This could also explain the higher implicit values of time for the car mode in 1990 than in 1989.

The coefficients of model 5 using pooled data for the group without seasonal pass are comparable to those of models 1 and 2, except for the coefficient for the toll cost. The coefficient for the toll cost in model 2 (using data from 1990) is about twice as large as that in model 5 (using pooled data from 1989 and 1990), since toll cost in 1989 was zero.

The pooled data models show that the group with a seasonal pass has a lower implicit value of car time than the group without seasonal pass. This is contrary to the results from separate models using data from 1989 or 1990. Note that the estimates of the marginal utility of cost are consistently lower for the group with a seasonal pass than the group without. The result should be a higher implicit value of time for the group with a seasonal pass. However, the estimates of the marginal utility of time are also consistently lower for the group with a seasonal pass. This should lead to a lower implicit value of time for this group. In this case, the overall shifts in the estimates of the marginal utilities of cost and time in the pooled model have resulted in a lower implicit value of time for the group with a seasonal pass.

Model 7 is the result of the estimation using pooled data for both groups, with and without seasonal pass. Toll cost for those with seasonal pass is set to zero. Two separate coefficients for the dummy variable "seasonal pass" are estimated, "seasonal pass, 89" and "seasonal pass, 90". The estimates of these coefficients are significant and positive. This implies that the group with seasonal pass had a higher utility for the modes car driver and car passenger both in 1989, before the introduction of the toll scheme, and in 1990 after the introduction of the toll scheme. However, the size of the coefficients for "seasonal pass, 90" is significantly larger than that of "seasonal pass, 89". The implication is straightforward. After the purchase of a seasonal pass, the use of the car increases.

To summarise, it would be erroneous to assume a toll cost per cordon crossing for those with seasonal pass for cordon toll. On the contrary, with a seasonal pass the utility of modes car driver and car passenger increases. With the assumption of a cost per cordon toll crossing for those with seasonal pass, the impact of the cordon toll scheme could be underestimated.

With toll cost set to zero for those with seasonal pass, demand elasticities with respect to the toll cost can be calculated for the group without seasonal pass. In the models presented in tables 4.6 and 4.7, the coefficients for car running costs and public transportation costs were assumed to be the same. However, separate coefficients for toll and parking costs were estimated. These coefficients are relatively close in size in the models using pooled data. Assuming the same coefficient for cost variables, these models were re-estimated. The results from these estimations are not shown here. These models produce similar toll elasticities as shown in table 4.8.

Table 4.8 Mode choice elasticities with respect to toll costs, travel purpose work.

Elasticity of demand w.r to toll costs:	All Tours	Tours crossing cordon toll
Car/Driver	-0.04	-0.14
Car/Passenger	0.04	0.09
Public Transport	0.03	0.04
Walk/Bike	0.01	0.06

The direct toll elasticity of the car driver mode is relatively low, about -0.04. All other modes have positive cross-elasticities, which, however, are as low. The direct toll elasticity of the car driver mode, for tours that cross the cordon line is significantly larger, about -0.14. Other modes have positive cross-elasticities which are less than 0.10.

As it was pointed out earlier, these elasticities are for the segment without seasonal pass for the cordon toll. However, we could easily get an estimate of the size of the direct toll elasticity, for the segment with seasonal pass; i.e., if the group with a seasonal pass were to use single pass for crossing the cordon toll.

It can be shown that cost elasticity is proportional to marginal utility of cost times income (Ramjerdi, 1990). While marginal utility of cost decreases in proportion to about 27/41, the average (household) income increases to about 31/35 for the group with a seasonal pass compared with the group without a seasonal pass. In this manner we can calculate a direct toll elasticity of about -0.10 for the group that chooses a seasonal pass.

For travel purposes other than work, we will only present some final results. Travel purpose business is excluded from the analysis. Table 4.9 shows the results from the logit models using the pooled data from the two periods, 1989 and 1990, and from applying the scaling technique. Model specifications are the same as for travel purpose work. However, we have assumed the coefficients for cost variables to be equal.

Model 1 is based on the group without a seasonal pass while model 2 is based on group with seasonal pass. The toll cost per cordon crossing for those with seasonal pass is set to zero. The scale factors of wave 1 relative to wave 2 are significantly different from 1. The implicit values of time for the group with a seasonal pass are higher than those for the group without a seasonal pass and higher for other travel purposes than for the travel purpose work.

Table 4.9 Logit models for mode choice, pooled data, other travel purposes.

Model	***1, No Pass, pooled***	***2, Pass, pooled***
Sample size	4788	2177
Final Likelihood	-7290.1	-3105.9
"Rho-Sq." w.r.t. 0	.199	.268
Variable [a]	***Coefficient (t-statistics)***	
Car Driver		
Car availability	0.8034 (5.3)	0.9178 (4.2)
In vehicle time, min	-0.0209 (4.5)	-0.0279 (4.0)
Total car cost, NOK	-0.0184 (5.5)	-0.0201 (3.7)
Car passenger		
Constant	-2.513 (15.4)	-2.431 (9.9)
Female	1.620 (14.4)	1.661 (10.2)
In vehicle time, min	-0.0333 (7.3)	-0.0435 (4.9)
Public Transport		
Constant	0.3249 (1.7)	-1.084 (2.6)
Female	0.8415 (7.3)	1.147 (5.3)
In vehicle time, min	-0.0079 (2.4)	-0.0167 (2.4)
Walking time, min	-0.0301 (7.5)	-0.0384 (3.9)
Waiting time, min	-0.0281 (3.2)	-0.0349 (1.8)
No. of transfers	-0.1341 (2.3)	-0.1842 (1.4)
Cost, NOK	-0.0184 (5.5)	-0.0201 (3.7)
Walk & Bike		
Constant	-0.8539 (5.2)	-1.559 (6.0)
Dist.<4 km, one way	-0.0353 (1.4)	0.0125 (0.3)
Dist. >4 km, one way	-0.1033 (12.2)	-0.0861 (6.3)
Scale, wave 1 / wave 2 (t-stat. w.r.t. 1)	0.9181 (49.9)	0.9107 (37.8)
Value of Time, in vehicle, NOK/hr		
Car Driver	68	83
Public Transport	26	49

[a] See table 4.6 for the definition of variables.

Table 4.10 shows mode choice elasticities with respect to toll costs for other travel purposes. These elasticities are much smaller than for travel purpose work. The direct toll elasticity of the car driver mode is relatively low, about -0.014. All other modes have positive cross-elasticities and are about the same size. The direct toll elasticity of the car driver mode for tours that cross the cordon line is larger, about -0.06. Other modes have positive cross-elasticities of the same magnitude. These elasticities are for the group without a seasonal pass for cordon toll.

Table 4.10 Mode choice elasticities with respect to toll, other travel purposes

Elasticity of demand w.r to toll costs:	All Tours	Tours crossing cordon toll
Car/Driver	-0.014	-0.06
Car/Passenger	0.015	0.05
Public Transport	0.018	0.05
Walk/Bike	0.013	0.06

To conclude, the impact of the Oslo cordon toll scheme, separated from other factors, at the level of mode choice for travel purpose work has been small. The impact of the cordon toll scheme, at the level of mode choice for travel purposes other than work, seems less significant than for travel purpose work.

The low level of the elasticities should be viewed in the light of the low level of toll fee compared with other components of the marginal private car cost. The toll fee, in a round trip (a tour) contributes to about 15 to 20 percent of the total private marginal cost. An increase of 100 percent in the toll fee will increase the total private marginal cost by about 17 to 20 percent while decreasing the demand for mode car by 14 percent. That implies a direct demand elasticity of the private marginal car cost of about -0.7 to -0.8.

These results presented above indicate that the impact of the cordon toll scheme should have been an increase in the mode share of modes other than car driver, including car passenger, i.e., an increase in car occupancy, however small.

4.6 Summary and Conclusions

The Oslo cordon toll has been intended as a financing scheme. The different aspects of design of the scheme, i.e., the location of the toll stations, the level of toll fees, fees undifferentiated by the time of the day and the extensive use of the seasonal passes (with a 20 percent introductory reduction), have caused the scheme to produce a small impact on travel behaviour in the Oslo region. All these factors have contributed to the success of the cordon toll as a financing scheme.

During the first year of the operation of the Oslo toll scheme there was still a strong recession in Norway and in particular in the Oslo region. The impact of the recession on travel behaviour seems to have been significant.

The evaluation of the impact of the cordon toll scheme is based on the panel study of 1989-1990. However, cross-sectional models were applied for the these assessments. Different evidence points to attrition and under-reporting in the panel. Both these phenomena lead to a decline in observed mobility. With our evaluation of underreporting of trips by purpose and mode of travel, we assess a 5 percent decrease in car trips, in the Oslo/Akershus region from 1989 to 1990. The decrease has been due to the recession as well as the introduction of the cordon toll scheme.

Two alternative models were estimated to evaluate the impact of the cordon toll at the level tour frequency and trip generation. These were a linear regression model, used for tour frequency, and a recursive model structure, used to describe work trip generation, discretionary trip generation and tour frequency.

At the level of trip generation, the impact of toll costs on travel purpose work is not significant, while the impact on discretionary travel is significant. The toll fee elasticity of demand for discretionary trips is about -0.016. These models produce a similar toll elasticity of overall demand for car travel, in terms of tours, of about -0.026 to -0.038. The two models also produce similar decrease in car traffic in terms of tours - due to the cordon toll scheme and separated from other factors - of about 3.5 percent from 1989 to 1990.

A logit model for the choice of seasonal pass was estimated. The variables that explain the choice of seasonal pass point to a higher car mobility among the group with a seasonal pass. Mode choice models using data from 1989, before the introduction of the scheme, show larger utilities for modes "car driver" and "car passenger" for the group with seasonal pass in 1990. The examination of different mode choice models indicates that the marginal toll cost for those with a seasonal pass should be equal to zero. Furthermore, the utility of the car mode increases once a seasonal pass is obtained. These models also point to higher implicit values of time for the group with a seasonal pass. One implication is that the measure of users' benefits for the group with seasonal pass from a toll scheme should be higher than the rest.

The impact of the toll, at the level of mode choice, for travel purpose work has been small. The direct demand elasticity of the toll fee on demand for the car driver mode is relatively low. For those without a seasonal pass the direct demand elasticity with respect to the NOK 10 toll fee is about -0.14 for tours that cross the cordon toll line and -0.04 for all the tours. The group with a seasonal pass has a slightly lower toll elasticity if a single pass is used for the cordon toll crossing. All other modes have positive cross-elasticities of smaller magnitude. This indicates that the impact of the toll (separated from other factors, i.e., the effects of the recession, increases in gasoline prices and improvements in road network) should have been an increase in the mode share of other modes including car passenger; i.e., an increase in car occupancy, however small.

For discretionary travel purposes, the direct demand elasticity of toll fee on the demand of the car driver mode is only -0.06 for tours that cross the cordon toll line.

In summary, the impact of the cordon toll scheme is more significant at the level of mode choice for work travel, while for discretionary travel the impact seems to be more significant at the level of trip generation.

A toll fee of NOK 10 could be considered fairly high and one could have expected to produce a larger impact on travel behaviour. Yet as a marginal cost, this should be compared with the running cost of a car. The cost of gasoline in October 1990 was more than NOK 7 per litre. The average parking cost in the central part of Oslo is about NOK 31 per day. The low level of these elasticities is due to the low level of toll fee compared with other components of the marginal private car cost. The implied direct demand elasticity of the private marginal car costs is about -0.7 to -0.8. Additionally, car ownership expenses in Norway are among the highest in Europe. With the high level of fixed car cost in Norway, a higher marginal cost can be justified for using the car. The level-of-service of public transportation, i.e., as an alternative to the car, has been another factor that explains the low impact of the toll. Public transportation costs are comparable to the car running costs in most respects, with higher door-to-door time, that includes walking time, waiting time and transfers.

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Essay no. five

An Evaluation of the Impact of the Oslo Toll Scheme on Destination Choices and House Prices

5.1 Introduction

A transport policy induces changes in the transport market as well as changes in markets for labour, land and retail and service industries by changing the generalised cost of travel. Johansson and Mattsson (1995) illustrate the mechanisms for these adjustments in the case of road pricing with a stylised model. The design of a road pricing scheme has important consequences on its impacts. A criticism of a cordon toll scheme is that short trips are affected to a larger extent than long distance trips. Consequently, households, businesses and properties which are located close to the toll ring will have to bear a larger burden than others. In the case of Oslo, where road pricing has been introduced in the form of a toll ring that is located 3 to 8 km from the city centre and with relatively low toll fee, these adverse effects ought to be fairly small. Nevertheless, the evaluation of these impacts is quite important.

The purpose of this study is to evaluate the impacts of the Oslo toll scheme on destination choices during its first year of operation and to analyse the effects on house prices.

In a previous study the impacts of the Oslo toll scheme on tour frequency, trip chaining and mode choice were found to be small (Ramjerdi, 1995). This study also indicated that there was no evidence of a relationship between changes in home and work locations and the introduction of the toll scheme. This suggests that the introduction of the Oslo toll scheme did not have any impact in the short-run on the destination choices of compulsory trips, such as commuting, business and education. However, the study suggests that the toll scheme may have had an impact on the destination choices of discretionary trips such as shopping and recreation, even in the short-run.

The Oslo toll ring opened in February 1990. A two-wave panel study conducted in the Oslo region in 1989 and 1990 provides for the main data for these evaluations. There is much evidence of attrition and underreporting in the panel study of 1989-90[1]. However, with some qualifications the panel study will be used to trace the impacts mentioned above.

The organisation of this paper is as follows. First we describe the panel study of 1989-90. The next two sections focus on the evaluation of the impacts of the Oslo toll scheme on destination choices for compulsory and discretionary travel. Then the impacts of the toll scheme on house prices will be analysed. In the final section we summarise the findings of the study.

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[1] Attrition is the phenomenon where some respondents drop out of the panel. Underreporting is the phenomenon where some respondents who are part of the panel underreport their mobility.

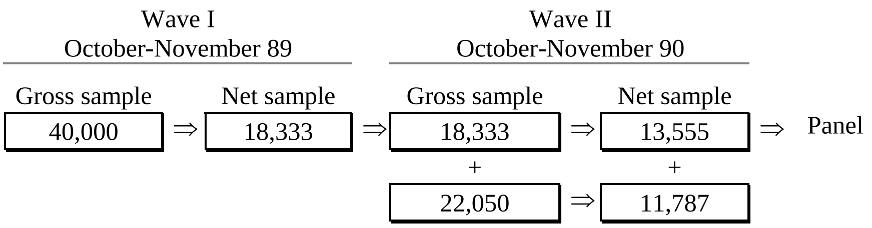
5.2 The Panel Study of 1989-1990

A two-wave panel study was conducted to evaluate the impacts of the Oslo toll scheme on travel behaviour. The first wave was conducted in October-November 1989, about 3 months before the introduction of the Oslo toll scheme. The second wave was conducted exactly one year later, in October-November 1990. An almost identical mail-back questionnaire, including a one-day travel diary, was used in each wave of this two-wave panel study.

In the first wave the questionnaire was sent to a random sample of 40,000 individuals of age 13-75 in the Oslo region. The response rate in the first wave was 46 percent[2]. In the second wave the questionnaire was sent to the respondents in the first wave plus an additional random sample of about 22,000 individuals.

The response rate of the respondents from the first wave was 74 percent. The response rate in the additional sample was only 53 percent. Hence, the response rate in the net sample in 1990 was 41 percent and the response rate in the panel is only 34 percent. Figure 5.1 is a schematic presentation of the panel study of 1989-90.

Figure 5.1 A schematic presentation of the panel study of 1989-1990.



Tables 5.1 and 5.2 show the changes in demand for travel by purposes in the panel and in the net sample of the panel study of 1989-90 respectively.

An earlier study produced different sets of evidence that indicated attrition and extensive underreporting in the panel study of 1989-90 (Ramjerdi, 1995). The comparison of the trend in retail trade in Oslo with the changes in the reported shopping trips is also interesting in this context (see table 5.3). Although there was a substantial decrease in employment in the retail trades,

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[2] By response rate we mean the ratio of responses that could be used to the number of questionnaires that were sent out. Three percent of the responses were excluded, mainly because of unspecified addresses on the returned questionnaires.

Table 5.1 Changes in travel demand by purpose, based on the panel data.

	1989	1990	% change 1989-90[a]
Net sample	13,555	13,555	
Reported no. of trips	36,136	32,125	-11
Average no. of trips per person	2.67	2.37	-11
Total no. of trips by purpose:			
Work and Education	7,811	7,135	- 9
Business	2,140	2,047	-4
Shopping and Private business[b]	6,711	5,601	-17
Recreation	3,148	2,731	-13
Social visit	2,159	1,659	-23
Home trip[c]	14,167	12,952	- 9

[a] % change 1989-90 = 100*[(entry in 1990)/(entry in 1989)-1].

[b] Includes daily & other shopping, private business and accompanying others.

[c] A trip where the destination is one’s home.

Table 5.2 Changes in travel demand by purpose, based on the net sample.

	1989	1990	% change, 1989-90
Net sample[a]	18,333	25,342	+38
Reported no. of trips[b]	47,825	57,338	-13
Average no. of trips per person[a]	2.61	2.26	-13
Total no. of trips by purpose[b]			
Work and Education	10,889	13,323	-11
Business	2,853	3,542	-10
Shopping and private business [c]	8,632	9,603	-20
Recreation	2,420	2,872	-14
Social visit	2,904	3,017	-25
Home trips[d]	20,127	24,981	-10

[a] % change 1989-90 = 100*[(entry in 1990)/(entry in 1989)-1].

[b] % change 1989-90 = 100*[(sample size in 1989/sample size in 1990)*
(entry in 1990)/(entry in 1989)-1].

[c] Includes daily & other shopping, private business and accompanying others.

[d] A trip where the destination is one’s home.

total retail sales in Oslo decreased by only 1 percent from 1989 to 1990, and the number of businesses increased by about 2 percent in the same period. As we shall see later the reported decrease in this period in trips for daily shopping was 23 percent and in trips for other shopping was 27 percent (see table 5.9). The reported decrease in shopping trips is thus much higher than the decrease in retail sales. If we believe that these data are correct the amount of transactions per shopping trip has increased by about 30 percent on the average in the Oslo region, and it increased even more for the trips that were not affected by the toll scheme. This suggests a major change in shopping behaviour in the Oslo region that is intuitively difficult to accept, at least as a short-run effect. It is more likely that the outcome is the result of underreporting and attrition.

Table 5.3 Trend in the retail trade in Oslo 1980-1992 (1980 = 100).

Year	No. of businesses	Employment	Total sales [a]
1980	100	100	100
1982	99	95	90
1984	100	96	94
1986	106	95	114
1988	107	95	99
1989	103	90	93
1990	105	80	92
1991	108	85	91
1992	113	82	95

[a] Retail sales in 1980 prices (Source: Statistisk årbok for Oslo, 1994).

The response rate in the first wave was only 46 percent, and the response rate in the additional sample in the second wave was 53 percent. These are fairly low response rates, and there is a possibility that the respondents had a lower mobility with respect to unobserved characteristics[3]. The Oslo/Akershus Travel Study of 1990-91 indicates this possibility (Vibe, 1991). The respondents in that survey reported 3.35 trips per day on the average, which is much higher than the corresponding figures in the panel study (see tables 5.1 and 5.2). Part of the difference can be explained by the differences in the methods of survey. The Travel Study of 1990-91 was conducted by telephone. However, the possibility of a lower mobility among the respondents in the panel study can be evaluated by comparing the trip rate per person per day for different travel purposes and different modes.

Twenty six percent of the respondents in the panel dropped out between waves one and two which suggests a high attrition rate. Part of the attrition may be related to the observed characteristics of the respondents. Kitamura and Bovy (1987) suggest that attrition is related to high mobility characteristics. As a result of attrition in the panel, the sample's mean of mobility is not a correct estimate of the population mean. However, attrition

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[3] The net samples in 1989 and 1990 and the sample in the panel give good representations of the population in the Oslo region with respect to observed characteristics (Hjorthol and Larsen, 1991).

can also be related to unobserved characteristics of those who stay in the panel that are important for the selection. There are now relatively sophisticated methodologies available for correcting for attrition. See Meurs (1991) for a review of these.

A clear example of underreporting in the panel is the percentage of respondents who reported no travel in 1990 compared with 1989. The percentage of respondents who had reported no travel in 1989 was 20.6 percent. This percentage increased to 25.5 percent in 1990 (Ramjerdi, 1995). Among the respondents who had reported travel, the average number of trips per person per day was 3.36 in 1989 and 3.18 in 1990. The decrease is only 5 percent compared to 11 percent in the total sample (see table 5.1). Underreporting is usually difficult to correct for.

With all the evidence that we have provided on the low quality of the data, we must still remember that the panel study of 1989-90 is the only data source available for the evaluation of the impacts of the Oslo toll ring. Furthermore, different studies suggest that some of these qualifications will not have a large effect on the estimates of the coefficients of the models that are used for these evaluations (Meurs, 1991). Given the above mentioned qualifications, the panel study will be used for the evaluation of the impacts of the cordon toll scheme on destination choices and house prices.

The *panel*, consisting of 13,555 respondents who took part in both waves, will be used to evaluate the impacts of the toll scheme on destination choices of compulsory travels. These impacts will be traced through changes in home and work locations. The sample in the panel gives a good representation of the population in the Oslo region in this respect (Ramjerdi, 1992a; Hjorthol and Larsen, 1991).

The *net samples* in 1989 and in 1990 will be used as cross-sectional data for the evaluation of the impacts of the toll scheme on the destination choices of discretionary travel. There is a large day-to-day variation in individuals' behaviour in discretionary travel compared to compulsory travel. Other members of an individual's household can execute the activity that is connected with discretionary travels (e.g., shopping) and the activity is not always executed on the same day of a week. Hence, the net samples will provide a larger set of data for analysis.

5.3 Impacts on Destination Choices of Compulsory Travels

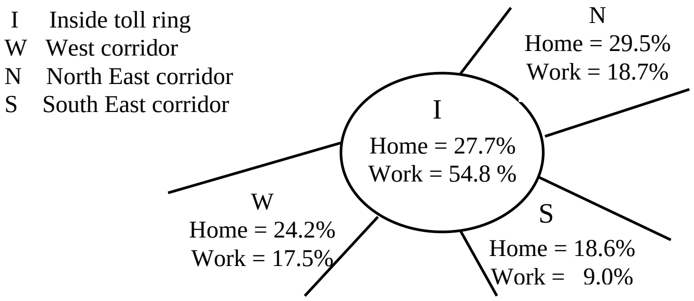
Any change in the destination choices for compulsory travel, such as work, education and business, could be traced back to changes in people's place of dwelling, work or study. These are usually not regarded as short-term changes. The level of the toll fee (NOK 10 in 1990 for a single pass) is not high enough to compensate for the transaction cost associated with changes of work or home locations. Consequently, it does not seem likely that changes in work and home locations are directly related to the introduction of the scheme. However, it is possible that those who are in the process of making a change in home or work locations consider the location of the toll ring in their decisions. In this section we examine the changes in home and work location patterns in the Oslo region related to the toll scheme in its first year of operation.

For the evaluation of changes in housing and work location patterns in the Oslo region, the panel data of 1989-90 is used. However, it is important to point out that the panel study of 1989-90 was a survey of individuals. Any changes in home location are most likely household decisions. In the following we shall evaluate these changes by examining the pattern of changes in housing and work locations in relation to

- the location of the toll ring, and
- the number of toll crossings between home and work locations.

Figure 5.2 shows the home and work location patterns in the Oslo/Akershus region in relation to the toll ring. About 28 percent of the home locations are inside the toll ring, compared with 55 percent of the work locations. The remaining home locations are almost equally distributed among the three corridors. The distribution of work locations among the three corridors is not as even.

Figure 5.2 Home and work location patterns in the Oslo region, 1989.



5.3.1 Reported Changes in Home Locations

Out of 13,555 respondents in the panel, 625 reported a change in home location in the Oslo region from 1989 to 1990. Among the respondents who reported a change in home location, 346 reported no change in work location. Table 5.4 shows the reported changes in home locations in relation to the toll ring. Table 5.5 shows the number of toll crossings from home to work for those who changed home location but did not change work location.

The null hypothesis postulates that the introduction of the toll did not influence the changes in home location during the first year that it was in effect, i.e. that the changes in home location related to the location of the toll ring, as depicted in tables 5.4 and 5.5, should be symmetrical. The statistical tests on the symmetry of the tables are presented under these tables.

In general, symmetry in a two dimensional square $I \times I$ table implies

$$x_{ij} = x_{ji}$$

where x_{ij} is the observed count in the (i, j) entry. It is possible to assume that these $\{x_{ij}\}$ are observations on independent Poisson variates with a mean $\{m_{ij}\}$ or an observation on a multinomial variate with cell probabilities $\{p_{ij} = m_{ij}/N\}$, where $\Sigma m_{ij} = \Sigma x_{ij} = N$. The model of symmetry can be represented by a log-linear model. The goodness-of-fit statistics used to test the model of symmetry are

$$G^2 = 2\sum_{i \neq j} x_{ij} \ln(2x_{ij} / (x_{ij} + x_{ji}))$$

or

$$X^2 = \sum_{i > j} (x_{ij} - x_{ji})^2 / (x_{ij} + x_{ji})$$

Both have asymptotic χ-square distributions with $n = I(I-1)/2$ degrees of freedom under the null hypothesis of symmetry (Bishop et al., 1974).

The statistical tests suggest that tables 5.4 and 5.5 are symmetrical. The null hypotheses for these tables can not be rejected at a 5 percent significance level. Hence, it can not be concluded that the changes in home location in the period of 1989 to 1990 have been related to the introduction of the toll scheme. It is possible to calculate the total number of toll crossings between home and work locations by adding the entry with one toll crossing to twice the entry with two toll crossings in 1989 and to compare the result with the corresponding result for 1990. Hence, even when the statistical tests support that a table is symmetrical there could be a significant change in the total number of toll crossings. Table 5.5 shows that the total number of toll crossings between home and work locations decreased from 216 in 1989 to 207 in 1990, a decrease of about 4 percent which is not significant at 10 percent level.

The incentive to change home location in order to avoid toll payment (a yearly pass for toll crossing was NOK 2,200 in 1990) should be compared with other incentives for suburbanisation, such as differences in local taxes. Unlike any of the neighbouring municipalities Oslo has a municipal property tax. This property tax amounts to 4‰ of the tax base (where the tax base is equal to 35% of the market price of the property) in 1989, and 4.2 ‰ in 1990. This amounts to an additional tax on property in Oslo of about NOK 1,400 /year for a house with a market price of NOK one million.

Table 5.4 Changes in home location from 1989 to 1990, in relation to the toll ring.

Home location	**I, 90**	**W, 90**	**N, 90**	**S, 90**	**Total, 89**
I, 89	140	72	41	36	289
W, 89	68	64	6	8	146
N, 89	49	7	45	15	116
S, 89	36	6	11	21	74
Total, 90	293	149	103	80	625

Number of missing observations: 0

$G^2 = 1.808$ & $X^2 = 1.803$ $\chi^2_{p,6} = 1.635,\ p = 0.05$

$I = 4 \Rightarrow n = 6$ $\chi^2_{p,6} = 2.204,\ p = 0.10$

Table 5.5 Changes in the number of toll crossings between home and work locations for those who changed home but not work location.

No. of toll crossings from home to work	**Zero, 90**	**One, 90**	**Two, 90**	**Total, 89**
Zero, 89	100	65	18	183
One, 89	62	50	0	112
Two, 89	24	0	28	52
Total, 90	186	115	46	346

Number of missing observations: 0

$G^2 = 0.931$ & $X^2 = 0.928$ $\chi^2_{p,3} = 0.584,\ p = 0.10$

$I = 3 \Rightarrow n = 3$ $\chi^2_{p,3} = 1.213,\ p = 0.25$

5.3.2 Reported Changes in Work Location

There were more respondents who reported a change in work location than in home location in the period of 1989 to 1990. Out of 13,555 respondents in the panel, 9,565 respondents reported a work location in 1989 and 1990. Of these, 1,926 reported a change in work location in the Oslo region. Table 5.6 shows the reported changes in work location in relation to the toll ring.

There were 1,776 respondents who had only changed their work location. The rest had changed both home and work locations. Table 5.7 shows the number of toll crossings between home and work locations for those who changed work location but did not change home location.

The statistical tests presented in these tables show that symmetries in these tables can be rejected at about a 5 percent significance level. An examination of table 5.6 suggests that employment locations are moving from the centre to the suburbs. This will reduces the differences in home and work locations and would be in agreement with the expected response to the toll ring. However, this trend may be unrelated to the toll scheme. The former hypothesis is supported by table 5.7 that shows that the total number of toll crossings between home and work locations increased from 1,120 in 1989 to 1,188 in 1990, an increase of about 6 percent which is significant at 5 percent level. This increase is in contradiction to the expected effects of the toll scheme.

There were 150 respondents who had changed both work location and home location. Table 5.8 shows the number of toll crossings between home and work for those had changed both home location and work location.

The changes in home and work locations from 1989 to 1990 do not seem to be significantly related to the introduction of the toll scheme. Rather, it is possible to detect the ongoing trends in the changes of the land use pattern in the Oslo region. The analysis presented here does not assess to what extent the introduction of the toll scheme has affected these trends.

Table 5.6 Changes in work location from 1989 to 1990, in relation to the toll ring.

Work Location	**I, 90**	**W, 90**	**N, 90**	**S, 90**	**Total, 89**
I, 89	857	182	131	73	1243
W, 89	178	118	17	9	322
N, 89	96	30	100	12	238
S, 89	59	4	15	45	123
Total, 90	1190	334	263	139	1926

Number of missing observations: 3990

$G^2 = 12.900$ & $X^2 = 12.777$ $\chi^2_{p,6} = 12.59,\ p = 0.950$

$I = 4 \Rightarrow n = 6$ $\chi^2_{p,6} = 14.45,\ p = 0.975$

Table 5.7 Changes in the number of toll crossings between home and work locations for those who had changed work but not home location.

No. of toll crossings from home to work	Zero, 90	One, 90	Two, 90	Total, 89
Zero, 89	545	186	118	849
One, 89	208	456	70	734
Two, 89	79	58	56	193
Total, 90	832	700	244	1776

Number of missing observations: 3862

$G^2 = 10.127$ & $X^2 = 10.074$ $\chi^2_{p,3} = 9.348$, $p = 0.975$

$I = 3 \Rightarrow n = 3$ $\chi^2_{p,3} = 11.340$, $p = 0.990$

Table 5.8 Changes in the number of toll crossings between home and work locations for those who had changed both work and home locations.

No. of toll crossings from home to work	Zero, 90	One, 90	Two, 90	Total, 89
Zero, 89	49	29	12	90
One, 89	26	5	7	38
Two, 89	12	8	2	22
Total, 90	87	42	21	150

Number of missing observations: 128

$G^2 = 0.230$ & $X^2 = 0.230$ $\chi^2_{p,3} = 0.216$, $p = 0.025$

$I = 3 \Rightarrow n = 3$ $\chi^2_{p,3} = 0.352$, $p = 0.050$

5.4 Impacts on Destination Choices of Discretionary Travels

The analysis of the panel study of 1989-90 shows that discretionary (non-work) travel accounts for more than 50 percent of the trips in the Oslo region (work and education account for less than 40 percent and business 10 percent). Transportation demand modelling has traditionally failed to focus on discretionary travel. This has partly been due to the difficulties of modelling discretionary travel compared with work travel. There is greater flexibility in the frequency, timing and destinations associated with discretionary travel. Another factor has been the high frequency of work travel during peak periods. With the policy focus on capacity expansion, a good travel demand model for the travel purpose work seemed to be sufficient. Except for some efforts related to modelling shopping behaviour (see for example Bacon, 1993; Algers and Widlert, 1992; Goulias and Kitamura, 1989), there do not seem to be many analyses in the literature that address other discretionary travel purposes. The increase in the share of discretionary travel coupled with the shifts in policy from capacity expansion to efficient use of the existing transportation system as well as greater concern with environmental impacts of the transportation sector show that there is a need for improvement in modelling the demand for this category of travel.

The impacts of the Oslo toll scheme on discretionary travel at the levels of mode choice and frequency of travel were reported in an earlier study (Ramjerdi, 1995). At the level of mode choice the impact was reported to be small. The mode choice elasticity for car with respect to toll cost was estimated to be -0.06. The average toll fee elasticity of trip frequency was reported to be about -0.04.

In this section we address the impacts of the Oslo toll scheme on destination choices for discretionary travel. These impacts can be analysed from two perspectives: the impacts on businesses and the impacts on households.

One expectation is that the impact of the Oslo toll scheme is more significant for destinations (businesses and services) that are in the vicinity of the toll ring and that the impacts decrease with increasing distance from the toll ring.

Another expectation is that the toll ring has a larger impact on destination choices for those who live in the vicinity of the toll ring and that the impacts decrease with increasing distance from the toll ring.

This evaluation is based on the net sample of the panel study of 1989-90. For the evaluation of the impact of the Oslo scheme on destination choice for discretionary travel we exclude the travel purpose "accompanying others". The destination choice for this travel purpose is not usually very flexible (e.g., child care centre). Furthermore we confine our analysis to trips that have their origins at one's home. Given this criterion, most of discretionary trips that are chained with compulsory trips will be excluded. Table 5.9 shows changes in the reported discretionary trips in relation to the purpose of travel from 1989 to 1990, based on the net sample.

Table 5.10 shows the reported change in discretionary trips, in relation to the purpose of travel and in relation to the number of toll crossings between the origin and destination of a trip, from 1989 to 1990. Table 5.10 shows a larger decrease for all travel purposes than table 5.9. Reported trips with a missing mode of travel or destination are not included in table 5.10. The differences between tables 5.9 and 5.10 are explained by the larger number of trips that are excluded based on missing modes and some missing destinations in 1990.

Table 5.9 Changes in discretionary trips in relation to the purpose of travel, based on the net sample, 1989 to 1990.

Travel purpose:	All trips			Trips with origin in the home		
	1989	1990	% change, 1989-90[a]	1989	1990	% change, 1989-90[a]
Daily shopping	2 146	2 287	-23	1251	1323	-24
Other shopping	1 651	1 676	-27	913	925	-27
Private business	1 918	2 112	-20	1055	1176	-19
Recreation	2 420	2 872	-14	1750	2037	-16
Social visit	2 904	3 017	-25	1778	1875	-24
Total	11 039	11 964	-22	6747	7336	-21

[a] % change 1989-90 = 100*[(sample size in 1989/sample size in 1990)* (entry in 1990)/(entry in 1989)-1].

Table 5.10 Changes in discretionary trips in relation to the number of toll crossings, 1989 to 1990.

Travel Purpose:	All trips		% change 89-90 No. of toll crossings			
	1989	1990	zero	one	two[a]	total
Daily shopping	1276	1186	-31	-22	+34	-29
Other shopping	777	692	-33	-31	-23	-32
Private business	842	794	-27	-29	-30	-28
Recreation	1527	1540	-20	-29	-31	-23
Social visit	1753	1539	-32	-30	-45	-33
Total	6175	5751	-29	-29	-33	-29

[a] based on 13 to 57 observations.

Table 5.10 shows that the change in number of discretionary trips from 1989 to 1990 is fairly indifferent to the number of toll crossings (between home and the destination of a trip). The reduction for travel purpose recreation was smaller for the trips that did not cross the toll ring than for those that did. However the pattern of reduction for travel purpose shopping is the opposite of that for travel purpose recreation.

It should be pointed out that about 70 percent of all discretionary trips were by travel car mode (driver or passenger) in 1989. The rest were equally divided between public transportation and walk/cycle.

Based on the net sample of the Oslo panel study of 1989-90 the impacts of the toll scheme on discretionary travel at the levels of mode choice and frequency seem small. Assuming that the Oslo toll scheme in its first year of operation had little impact on the frequency and mode choice of discretionary trips, we shall analyse the impacts on the destination choices from the two perspectives we explained earlier:

First perspective: The impacts of the Oslo toll scheme on destination choices in relation to the distances of the destinations (locations of businesses and services) from the toll ring.

Second perspective: The impacts of the Oslo toll scheme on the travel behaviour of households, in terms of changes from destinations that require crossing the toll ring to alternative locations that do not require crossing the toll ring, in relation to the distances of home locations from the toll ring.

We start with the assumption based on the conclusions above, that there was no significant change in either the frequency or mode share of discretionary travel after the introduction of the toll scheme. That implies that all observed changes come from changes of destination. The introduction of the toll scheme would cause some travellers who used to cross the toll ring in 1989 to choose a destination that did not require crossing the toll ring in 1990. The probability of a change would depend on the availability and attractiveness of alternative destinations that did not require crossing the toll ring in 1990 and on the differences in the car cost (time and money costs including toll fee) of the chosen destination in 1989 and the potential destinations in 1990. Furthermore, we expect that the probability of a change will decrease with distance from the toll ring. In examining the resulting shifts, one can compare shifts in probability density functions of destination choices (over distance from the toll ring) for 1989 and 1990 for the trips that did not pass the toll ring and the trips that did pass it.

5.4.1 Changes in Destination from the First Perspective (Location of Businesses and Services)

Table 5.11 shows the frequency distribution of destination choices, in relation to the number of toll crossings in 1989 and 1990 for all modes of transport. The preparation of data for this table is based on the first perspective, mentioned above. The examination of this table suggests that the overall shifts in destinations have been significant for car and walk/cycle modes.

We pointed out earlier that the total share of the walk/cycle mode was about 15 percent compared with 70 percent for car (driver and passenger) in 1989. The shifts for walk/cycle in relative terms seem large. However, the shifts in absolute terms are not so large because of the small number of observations, especially for the trips that crosses the toll ring. We shall confine our analysis to the travel car mode only. Table 5.11 also shows that there has been some overall shifts in destinations for different discretionary travel purposes with the car mode.

Table 5.12 shows the frequency distribution of destination choices for various distance intervals of destinations (businesses and services) from the toll ring, in relation to the number of toll crossings between home location and destination, by car mode. The preparation of data for this table is based on the first perspective.

To analyse shifts in destination choices, a number of probability density functions were examined (with *STATGRAF* software). A Weibull distribution seems to fit the observed distribution best. *SHAZAM* (an Econometrics Computer Program) was used for the estimation of the parameters of the probability density function.

A random variable *X* has a Weibull distribution function if its probability density function is given by:

$$f_X(t) = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} \exp\left[-\left(\frac{t}{\eta}\right)^{\beta}\right] \quad t \geq 0 \qquad \eta, \beta > 0$$

$$= 0 \text{ otherwise}$$

where η is the scale parameter and β is the shape parameter.

Table 5.13 shows the estimates of parameters for Weibull distribution functions for data in table 5.12 related to the first perspective. Figure 5.3 shows Weibull distribution functions for destination choices in relation to the distance of the destination (businesses and services) from the toll ring, and the number of toll crossings between home and destination, with the car mode.

The examination of Figures 5.3 (a) and (b) shows that the directions of the shifts in destination from locations that required a toll crossing to locations that did not require one have been as expected. The frequency distribution functions for 1990 have shifted to the right of the frequency distribution functions for 1989. Businesses and services that are located closer to the toll ring seem to have been affected more by these shifts in destination. In a similar manner these impacts were evaluated by looking at the destinations (businesses and services) that were located inside and outside the toll ring (these results are not presented in this essay). These impacts seem to be slightly more pronounced for the destinations that were located outside the toll ring.

To change a destination from a location that requires a toll crossing to a destination that does not, one should travel farther or make compromises on the attractiveness of the new destination. These shifts in destination are likely to increase the average trip distance. It is however difficult to draw any conclusions about the changes in the average trip distance because of the quality of the data.

Table 5.11 Distribution of discretionary trips in relation to the number of toll crossings, by modes

(1) Car

Travel purpose:	No. of toll crossings, 1989				No. of toll crossings, 1990			
	zero	one	two	Total	zero	one	two	Total
Daily shopping	19	2	0	21	19	2	1	22
Other shopping	11	3	0	15	10	2	0	13
Private business	12	4	1	17	13	4	0	18
Recreation	16	6	1	23	17	5	1	23
Social visit	14	9	2	25	15	8	2	25
Total	72	24	4	100	75	21	4	100

(2) Car passenger

Travel purpose:	No. of toll crossings, 1989				No. of toll crossings, 1990			
	zero	one	two	Total	zero	one	two	Total
Daily shopping	11	1	0	13	12	2	0	14
Other shopping	9	4	0	13	9	3	0	13
Private business	8	3	0	11	8	3	0	12
Recreation	22	7	2	30	22	7	1	31
Social visit	18	10	3	32	17	10	3	30
Total	69	25	6	100	69	26	5	100

(3) Public transport

Travel purpose:	No. of toll crossings, 1989				No. of toll crossings, 1990			
	zero	one	two	Total	zero	one	two	Total
Daily shopping	4	1	0	5	4	2	0	7
Other shopping	10	7	0	17	10	7	0	17
Private business	11	11	0	22	11	10	1	21
Recreation	16	13	1	29	15	13	1	29
Social visit	11	13	2	26	11	13	2	26
Total	52	44	4	100	51	45	4	100

(4) Walk/Cycle

Travel purpose:	No. of toll crossings, 1989				No. of toll crossings, 1990			
	zero	one	two	Total	zero	one	two	Total
Daily shopping	29	1	0	31	24	1	0	25
Other shopping	9	0	0	9	9	1	0	10
Private business	11	0	0	11	11	1	0	12
Recreation	25	2	0	27	32	3	0	35
Social visit	22	0	0	22	15	2	0	17
Total	95	5	0	100	91	8	1	100

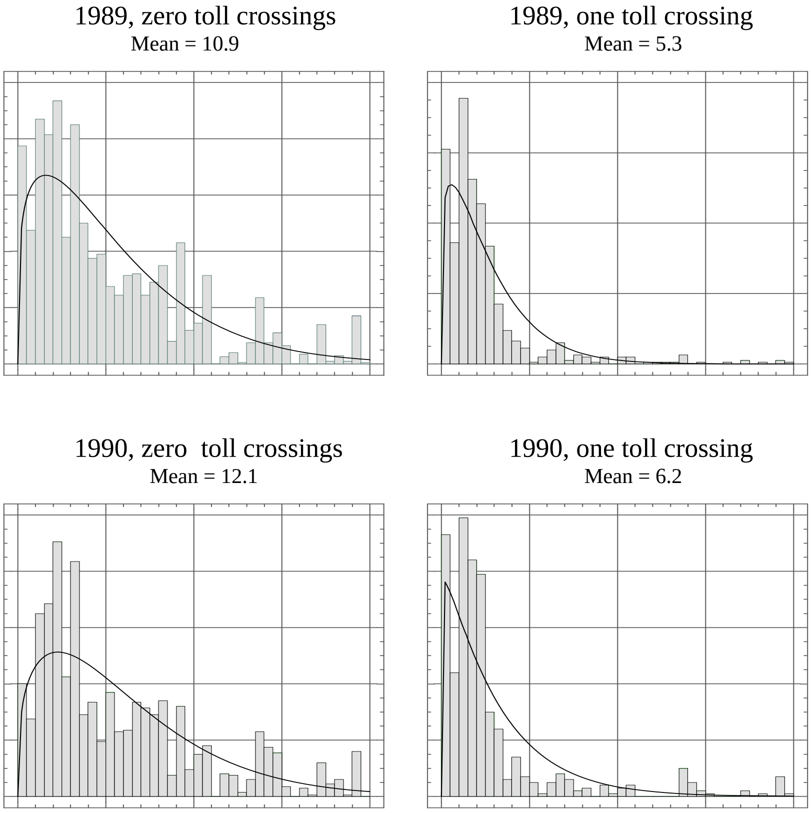
Table 5.12 Distribution of destination choices for various distances of destinations (business and services) from the toll ring in relation to the number of toll crossings for car mode (first perspective), per mil.

Distance band, km	1989 No. of toll crossings				1990 No. of toll crossings			
	zero	one	two	Total	zero	one	two	Total
1 (0-1)	25	27	4	57	20	25	1	46
2 (1-2)	46	28	5	79	27	22	2	51
3 (2-3)	37	25	2	64	30	21	2	53
4 (3-4)	58	47	2	107	54	44	1	99
5 (4-6)	98	58	6	163	115	48	3	166
6 (6-8)	91	22	5	118	93	14	5	112
7 (8-10)	31	6	2	39	29	6	1	37
8 (10-15)	105	10	5	121	119	11	6	136
9 (15-20)	78	5	3	86	85	4	3	92
10 (20-30)	65	5	3	73	80	9	5	94
11 (30-40)	37	3	2	41	47	5	3	56
12 (40-50)	16	1	1	17	19	2	2	23
13 (50 +)	34	0	1	35	31	1	2	34
Total	722	238	40	1000	750	213	37	1000

Table 5.13 Parameters for the Weibull distribution function (first perspective).

	Shape	t-value	Scale	t-value
<u>Zero toll crossings:</u>				
1990	1.33	55.35	13.15	56.17
1989	1.25	59.52	11.73	56.95
t-value (Difference 1990-89)	2.49		4.91	
<u>One toll crossing:</u>				
1990	1.05	33.38	6.31	24.45
1989	1.18	39.28	5.57	31.85
t-value (Difference 1990-89)	-3.02		2.44	

Figure 5.3 The Weibull distribution function for destination choices for various distances of destinations (businesses & services) from the toll ring in relation to the number of toll crossings (first perspective) 1989 and 1990.



1989, zero toll crossings
Mean = 10.9

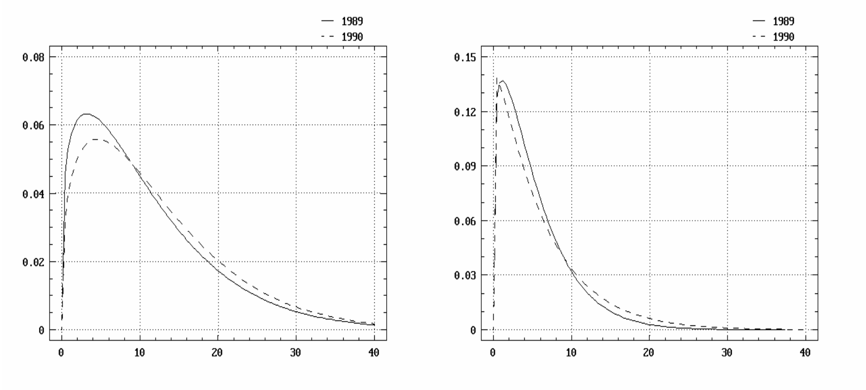
1989, one toll crossing
Mean = 5.3

1990, zero toll crossings
Mean = 12.1

1990, one toll crossing
Mean = 6.2

(a) zero toll crossings

(b) one toll crossing



To test whether these shifts in destination are statistically significant, one can examine the differences between the estimates of the parameters of the Weibull distribution functions and assess the estimates by means of a t-statistics that can formulated as

$$t = (\alpha_i - \alpha_j)/[(\alpha_i/t_i)^2 + (\alpha_i/t_j)^2]^{1/2}$$

where α_i and α_j are the parameters and t_i and t_j are the t-statistics ($i = 1990$, $j = 1989$) shown in table 5.13. The t-values for the difference between the parameters of the Weibull distributions are shown in the same tables.

The examination of the t-values of the differences in the parameters of Weibull distribution functions presented in table 5.13 suggest that the impacts of the toll scheme on destination choices have been statistically significant for the location of destinations (location of businesses and services) that were located closer to the toll ring. However, the extent of the impacts is small. The small impact of the toll scheme on destination choices has been due to the deliberate choice of the location of the toll ring in order to minimise these impacts (for a description of the design of the Oslo toll scheme see Ramjerdi, 1994).

5.4.2 Changes in Destination from the Second Perspective (Households)

Table 5.14 shows the frequency distribution of destination choices for distance intervals of home locations from the toll ring, in relation to the number of toll crossings between home and destination, for car mode. The preparation of data for this table is based on the second perspective. We have excluded discretionary trips that are chained with compulsory trips or other discretionary trips. Out of a total of 3,391 trips, 1,827 trips were by car mode. There were few observations with two toll crossings between home and destination. Hence, these observations are not included in the analysis. The examination of this table shows that the percentage of trips that had zero toll crossings has increased in almost all distance bands. The overall increase is significant.

Figure 5.4 shows the changes in the percentage of trips with zero toll crossings for various distance intervals of home locations from the toll ring from 1989 to 1990. The changes in destination from a location that requires a toll crossing to a destination that does not require one seem to have been influenced by the availability and attractiveness of alternative new destinations. The changes are much more pronounced for the households which were located in the inner city and close to the toll ring. The changes

Table 5.14 Distribution of destination choices for various distances of home locations from the toll ring, in relation to the number of toll crossings for car mode (second perspective).

Distance from the toll ring:	1989 No. of toll crossings			1990 No. of toll crossings			Percentage of trips with zero crossings	
distance band, km	zero	one	Total	zero	one	Total	1989	1990
Inside the toll ring:								
5-8	122	38	160	138	23	161	76	86
3-5	113	43	156	101	25	126	72	80
0-3	37	19	56	38	12	50	66	76
Next to the toll ring[a]	36	26	62	19	7	26	58	73
Outside the toll ring:								
0-3	41	44	85	31	29	60	48	52
3-5	53	81	134	43	28	71	40	61
5-7	71	54	125	52	39	91	57	57
7-9	103	49	152	79	38	117	68	68
9-11	59	22	81	55	20	75	73	73
11-13	129	41	170	81	18	99	76	82
15-20	124	48	172	101	15	116	72	84
20-25	81	25	106	22	7	29	76	82
25-30	18	8	26	29	4	33	69	86
30-40	39	11	50	39	6	45	78	88
Total	1026	509	1535	828	271	1099	67	75

[a] Trips reported by households located in the same traffic zone as the toll ring.

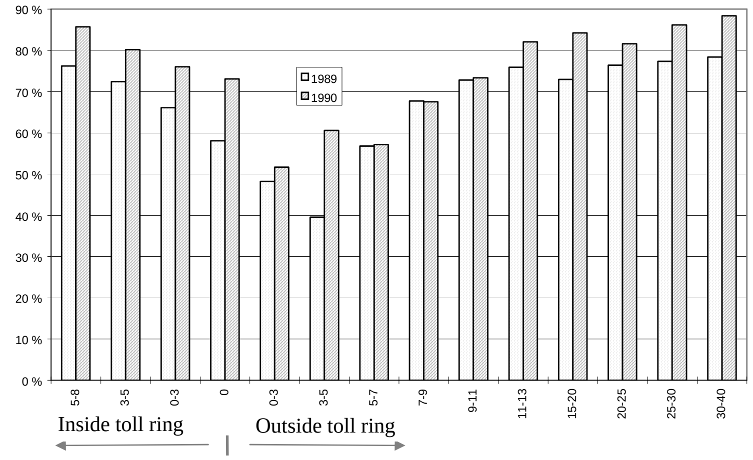


Figure 5.4 Percentage of trips with zero toll crossings for various distance intervals of home location from the toll ring in 1989 to 1990.

are quite small for the households located 5 to 11 kilometres outside the toll ring. The availability of different suburban centres outside the toll ring might explain this.

5.5 The Impacts of the Oslo Toll Scheme on House Prices

Arnott and Stiglitz (1981, p. 331) remark "That there exists a relationship between land rents and transport costs has been recognised at least since the time of von Thünen. The precise relationship between the two is, however, not generally well understood". The situation today does not seem to be very different from that at the beginning of the eighties. Anderstig and Mattsson (1992) provide an overview of the theoretical debate about the relation between the two. A transport project changes the cost of transport and consequently the demand for transport. In the new market equilibrium prices and quantities of other goods will change, including land price or rent and land use. The relationship between all the benefits from a transport project and the changes in rents is the subject of debate.

Most empirical studies on the evaluation of the relationship between property values and changes in transport services rely on hedonic pricing theory. The theory implies that the price of a property reflects the expected future benefits of the characteristics of the property. The characteristics of a property usually include broad categories such as physical characteristics of the property, market conditions, and external characteristics. For a survey of this approach see Brookshire et al. (1982).

There were two main reasons for not using a hedonic pricing approach for the evaluation of the impacts of the Oslo toll scheme on property prices. Data on selling prices of properties in the Oslo region (that includes some of the characteristics of the property) have been taken from the governmental register of properties. These data do not adequately cover all the necessary characteristics of the properties. Furthermore, these data have been collected only since the beginning of 1988.

The debate about the introduction of a toll scheme in Oslo started much before the Norwegian Parliament approved it in the summer of 1989. Evidence suggests that land value could adjust with anticipated changes in transportation (McDonald and Osuji, 1995). In principle, with the approval of the toll scheme all the impacts of the toll scheme should have been capitalised in the property values.

The data on selling prices of houses have been used for the estimation of the changes in house prices in different districts in Oslo since 1988[4]. Table 5.15 shows the percentage decrease in house prices in different districts in Oslo during the period 1988-1994. Figure 5.5 shows the percentage decrease in house prices in different districts in Oslo, from 1st quarter, 1988 to 1st quarter, 1990. The decrease ranges from about 10 percent to 27 percent. The observed reductions reflect the collapse of the housing market in Oslo rather than a response to the Oslo toll scheme or other transport projects in Oslo.

Table 5.15 Percentage decrease in house price indices in districts in Oslo as compared to 1988.

year-quarter	Districts[a]										
	24	23, 25	1, 2, 3, 22	17, 18	16, 19	15, 20	7, 10	8, 9	11, 12	6, 13, 14	4, 5, 21, 26, 27
1989- 1q	6	14	12	18	24	4	15	1	-4	19	15
1990- 1q	19	13	15	23	27	15	20	19	10	23	21
1991- 1q	19	23	20	39	35	29	29	23	21	29	27
1992- 1q	27	20	32	38	45	33	29	31	30	40	36
1993- 1q	34	29	31	54	56	46	45	35	35	52	43
1994- 1q	11	18	12	27	39	30	26	27	28	39	34
1994- 3q	11	10	11	26	30	16	8	17	22	32	30

[a] Districts in Oslo: (1) Bygdøy-Frogner, (2) Uranienborg-Majorstuen, (3) St. Hanshaugen-Ullevål, (4) Sagene-Torshov, (5) Grünerløkka-Sofienberg, (6) Gamle Oslo, (7) Ekeberg-Bekkelaget, (8) Nordstrand, (9) Søndre Nordstrand (10) Lambertseter, (11) Bøler, (12) Manglerud, (13) Østensjø, (14) Helsfyr-Sinsen, (15) Hellerud, (16) Furuset, (17) Stovner, (18) Romsås, (19) Grorud, (20) Bjerke, (21) Grefsen-Kjelsås, (22) Sogn (23) Vinderen, (24) Røa, (25) Ullern, (26) Center, (27) Marka.

The Oslo toll scheme was designed in such a way that it would minimise the impacts on car traffic. According to our findings it had a small impact on travel behaviour during its first year of operation. However, as for the case of the impacts on travel behaviour, we expect that the impacts of the toll scheme on house prices would be greatest in the vicinity of the toll ring.

For the evaluation of the impacts of the toll scheme on house prices we use Wheaton's proposition (1977). He suggests that the change in consumer surplus, if demand is adequately estimated, captures all the benefits from a transport project and is equal to the changes in the housing market and land market that accompanies the transport project. For a summary of the debate on Wheaton's work see Anderstig and Mattsson (1992).

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[4] Rolf Barlindhaug, at the Norwegian Institute for Building Research, has made these estimations. For this purpose he has used data on repeated sales. For a description of methodology see Shiller (1991).

For the calculation of the changes in consumers' surplus we focus on travel to work. In this way we can assume that origin, destination, and the frequency of travel are fixed. Hence, a mode choice model can adequately represent the demand model. For the mode choice model we use a logit model that has been estimated on the basis of the panel study of 1989-90 (Ramjerdi, 1995)[5]. In this case the change in consumers' surplus or the change in users' benefits, due to a transport project will be:

$$\Delta UB = \frac{1}{\mu}\sum_{n}\left[\ln\sum_{j}\exp(V_{jn}^{f}) - \ln\sum_{j}\exp(V_{jn}^{0})\right]$$

where μ is the marginal utility of income, V_{jn} is the conditional indirect utility function of mode *j* for individual *n* and *0* and *f* stand for before and after changes in transport services through a transport project.

For the calculation of the changes in consumer surplus we assume that the housing market responds only to the toll fee introduced in 1990. The response does not include any changes in traffic due to the toll scheme. Hence we can assume that there were no other changes in the service qualities of alternative modes of transport, except for the toll fee in 1990.

A toll fee in 1990 brings about a welfare loss for those who were driving to work and had to cross the toll ring from home to work. The size of the loss depends on the availability and the quality of services of alternative transport modes.

Table 5.16 shows the maximum and the minimum expected loss of welfare for a round trip to work that required a toll payment, as well as the average expected loss of welfare in different districts in Oslo. The calculation is based on a sample of 1,124 respondents, located in different districts in Oslo in 1989 (from the panel), who reported a work trip. Note that the maximum expected loss of welfare for a round trip is less than the amount of toll fee (NOK 10 for one toll crossing between home and work and NOK 20 for two toll crossings between home and work). There were some observations in the sample with two toll crossings between home and work.

Any change in house prices due to the toll scheme should be based on the expected future loss of welfare. The calculation of present values is based on

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[5] It is assumed that seasonal passes are not available. Hence mode choice model no. 5 is used for this purpose (Ramjerdi, 1995, p.123 and in Essay no. four, p. 107).

Table 5.16 Expected average loss of welfare for districts in Oslo due to the toll scheme.

Dis-tricts[a]	No. of obs.	No. of obs. affected by toll	Max[b] $[1/\mu \ln \Sigma \exp V_i]_0^f$	Min[c] $[1/\mu \ln \Sigma \exp V_i]_0^f$	Average[d] $[1/\mu \ln \Sigma \exp V_i]_0^f$
1	56	1	6.368	6.368	0.114
2	74	8	7.057	0.164	0.519
3	86	11	8.269	0.901	0.665
4	67	7	6.722	3.012	0.538
5	50	1	6.670	6.670	0.133
6	26	2	5.360	4.137	0.365
7	21	4	2.170	0.824	0.252
8	33	22	7.362	0.157	1.321
9	41	23	16.829	0.101	1.914
10	18	7	5.323	0.311	1.059
11	45	2	6.076	5.705	0.262
12	40	7	8.103	0.483	0.736
13	34	1	7.732	7.732	0.227
14	56	3	7.190	4.511	0.319
15	42	2	5.848	1.437	0.173
16	49	24	13.429	0.182	1.591
17	38	14	16.585	0.732	1.578
18	14	5	6.736	0.664	1.424
19	29	12	6.899	0.356	1.321
20	79	10	8.296	0.682	0.644
21	39	7	6.542	2.963	0.891
22	38	6	7.344	3.467	0.947
23	38	16	5.883	0.490	1.040
24	46	18	7.205	0.321	0.944
25	60	26	8.035	0.402	0.895
26	3	1	4.512	4.512	1.504
27	2	1	2.134	2.134	1.067

[a] See table 5.15 for the names of the districts.

[b] $[....]_0^f$ stands for the change from before the toll scheme to after the toll scheme was introduced.

[c] Minimum for those with a toll crossing.

[d] Average for all, including those who did not have a toll crossing from home to work location.

a time horizon of 25 years (the result will not be significantly different with an infinite time horizon) and a discount rate of 7 percent. House prices are based on 70 square metres of floor space and a unit price that varies between the districts[6]. We assume that in a household with more than one worker only one uses car for commuting. All these assumptions are conservative, in the sense that they will overestimate the impact of the toll scheme on house prices.

Table 5.17 column (1) shows the average expected loss of welfare in NOK/day for the different districts in Oslo. The annual loss of welfare based on 250 and 350 working days per year are shown in columns (2) and (3). Columns (4) and (5) show the present values of the annual loss of welfare based on 250 and 350 working days per year.

Table 5.17 Loss of welfare and expected changes in house prices for districts in Oslo.

Districts in Oslo [a]	(1) Average loss of welfare, NOK/day	(2) Annual loss of welfare, 250 day/year, NOK/year	(3) Annual loss of welfare, 350 day/year, NOK/year	(4) present value for 250 day/year in NOK [b]	(5) present value for 350 day/year in NOK [b]
1	0.114	28.4	39.8	331	464
2, 3, 4	0.574	143.5	201.0	1673	2342
5, 6, 7	0.250	62.6	87.6	729	1021
8, 9, 10	1.431	357.8	501.0	4170	5838
12	0.736	184.0	257.7	2145	3003
11, 13, 14, 15	0.245	61.3	85.9	715	1001
16, 17	1.584	396.1	554.5	4616	6462
18, 19	1.372	343.1	480.4	3999	5598
20, 21	0.767	191.8	268.5	2235	3129
22, 23	0.993	248.3	347.6	2894	4051
24, 25	0.920	229.9	321.8	2679	3751
26	1.504	376.0	526.5	4382	6135
27	1.067	266.8	373.5	3109	4353

[a] See table 5.15 for the names of the districts.
[b] Present value for a discount rate of 7% and a time horizon of 25 years.

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[6] The average floor space is not the same in different areas in the Oslo region and it is larger than 70 square metres. However, a lower estimate of the average floor space is a conservative figure and will result in a higher estimate of the impacts of the toll scheme on house prices.

Table 5.17 (Continued) Loss of welfare and expected changes in house prices for different districts in Oslo.

Districts in Oslo	(6) Average price in 1000 NOK/m^2	(7) Average house price in 1000 NOK[c]	(8) Maximum expected decrease in house price[d], %	(9) Expected decrease in house price, % 250 days/year	(10) Expected decrease in house price, % 360 days/year	(11) Decrease in house price 1988-90 %
1	12.2	854	3.4	0.0	0.1	11.7
2, 3, 4	12.2	854	3.4	0.2	0.3	12.9
5, 6, 7	10.7	749	3.9	0.1	0.1	16.4
8, 9, 10	10.7	749	3.9	0.6	0.8	5.5
12	10.7	749	3.9	0.3	0.4	-4.0
11, 13, 14, 15	10.7	749	3.9	0.1	0.1	9.5
16, 17	9.8	686	4.2	0.7	0.9	21.1
18, 19	9.8	686	4.2	0.6	0.8	21.1
20, 21	10.7	749	3.9	0.3	0.4	9.9
22, 23	12.2	854	3.4	0.3	0.5	13.0
24, 25	12.2	854	3.4	0.3	0.4	9.9
26	10.7	749	3.9	0.6	0.8	15.4
27	12.2	854	3.4	0.4	0.5	15.4

[c] Based on an average house of 70 sq. m.

[d] Present value of 2500 NOK/year at a discount rate of 7% and a time horizon of 25 years is NOK 29,134.

Column (6) in table 5.17 shows the average unit prices of floor space and column (7) shows the average house prices in different districts. Column (8) in table 5.17 shows the maximum expected decrease in house prices due to the toll scheme in different districts. In this calculation we have assumed that the toll applies to everyone and that no one can leave home without a toll payment. The effects can thus be compared with the effects of a property tax[7]. As column (8) shows, the higher the house price the lower is the impact. The maximum expected decrease in house prices, given that the housing market would respond to the toll scheme in a similar manner to a property tax, is in the North East and South East corridors, outside the toll ring. Columns (9) and (10) in table 5.17 show the expected decrease in house prices with assumptions of 250 and 350 work days per year. Finally column (11) shows the actual decrease in house prices between first quarter in 1988 and first quarter in 1990. A comparison of column (10) and (11) suggests that the expected decreases in house prices due to the toll scheme are minute in comparison with the actual decreases in house prices.

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[7] We mean a tax that is not related to the value of the property and is the same for all properties.

Figure 5.6 shows the expected decrease in house prices due to the toll scheme in different districts in Oslo (based on 250 working days per year). The expected decrease in house prices is highest outside the toll ring in the North East and South East corridors. These corridors differ from the West corridor in two ways. One is that in the West corridor the house prices are on the average much higher. The other is work locations. While knowledge based work places are concentrated in the West corridor there are not many work places in the North East and South East corridors outside the toll ring.

Figure 5.5 Percentage decrease in actual house prices in different districts in Oslo, from 1st quarter, 1988 to 1st quarter, 1990.

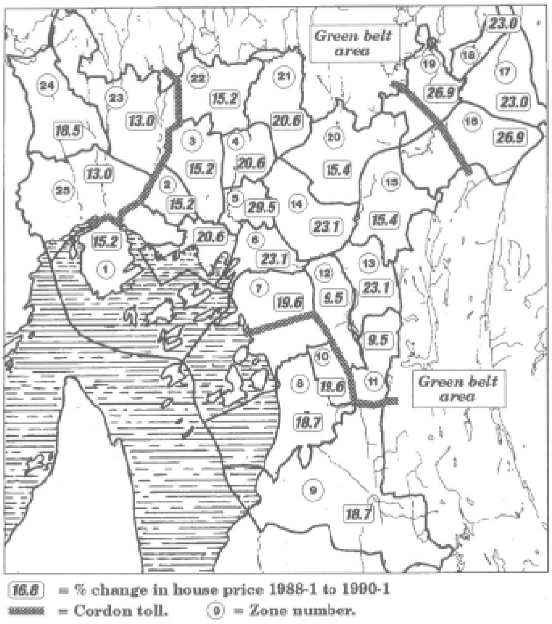
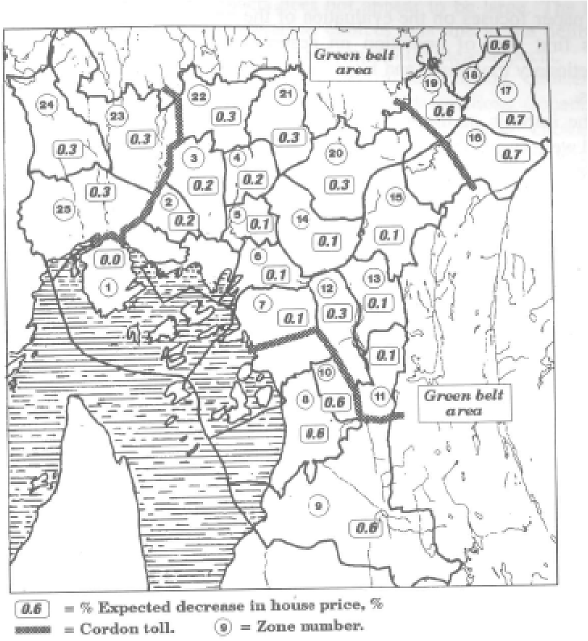


Figure 5.6 Expected percentage decrease in house prices due to the toll scheme in different districts in Oslo.



The expected decrease in house prices due to the toll scheme is small. However, the percentage decrease is negatively related to house price (a proxy for household income) and is positively related to the number of toll crossings between home and destination and depends on the availability and quality of alternative transport modes. Since house price can be used as a proxy for household income, the expected percentage decrease in house prices in the different districts in Oslo reflects the distributional impacts of the toll scheme.

5.6 Summary and Conclusions

This paper focuses on the evaluation of the impacts of the Oslo toll scheme in its first year of operation on destination choices for compulsory and discretionary travelling, and likewise the impacts of the toll scheme on house prices.

The impacts of the toll scheme on destination choices for compulsory travel were traced through changes in home and/or work locations from 1989 to 1990. The changes in home or work locations do not seem to be significantly related to the toll scheme. Rather, it is possible to detect the ongoing trends in the changes of the land use pattern in the Oslo region. The analysis presented here does not assess to what extent the introduction of the toll scheme has affected these trends.

The impacts of the toll scheme on destination choices for discretionary travel were analysed from two perspectives:

First perspective: The impact of the Oslo toll scheme on destination choices in relation to the distance of destinations (locations of businesses and services) from the toll ring.

Second perspective: The impacts of the Oslo toll scheme on the travel behaviour of households in terms of changes from destinations that require crossing the toll ring to alternative locations that do not require crossing the toll ring, in relation to the distances of home locations from the toll ring.

Our analysis shows that there have been shifts in these destinations from locations that required a toll crossing in 1989, before the introduction of the toll scheme, to locations that do not require toll crossing in 1990, after the introduction of the toll scheme.

The estimates of parameters of the Weibull distribution functions for the frequency distribution of destinations over the distance of destinations (the locations of businesses and services) from the toll ring in 1989 and 1990 were compared. This comparison shows that the impacts of the toll scheme on destination choices have been statistically significant, and the destinations (locations of businesses and services) that were located closer to the toll ring were affected most.

A similar comparison shows that there have been shifts in the destination choices of households. After the introduction of the scheme, households have chosen alternative destinations that did not require toll crossings. The shifts are more marked for households that were located in the inner city and close to the toll ring. The shifts are very small for households located 5 to 11 kilometres outside the toll ring. The availability of different suburban centres outside the toll ring may explain this. Hence, the availability and attractiveness of new alternative destinations seem to have influenced the shifts in destinations. The shifts in destinations will accompany changes in travel distances. However, the quality of the data does not allow an assessment of these changes.

The magnitude of these impacts does not appear to be large. The small impact of the toll scheme on destination choices was due to the deliberate choice of the location of the toll ring so as to minimise these impacts.

The impacts of the Oslo toll scheme on destination choices for discretionary travel, both as regards changes in destinations (location of businesses and services) and changes in the destination choices of households, decrease with distance from the toll ring. This reflects the distributional impacts of the scheme. An alternative toll scheme, with road pricing as an objective, should have been designed quite differently from the present scheme (Ramjerdi, 1992b). This analysis suggests that these (distributional) impacts in a road pricing scheme may be a matter that requires attention.

The available data does not permit the use of hedonic pricing theory in the evaluation of the impacts of the Oslo toll scheme on house prices. In evaluating these impacts, we assume that the change in consumer surplus, given an adequately estimated demand model, captures all the benefits of a transport project (toll scheme) and is equal to the changes in the housing market and land market that accompany the transport project (Wheaton, 1977).

The expected percentage decrease in house prices due to the toll scheme has been small in different districts in Oslo. These impacts have been highest outside the toll ring in the North East and South East corridors. These corridors differ from the West corridor in two aspects. One is that in the West corridor the house prices are much higher on the average. There is also a much greater incidence of job locations. Whereas knowledge-based work places are concentrated in the West corridor, there are not many work places in the North East and South East corridors outside the toll ring. The decrease in house prices in the different districts in Oslo reflects the distributional impacts of the toll scheme.

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