DIFFERENT

User Reaction and Efficient Differentiation of Charges and Tolls

THE DIFFERENT PROJECT: RESULTS FROM URBAN CASE STUDIES

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EXECUTIVE SUMMARY

A key issue in putting differentiated charges into practice is the need for good understanding of user reactions to differentiated prices. Out of all the groups of direct infrastructure users, car drivers constitute the group whose reaction to user charges is most difficult to predict: in contrast to large companies, such as airlines or railway operators, whose reaction is more or less entirely dictated by consideration of costs and benefits, car drivers can be expected to react with a mix of rational and irrational behaviour.

To investigate the effects and the potential for differentiated charges for drivers in urban areas, this report presents four types of evidence under the heading over various "case studies":

- Real-life case studies,
- Modelling exercises.

Most of this is solely concerned with urban user road charging, but some part of it also addresses the interrelationship between urban and motorway charging. The key findings from each of the case studies are as follows:

- The first case study is **Trondheim**, where a cordon charge, introduced in 1991, led to a reduction of 10% in car traffic crossing the cordon during both the high and low charged periods. However, this was offset by increases of 8 to 9% in the evening and on weekends, so that, overall, there was no notable traffic reduction. It should be noted that this happened during an economic recession period with zero annual general growth in traffic. The main effect was a shift in departure times: although the traffic increases in the early morning before charging hours and in the evenings after charging hours for home to work trips were minimal, for evening trips after charging hours from work to home the increase was 13 % points and for home to shopping 19 % points. Overall, it was very visible how drivers delayed their cordon crossing in the evening to avoid the charge.

  Concerning the relationship between charging level and traffic reduction, it was found that during the highest charge in the morning peak there was only a 4 % point reduction for home to work and home to shopping trips, while the main reductions occurred during the low charge period from 10:00 to 17:00 with -13 % points for work to home and -15 % points for home to shopping trips.

  The main effect of the introduction of the zonal system in 1998 was, as in 1992, a time shift. A comparison of figures available for 1992 and 2001 shows that, during the intervening time period, there was overall a strong growth in car use, but that the increase in mode share during the high charge period was very small (1 % point), during the low charge period slightly higher (6 % points), and highest during uncharged evenings and at weekends (13 and 21 % points respectively).

  When the charge was discontinued in 2005, traffic levels inbound across three typical toll stations increased at the rate of 3.8% overall and 11.5% during (previous) charging hours. The overall increase was in line with the general traffic growth in the area. Traffic impacts were in many ways mirror images of the impacts when charging was introduced. Changes in departure times and route choices were the most visible responses to the annulment of charging by car drivers.

  Model runs show that the average generalised cost per car trip in the city for weekdays decreased by 22% from 2005 to 2006 as a result of the annulment of tolls. The elasticity value with respect to kilometres travelled was estimated to -0.32.

  The introduction of the charge led to a very small short term-loss in city centre trading, while in the long-term there was still overall growth albeit with some loss in market share. However, the cessation of charge did not, at least not in the short-term, lead to any up-turn in trade.

- In **London**, there was a dramatic effect at the time of the original introduction of the congestion charge in February 2003 with a reduction of 14% of all traffic and 33% of cars. However, when the level of the charge was increased from £ 5.00 to £ 8.00 in 2005, the effect was very small with a 3% reduction of all vehicles and 3% of cars. Similarly, the number of bus passenger increased from 77,000 to 106,000 from 2002 to 2003, while the 2005 price increase had no detectable impact.

Similar to Trondheim, there was shift in departure times from the charged to the non-charged periods: a small shift to earlier starts in the morning and a larger shift to later departures in the evening.

The traffic reduction initially also led to a substantial reduction in congestion, in the range of 30% in 2003 and 2004 compared with 2002, but then congestion increased again to nearly old levels, which is attributed by Transport for London to the combined effect of traffic management measures that reduce road space in favour of cyclists and pedestrians and increased levels of roadwork.

The exemptions for licensed taxis, buses and coaches, and all two-wheelers led to a substantial shift in the mix of traffic away from chargeable vehicles (in particular cars, vans and lorries) to non-chargeable vehicles with 30% reduction of the former from 2002 to 2006 and 16% increase of the latter.

The economic impact of the congestion charge is somewhat disputed: while the Chamber of Commerce and one of the major retailers claim that the charge had a negative impact on retail, Transport for London claims a positive impact on jobs, business turnover and profits and a neutral effect on retail. And while one prominent publication calls the London scheme "an economic failure", it is the public and professional majority consensus that it has been an overall success.

- Although the congestion tax has been introduced in **Stockholm** as a permanent feature in August 2007, only little data is available from this and the case study had to be based on the trial carried out in the first half of 2006.

  The introduction of the trial scheme led to traffic reductions of up to 35% on some arterials and the average reduction of traffic crossing all cordons was 22% during the charging period, and by 19% for the 24-hour day. Overall, and for all modes, it is estimated that 110,000 trips per day 'disappear', i.e. are diverted from the city centre or no longer take place at all. It is possible, however, that not all of these reductions are due to the congestion charge, since one study found a general trend of decrease in travel between 2004 and 2006. In contrast to Trondheim and London, there was very little, if any, shift in traffic to non-charging hours; some of the data even indicates a decrease in traffic for all hours of the day.

  The traffic reduction also reduced congestion significantly. During the morning peak, for traffic travelling into the city, congestion was reduced by around 30% and the respective travel times by around 20%. For outbound traffic, congestion was much smaller in the first place, but the tax could reduce this further by 40% and the travel times by around 20%, which means in effect that traffic was flowing quite freely.

  Similar to Trondheim, within the charging period, the lowest traffic reductions are found in the morning during the main peak and the post-peak shoulder. The general assumption for explaining this phenomenon is that commuters as well as business travellers, who may be on the way to their first appointment during this time, have the lowest elasticities.

  However, both in the morning and in the afternoon, the traffic reduction is larger in the pre-peak shoulder with the € 1.50 charge than in the main peak with the € 2.00 charge and, furthermore, the biggest reductions overall occur during the first charging period in the morning and the last in the afternoon, when the charge is only € 1.00. Neither the Swedish reports nor any of the work carried out within the DIFFERENT project can shed any light on this finding, and this is therefore an area that deserves further research and investigations.

  The figures available so far from the permanent scheme show that the results from the trial, as far as traffic reductions and other headline figures are concerned, were very close indeed to those figures that so far emerged from the permanent scheme. Therefore the trial has to be considered a resounding success both in terms of predicting the effect of the congestion tax as well as in terms of persuading the Stockholm residents to vote for it in the public referendum.

- In **Milan**, where the *Ecopass*, a pollution charge has only been introduced as recently as 2 January 2008 for vehicles entering the city centre, only very preliminary results are available. In the first month, the traffic reduction during charging hours was 26% in the charging zone and

12.5% outside; and, as in the Trondheim and London, there is a very small increase in traffic in the morning before charging starts, but a clear peak in the evening after the end of charging. In February and March traffic reduction was significantly lower (14% in the charging zone and 8% outside).

What was very noticeable is the strong shift from higher to lower emitting cars as a result of the charge. The share of passenger cars with for emission class 3 (€ 2.00 per day) among all cars went in February down from 14% to 9% and for class 4 (€ 5.00) from 25% to 11%. For Light Duty Vehicles numbers the share of class 4 went down from 51% to 38% and for class 5 (€ 10.00) from 20% to 15%. At the same time, the share of low emitting cars increased accordingly.

Air quality improved initially as well, but weather conditions could explain the largest part of the reduction of pollution, since in March air quality in the charging area was not better than outside; observations over a much longer time period will be need to reach conclusive findings.

Public transport benefited as well with an increase of 9% in underground passengers and an increase in surface commercial speed, initially as high as 11% but soon reduced to a 4% gain.

- The road pricing scheme in **Singapore** has developed over time from a simple paper-permit area charge to a highly differentiated electronic charge, where different charges are used for different groups of road users. A key feature of the current scheme is that charges vary from place to place and during the day depending on congestion levels – making it difficult for drivers to predict the charges they will incur when they start their journey.

  The electronic scheme has reduced traffic levels in the Central Business District by 15% for the whole day and by 16% in the morning peak when it was initially introduced. Unfortunately, there is no data available concerning the effects of the current differentiated scheme - which is the most interesting scheme from the DIFFERENT perspective. Although the current scheme appears to be widely accepted in Singapore, It is not clear whether European drivers would so readily accept such a detailed attempt by state authorities to influence driver behaviour.

- In **Rome** extensive modelling has been carried out over the years to investigate the effects of a day-time scheme and a summer and winter variant for a night-time scheme for the city centre. For the day-time scheme seven different scenarios have been modelled, five scenarios for the night summer scheme and 4 for the night winter scheme. The main differences between these scenarios are the charging level and the level of public transport supply. The modelling distinguishes further between regular and occasional users, cars, mopeds and PT users, and between work, recreational and shopping trips.

  For the day-time scheme it was found that none of scenarios has a substantial impact on modal split but, instead the main impact comes from the reduction of through-trips. In contrast, for the summer night scheme there is a reduction in car use by one third for work trips at a charge of € 6.00 per trip and by three quarters for shopping trips, while – somewhat surprisingly – the effect on recreational trips is very low; the highest impact by far comes also here from the reduction in crossing trips. Aggregate figures for the winter night scheme also show an overall reduction in car use by two thirds for the most expensive scheme; crossing trips by car are reduced by 85% already at a charge of € 3.00 per trip, and nearly disappear altogether at the € 6.00 charge.

  Overall it appears that a per trip car pricing scheme (time based or not) during the daytime would not be as effective in reducing car use consistently as the current mix between permits and flat-fare pricing scheme is. This result matches ex-ante surveys where both residents and shopkeepers in the charging zone consider a mix of measures, such as improvement of PT and reducing the number of entrance permits, to be more effective in reducing historic centre traffic and pollution problems than a per trip time based pricing scheme. In contrast, for the night-time schemes with different characteristics of travellers, a charge per trip would probably be most effective.

- The **Edinburgh** charging scheme was aborted following a resounding rejection by the public in a referendum, but extensive modelling had been carried out over the years with two different models.

  From the first set of model runs, it was found that one of the key effects of any of the investigated charging schemes was the shift from car travel to public transport use. The reductions in flows across the cordons for the 24-hour day were up to a maximum of 24% for a £ 4.00 charge at the cordon across the inner suburbs, with charges of £ 2.00, £ 1.00 and £ 0.50 leading to reductions of 16%, 8% and 5 % respectively.

The gain in PT passenger trips was considerably higher than the loss in car trips. This was in part due to the fact that the average car carries more than one passenger, and in part due to the reduction in bus travel times due to reduced congestion, which attracts additional passengers. The modal shift increased with the level of charges, but the relationship between the charging level and the modal shift was not linear and the marginal effect of charge increases on modal shift decreased more and more the higher the charge became.

Overall, and at least in this modelling exercise, there is no impact from any differentiation of charges on traffic reduction, neither by number of cordons nor by differentiation over the day. All differences in impact on traffic volumes can be simply explained by the overall charging level.

The analysis of the economic impact also confirms the non-linearity of the impact of higher charges: a "spatial differentiation" of charges is overall more effective than a mere increase in the level of charges at one particular cordon, i.e. 'catching' more people in the cordons has a stronger effect than charging fewer drivers more money.

From the second modelling exercise it is unfortunately not possible to draw any general conclusions. Differences in traffic reductions between different schemes are largely due to the simple question of whether the charging is operating at any cordon during the time period considered, without any obvious further effects of differentiation by time of day.

- Furthermore, loosely based on the Edinburgh network, a **conceptual model** has been used to investigate the comparative benefits of various charging schemes with different degrees of differentiation as well as to explore the importance of correct estimates of elasticities for the outcome of these comparisons.

  Two of the schemes modelled were primarily for benchmarking purposes: a system of MSC tolls applied across the whole network, and a Uniform scheme (at a common rate per km across the whole network) intended to act as a proxy for a fuel duty increase. Other schemes modelled were cordon-based, distance-based and area-based, plus some motorway-based schemes that were largely for use in the co-introduction study in chapter 10. The positions of the two cordons were fixed, and corresponded with those proposed for actual implementation in Edinburgh. This gave a set of eleven schemes in the main body of tests, each of which was modelled at a number of different charging levels.

  It was found that the system of MSC tolls gives the greatest reduction in total network delay, and the greatest "benefit" as measured by the sum of the reductions in the cost of total delay and externalities, from the base, "no tolls", case, but that no one scheme could be said to be best under all aggregate measures.

  The simple Uniform scheme was perhaps surprisingly similar to the first-best MSC tolls scheme. This shows that it is the spatial nature of the charging scheme that is more dominant than the precise link-by-link level of charge once the total toll revenue is kept fixed. The next most effective schemes are those involving charging both within the inner city and within the city by-pass.

  Direct comparisons of area-based and distance-based schemes indicate that, whilst they give similar reductions in demand, the area-based scheme gives a much greater reduction in total delay, whilst the distance-based scheme gives a much greater reduction in veh*km in the relevant regions. In each case, the pure cordon scheme gives a rough compromise between the distance-based and area-based equivalent, but with a somewhat smaller reduction in demand. An important distinction between the area-based and distance-based schemes is that, in the latter, drivers will seek to reroute to minimise the charge they incur, which can induce a considerable increase in veh*km.

  The results for the specific network modelled show that the size of the area covered by the scheme, and therefore the overall number of drivers who would have to pay the charge is more important in terms of overall effect of the scheme than the type of scheme used or the degree of differentiation within it; and it seems safe to say that this is not specific to the network modelled here, but would be found in other networks as well.

Whilst the results described here were obtained assuming a value for elasticity of *e* = 0.3, a further series of tests were conducted assuming different values for *e*. The sample results from these further tests confirm that, whilst the numerical value of measures such as total delay obviously depend on the value of *e*, the broad nature of the results, and the relative ranking of schemes, is not significantly affected by this. Therefore, it appears safe to say that generally the precise estimate of elasticities is much less crucial for the comparison between different schemes than for the estimate of their effects in absolute terms.

- In order to put urban road user charging into a wider context, the impacts of the **combined** introduction **of urban and motorway charges** were examined. Different scenarios of such a co-introduction were explored, using the aforementioned conceptual model and other external evidence.

  The investigation concluded that considerable problems are likely to occur if charges on urban roads are designed without regard to their potential impact on any adjacent motorways or if charges on motorways passing through metropolitan areas are designed without regard to their potential impact on the roads in those areas or on the local economy. Some diversion of traffic from one network to the other is an inevitable consequence of introducing charges. Although some diversion may be desirable in order to achieve a better match of demand to capacity or to prioritise particular types of traffic, excessive diversion can cause serious problems. Diversion of traffic from motorways to other roads can be particularly serious because it leads to increased accident risk and environmental externalities.

  Cooperation on technical and procedural issues, and over detailed definitional points such as start and finish times, vehicle classifications and exemptions, is desirable and can be effective even if the two road authorities have different objectives. In the absence of such cooperation the resulting complexity will increase costs for system operators and end users and cause particular resentment among the latter. Although it has not been proven by detailed modelling, it appears unlikely that a scheme designed to maintain free-flow on the motorways or maximise revenue for the motorway manager would simultaneously minimise congestion and other externalities within the urban area. It follows that, in order to maximise overall benefits, a degree of prioritisation or compromise is required, which also involves the introduction of different charges on the different road types.

  It seems likely that overall benefits (defined as minimisation of delay, accidents and other externalities while maximising the benefits to society and the economy) will be maximised by combining a charge on the urban roads with charges designed to give a degree of protection to traffic using motorways and other strategic links. The urban charge might be levied on traffic crossing specified cordons or using roads within a specified area, while the strategic-link-protection charge might involve specific charges for using motorway access or egress links or dynamic charges just sufficient to preserve free flow conditions.

- Furthermore, the main findings from a UK study with a view to the potential introduction of a **UK wide road user charging scheme** are analysed. The basis of the charging was marginal social cost (MSC) pricing, with the charge reflecting the average cost of marginal externalities (comprising congestion, infrastructure, accidents and pollution). The study found that a highly differentiated MSC-based pricing scheme with 75 different levels of charges (ranging from zero to 80 pence per km) should deliver substantial benefits - largely due to time saving reductions - of the order of £ 10 billion per year. However, simplified MSC schemes (for example, with just 10 separate levels of charge per km, rather than the full 75) can produce a very large proportion of the potential congestion reduction.

  Also a simple revenue neutral version of MSC pricing (in which fuel duty would be reduced by such an amount as to offset the revenue raised from road pricing) would deliver benefits that are not significantly less than a full MSC scheme. This demonstrates clearly that it is the structure of charges that is important and not the overall level. On the other hand, an increase in fuel duty to raise the same revenue as an MSC pricing scheme would reduce congestion by only one-fifth of that given by MSC pricing.

  If charging were imposed only in urban areas (for example, in all cities with population in excess of 10,000), this would produce benefits that were not far short of those from a full MSC scheme. Simple charging systems by road type, area type or time of day reduce overall traffic volumes more than the full MSC scheme, and for the charge based on area type even in urban areas, but they all have only a fraction of the MSC scheme's impact on congestion. However, it should be noted that the report contains a series of caveats, so the results should be taken with a degree of caution.

The local modelling carried out was quite limited in scope, but indicated that cordon-based schemes could produce overall benefits, even if these are likely to be smaller than distance-based schemes. It also suggested that, with highly differentiated charges, distance-based charging could lead to a significant amount of rerouting, with drivers seeking circuitous routes to avoid or minimise the charge.

The local modelling also found that a simple, flat-rate charge imposed in urban areas could produce significant benefits. This was somewhat at odds with the findings from the national modelling in the main part of the report. However, it is important to appreciate that the national modelling covered the whole of the country with a sample of links rather than a network representation, whereas the local modelling covered predominantly congested urban areas, and used a network structure capable of modelling rerouting. The findings about the flat-rate distance charge are consistent with the findings from the conceptual model for the Uniform scheme.

- Finally, the findings from a study, named '**Spitsmijden**' and carried out in The Netherlands are presented. Spitsmijden was an experiment in which is examined whether car drivers can be persuaded to avoid the rush hour on a congested motorway corridor by providing them with positive stimuli through a reward scheme.

  The data collected in the experiment was used to estimate a number of discrete choice models that describe commuter's behaviour with respect to departure time choice as well as transport mode choice. The estimated behavioural parameters were all significant, with the expected signs, and give a clear indication that a reward can be used as an effective policy instrument.

  The analysis of the participant's behaviour revealed that the shadow prices of schedule delay in the experiment are close to constant, a finding in line with the classic assumptions in literature, but departing from other recent findings. The correlation in preferences for different departure times for car trips within the rush hour matches expectations and indicates that shifting departure time is likely to be a more important behavioural response to policies for congestion relief, compared to a modal shift or teleworking, albeit with the caveat that quality of the other modes in the specific setting of the experiment was limited.

  Comparing the relative size of the different valuations of schedule delay early, schedule delay late and travel time as well as the absolute size of travel time valuation under a reward stimulus, results are similar to past findings in literature.

Overall Findings for the Effects of Differentiation for Car Drivers in Urban Areas

Concerning the findings with regard to the specific effect of the differentiation of charges, which is, from the overall perspective of the project, the key issue in this report, unexpected conclusions have emerged. In the most important ones of the real-life case studies, namely Trondheim and Stockholm, it is not only that surprisingly little recognisable effects of differentiation by time-of-day could be shown, but moreover in the case of Stockholm some effects were observed that are very counterintuitive.

Furthermore, the modelling exercises with the conceptual model also show less impact of a charge differentiation that reflects Marginal Social Costs than could have been reasonably expected.

The analysis of the effect of differentiation by type of vehicle class shows, however, very different results: both in Milan and in London, clear effects could be observed and, moreover, these point into the direction that would have been expected and predicted in the first place.

Very clearly, more research is needed in this area to explain these results and to allow accurate forecasts of the likely effect of the introduction of a new differentiated charging scheme elsewhere, most notably if the differentiation is done by time of day. What could be most revealing would be further research into the breakdown of the actual travel behaviour in Stockholm by different groups of travellers.

1 INTRODUCTION

In the European Union, levels and structures of transport infrastructure charges vary strongly across transport modes and countries. Some degree of convergence exists on the intention to apply the principle of marginal cost pricing in various transport sectors, but, in the presence of unsolved difficulties in funding transport investment and even serious concerns about marginal social cost pricing in several countries, any such convergence is slow. At present, the charging regimes that can be observed are often far from internalising external costs and are rarely based on efficiency principles.

In this situation differentiation of existing charges appears to be a sensible intermediate step. A possible way to increase the efficiency of pricing structures would be to take existing structures as a starting point and try to increase their efficiency by making them more differentiated. This may, however, lead to a number of questions such as: how differentiated should these price structures be in order to lead to efficiency gains, how do users react, what are the effects on equity and revenues, etc.

A key issue in putting differentiated charges into practice is the need for good understanding of user reactions to differentiated prices. Out of all the groups of direct infrastructure users, car drivers constitute the group whose reaction to user charges is most difficult to predict: in contrast to large companies, such as airlines or railway operators, whose reaction is more or less entirely dictated by consideration of costs and benefits, car drivers can be expected to react with a mix of rational and irrational behaviour.

To investigate the effects and the potential for differentiated charges for drivers in urban areas a series of case studies has been carried out. The results of these case studies were reported in deliverable “D9.1 Results from Urban Case Studies”, which was submitted to the European Commission in May 2008, but, since it had been classified as ‘restricted’, has only been made available to the consortium and the DIFFERENT Advisory Board. This present report is a slightly abridged and edited version of D9.1.

This report presents four sets of evidence:

- The report starts off with the findings from five real-life case studies:
    - The first case study is Trondheim, which is one of the first cities in Europe to introduce an urban road user charge, though also the first one to discontinue it. The Trondheim scheme was a cordon charge that covered the entire city.
    - The second is London, in this case an area charge in the core city centre introduced in 2003, and extended to an adjacent part of the city in 2007, nearly doubling the charged area in size.
    - The third is Stockholm, with a congestion tax levied on a cordon around the inner city. This tax is highly differentiated by time of day.
    - The fourth is Milan, where a charge has only been introduced as recently as 2 January 2008 for vehicles entering the city centre. This charge is differentiated by vehicle emission class. Since it is so recent, only very preliminary results are available, but since the scheme is very relevant in the DIFFERENT context, even these early findings are presented here.
    - Finally, although from outside Europe and therefore possibly less relevant due to likely cultural differences in user reaction, the oldest charging scheme in the world, the one in Singapore, which has developed over time from a simple paper-permit area charge to a highly differentiated electronic charge.
- The second group of findings comes from a number of modelling exercises:
    - The first group of results comes from Rome, where extensive modelling has been carried out over the years to investigate the effect of a range of schemes and scheme variants, some of which have been introduced in the meantime.

- The Edinburgh charging scheme was aborted following a resounding rejection by the public in a referendum, but extensive modelling had been carried out over the years with two different models, and some of this is of potential relevance to DIFFERENT.
- Furthermore, loosely based on the Edinburgh network, a conceptual model has been used to investigate the comparative benefits of various charging schemes with different degrees of differentiation as well as to explore the importance of correct estimates of elasticities for the outcome of these comparisons.

➢ In order to put urban road user charging into a wider context, it was also investigated which impacts a combined introduction of urban and motorway charges would have. To this effect two specific chapters are included in this report:

- In the first place, different scenarios of such a co-introduction are explored by using evidence from a range of case studies and modelling exercises as well as from the aforementioned conceptual model.
- Furthermore, the main findings from a UK study with a view to the potential introduction of a nationwide road user charging scheme are analysed.

➢ Finally, the findings from a study, named 'Spitsmijden' and carried out in The Netherlands are presented. Spitsmijden was an experiment in which is examined whether car drivers can be persuaded to avoid the rush hour by providing them with positive stimuli through a reward scheme.

The report closes with a short section highlighting some of the main conclusions, but the main recommendations and key conclusions can be found in the (also public) DIFFERENT Deliverable D9.3.

2 TRONDHEIM

2.1 POLICY BACKGROUND

During the 1970s and early 80s, Trondheim experienced a significant increase in traffic, accompanied by congestion and environmental problems. In particular, adverse effects resulting from through-traffic in the city centre attracted much attention. The proper solution was envisaged to be a network of main roads that would move traffic away from the city centre and dwelling areas. The policy initiative concerning the toll ring originated in 1985, during the last stage of preparing a new transportation plan for Trondheim. The first milestone was a unanimous declaration in the City Council, asking for a feasibility study of a local financial contribution to road construction, provided the State would allocate additional funds. The initiation phase was inspired by a recent agreement between the central authorities and the city of Bergen on a toll ring that released such an additional financial grant. Thus, the main actors in Trondheim assumed that user fees would give an impetus to road construction that could avert congestion and environmental problems. With ordinary State funds only, completion of the new road network would probably take 35 to 50 years. With the envisaged financing plan, construction could be accomplished in 10 to 15 years. The road investment plans were clearly linked to other policy goals: by-pass roads alleviating the environmental degradation of the city centre were considered a prerequisite for urban renewal. Furthermore, increased mobility was regarded as an asset that could help attract the flourishing oil industry to the region.

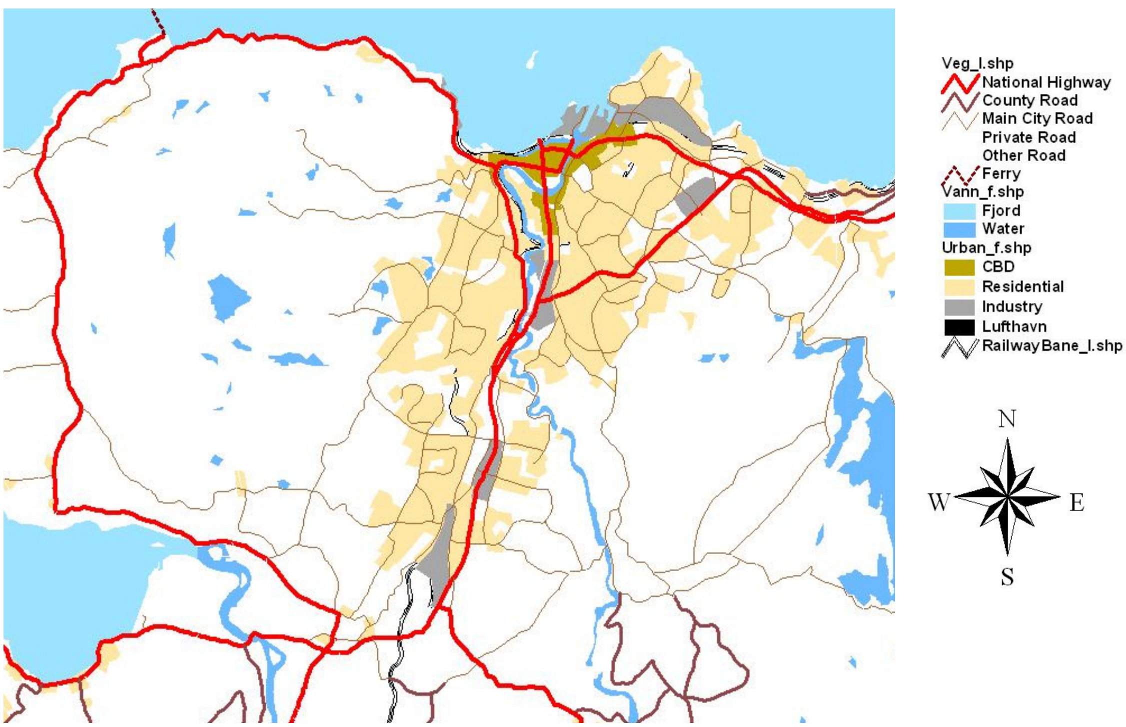


Figure 2-1 Trondheim Main Road Network

During the period of preparing the toll ring and the investment package, shifting political preferences influenced the plans. Especially, the environmental upswing in the late 80s / early 90s was reflected in a demand management element in the fee structure, as well as in the allocation of part of the revenue to public transport, safety and environmental upgrading. Thus, the debate over the Trondheim toll ring has reflected a variety of arguments over the years. The following arguments were frequently used in the written public debate (newspaper articles and letters from the readers, information material from the public planning authorities, from 1986 to 1995):

Frequent pro arguments:

- The ring pays for an improved network of main roads.
- Funds are built for investment in traffic safety, public transport, and environmental improvement.
- The toll ring regulates the traffic.
- The toll ring is a technically advanced and efficient charging measure.

Frequent con arguments:

- As a payment device, the ring strikes unjustly and arbitrarily.
- Motorists pay enough already; public roads are the responsibility of the State.
- The toll ring is not well designed. Various arguments criticising, e.g., too high, low, or biased regulation effects, and the possibilities for avoiding payment by crossing residential areas.
- The road projects are not needed; the money should be used for other purposes.

2.2 The Political Decision-Making Process

The success story of Trondheim's toll ring is a story of twisting and turning political preferences and compromises, and corresponding adjustments of the scheme design. Thus, a major planning challenge has been to secure sufficient agreement on the toll ring through more than a decade of numerous minor decisions. All the City Council debates concerning scheme design and adjustments, revenue use and road projects, have provided opportunities for the opponents to contest the toll ring principle and the ‘Trondheim Package’. The planners' abilities to gain continuing support rest on an understanding of the political climate, close cooperation with leading politicians, and responsiveness to public involvement claims. The planning and decision-making story, starting in 1985, is outlined more detail in (Langmyhr, Sager 1997).

Three main "areas of preference" can be distilled from the public and political debate in Trondheim. Since 1985, no single "interest coalition" has been in the position to take a City Council majority for granted. Thus, some sort of compromise had to be aimed for in planning and decision-making concerning the toll ring. The preferences concern both the charging scheme design and the revenue use.

“The mobility interests” prefer to solve mobility problems by expanding road capacity. If road user charges are considered inevitable, the favourite solution is the use of toll roads, implying a close link between the charging and the benefit for road users. The demand management effects of charging are largely considered adverse by-products. Revenues should preferably be earmarked for road construction only. In Trondheim the ‘mobility interests’ included the Conservative Party, the Norwegian Automobile Federation and major commercial actors. It is easier to gain support from these actors when the arrangement is limited in time and when the local fund raising generates transfers from the State.

"The regulation interests" prefer a transportation system favouring the "green" modes. Road building is tolerated as a necessary evil only where substantial environmental and safety improvements to dwelling areas or the city centre are expected. Charges on the use of private cars are considered a feasible means to reduce traffic, and to provide revenue for public transport and environmental improvements. A toll ring is an acceptable pricing system as long as the revenue spending is not too pro-car. In Trondheim, this preference cluster included environmental interest groups and left wing City Council parties. During the environmental turn phase, a major part of the Labour Party sympathised with the regulation interests.

"The carrot and stick interests" have preferences revealing a belief in a transportation system which is both efficient and environmentally friendly. Promoting public transport by improving its quality is preferred to severe restrictions on car use. The demand management effects of the toll ring are nevertheless rated as positive. The revenue spending called for is a "balanced" solution, allocating resources to road construction as well as public transport and environmental improvements. In

Trondheim, some parties in the political centre, as well as a varying proportion of the Labour Party have revealed "carrot and stick interests".

The most important lessons are:

- Road pricing schemes can be hooked up with several interests and objectives which are likely to be negotiated and reinterpreted on several occasions throughout the long and messy policy process, even after implementation.
- Compromises in the scheme design do not necessarily jeopardise the road pricing rationale or corrupt "rational" transport planning. It seems more fruitful to speak of changed emphasis responding to public attitudes and political preferences.
- The often formulated ideal of one principal and unambiguous goal as the best way to implement road pricing or congestion pricing is not supported by the Trondheim case. Several objectives have been present, preparing some common ground for agreement and flexibility.
- Experience from Norway clearly indicates that earmarking of revenues for specific purposes has been of major importance in securing local support for the cordon pricing schemes.
- "Immediate" road construction to relieve bottlenecks reduced the unpopularity of user fees. (In addition, user fees have been supplemented by state funds, thus increasing the total amount of investment resources.)
- Evidence from Norway indicates that, if the range of disbursement purposes becomes wide (i.e., less biased towards road construction), the role of the County Roads Offices as road pricing promoters may be jeopardised. Thus, a strategy for building scheme support through revenue allocation must rest on an assessment of the institutional system, especially an evaluation of which actors may serve as prominent "innovation" promoters.

2.3 History and Main Characteristics of the Charging Scheme

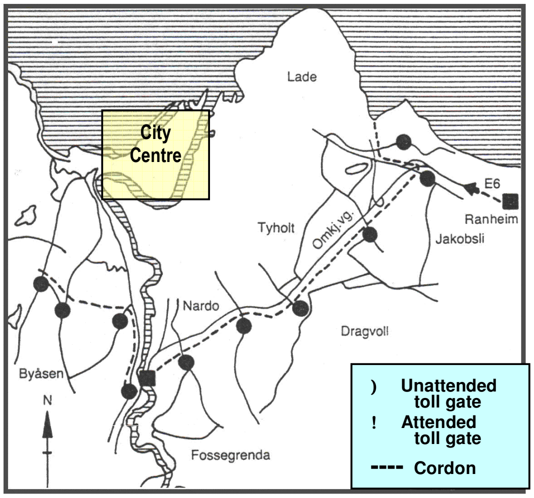
2.3.1 Overview

The original Trondheim toll ring system, implemented in 1991, went through two major revisions. Firstly, in 1998 some charging points were relocated and 6 more were added, making it into a multizonal system comprising 18 stations. The basic charge increased from NOK 10 to NOK 12 and the operating time was prolonged from 17:00 to 18:00. A second price increase came in February 2001, raising the basic charge to NOK 15 (at that time approximately € 1.80). The last revision of the scheme layout was made in November 2003 by adding an inner CBD (city centre) ring. This increased the number of stations to 24.

On 30 December 2005 the urban tolling system in Trondheim was turned off, nine months before the legal concession period of 15 years had elapsed. The local decision makers chose to stick to this date, even if implementation was delayed from January to October 1991. Trondheim was the third city in Norway to introduce a toll ring, following the examples of Bergen from 1986 and Oslo from 1990. So, while Bergen and Oslo have decided to continue their charging systems to finance new transport projects, Trondheim became the first Norwegian city to discontinue charging and dismantle their charging equipment.

2.3.2 The 1991 Toll Ring

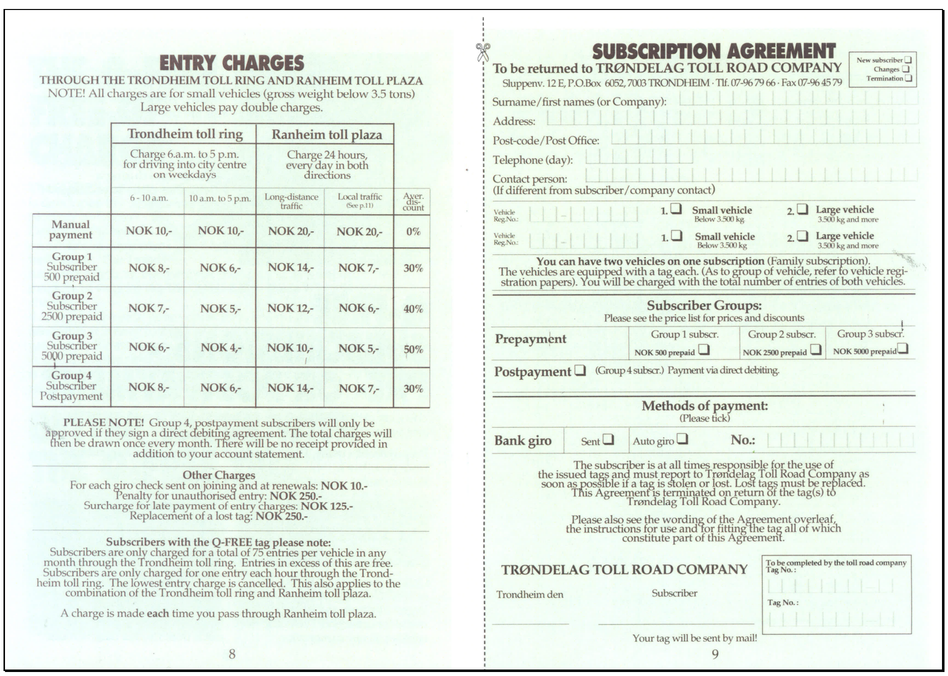
The Trondheim scheme was unique in three aspects when it was introduced in 1991, (i) it was fully electronic with non-stop toll lanes from the start, (ii) it had time-differentiated charges, and (iii) only a ‘payment for each trip’ option was available. Figure 2-2 shows key aspects of the toll ring. 11 new automatic toll stations were built, of which only one had additional manned operation. In addition, one existing manned motorway toll station to the east at Ranheim completed the ring. 21 of the 35 lanes leading in to the toll stations were non-stop lanes for tag holders.



- Fully electronic from the start
- All stations had non-stop lanes
- 80% of transactions in morning peak by electronic tags at opening in October 1991
- Only inbound crossings were charged
- Monday-Friday, 6am – 10am:
  - Full charges
- Monday-Friday, 10am – 5pm:
  - Reduced charges
- Evenings, Weekends:
  - No charges
- For subscribers, a maximum of one crossing per hour and 75 crossings per month were charged for

Figure 2-2 The 1991 Trondheim Toll Ring

Only subscribers (i.e. vehicles equipped with a tag and having an agreement with the toll road company) benefited from the reduced charges after 10:00 and from the rule limiting payment to one passage per hour and 75 passages per month (Figure 2-3). Subscribers were offered a 20 to 40% rebate on crossings before 10:00, and an additional 25 to 33% off for crossings after 10.00, depending on the amount of money being prepaid. A post payment option with discounts was also available.



ENTRY CHARGES

THROUGH THE TRONDHEIM TOLL RING AND RANHEIM TOLL PLAZA

NOTE! All charges are for small vehicles (gross weight below 3.5 tons)
Large vehicles pay double charges.

	Trondheim toll ring		Ranheim toll plaza		
	Charge 6.a.m. to 5 p.m. for driving into city centre on weekdays		Charge 24 hours, every day in both directions		
	6 - 10 a.m.	10 a.m. to 5 p.m.	Long-distance traffic	Local traffic (See p.11)	Aver. dis-count
Manual payment	NOK 10,-	NOK 10,-	NOK 20,-	NOK 20,-	0%
Group 1 Subscriber 500 prepaid	NOK 8,-	NOK 6,-	NOK 14,-	NOK 7,-	30%
Group 2 Subscriber 2500 prepaid	NOK 7,-	NOK 5,-	NOK 12,-	NOK 6,-	40%
Group 3 Subscriber 5000 prepaid	NOK 6,-	NOK 4,-	NOK 10,-	NOK 5,-	50%
Group 4 Subscriber Postpayment	NOK 8,-	NOK 6,-	NOK 14,-	NOK 7,-	30%

PLEASE NOTE! Group 4, postpayment subscribers will only be approved if they sign a direct debiting agreement. The total charges will then be drawn once every month. There will be no receipt provided in addition to your account statement.

Other Charges
For each giro check sent on joining and at renewals: **NOK 10.-**
Penalty for unauthorised entry: **NOK 250.-**
Surcharge for late payment of entry charges: **NOK 125.-**
Replacement of a lost tag: **NOK 250.-**

Subscribers with the Q-FREE tag please note:
Subscribers are only charged for a total of 75 entries per vehicle in any month through the Trondheim toll ring. Entries in excess of this are free. Subscribers are only charged for one entry each hour through the Trondheim toll ring. The lowest entry charge is cancelled. This also applies to the combination of the Trondheim toll ring and Ranheim toll plaza.

A charge is made **each** time you pass through Ranheim toll plaza.

8

SUBSCRIPTION AGREEMENT

To be returned to TRØNDELAG TOLL ROAD COMPANY
Sluppenv. 12 E, P.O.Box 6052, 7003 TRONDHEIM · Tlf. 07-96 79 66 · Fax 07-96 45 79

New subscriber ❑
Changes ❑
Termination ❑

Surname/first names (or Company):
Address:
Post-code/Post Office:
Telephone (day):
Contact person:
(If different from subscriber/company contact)

Vehicle Reg.No.: 1. ❑ **Small vehicle** Below 3.500 kg 2. ❑ **Large vehicle** 3.500 kg and more
Vehicle Reg.No.: 1. ❑ **Small vehicle** Below 3.500 kg 2. ❑ **Large vehicle** 3.500 kg and more

You can have two vehicles on one subscription (Family subscription). The vehicles are equipped with a tag each. (As to group of vehicle, refer to vehicle registration papers). You will be charged with the total number of entries of both vehicles.

Subscriber Groups:
Please see the price list for prices and discounts

Prepayment	Group 1 subscr. NOK 500 prepaid ❑	Group 2 subscr. NOK 2500 prepaid ❑	Group 3 subscr. NOK 5000 prepaid ❑

Postpayment ❑ (Group 4 subscr.) Payment via direct debiting.

Methods of payment:
(Please tick)

Bank giro	Sent ❑	Auto giro ❑	**No.:**

The subscriber is at all times responsible for the use of the issued tags and must report to Trøndelag Toll Road Company as soon as possible if a tag is stolen or lost. Lost tags must be replaced. This Agreement is terminated on return of the tag(s) to Trøndelag Toll Road Company.

Please also see the wording of the Agreement overleaf, the instructions for use and for fitting the tag all of which constitute part of this Agreement.

TRØNDELAG TOLL ROAD COMPANY

Trondheim den

Subscriber

To be completed by the toll road company
Tag No.:
Tag No.:

Your tag will be sent by mail!

9

Figure 2-3 Entry Charges and Subscription Agreement for the 1991 Trondheim Toll Ring

The electronic tags were handed out to car owners in the Trondheim area free of charge. Still, motorists needed sound and easily understandable reasons to make the effort necessary to obtain the electronic tag, accompanied by a payment contract with the toll road company. “Simpler and less costly” was the main message put forward in the marketing campaign. For the charging system to work, it was really necessary that a large percentage of the cars making inbound trips during the morning peak were equipped.

The fact that this percentage was 80 already during the first days of operation indicated a successful campaign, and it assured that the charging system worked without creating undue queues and delays. A poll among frequent users of the charging system conducted one month after the introduction showed that 82% believed that the charging system functioned well.

2.3.3 The 1998 Zone Based Road Pricing System

In June 1996, the City Council in Trondheim decided on a revised toll charging scheme. This zonal-like system was fully implemented during the first months of 1998 (Figure 2-4). Two main objectives motivated the revision of the single cordon scheme: Firstly, more revenue was needed to fulfil the transport investment plans. Secondly, a more "equitable" scheme was called for (interpreted as a system charging a higher portion of the motorists). To some extent, the revised system was designed to provide daily service facilities inside each zone. The revised fee structure included a raise in the basic charge from NOK 10 to NOK 12, extended opening hours from 17:00 to 18:00, and a lowering of the maximum number of charged crossings per month from 75 to 60.

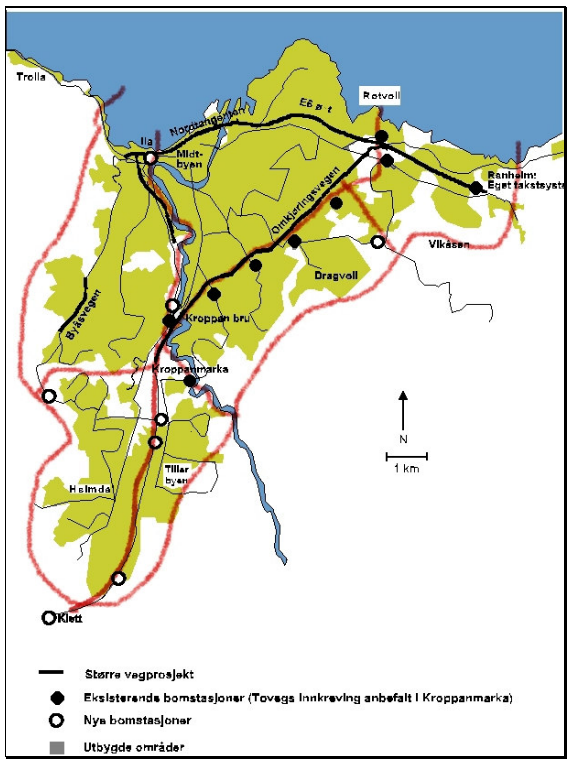


Figure 2-4 The 1998 Trondheim Zone Based Tolling System

2.3.4 The 2004 Extended Zone Based Road Pricing System

A third and final extension involving six additional stations closer to the city centre came into operation 1 November 2003. The basic charge level had already been raised from NOK 12 to NOK 15 on 26 February 2001. With a typical discount of 30 to 40 % for tag holders, this implied a price per passage of around € 1.20. The layout of the scheme which now consisted of 24 stations (or strictly speaking 26 if stations located very close together to the south are counted separately) and 59 payment lanes is shown in Figure 2-5. Examples of typical charging stations are shown in Figure 2-6.

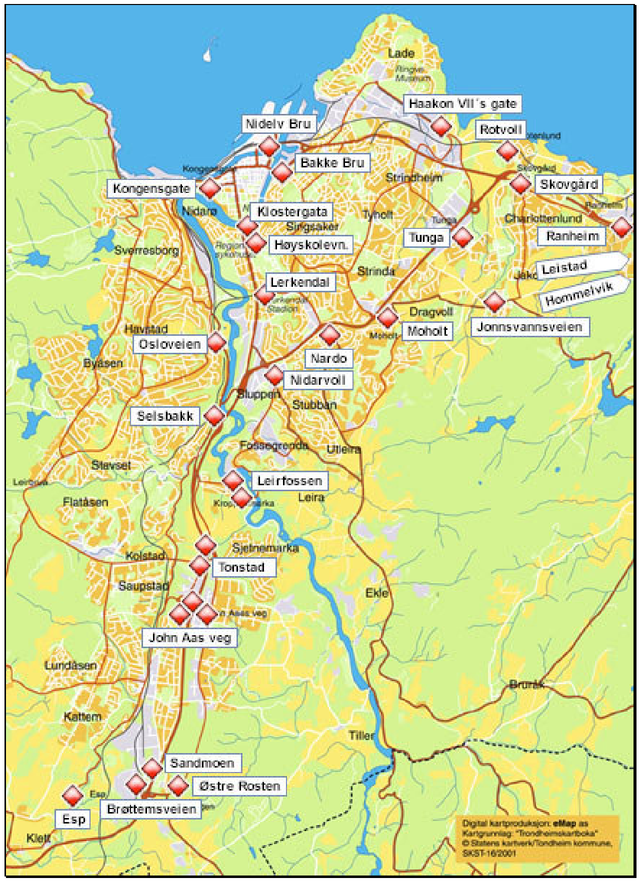


Figure 2-5 The 2004 Trondheim Extended Tolling System

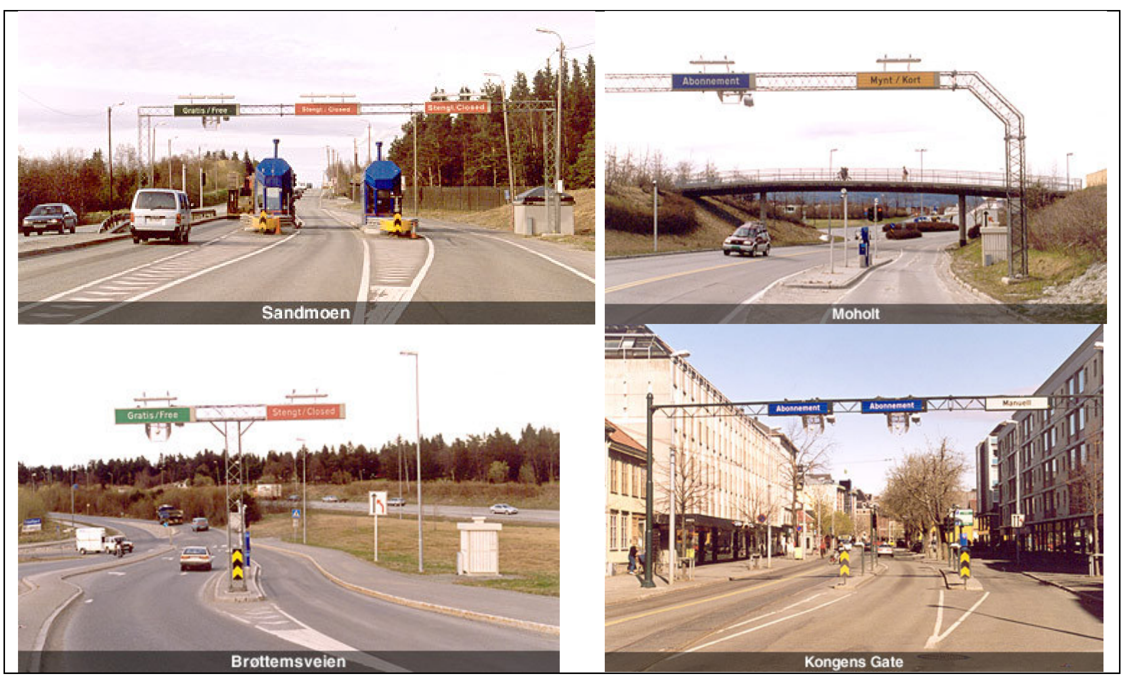


Figure 2-6 Examples of Trondheim Charging Stations

The motivation for this final revision was to cover cost overruns on a remaining highway construction project, and this solution was preferred by the politicians rather than to run the scheme for the full 15 year period until 1 October 2006, or to extend payment periods to cover evenings and weekends. Prices per passage for light vehicles during the last years of operation are shown in Table 2-1. Heavy vehicles (gross weight more than 3.5 tons) always paid twice these amounts. Disabled drivers, electric powered cars and public utility vehicles were exempted. The one hour rule was always in force: No vehicle was charged for more than one crossing within an hour. Also, a maximum limit of 60 chargeable crossings within a month applied.

Table 2-1 Prices per Passage (2005) for Light Vehicles in the Trondheim Toll Ring System

Charges (NOK) depending on payment options	Monday - Friday	
	6:00-10:00	10:00-18:00
Manual payment (basic charge)	15.00	15.00
Prepayment of NOK 500	12.00	9.00
Prepayment of NOK 2500	10.50	7.50
Prepayment of NOK 5000	9.00	6.00
Postpayment by bank giro:		
5 or less passages/week	15.00	12.00
10 or less passages/week	13.50	10.50
More than 10 passages/week	12.00	9.00

2.4 Acceptability, Attitudes to Policy Options and Equity Issues

2.4.1 Public Acceptance of the Charging System

Opinion polls on the attitudes to the Trondheim toll ring indicated decreased opposition after implementation. In April 1991, six months prior to the implementation date, about 70% of the respondents objected to the toll ring. In December 1991, two months after implementation, the negative share had dropped to below 50% (Figure 2-7). During the summer of 1992 the mood was such that slightly more people were positive (37%) than negative (35%). However, as time went by, the negative share increased and the positive share decreased until a peak in October 2003, when four times more were negative than positive. The very low support in 2003 is related to negative publicity and discussions at that time about the immediate introduction of five new charge stations close to the city centre.

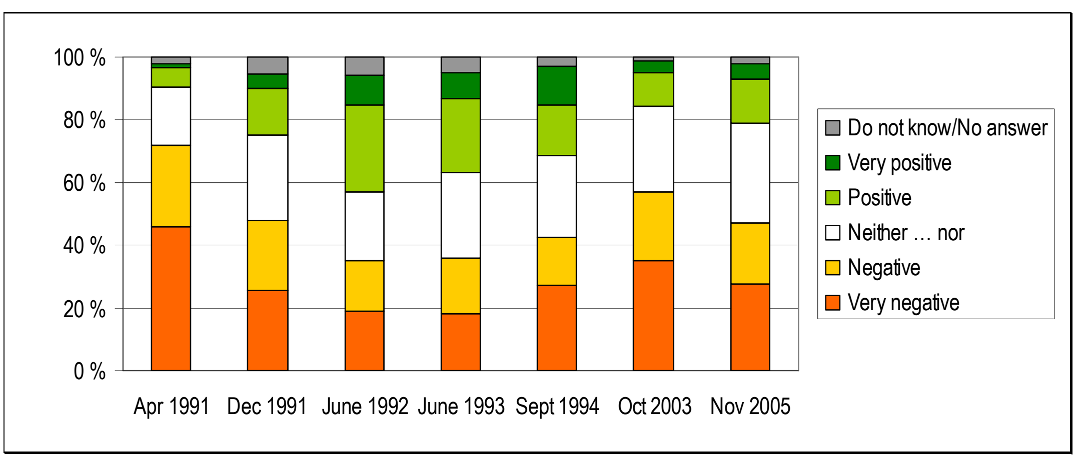


Figure 2-7 Public Attitudes to the Trondheim Charging Scheme

The November 2005 result can be interpreted as a continuation of the long term trend of increasing tiredness and frustration about the charging. The single group being most negative to urban tolling was daily car drivers. The most typical supporters were men living inside the original cordon and driving a car less frequently than on a daily basis. One possible explanation for the diminishing support is the lack of sufficient information and publicity about the purpose of charging as time went on. Public relations work was taken much more seriously by the authorities prior to implementation and during the first year of operation.

A strong indication of the importance of information is that, when respondents were reminded about what type of projects the revenues from charging were financing, the support increased considerably. This can be seen in Figure 2-8. When respondents in 2005 were asked about their attitudes to urban tolling, taking into account the use of revenues, the negative share decreased from 47% to 38%, and the positive share increased from 19% to 30%. The most typical supporters now were men in the 18 to 29 years age group.

What is perhaps more surprising, is the delight with which respondents in 2006 responded to the same question, when asked about their attitude to having had urban tolling in Trondheim. The negative share now dwindled to 27% and the positive share increased to 48%. Subgroups having high shares being positive or very positive to having had urban tolling were men, people living inside the old cordon and the 45 to 59 years old age group. Additionally, support increased with increasing income, increasing education level and decreasing car ownership.

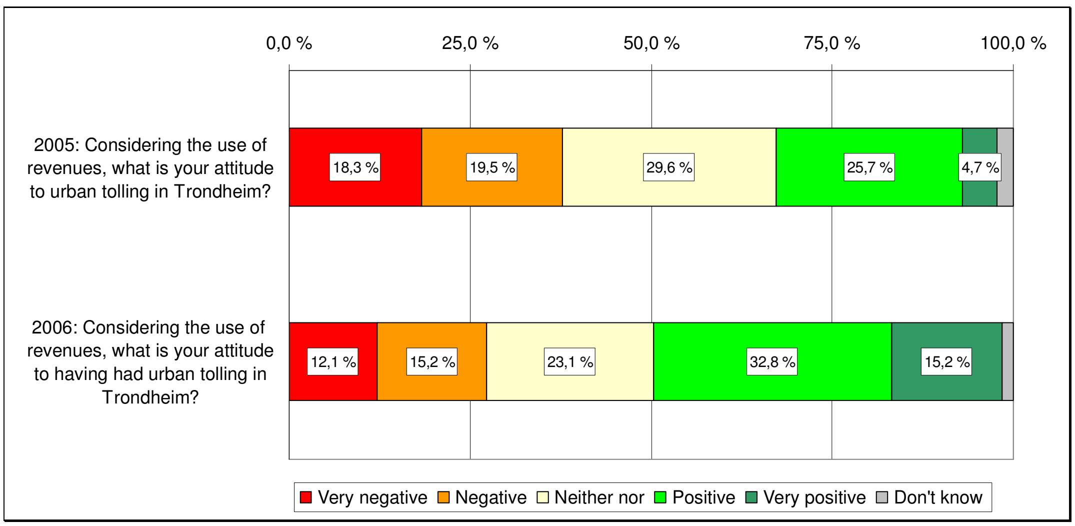


Figure 2-8 Attitudes to the Trondheim Charging Scheme after Being Reminded about the Use of Revenues

2.4.2 Preferences for Pricing Principles and the Use of Revenues

The coming to an end of urban charging in Trondheim meant that revenues in the order of € 28 million annually for use on local transport initiatives disappeared. In the local transport plan 2006 to 2015 a gap between ambitions to improve transport and financial strength had been highlighted. On this background, respondents were asked which principle for raising private sector money they considered most just. This is a question which also formed part of a local survey in 1994 (Tretvik, 1994).

Figure 2-9 shows that congestion charging (explained to the respondents as differentiated charging depending upon where and when you were driving) was preferred by 42% of respondents in 2006, compared to 30% in 1994. The principle labelled quantity (exemplified as a local sales tax on engine fuel) was preferred by 32% in 2006 and 40% in 1994. The experience of the Trondheim differentiated charging scheme over the years seems therefore to have made respondents more ready for accepting the principle of congestion charging in the future.

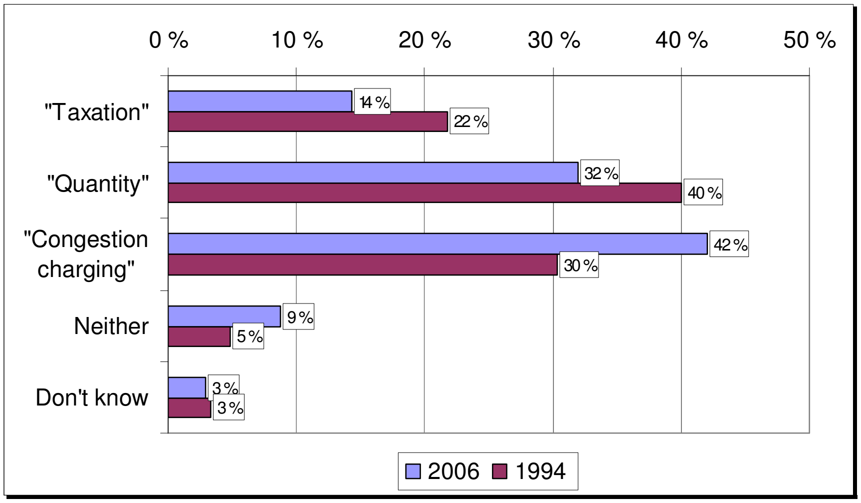


Figure 2-9 What Is the Fairest Principle for Local Urban Charging?

Subgroups with above average support for road pricing were women and people in the 45 to 59 years old age group. Support increased with increasing education level, and somewhat surprisingly, with decreasing income.

A second question from 1994 that was repeated focused on respondents' preferred distribution of money on transport measures. Figure 2-10 shows that *Public transport* was the single measure that people wanted to allocate most money to in both years, in fact around a quarter of the budget. In 2006 the two measures *Traffic safety* and *Improve existing roads* came very close with 22% of the budget each. Spending money on *Environment* and *Bicycle facilities* was preferred more in 1994 than in 2006. This result can perhaps be credited to the fact that around 20% of the revenues during the lifetime of tolling and The Trondheim Package were spent on environmental and soft mode measures.

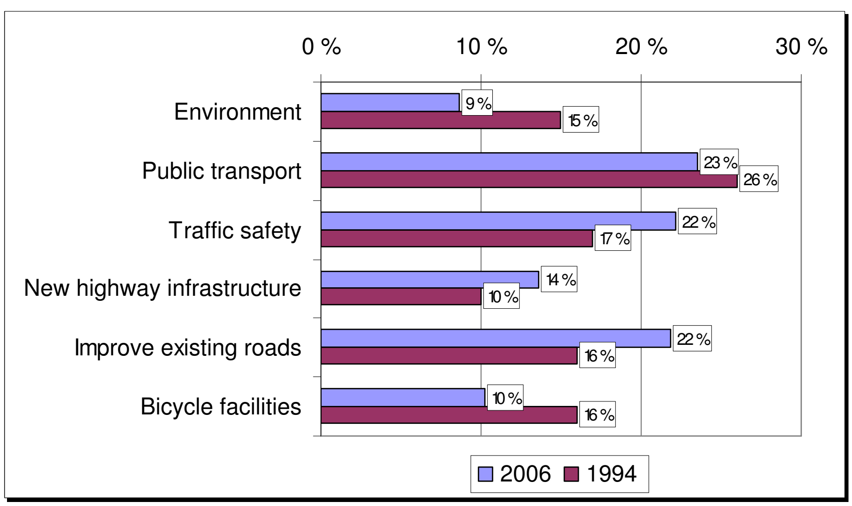


Figure 2-10 Preferred Distribution of Revenue on Transport Measures

Surprisingly to some, *new highway infrastructure* was allocated only 14% of the budget in 2006 and 10% in 1994. More than average support in 2006 for this measure was given by men (18%, compared to 9% by women), daily car drivers, the 30 to 44 years old age group, respondents from households with two or more cars and from people belonging to the group with the highest education level. Also, support increased with increasing income levels.

2.4.3 Equity Issues

Considerations of road pricing and equity deal with two main themes: how to allocate the burdens of charges and how to distribute the benefits. Both burdens and benefits may be allocated according to several different distributive principles, thus making equity considerations very complicated.

Experience from Norway has shown a multitude of ways to approach "fair" and acceptable charging schemes. One important point is to relax on the ambition to design "optimal" schemes, in a way that responds to important con-arguments and reduces opposition. The following features were included in the 1991 toll ring:

- The "one hour rule": Only one crossing per hour is charged, partly due to claims that parents bringing children to kindergarten before travelling to work would be unduly hurt if charged for several crossings.
- Disabled drivers are allowed free crossings.
- A charging system with free passage after 17:00 and in the weekends. The "equity argument" was to avoid charging "social travel", e.g., visits or accompanying children to activities.

The most difficult equity issue has surrounded the question where to locate the toll stations in a "fair" way. The 1991 ring was a compromise between fairness arguments, practical considerations and revenue maximisation. The fairness aspect indicated that motorists benefiting from the new infrastructure should have to pay.

The revised tolling scheme (implemented in 1998) was advertised as fairer by charging a higher proportion of the motorists. (Raising more revenue for infrastructure was the other main argument.) The zonal system implies that the number of total households in Trondheim that pay toll charges during one ordinary (randomly chosen) working day increased from 28% to 42%. However, even after this revision, there was still much public debate on how to further improve the "fairness" of the system.

An assessment of the distributive effects of road pricing must take into account how revenues are spent. A redistribution of revenues to the car users (e.g. by lowering the car purchase tax) is not necessarily "fair" because there will be winners and losers among the motorists. Road pricing is prone to opposition based on equity arguments, because high-income motorists and commercial traffic (valuing time savings higher than the fee) constitute the most likely "winners". "Losers" are likely to be found among low income, car-dependent households.

The most common suggestion on how to compensate losers is to use revenue to improve public transport. In Trondheim part of the revenue was earmarked public transport infrastructure, as well as investments in walking and biking facilities. Furthermore, city centre retailers have been "compensated" by investments improving the environmental quality.

2.5 Traffic Impacts of the Scheme

2.5.1 Short Term Effects of the 1991 Scheme

The evaluations based on 1990 and 1992 travel survey data and traffic counts concluded that over the week as a whole, there was a small decrease in total car traffic crossing the toll ring in the inbound direction. However, this decrease was smaller than the general reduction in car traffic in Trondheim during the same period. It should be noted that the early nineties were a recession period in the Norwegian economy. For a number of years there was no increase in car ownership and, in general, zero growth in traffic on the roads.

Looking at time periods, inbound car traffic through the toll cordon decreased by 10% during both the high and low charged periods, and this decrease was almost offset by an 8 to 9% increase in inbound car traffic during uncharged periods at evenings and at weekends. Thus, the toll ring caused a general shift in timing for car trips away from the charged hours, but the percentage reduction was not affected by the differentiation between peak and off-peak charges.

Table 2-1 shows that for some trip purposes, adjustments were more substantial. The change in departure time was largest for home-based shopping trips, with a major increase in the number of trips outside the charged periods. Also for trips from work to home, the motorists adjusted their time of travel according to the charging system.

The travel surveys show that the number of CBD shopping trips increased in toll-free periods and decreased in tolled periods. No significant changes in destinations for shopping trips were detected. The travel surveys indicate a slight increase in the use of public transport and cycling. However, the toll ring effects are difficult to single out because of parallel improvements in public transport and in the bicycle road network. More car sharing was not detected as a response to the charging.

Table 2-2 Time Profile of Inbound Car Driver Trips through the Toll Ring 1990 and 1992 on Weekdays

	Home – Work		Work – Home		Home - Shopping	
Time Period	1990	1992	1990	1992	1990	1992
0:00 - 6:00 (No charges)	3%	4%	0%	2%	0%	0%
6:00 – 10:00 (High charges)	80%	76%	2%	1%	19%	15%
10:00 – 17:00 (Low charges)	10%	9%	81%	68%	54%	39%
17:00 – 24:00 (No charges)	7%	10%	17%	30%	27%	46%

2.5.2 Aggregated Effects of the 1991 and 1998 Schemes

How to Capture Effects of the Schemes Based on Analyses of Travel Surveys

The 1991 scheme was "embedded" by travel surveys one year before and one year after the introduction. A third travel survey was conducted in 2001. Thus, effects of the 1998 revision of the scheme had to be captured by surveys from six years before and three years after.

The 1991 and 1998 tolling schemes affected specific OD-relations, mainly in one direction, towards the city centre. The trips in the travel surveys can be categorized by their relation to the toll cordons in the two tolling schemes:

- Crossing a toll cordon in charged direction
- Crossing a toll cordon in direction without charging (free)
- No toll cordon on relation

With the 1998 revision of the RUC scheme, there was a significant increase in number of car trips crossing a cordon in the charged direction. With the 1991 scheme represented by the 1992 survey, 16% of all car trips were of this category – the corresponding figure the 1998 scheme was 29% (2001 survey). In addition to the spatial aspects of the tolling schemes, there was also a temporal dimension, since the charging was not continuous, but differentiated throughout the day and week. Thus, the trips in the travel surveys have been categorized by during which time period the trip commenced for the two tolling schemes:

- High toll period, Monday-Friday
- Low toll period, Monday-Friday
- Free period, Monday-Friday
- Free period, Saturday-Sunday

The high toll period lasted from 6:00 to 10:00 for both schemes. The low toll period lasted from 10:00 to 17:00 for the 1991 scheme, but was extended by one hour for the 1998 scheme, to 18:00. The Monday to Friday free periods were then correspondingly 17:00 to 6:00 and 18:00 to 6:00 for the two charging schemes. There was no charging on weekends.

With the 1998 extension of the charging to 18:00, there was a modest increase in number of trips being carried out during charged hours. With the 1991 scheme represented by the 1992 survey, 54% of all trips were of this category – the corresponding figure the 1998 scheme was 56% (2001 survey).

For each of the two RUC schemes, the temporal and spatial dimensions can be combined to a joint categorisation of the trips (Table 2-3):

Table 2-3 Trip Categories

Toll period	**Toll cordon**		
	Charged direction	**Free direction**	**No cordon**
High toll, Mon-Fri	1	2	3
Low toll, Mon-Fri	1	2	3
Free, Mon-Fri	2	2	3
Free, Sat-Sun	2	2	3

The categories are:

1. Trips crossing a toll cordon in charged direction during charging periods (charged);
2. Trips crossing a toll cordon in charged direction during free periods or crossing a toll cordon in direction without charging (free);
3. Trips with no toll cordon crossing, all periods (free).

The three trip categories were studied separately for the two RUC schemes, and they were merged further to a joint categorisation for the two schemes, taking into account whether or not the trip type had undergone a change in relation to tolling. This made a total of nine trip categories, which were further aggregated to four main groups, as shown below (Table 2-4).

Table 2-4 Groups of Trip Categories

1991-scheme	**1998-scheme**		
	1) Toll cordon, charged	**2) Toll cordon, free**	**3) No toll cordon**
1) Toll cordon, charged	B-1	D-2	D-3
2) Toll cordon, free	C-4	A-5	A-6
3) No toll cordon	C-7	A-8	A-9

The trip groups (A-D) and categories (1-9) are:

- B-1 Toll cordon, charged 1991 & 1998;
- D-2 Toll cordon, charged 1991, free 1998;
- D-3 Toll cordon, charged 1991, No toll cordon 1998;
- C-4 Toll cordon, free 1991, charged 1998;
- A-5 Toll cordon, free 1991 & 1998;
- A-6 Toll cordon, free 1991, No toll cordon 1998;
- C-7 No toll cordon 1991, Toll cordon, charged 1998;
- A-8 No toll cordon 1991, Toll cordon, free 1998;
- A-9 No toll cordon 1991 & 1998.

The trips categories are grouped as follows:

- *Group A* holds the trips which are not subject to charging in any of the two schemes, either because there is no cordon on the route, or because the cordon is crossed in free direction or outside the charged hours.
- *Group B* holds the trips crossing a cordon in charged direction during the charged hours in both schemes.
- *Group C* holds the trips not subject to charging with the 1991-scheme, but which are crossing a cordon in charged direction during the charged hours with the 1998-scheme.
- *Group D* holds the trips which were crossing the cordon in charged direction during the charged hours with the 1991-scheme, but which are not subject to charging with the 1998-scheme.

This categorisation and grouping provided a useful tool for studying aggregated effects of the tolling system with regard to the distribution of trips in time and space.

Effects on Mode Choice

Findings from the evaluation of the initial 1991 RUC scheme indicated that there was a shift in mode choice during the charged hours for the trips affected by the charging, with a drop in car trips during the entire charged period, an increase in use of two-wheeled modes during the high-toll period, and an increased use of public transport during the low-toll period. Did the 1998 revision of the RUC-scheme give similar effects?

Although the general trend was an increased use of the car, the data suggests that both the 1991 introduction and the 1998 revision of the RUC scheme did affect the modal split on the relations and time periods which were directly affected by the change.

The data from the travel surveys show that the car generally has become an increasingly important mode of travel in Trondheim. As the RUC scheme targets the car trips only, a possible effect would be a reduction or lower increase in car driver share for trips crossing the cordon in charged direction during the charging hours, than for the other categories of trips.

As the size of Table 2-5 illustrates, even with only four categories describing the trips' relation to the 1991 RCU scheme, the picture quickly gets quite complex. To enhance the main trends indicated by the three travel surveys, graphs with changes over time have been made for the period 1990 to 2001. As the travel surveys only provide data for the years 1990, 1992 and 2001, the figures for the remaining years have been interpolated. This clearly is a very rough approach, and thus the graphs should be interpreted with caution. The main function of the graphs is to provide a basis for comparison between the trip categories.

Table 2-5 Modal Split during Charging Hours (Monday-Friday, 6:00-18:00)

Trip category - mode	Survey year 1990	1992	2001	Change 1990 – 1992	1992 - 2001	1990 - 2001
A) Free/no cordon 1991 & 1998	N=357150	N=303230	N=327822			
Car driver	45 %	46 %	52 %	1%	6%	8%
Car passenger	14 %	14 %	11 %	0%	-3%	-3%
Public transport	8 %	8 %	7 %	1%	-1%	0%
Two wheels	8 %	11 %	11 %	3%	0%	2%
Pedestrian	25 %	20 %	18 %	-5%	-2%	-7%
Other mode	0 %	0 %	1 %	0%	0%	1%
B) Charged 1991 & 1998	N=35927	N=30744	N=29855			
Car driver	56 %	51 %	57 %	-5%	7%	2%
Car passenger	13 %	11 %	8 %	-2%	-3%	-5%
Public transport	23 %	27 %	24 %	4%	-2%	1%
Two wheels	5 %	9 %	8 %	4%	-1%	3%
Pedestrian	3 %	2 %	2 %	-1%	0%	-1%
Other mode	0 %	0 %	0 %	0%	0%	0%
C) Free/no cordon 1991, charged 1998	N=32454	N=28530	N=31536			
Car driver	63 %	62 %	67 %	-1%	5%	4%
Car passenger	16 %	16 %	11 %	0%	-5%	-5%
Public transport	11 %	11 %	12 %	0%	1%	1%
Two wheels	5 %	5 %	6 %	1%	1%	1%
Pedestrian	5 %	4 %	3 %	0%	-1%	-1%
Other mode	0 %	1 %	1 %	0%	1%	1%
D) Charged 1991, free/no cordon 1998	N=3397	N=2763	N=4607			
Car driver	71 %	63 %	61 %	-8%	-2%	-10%
Car passenger	12 %	17 %	9 %	5%	-7%	-3%
Public transport	6 %	6 %	16 %	0%	11%	10%
Two wheels	3 %	1 %	7 %	-1%	6%	4%
Pedestrian	8 %	13 %	5 %	5%	-9%	-3%

Figure 2-11 illustrates the main trends in modal split for the periods 1990 to 2001 for each of the four main trip categories. One of the most striking characteristics shown is the trend-break captured in the 1992 survey for the trips exposed to charging in 1991 (groups B and D), with a clear drop in car driver share, mainly compensated with a higher share of the “soft” modes. The survey data does not reveal a corresponding trend-break for the 1998 scheme, but this does not necessarily mean that there was none. Any effects of the 1998 scheme are blended with more long-term general trends, making it harder to identify scheme-specific effects. However, the more modest increase in car driver share from 1992 to 2001 for group C suggest that this group of trips is worth a closer examination.

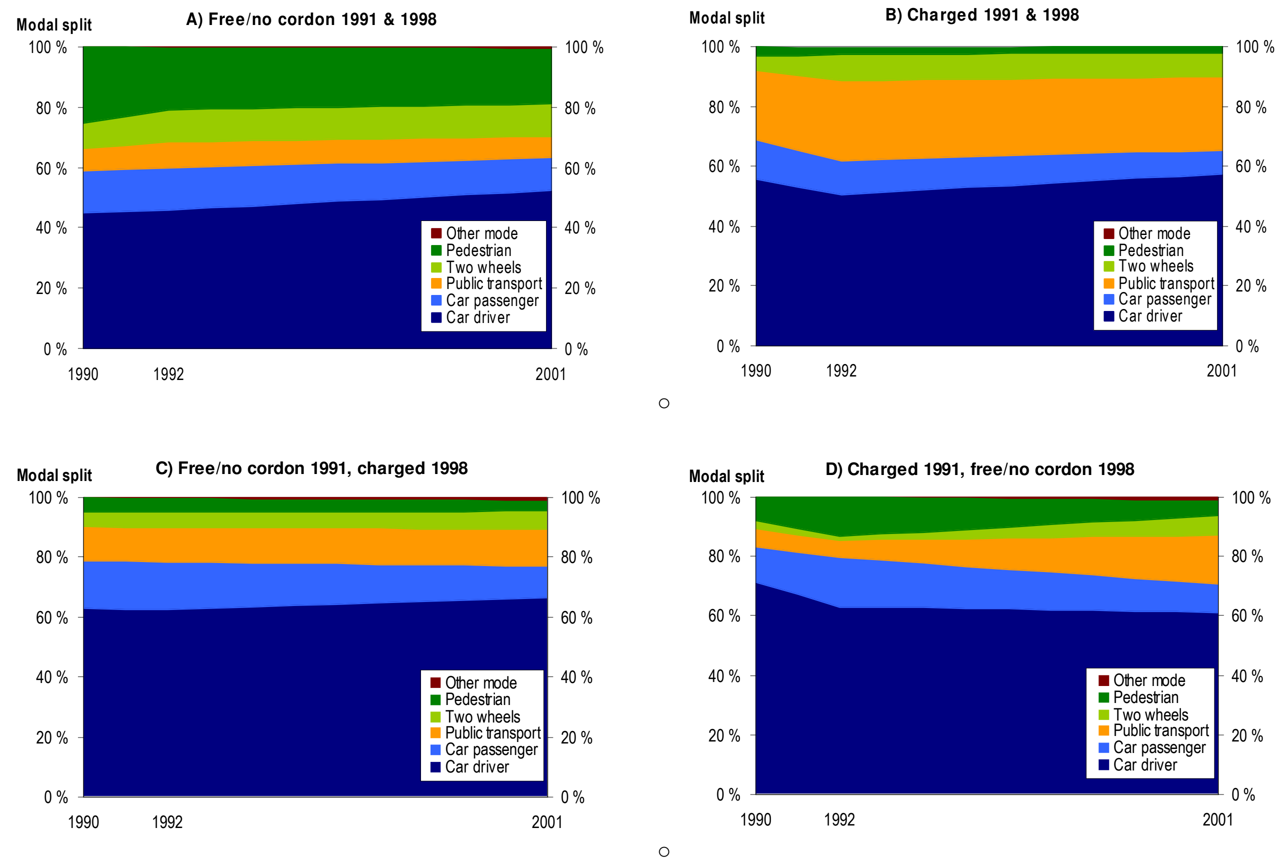


Figure 2-11 Modal Splits for Groups of Trip Categories during Charged Hours

A study of the mode choice for trips directly affected by the 1998 revision of the RUC scheme, suggest that the revision indeed may have had an effect on the travel patterns, similar to what was found for the 1991 scheme (Table 2-6).

Table 2-6 Mode Choice for Trips Affected by the 1998 Revision for an Average Whole Week

	Trip category C): Trips crossing no cordon in 1991-scheme, crossing cordon in charged direction in 1998-scheme									
	Monday - Friday						Weekend		Total	
	6:00 - 10:00		10:00 - 18:00		18:00 - 6:00					
Mode	**1992**	**2001**	**1992**	**2001**	**1992**	**2001**	**1992**	**2001**	**1992**	**2001**
Car driver	61 %	62 %	62 %	68 %	58 %	71 %	50 %	71 %	58 %	68 %
Car passenger	12 %	6 %	17 %	10 %	29 %	15 %	34 %	23 %	23 %	14 %
Public transport	13 %	16 %	11 %	11 %	4 %	5 %	5 %	1 %	9 %	8 %
Two wheels	10 %	10 %	4 %	5 %	4 %	6 %	4 %	3 %	5 %	6 %
Pedestrian	3 %	4 %	5 %	4 %	5 %	2 %	6 %	2 %	5 %	3 %
Other mode	0 %	1 %	1 %	1 %	0 %	0 %	1 %	2 %	1 %	1 %
Total	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %

For the OD-relations which were without a cordon in the 1991 scheme, but which cross a cordon in charged direction with the 1998 scheme, there was a total increase in car driver share from 58% in 1992 to 68% in 2001. This increase was however not uniform throughout the day and week. For the high-toll period (Mon-Fri, 6:00-10:00), there was hardly any change at all, and also for the low toll period (Mon-Fri, 10:00-18:00) the increase was more modest than for the free periods in the evenings (Mon-Fri, 18:00-6:00) and weekends. For the morning peak period, the data suggests an increase in the use of public transport.

Some other main characteristics of the modal split for the four groups of trip categories:

- *Group A* had initially a lower share of private motorized transport alternatives (45% car drivers, 14% passengers in 1990), and more use of "soft" modes (33% in 1990) than the other groups. On average, the trips in this group are shorter, making walking or using a bicycle a relevant alternative for a larger proportion of the trips. By 1992, the share of trips on foot had decreased by 5 %-points, mainly shifted to bicycle. During the 1992 to 2001-period there was an increase in car driver share of 6 %-points, mainly at the expense of the car passenger alternative. Although the RUC schemes probably has affected trips in this group as well, the shifts identified here is the best indication of general trends in modal split during the period from 1990 to 2001.
- The trips in *group B* are mainly directed towards the city centre, as the tolling generally applies for CBD-bound traffic. As the public transport services are based on a radial pattern, with the CBD as hub, the public transport alternative is generally better than average for this group of trips. Thus, it is no surprise that group B had a higher public transport share than the other groups in 1990 (23%). However, the further increase of 4 %-points by 1992 was unique for this group, and can be considered a consequence of the RUC scheme introduced in 1991. Furthermore, the share of bicycle- or MC trips was almost doubled from 1990 to 1992, up from 5% to 9%, and there was a drop in car driver share (-5 %-points) from 1990 to 1992. This, and a decrease in car passengers, was the basis for the increase in use of public transport and two-wheel-alternatives.
- Four out of five trips in *group C* were by private motorized transport, either as car driver (63%) or car passenger (16%) in 1990. The remaining trips were equally distributed between public transport and the "soft" modes. This distribution remained unchanged in 1992, and the only change by 2001 was a 4-5 %-points shift from car passenger to car driver. The lack of shift in modal split from 1990 to 1992 is consistent with what could be expected, as these trips were not directly affected by the 1991 RUC scheme.
- *Group D* had the highest car driver share in 1990 (71%), but by 1992 this was down 8 %-points, mainly due to a shift to car passenger and pedestrian trips. This drop in car driver share is consistent with what could be expected, as these trips were subject to charging in the 1991 RUC scheme. After the 1998-revision of the scheme, these trips were no longer directly affected by the road tolls, and one could therefore anticipate a shift towards car driver. Instead, the car driver share dropped slightly from 63% in 1992 to 61% in 2001. This result is counter-intuitive, and can be explained by the fact that category D trips constituted a very small fraction of the total traffic considered. From 1992 to 2001 there has been a shift from car passenger and pedestrian to public transport and two-wheeled transport alternatives.

Effects on Spatial and Temporal Distribution of Car Driver Trips

The RUC schemes seem to have had an effect on the spatial and temporal travel pattern for car drivers in Trondheim (Table 2-7). While the proportion of trips of category group B has dropped steadily, the proportion of trips of category group A has increased accordingly throughout the first decade of road user charging in Trondheim. The shares of trips of category groups C and D have remained unchanged.

A further inspection of the changes for the trip categories within group A suggests that the increase in this group mainly is the result of a temporal change. The increase mainly comes from the category of trips with no cordon in the 1991-scheme, and with free crossing of a toll cordon in the 1998-scheme (A-8).

Table 2-7 Trip Categories by Toll Cordon Crossings and Toll Periods, Percentage of Car Driver Trips

RUC scheme / Trip category	Survey year 1990	Survey year 1992	Survey year 2001	Change 1990 – 1992	Change 1992 - 2001	Change 1990 - 2001
Trip category						
B-1) Toll cordon, charged 1991 & 1998	10 %	9 %	8 %	- 1 %	- 1 %	- 2 %
D-2) Toll cordon, charged 1991 & free 1998	0 %	0 %	1 %	- 0 %	+ 0 %	+ 0 %
D-3) Toll cordon, charged 1991 & No toll cordon 1998	1 %	1 %	1 %	- 0 %	- 0 %	- 0 %
C-4) Toll cordon, free 1991 & charged 1998	2 %	2 %	2 %	- 0 %	+ 1 %	+ 0 %
A-5) Toll cordon, free 1991 & 1998	23 %	23 %	23 %	+ 0 %	- 1 %	- 0 %
A-6) Toll cordon, free 1991 & No toll cordon 1998	2 %	2 %	2 %	- 0 %	+ 1 %	+ 0 %
C-7) No toll cordon 1991 & Toll cordon, charged 1998	8 %	9 %	7 %	+ 1 %	- 1 %	- 1 %
A-8) No toll cordon 1991 & Toll cordon, free 1998	13 %	13 %	15 %	+ 0 %	+ 2 %	+ 2 %
A-9) No toll cordon 1991 & 1998	41 %	42 %	41 %	+ 1 %	- 1 %	+ 0 %
Aggregated trip groups						
A) Free/no cordon 1991 & 1998	79 %	80 %	81 %	+ 1 %	+ 1 %	+ 2 %
B) Charged 1991 & 1998	10 %	9 %	8 %	- 1 %	- 1 %	- 2 %
C) Free/no cordon 1991, charged 1998	10 %	10 %	10 %	+ 0 %	- 0 %	- 0 %
D) Charged 1991, free/no cordon 1998	1 %	1 %	1 %	- 0 %	+ 0 %	+ 0 %

One objective for revising the Trondheim RUC scheme into a zone-based system in 1998 was to obtain increased “fairness” in terms of more travellers contributing to the financing of the local transport infrastructure investment plan. The travel survey data were investigated to see whether this objective had been met.

In the 1992 survey, 19% of all drivers’ licence-holders travelling on a workday (Monday to Friday), were paying road tolls for at least one of the trips. The corresponding share for the 2001 survey, representing the 1998 scheme, was 30%. This indicates that the revision of the RUC scheme led to an increase of 11 %-points in share of the potential car-driving population who contribute to the infrastructure financing.

2.5.3 Traffic and Income Flows during 1992-2005

The number of vehicles crossing the toll stations increased from close to 21 millions during 1992, the first full year of operation, to more than 50 millions in 2005, the last year of operation (Figure 2-12).

Some interesting findings on longer-term effects appear, when looking at the period 1992-97, during which the payment scheme was unchanged. During this 5-year period there was a slower average annual growth in total traffic crossing the toll cordon (1.8%), compared to the general growth in the Trondheim area (2.8%) or the County of Sør-Trøndelag (2.6%). Most of the growth in traffic crossing the cordon occurred during the charged hours, indeed 2.9% compared to only 0.8% during the uncharged hours. Paid crossings constituted 48.6% in 1992, but grew to 51.3% in 1997.

Firstly, this indicates that the Trondheim charging scheme is associated with a slower growth in total in-bound traffic crossing the cordon than what would otherwise have been expected. Secondly, a gradual return of traffic that initially was “priced out” of the more preferred charged time periods is evident.

	Annual number of vehicles passing the toll stations			
Year	Total number	paying vehicles during charging hours	% paying	Average number of paying vehicles per charging day
1992	20 965 761	10 194 785	48,6 %	40 397
1993	20 792 671	10 347 111	49,8 %	40 505
1994	21 099 409	10 561 013	50,1 %	41 743
1995	21 434 954	10 709 671	50,0 %	42 668
1996	22 162 491	11 195 076	50,5 %	44 521
1997	22 952 890	11 768 635	51,3 %	46 802
1998	31 853 376	18 007 096	56,5 %	71 362
1999	34 884 034	19 751 748	56,6 %	77 967
2000	35 655 190	20 155 562	56,5 %	79 666
2001	36 235 074	20 419 940	56,4 %	81 246
2002	36 708 675	20 476 902	55,8 %	80 618
2003	38 836 339	21 774 674	56,1 %	86 066
2004	49 623 413	28 341 011	57,1 %	111 141
2005	50 177 502	28 638 001	57,1 %	113 194

Figure 2-12 Number of Vehicles Passing the Toll Stations 1992-2005

The 1998 revision of the scheme led to a major increase in traffic crossing the toll cordons, and also in the percentage of vehicles being charged. Compared to the previous year, the total number of vehicles crossing toll stations increased by 39% and charged traffic increased by 53%. The main reason for the large increase in charged traffic was the one hour extension of the charging period.

The final extension of the scheme with six additional toll stations 1 November 2003 is already evident in the traffic data for 2003, but the full effect came in 2004 and 2005. Compared to 2002, the total number of vehicles crossings in 2005 is up by 37% and charged crossings is up by 40%.

Figure 2-13 shows how the flow of gross revenues developed during the lifetime of the charging system. The increase in 1998 is due to the introduction of the zonal scheme. A second large increase came in 2001 after a 25% raise in the basic toll level and a third large increase in 2004 is attributable to the final extension of the scheme. In total the charging scheme brought in 1,818 million NOK in gross revenues.

Annual operation costs for the Trondheim charging scheme have been 10 to 11% of gross revenues throughout its period of operation.

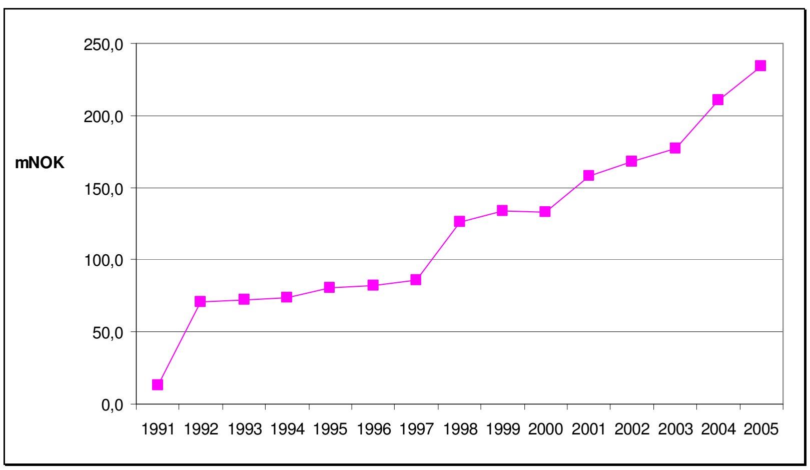


Figure 2-13 Gross Annual Charging Revenues (Millions NOK) 1991-2005

2.5.4 Measured Traffic Changes 2005-2006

When charging was discontinued at the end of 2005, the vehicle counting equipment at all stations stayed in operation for at least three months. Automatic counting was kept running for six months at five stations, and for the whole of 2006 at only one of the closed stations. This enabled traffic changes between 2005, the last year with tolling, and 2006, the first year without tolling, to be studied hour by hour and day by day.

A result for typical local traffic is shown in Figure 2-14 for three stations located along the main by-pass road. Whilst traffic in the formerly charged periods increased by 11.5%, traffic for the whole week increased by only 3.8%, and traffic at working day evenings and at weekends decreased. The total increase for working days constituted 7.5%.

Looking at percentage of traffic within charged hours for working days, this increased to 76.5% in 2006 from 73.9% in 2005. This shows that motorists that were priced out during charging have returned back to the more preferred periods for making trips.

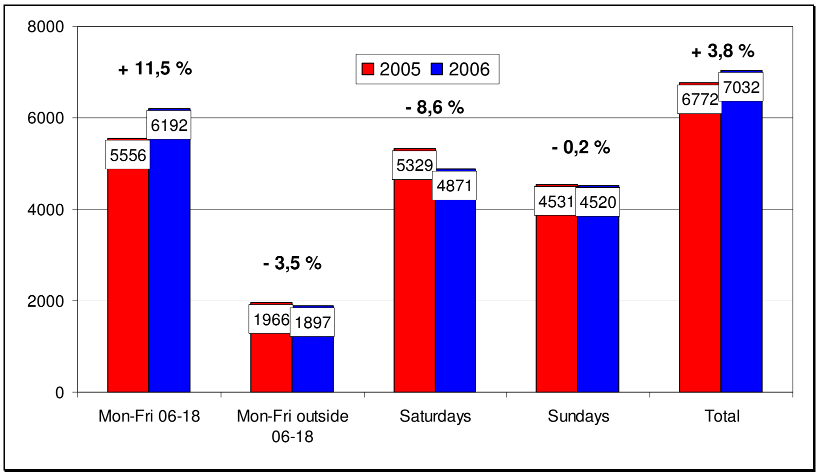


Figure 2-14 Average Daily Volumes January-June 2005 and 2006 for Moholt, Nardo and Nidarvoll

Figure 2-15 provides evidence that some drivers in 2005 started early to avoid being charged; traffic in 2006 between 5:00 and 6:00 decreased by 11 % whilst traffic between 6:00 and 7:00 increased by 11%. In the afternoon, shifts in departure times to avoid being charged are even more evident; the last of the charged hours, between 17:00 and 18:00, has a 20% increase in 2006, and an 8% decrease in the following hour.

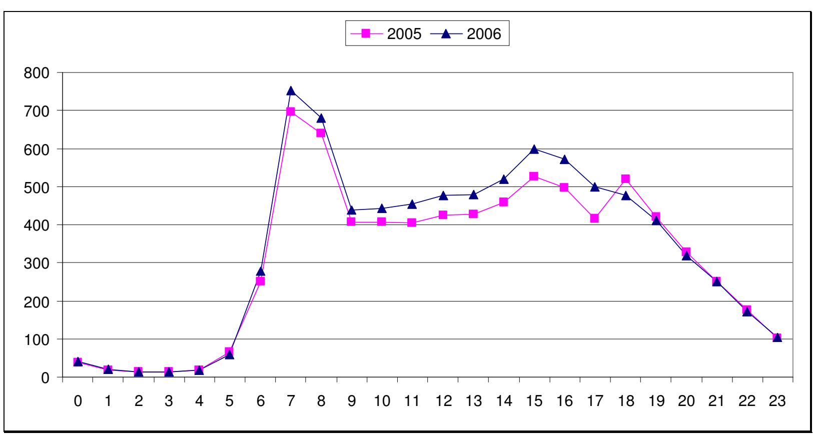


Figure 2-15 Average Hourly Volumes for Working Days January-June 2005 and 2006 for Moholt, Nardo and Nidarvoll

Finally, Figure 2-16 shows that increases in volumes for working days were largest in the afternoon, smaller during the middle of the day and smallest in the morning. This pattern may at first glance seem surprising, considering that charges were higher in the morning hours 6:00-10:00 than later in the day (see Table 2-1 showing the charge structure in the Trondheim toll ring system).

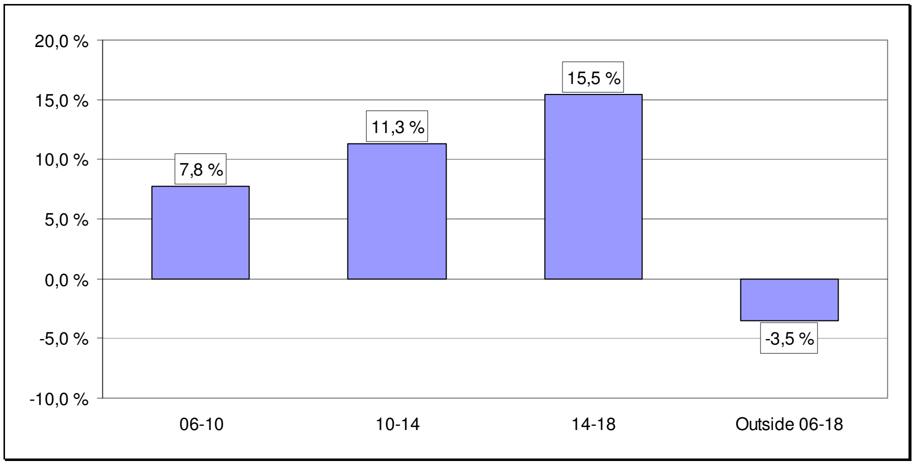


Figure 2-16 Average Changes in Volumes between 2005 and 2006 for Time Intervals during Working Days January-June for Moholt, Nardo and Nidarvoll

The explanation for this has to a large degree to do with how trip purposes are distributed in time during an average working day. Work, school and business trips are fairly inelastic with regard to departure time compared to other trip purposes. The split between these two groups of purposes is shown in Figure 2-17 for the same origin-destination segment as in Figure 2-16. For the part of the day that was charged during 2005, there is clearly a negative correlation between the shift in volumes in time periods and the share of work, school and business trips in the same time periods. The larger the share of other trips, the larger are the changes in volumes. This indicates that the progressively larger increases throughout the day can be explained by a corresponding larger share of private trip purposes, having a larger elasticity of demand with regard to the choice of departure time.

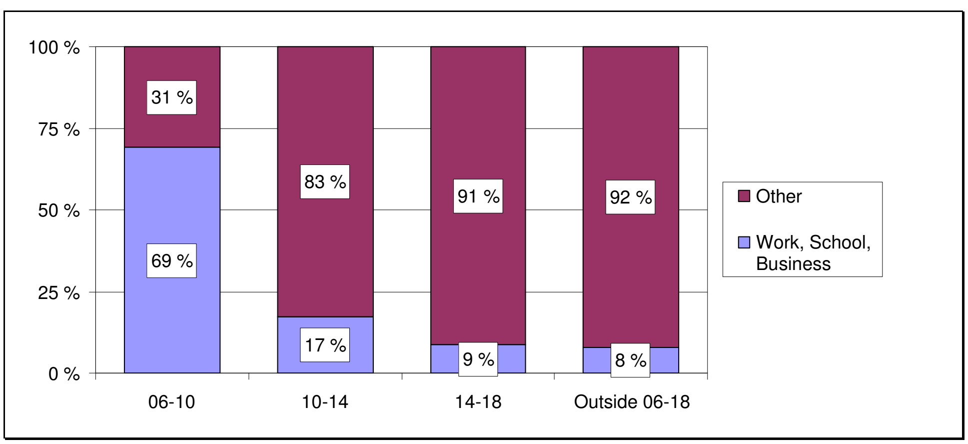


Figure 2-17 Trip Purposes by Time Intervals for Car Drivers during Working Days Inbound Across the By-pass Road from the 2001 Travel Survey

Traffic entering the city from the east is clearly affected by the fact that the Ranheim toll plaza (Figure 2-5) is still in operation. This is a bi-directional charging station in operation 24 hours a day and 7 days a week with the purpose of providing revenues for the E6 East motorway project. When the municipal charging stations were demolished, motorists in 2006 were able to make detours using routes that were now free of charge, to avoid passing through Ranheim. The result was a considerable increase between 2005 and 2006 at places like Skovgård (48% for charged periods and

25% for average daily traffic) and Tunga (20% for charged periods and 16% for average daily traffic), and corresponding decreases at Ranheim (-17% for charged periods and – 11% for average daily traffic).

Some of the stations that came into operation close to the city centre during the last expansion of the charging system were also affected by route change adjustments. Considerable increases in traffic levels at these stations in 2006 indicate that motorists returned back to preferred routes which they had been priced out from using.

On the whole, traffic in the formerly charged periods Monday to Friday 6:00 to 18:00 increased much more than traffic during other periods of the week between 2005 and 2006. For most parts of the municipality, traffic increases for the week as a whole were in line with the general traffic growth in the county. For the southern part of the municipality, it can be argued that the stop of charging led to traffic increases that were higher than otherwise expected.

2.5.5 Car Drivers' Own Assessments of Changed Travel Behaviour between 2005 and 2006

A survey was conducted during the autumn of 2006, asking, among other things, car drivers to assess if and how their own car use had been altered after the disappearance of charging. A total of 23% of regular car users stated that they had made some change or considerable change to their car use for at least one of the trip purposes work/school, shopping or other. 'Some change' was more common than 'considerable change', and shopping trips were most affected (13%), followed by other trips (10%) and work/school trips (8%).

Figure 2-18 shows how different types of changes were distributed for each trip purpose and in total for all trip purposes. Change of departure time and making more car trips were the most common forms of adjustments for shopping and other trips. This implies that car trips that in 2005 were "priced out" or shifted to evenings and weekends have returned to more preferred times for travelling, i.e. at daytime before 18:00 on weekdays. Making more car trips for work/school probably means that trips have been switched from other modes, since the average number of work and school trips per person would be fairly constant from one year to the other.

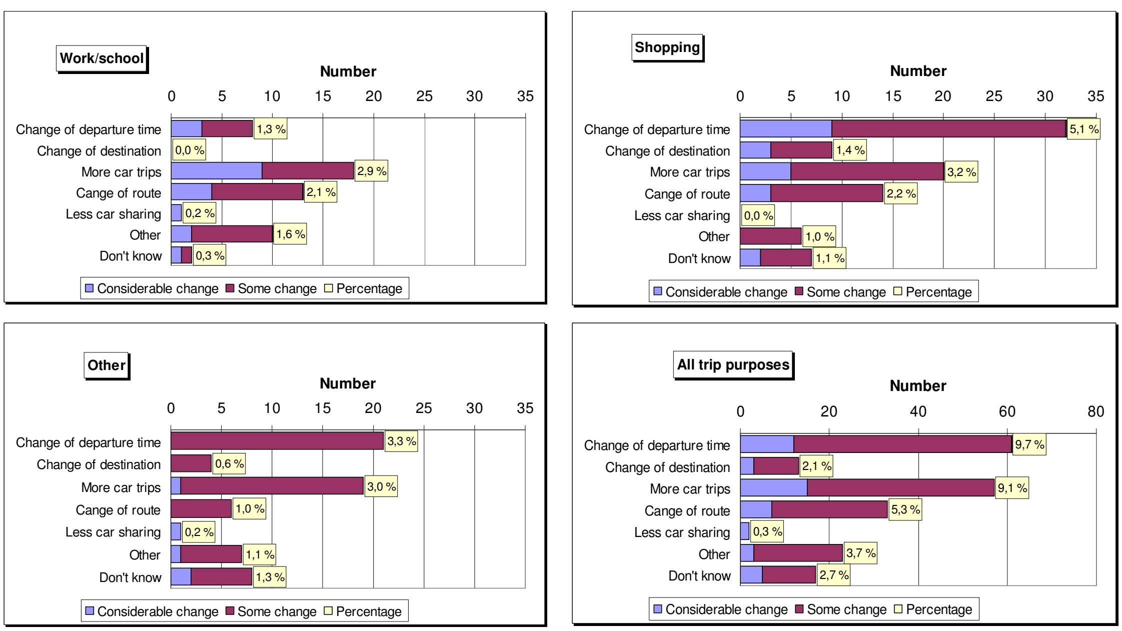


Figure 2-18 Car Use Adjustments during the First Year with No Urban Tolling

It can be noted that less car sharing occurred only infrequently. This implies that car sharing was not a common response to charging.

2.5.6 Modelled Impacts: 2005-2006

In this section, some results from the modelling of three alternatives are presented: The situation in 2005 with the tolling system in operation (2005), a scenario for 2006 with tolling (2006WT) and the situation in 2006 with no tolling (2006WNT).

Looking at the right hand column of Table 2-8 describing changes between 2005 and 2006WNT, it can be seen that a growth in the share of car driver trips of 3.1 percentage points was predicted, and that the shares of other modes were predicted to decrease.

Table 2-8 Mode Distribution Trondheim Municipality; 2005, 2006 with Tolling (2006WT) and 2006 With No Tolling (2006WNT)

	Alternative			Change		
Mode	2005	2006WT	2006WNT	2005 -> 2006WT	2006WT -> 2006WNT	2005 -> 2006WNT
Car driver	49.6 %	49.9 %	52.7 %	+ 0.2 %	+ 2.9 %	+ 3.1 %
Car passenger	8.6 %	8.7 %	7.0 %	+ 0.1 %	- 1.7 %	- 1.6 %
Public transport	10.4 %	10.4 %	10.0 %	+ 0.1 %	- 0.4 %	- 0.4 %
Pedestrian/bicycle	31.4 %	31.0 %	30.2 %	- 0.3 %	- 0.8 %	- 1.1 %
Total	100.0 %	100.0 %	100.0 %			

Table 2-9 shows that a 2% increase in the total number of trips was predicted, and all of this increase is by car drivers. Car driver trips were predicted to increase by 8%, mainly at the expense of car passenger trips (-17%), but also trips by public transport and pedestrian/bicycle were predicted to decrease slightly.

Average speeds by car were predicted to decrease in the alternative 2006WNT. Coupled with the increase in the number of trips, this leads to 15% increase in vehicle time.

Total energy consumption for passenger transport in Trondheim was computed at around 1,900 mWh in 2005 and an increase of 7% to around 2,000 mWh in 2006 with no tolling (Table 2-10). The increase in energy consumption by passenger cars is around 8% while for buses there was almost no change. Buses constitute 7-8% of the total consumption.

Converted to energy consumption per hour, this is highest in the afternoon, and estimated at 172 mWh per hour in 2005 and 189 mWh per hour in 2006.

Table 2-9 Transport Indicators for Working Days Trondheim Municipality; 2005, 2006 with Tolling (2006WT) and 2006 with No Tolling (2006WNT)

Mode	Alternative			Change					
				2005 -> 2006WT		2006WT -> 2006WNT		2005 -> 2006WNT	
Unit	2005	2006WT	2006WNT	Absolute	Relative	Absolute	Relative	Absolute	Relative
Car driver									
Trips	297,751	305,137	323,040	+ 7,386	*+ 2 %*	+ 17,903	*+ 6 %*	+ 25,289	*+ 8 %*
km	3,155,730	3,251,480	3,414,216	+ 95,750	*+ 3 %*	+ 162,736	*+ 5 %*	+ 258,486	*+ 8 %*
min	4,626,557	4,818,557	5,317,183	+ 192,000	*+ 4 %*	+ 498,626	*+ 10 %*	+ 690,626	*+ 15 %*
km/h	41	40	39	- 0		- 2		- 2	
km/trip	11	11	11	+ 0		- 0		- 0	
mins/trip	16	16	16	+ 0		+ 1		+ 1	
Car passenger									
Trips	51,685	53,203	42,857	+ 1,518	*+ 3 %*	- 10,346	*- 19 %*	- 8,828	*- 17 %*
km	510,530	532,742	417,609	+ 22,212	*+ 4 %*	- 115,133	*- 22 %*	- 92,921	*- 18 %*
min	682,942	719,059	565,575	+ 36,117	*+ 5 %*	- 153,484	*- 21 %*	- 117,367	*- 17 %*
km/h	45	44	44	- 0		- 0		- 1	
km/trip	10	10	10	+ 0		- 0		- 0	
min/trip	13	14	13	+ 0		- 0		- 0	
SUM Car diver + passenger									
Trips	349,436	358,340	365,897	+ 8,904	*+ 3 %*	+ 7,557	*+ 2 %*	+ 16,461	*+ 5 %*
km	3,666,260	3,784,222	3,831,825	+ 117,962	*+ 3 %*	+ 47,603	*+ 1 %*	+ 165,565	*+ 5 %*
min	5,309,499	5,537,616	5,882,758	+ 228,117	*+ 4 %*	+ 345,142	*+ 6 %*	+ 573,259	*+ 11 %*
km/h	41	41	39	- 0		- 2		- 2	
km/trip	10	11	10	+ 0		- 0		- 0	
min/trip	15	15	16	+ 0		+ 1		+ 1	
Public transport									
Trips	62,320	63,916	61,498	+ 1,596	*+ 3 %*	- 2,418	*- 4 %*	- 822	*- 1 %*
km	570,411	592,276	570,582	+ 21,865	*+ 4 %*	- 21,694	*- 4 %*	+ 171	*+ 0 %*
min	832,316	862,879	831,999	+ 30,563	*+ 4 %*	- 30,880	*- 4 %*	- 317	*- 0 %*
km/h	41	41	41	+ 0		- 0		+ 0	
km/trip	9	9	9	+ 0		+ 0		+ 0	
min/trip	13	14	14	+ 0		+ 0		+ 0	
Pedestrian/bicycle									
Trips	188,048	189,753	185,144	+ 1,705	*+ 1 %*	- 4,609	*- 2 %*	- 2,904	*- 2 %*
km	521,271	530,018	513,186	+ 8,747	*+ 2 %*	- 16,832	*- 3 %*	- 8,085	*- 2 %*
min	6,255,252	6,360,216	6,158,232	+ 104,964	*+ 2 %*	- 201,984	*- 3 %*	- 97,020	*- 2 %*
km/h	5	5	5	0		0		0	
km/trip	3	3	3	+ 0		- 0		- 0	
min/trip	33	34	33	+ 0		- 0		- 0	
Total									
Trips	599,804	612,009	612,539	+ 12,205	*+ 2 %*	+ 530	*+ 0 %*	+ 12,735	*+ 2 %*
km	4,757,942	4,906,516	4,915,593	+ 148,574	*+ 3 %*	+ 9,077	*+ 0 %*	+ 157,651	*+ 3 %*
min	12,397,067	12,760,711	12,872,989	+ 363,644	*+ 3 %*	+ 112,278	*+ 1 %*	+ 475,922	*+ 4 %*

Table 2-10 Estimated Energy Consumption (kWh) Trondheim Municipality; 2005, 2006 with Tolling (2006WT) and 2006 with No Tolling (2006WNT)

		Alternative			Change		
Period	**Unit**	**2005**	**2006WT**	**2006WNT**	**2005 -> 2006WT**	**2006WT -> 2006WNT**	**2005 -> 2006WNT**
1 Evening-night	Passenger car	369,503	382,358	386,394			
(18-06)	Bus	35,959	37,281	36,983			
	SUM	405,462	419,638	423,377	+ 3.5 %	+ 0.9 %	+ 4.4 %
	kWh/hour	33,789	34,970	35,281			
	% from bus	*9 %*	*9 %*	*9 %*			
2 Morning	Passenger car	223,128	232,555	246,420			
(06-09)	Bus	20,947	21,633	21,139			
	SUM	244,075	254,189	267,559	+ 4.1 %	+ 5.3 %	+ 9.6 %
	kWh/hour	81,358	84,730	89,186			
	% from bus	*9 %*	*9 %*	*8 %*			
3 Mid day	Passenger car	654,943	669,763	704,083			
(09-15)	Bus	55,331	57,212	55,407			
	SUM	710,274	726,975	759,490	+ 2.4 %	+ 4.5 %	+ 6.9 %
	kWh/hour	118,379	121,162	126,582			
	% from bus	*8 %*	*8 %*	*7 %*			
4 Afternoon	Passenger car	488,078	503,638	540,922			
(15-18)	Bus	28,098	29,411	27,493			
	SUM	516,176	533,049	568,415	+ 3.3 %	+ 6.6 %	+ 10.1 %
	kWh/hour	172,059	177,683	189,472			
	% from bus	*5 %*	*6 %*	*5 %*			
Total	Passenger car	1,735,652	1,788,314	1,877,819	+ 3.0 %	+ 5.0 %	+ 8.2 %
	Bus	140,336	145,537	141,021	+ 3.7 %	- 3.1 %	+ 0.5 %
	SUM	1,875,987	1,933,851	2,018,840	+ 3.1 %	+ 4.4 %	+ 7.6 %
	kWh/hour	78,166	80,577	84,118			
	% from bus	*7 %*	*8 %*	*7 %*			
Distribution by period	1	21 %	21 %	20 %			
	2	14 %	14 %	14 %			
	3	36 %	36 %	36 %			
	4	29 %	29 %	29 %			

2.5.7 Elasticity Estimates: 2005-2006

Results for average duration and length of car trips as well as total kilometres travelled from the model runs, average tolls paid per vehicle for 2005 from the toll road company and standard national unit values for values of time, vehicle costs and distribution of trip purposes have been used to estimate an aggregate elasticity value. Table 2-11 shows that the average generalised cost per car trip decreased by 22% from 2005 to 2006, as a result of the end of tolling. The estimated elasticity value with respect to kilometres travelled of -0.32 implies an increase in car traffic by 7% for weekdays. This result fits well with observed values.

Table 2-11 An Aggregate Estimation of Elasticity

Cost component	Unit	Share of total traffic	Value	Share	Average trip time 2005	Average trip length 2005	Genaralized travel cost, excluding toll, 2005	Average toll	Genaralized travel cost, including toll, 2005
VOT business			198	0.17			8.05		
VOT work		0.923	57	0.24			3.27		26.97
VOT other	Hour		53	0.59			7.48		
VOT HGV		0.038	464	0.50	15.54	10.60	2.28	8.18	12.04
VOT busses		0.038	321	0.50			1.58		
Vehicle cost, light vehicles	Kilometer		2.08	0.92			20.37		20.37
Vehicle cost, heavy vehicles			4.95	0.08			3.99		3.99
SUM	-		-	-	-	-	-	-	63.38

Cost component	Unit	Share of total traffic	Value	Share	Average trip time 2006	Average trip length 2006	Genaralized travel cost, 2006		Genaralized travel cost, 2006
VOT business			203	0.17			8.72		
VOT work		0.923	58	0.24			3.54		20.36
VOT other	Hour		54	0.59			8.10		
VOT HGV		0.038	475	0.50	16.46	10.57	2.47		4.19
VOT busses		0.038	328	0.50			1.71		
Vehicle cost, light vehicles	Kilometer		2.13	0.92			20.78		20.78
Vehicle cost, heavy vehicles			5.06	0.08			4.07		4.07
SUM	-		-	-	-	-	-	-	49.40

Change in generalized travel cost: -22%

Arc elasticity:

		ln	Elasticity
Kilometers 2006:	3,414,216	15.0434584	
Kilometers 2005:	3,155,730	14.9647304	-0.32
Generalized travel cost 2006:	49.40	3.89991474	
Generalized travel cost 2005:	63.38	4.14907463	

2.6 SUBSCRIPTIONS AND EXEMPTIONS

The automatic electronic payment option was always the main option for motorists using the scheme. The percentage of charged crossings paid for by automatic charging increased from 80% in 1992 to 95% in 2005 (Figure 2-19).

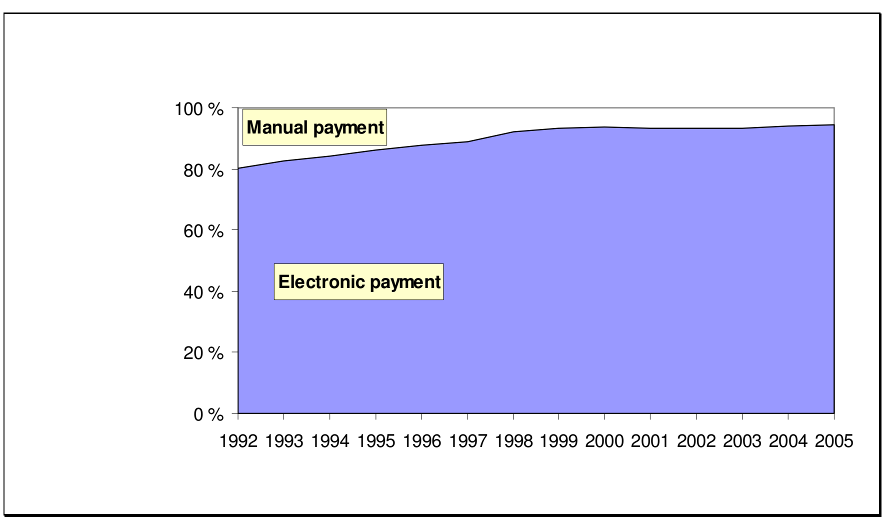


Figure 2-19 Split Between Manual and Electronic Payment 1992-2005

Four categories of vehicles had exemptions from being charged in the Trondheim scheme:

- Handicapped with a parking permit;
- Emergency vehicles / uniformed vehicles;
- Public transport vehicles;
- Electric vehicles.

A vehicle which qualified for one of the exemption categories was equipped with an electronic tag identifying it as such. Statistics for the distribution of exempt categories in relation to total numbers of contracts at a certain date in 2003 was provided by the toll operator and is shown in Table 2-12. Overall, less than 2% of the total number of nearly 140,000 contracts belonged to one of the exempt categories. Of the heavy vehicles registered with a subscription, 10.2% were exempt from paying the toll, while the same applied to only 1.5% of the light vehicles (weight 3.5 tonnes or less).

The exempt vehicles are dominated by the handicapped with a parking permit (57%), followed by public transport vehicles (36%), and uniformed or emergency vehicles (5%). According to the toll operator, the number of exemptions has been stable over time, with only a modest growth due to increased issuing of parking permits for handicapped in the neighbouring municipalities of Trondheim.

Table 2-12 Total Number of Contracts and Exemptions in the Trondheim Scheme by 6 May 2003

	Private customers			Companies			Total		
Subscription type	**Light vehicles**	**Heavy vehicles**	**Total**	**Light vehicles**	**Heavy vehicles**	**Total**	**Light vehicles**	**Heavy vehicles**	**Total**
Total tags / Contracts	**127,473**	**3,501**	**130,974**	**4,844**	**3,298**	**8,142**	**132,317**	**6,799**	**139,116**
Exemptions	*1,573*	*7*	*1,580*	*424*	*689*	*1,113*	*1,997*	*696*	*2,693*
Handicapped	1,533	7	1,540			0	1,533	7	1,540
El-car	36		36	17		17	53	0	53
Public transport			0	297	672	969	297	672	969
Emergency vehicle			0	10		10	10	0	10
Uniformed vehicle	3		3	100	17	117	103	17	120
Other (test vehicle)	1		1			0	1	0	1
% of category Exemptions	1.2 %	0.2 %	1.2 %	8.8 %	20.9 %	13.7 %	1.5 %	10.2 %	1.9 %

2.7 Economic Impacts: City Centre Traders

2.7.1 Short Term Impacts of the 1991 Scheme

Prior to implementation, there was a lot of concern about negative effects on the attractiveness of the CBD for business activity, and great uncertainty prevailed about the possible effects on shopping trips. For instance, a shopping survey in 1990 concluded that 25% of respondents in Trondheim and surrounding areas were likely to change their shopping behaviour because of the toll ring by moving their shopping to other destinations or times. The follow-up study in 1992 revealed that respondents had changed their shopping behaviour only modestly (10% rather than 25%).

The Trondheim Chamber of Commerce carried out a special survey of trade turnover in Trondheim starting September 1991 (one month before the opening of the toll ring) and ending September 1992. A sample of 40 firms representing about 25% of total turnover in Trondheim took part. The firms were located throughout the municipality (both inside and outside the toll ring) and covered the major business sectors. The conclusion from the study was that a long lasting trend of growth in areas outside and decline in areas inside of the toll cordon levelled out during the study period. During the first months of 1992 there was evidence of some businesses located inside the toll ring losing trade.

From the summer of 1992 no distortion of competition due to the toll ring could be read out of the statistics. Business people located in the CBD had prior to the toll ring predicted major negative swings in trade once the toll ring came into operation. The Chamber of Commerce in its own study concluded that there was hardly any effect of the toll ring on trade at all.

2.7.2 Longer Term Effects on Retailing

A study of retail sales data for the period 1987 to 1997 shows that the CBD did loose trade in real terms in the period 1987 to 1990 (Figure 2-20). Then, starting in the same year as the introduction of the toll ring, city centre trade has in real terms been on a general trend line of modest but steady growth.

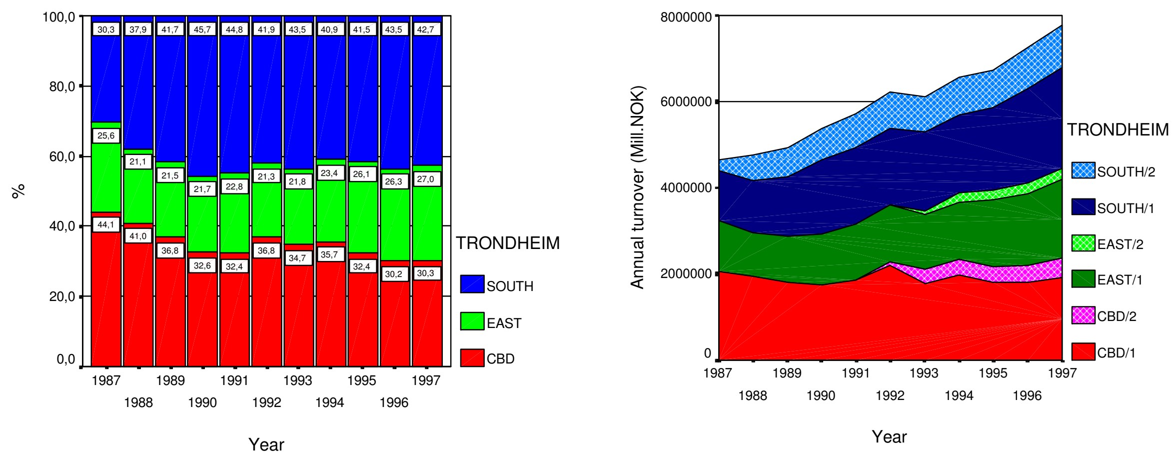


Figure 2-20 Retail Market Share and Volumes by City Sector 1987-1997

The loss in market share to other sectors in the municipality is simply a result of these sectors having a faster growth. It can be concluded that in spite of the toll ring, the city centre has had a modest growth in trade.

2.7.3 Short Term Impacts of the Discontinuation of Charging

Figure 2-21 shows what happened to CBD retail trade in relation to other areas in the municipality since the turn of the century. It should be noted that ‘CBD’ now has a different definition from the one used in the previous figure. The long term trend of decreasing market shares has continued, even though the net sales volumes have grown modestly. However, the market share did not drop during 2005, and the drop during 2006 was smaller than in previous years. Still, the end of road user charging did not lead to an upswing in city centre trade during 2006.

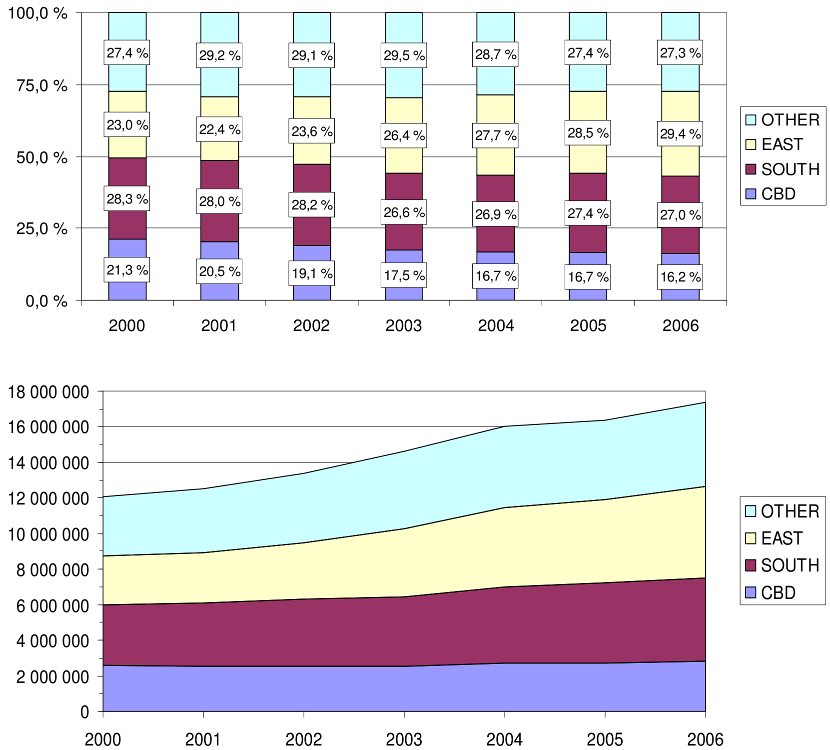


Figure 2-21 Retail Market Share and Volumes by City Sector 2000-2006

2.8 CONCLUSIONS

During 1992, the first year of operation of the Trondheim toll ring, inbound car traffic through the cordon decreased by 10% during both the high and low charged periods. This decrease in traffic was offset by increases in inbound car traffic in evenings and at weekends. Thus, over the week as a whole, total traffic volumes across the toll ring were virtually unaffected by the charging. For some trip purposes like inbound work-home and home-shopping, there were substantial shifts away from the charged afternoon period to the uncharged evening period.

When charging was terminated at the end of 2005, traffic impacts were in many ways mirror images of the impacts when charging was introduced. Changes in departure times and route choices were the most visible responses to the end of charging by car drivers. In general, the Trondheim charge levels were modest, but traffic still displayed sensitivity to tolls.

Model runs show that the removal of charging caused the private car to increase its modal share at the expense of all other modes. If charging had continued, increases in total number of trips would have been more uniformly distributed among travel alternatives.

3 LONDON

3.1 HISTORY AND MAIN CHARACTERISTICS OF THE CHARGING SCHEME

3.1.1 Political Background

The idea for some form of road pricing in London had been around for several decades before the planning and implementation of the current congestion charge that has been in operation since February 2003. In 1995 the London Congestion Research Programme examined possible pricing options and predicted net benefits for a pricing scheme in central London. The Greater London Authority, formed in 1999, was given the power to introduce congestion charging. At this time the ROCOL group was formed (Review of Charging Options for London) to study and report on the implications of introducing charging, and to inform candidates for London Mayor.

Introduction of the congestion charge was part of the election manifesto of Ken Livingstone, when he stood as an independent candidate for London Mayor in 2000. Once elected as Mayor, Livingstone followed through on this election pledge and initiated an extensive period of consultation and detailed planning prior to the introduction of the congestion charge. Following an initial period of consultation with “key stakeholders” (local councils, businesses and road user representatives), Transport for London (TfL) issued the first “Greater London (Central Zone) Congestion Charging Order” and wider public consultation took place for ten weeks from July 2001. The scheme was publicised widely, via a public information leaflet, newspaper and radio advertising, a public exhibition, public meetings, a call centre and a website. Public responses could be submitted via post, on-line or by e-mail or by form-filling at the public exhibition or at TfL’s offices.

All “representations” received were analysed and a small number of modifications to the proposed scheme were made (mostly relating to discounts and exemptions). A further consultation then took place on the modified scheme. Again all representations were analysed and a final report to the Mayor on the final proposed congestion charging scheme was made. On the basis of this report, the Mayor decided to proceed with the congestion charge for central London.

The policy reasons stated by the Mayor to introduce congestion charging in central London were stated at this time as:

- Every weekday morning, the equivalent of 25 busy motorway lanes of traffic tries to enter central London.
- London suffers the worst traffic congestion in the UK and amongst the worst in Europe.
- Drivers in central London spend 50% of their time in queues.
- It has been estimated that London loses between £ 2 to 4 million every week in terms of lost time caused by congestion.

3.1.2 Aims of the Scheme

The congestion charging scheme is part of an overall transport strategy, which aims “to create a world class transport system for the city, meeting the needs of business and of residents and visitors to the city.” As is the case with other road charging schemes, the charge is intended to ensure that those using valuable and congested road space make a financial contribution, thus encouraging the use of other modes of transport. For drivers who then choose to pay and therefore drive in the charging zone, journey times will be quicker and more reliable.

The Mayor’s transport strategy, which was published on 10 July 2001, had ten key priorities. Congestion charging aimed to address four of these:

- Reducing traffic congestion;
- Making radical improvements to bus services across London;

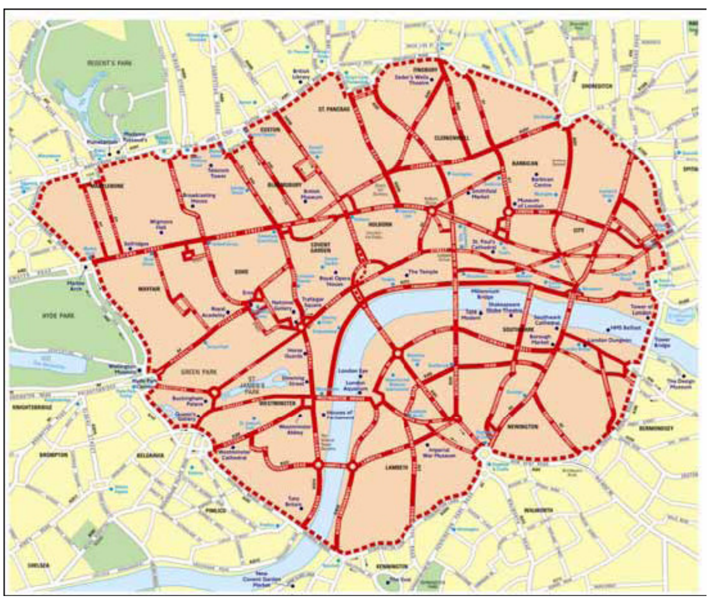
- Improving journey time reliability for car users;
- Making the distribution of goods and services in London more reliable, sustainable and efficient.

Money raised from the congestion charge can only be spent on improvements to transport to meet the aims of this transport strategy, making make public transport easier, cheaper, faster and more reliable. The congestion charge came into effect in central London on 17 February 2003. A number of "variations" to the initial scheme order have been implemented since then, most notably, in July 2005 an increase in charging levels and in February 2007 an expansion of the charging zone.

3.1.3 Type of Scheme and Area Covered

The London congestion charge is a cordon (or area) scheme, with drivers paying a flat daily fee to enter the congestion charging zone. The charging zone is monitored by an extensive network of cameras (at all entries to the zone and at points within the zone) so that there are no tollbooths or barriers around the congestion charging zone and no physical tickets or passes are required. The charge can be paid online, by telephone or text message or at dedicated paypoints.

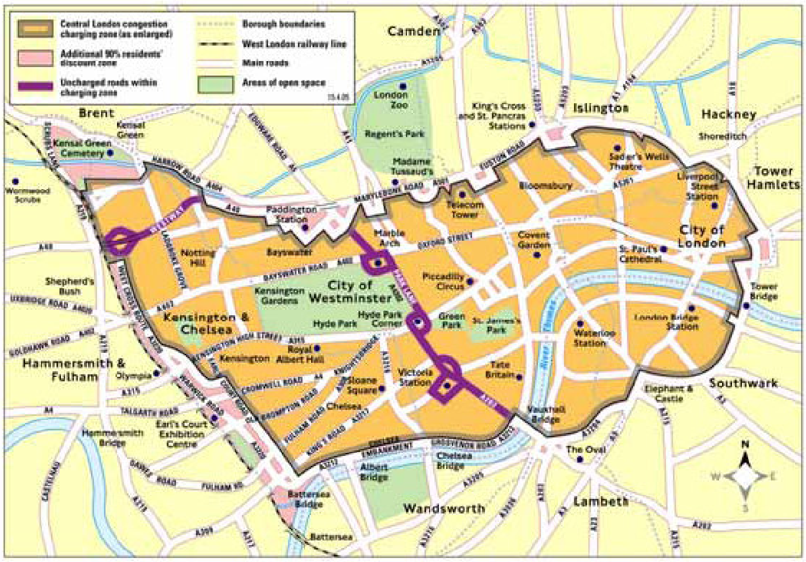
The area covered by the original charging zone that was in operation from 17 February 2003 to 18 February 2007 (Figure 3-1) is the area of central London bounded by the city's inner ring road (formed by Marylebone Road, Euston Road, Pentonville Road and City Road to the north, Commercial Street, Mansell Street, Tower Bridge Road and New Kent Road to the east, Kennington Lane and Vauxhall Bridge Road to the south, and Grosvenor Place and Park Lane to the west). This area is characterised as containing the main finance centre of the City of London, and the commercial and entertainment areas of the west end.



Source: TfL 2007a

Figure 3-1 The Original Central London Congestion Charging Zone

In February 2007 the congestion charging zone was expanded to include the western extension. The southern boundary of the zone now continues west along the Chelsea Embankment on the north bank of the Thames, and the northern boundary extends west along a number of streets just to the south of Harrow Road. The western boundary of the extended zone is now formed by the A3220 and A219. The current congestion charging zone, including the western extension, is shown in Figure 3-2. The western extension extended the zone west to include the more residential areas of Kensington and Chelsea. As well as increasing the area where the charge is to be paid by drivers, the western extension added 60,000 (source: cchargelondon.com) residents to the zone, who are eligible for the congestion charge discount.



Source: TfL 2007a

Figure 3-2 Current Congestion Charging Zone in London Including the Western Extension

3.1.4 Technology Used

Automatic number plate recognition (ANPR) is used to monitor vehicles driving in the charging zone. Vehicles' number plates are captured from over 203 fixed CCTV cameras in the original zone plus 137 in the western extension (current at February 2007), and also from a small number of mobile cameras. Private drivers must pay to enter the congestion charging zone on the charging day (online, by telephone or text message or via a dedicated paypoint). Since June 2006 private vehicle drivers have had the option to "pay next day" (that is to pay for using the congestion charging zone on the previous charging day) against a 25% surcharge. This has reduced the number of (and revenue from) penalty notices.

Using ANPR software the registration numbers of recorded vehicles are then matched against the database of vehicles which have paid the charge, or are exempt from the charge. The registered owners of those vehicles that are found not to have paid the charge by midnight on the "day after" they have driven in the zone (in fact if the charging day is a Friday, then the "next day" will be Monday) are sent penalty charge notices.

3.1.5 Hours of Operation

The charge is currently in operation from 7:00 to 18:00 from Monday to Friday. There is no charge for driving in the zone after 18:00 or before 7:00, on Saturday and Sunday and on public holidays. During the first four years of charging, the hours of operation ran from 7:00 until 18:30, but at the time the western extension came into operation (in February 2007) the length of the charging day was shortened by 30 minutes. The major congestion problems in the area are experienced during the AM peak (from 7:00 to 10:00) and this time period has been the focus of traffic modelling work undertaken before charging was implemented and of monitoring the impact of charging on traffic patterns and congestion since charging has been in operation.

3.1.6 Charging Level

The initial fee to enter the congestion charging zone was a flat daily fee of £ 5; in July 2005 the charge increased to £ 8.

The charge is paid in a different way by the operators of fleets of more than 10 vehicles. This is not specific to a type of vehicle (such as car or HGV) but relates to the way in which the vehicle is operated. Fleet operators who wish to pay the charge via the automated fleet scheme must register and pay a £ 10 charge for each vehicle in their fleet. Payments are then automatically deducted from the fleet account for each vehicle identified by ANPR operating in the charging zone on a charging day. In this way fleet drivers do not need to remember to pay the fee (and therefore will not receive penalty notices if they forget or otherwise do not pay). The payment automatically deducted is currently £ 7 per vehicle per day, compared against £ 8 for vehicles not in the scheme. Prior to the July 2005 variations, the daily charge in the automated fleet scheme was £ 5.50.

3.1.7 Discounts and Exemptions

Several groups of vehicles/drivers are eligible for complete exemption or different levels of discount.

Vehicles that are completely exempt (not even required to register):

- Two wheeled motorbikes (and sidecars), mopeds and bicycles;
- Black cabs (taxis) licensed with the Public Carriage Office (PCO);
- Mini cabs licensed with the PCO;
- Emergency Service vehicles - e.g. ambulances / fire engines;
- NHS vehicles that are exempt from road tax;
- Vehicles used by the disabled that are exempt from vehicle excise duty (road tax) under the 'disabled' class;
- Vehicles for more than one disabled person (e.g. Dial-A-Ride) exempt from road tax;
- Public transport vehicles with nine or more seats that are listed within the taxation classes Buses or Reduced Pollution Buses.

Blue badge holders receive a 100% discount but are required to register. There is a £ 10 initial registration charge and each blue badge holder can register up to two vehicles. Registered vehicles will be entered in the database as entitled to 100% discount (effectively exempt from the charge) and, at least in theory, will not receive penalty charge notices if they are detected driving in the charging zone during charging hours.

Several classes of vehicle are eligible for 100% discount from the charge, but must be registered at an annual charge of £ 10 per vehicle:

- Alternative fuel vehicles – powered by alternative fuel, bi fuel or dual fuel (i.e., not solely by petrol or diesel);
- Electrically-powered vehicles, as registered with the DVLA;
- Vehicles with nine or more seats (not covered by the exemption above);
- Motor tricycles of particular dimensions;
- Roadside recovery vehicles.

Residents within the zone and in some defined areas just outside the charging zone receive a 90% discount upon registration of their primary vehicle. Residents must pay for a minimum of one week (five consecutive charging days) for which the charge is currently £ 4. They may also pay monthly or annually. Residents must still remember to pay the congestion charge, and are liable to the full £ 10 next day charge or will receive a penalty charge notice if they forget to pay. Each member of a household may register one vehicle, for a £ 10 registration fee.

Roads on the boundary of the zone do not incur a charge; additionally there are a few designated through routes in the zone that do not incur the charge.

3.1.8 Differentiation in Charging

Differentiation in congestion charging payments therefore exists:

- Between those who pay and those who are exempt or receive 100% or 90% discount,
- Between private drivers who pay £ 8 now and those in the fleet scheme, who pay £ 7,
- Between times of day when the charge is in operation and those hours when it is not. There is no time of day differentiation within the 11 hours of the (current) charging day from 7:00 to 18:00, but the charge does have some effect on the distribution of trips with charging hours and just after the end of charging hours.

3.1.9 Level of Income Generated and Use of Revenues

Every year since the introduction of the congestion charge, TfL has issued a *Central London Congestion Charging: Impacts Monitoring Annual Report.* In the fourth of these (TfL, 2006) it was reported that annual operating costs of the scheme (in 2005 prices, based on the £ 5 daily charge) amounted to £ 110m per year. This was made up of: TfL's costs for administration, supervision and monitoring of the scheme; payments to contractors to operate and enforce the scheme; and the cost of providing extra buses to accommodate car drivers switching modes in response to the charge.

Revenue raised from the congestion charge amounted to £ 190m per year, from charge payments and penalty charge payments (Table 3-1). In addition the extra buses laid on attracted £ 15m in fares. According to these figures, weighing £ 110m of annual costs against £ 205m of net revenue gives additional revenue of £ 95m from the congestion charge, to be spent on transport improvements in London.

Table 3-1 Scheme Revenue at 2005 Prices

	Revenue **£ millions at 2005 values**
Scheme Operating Costs[1]	
TfL administration	- £ 5
TfL contractors	- £ 85
TfL extra buses	- £ 20
	- £ 110
Revenues and Fare Income	
Charge Payments	£ 120
Penalty Charge Payments	£ 70
Extra public transport fares	£ 15
	£ 205
Net Revenue	**£ 95**

Source: TfL, 2006

Provisional cost and revenue figures reported in Transport for London's *Central London Congestion Charging: Impacts Monitoring* reports for three separate financial years are shown in Table 3-2. (It should be noted that in contrast to Figure 3-1 these figures only relate to cars, vans and lorries and exclude operation costs for, and income from, public transport.)

Revenue raised by the congestion charge is hypothecated, i.e. it must be spent on measures that work towards achievement of the Mayor's transport strategy. The largest proportion of spending (approximately 80%) has been on improvements to bus network operations – improvements to bus frequencies, introduction of additional routes, introduction of low-floor accessible buses and articulated

1 this excludes up-front costs.

("bendy") buses, bus stop improvements, bus location systems and modernisation of bus depots and stations. The remaining revenue has been spent on road safety programmes and accident remedial measures, safer routes to school programmes, road and bridge improvements and the promotion of walking and cycling.

Table 3-2 Revenues and Costs Reported for Three Charging Years, All Values in £m

	2004/05	2005/06	2006/07
Revenue:			
Standard charge*	98	121	125
Fleet charge**	17	19	27
Resident vehicles***	2	2	6
other	-	2	-
Enforcement income	72	65	55
Total Income	190	210	213
Operating costs	92	88	90
Net Revenue	98	122	123

* In 2004/05 the standard charge was £ 5 per day, from July 2005 the standard charge was £ 8 per day
** 2005/06 the fleet charge was £ 5.50 per day, from July 2005 the fleet charge was £ 7 per day
*** 2006/07 the resident charge was £ 2.50 per week, from July 2005 it was £ 4 per week, and from January 2007 there were more eligible residents in the western extension

Sources: TfL 2005, TfL 2006, TfL 2007a

For the financial year 2006/07, for example, (reported in TfL 2007a) revenues from the standard, fleet and residents' charges were £ 158m, with income from enforcement (penalty charge notices) of £ 55m. With operation and administration costs of £ 90m this gave net revenue for the financial year 2006/2007 of £ 123m.

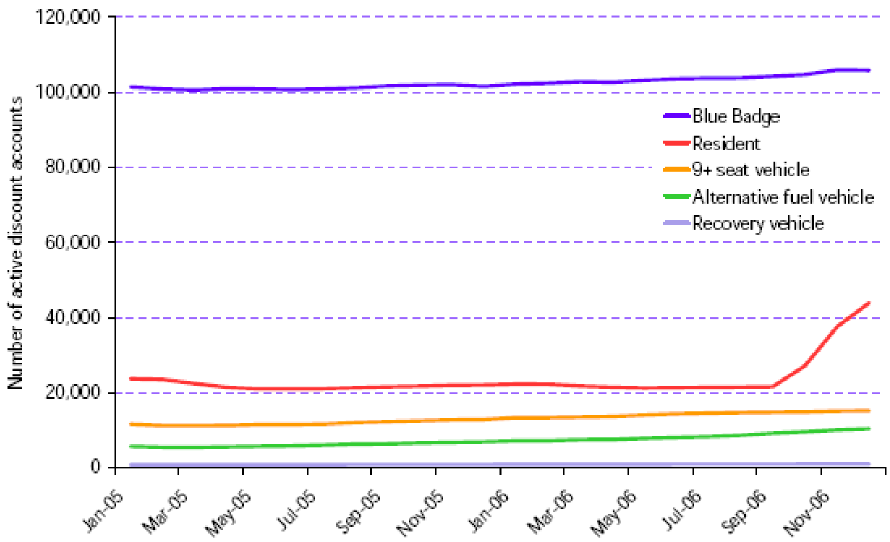
What should be noted, however, is that all of the above figures for costs only cover the running costs of the scheme to TfL and ignore the depreciation of initial investment costs for the scheme installation borne by the UK government of approx. £170 million, which would need to be taken into account in any wider economic analysis.

Income from Penalty Charges

The "pay next day" option was introduced in June 2006 in response to criticism that too high a proportion of income was coming from the enforcement of penalty charge notices. Currently the penalty charge is £ 120 (reduced to £ 60 if paid within 14 days, or increased to £ 180 if not paid within 28 days). This has increased twice since the start of charging in 2003. Allowing late payment has reduced some income from penalty charges. The immediate effect of the introduction of the "pay next day" option was a 15% reduction in penalty charge notices (PCNs) issued; by the end of the year the reduction was 12% (TfL 2007a). Overall 17% fewer PCNs were issued in 2006 compared against 2005. This has led to a greater income from charges but a lower income from penalties, as seen in Table 3-2. It is not possible to further analyse penalty charge data as there are three levels of charge – if payment is made within 14 days, after 14 to 28 days, or after 28 days, and that affects income from penalty charges.

Residents' Discount Accounts

The addition of the western extension to the charging zone has added more residents eligible for 90% discount from the charge. Figure 3-3 shows a steep increase in the number of "active discount accounts" for residents from October 2006, when residents in the western extension were first allowed to "pre-register" for the residents' discount.



Source: TfL, 2007a

Figure 3-3 Number of Active Residents' Discount Accounts

3.1.10 Current and Future Developments in the London Congestion Charge

It was proposed in 2007, under the mayoralty of Ken Livingstone, that in future the charge was to be based on the CO2 emissions of each vehicle, replacing the current tariff of £ 8 and £ 7 charges. A variation order was passed by the Greater London Authority on 12 February 2008 to introduce CO2 charging in the congestion charging zone. This proposal would give a 100% discount (upon payment of £ 10 registration charge) to low CO2 vehicles and would impose a higher charge (£ 25) to vehicles with higher CO2. The variation order stated that this new method of charging would come into effect on 27 October 2008.

However, in May 2008, Ken Livingstone lost the mayoral election to the conservative candidate Boris Johnson. In his election manifesto, the new Mayor has stated his opposition to the new CO2 charge, so this plan appears to be abandoned for now. The new Mayor has announced plans to "reform the congestion charge", but the exact details of this reform have not yet been announced (at time of writing in June 2008).

Also now in operation (since 4 February 2008) in London is the LEZ, or low emission zone. This covers a much wider area, approximately the whole of greater London, than the congestion charge zone. The LEZ operates 24 hours a day and 7 days a week (not just from 7:00 to 18:00 on weekdays). A vehicle subject to the LEZ charge of £ 200 per day is also liable to pay the congestion charge if it enters the charging zone. The LEZ operates in the same way as the congestion charge, enforced by ANPR and monitoring cameras. The purpose of the LEZ is different from the congestion charging zone as it is solely focussed on reducing traffic pollution.

3.2 RESULTS FROM EX-ANTE MODELLING OF CONGESTION CHARGING IN CENTRAL LONDON

3.2.1 Traffic Impact

Before implementation of the charge, predictive models were used to estimate the likely range of possible effects of the charge on the city's traffic and transport patterns. Models were initially developed to provide input to the initial scheme proposal and public consultation, and further projections of the scheme's impact were made after the initial public consultation. Projections of scheme impact were made using the London Transportation Studies (LTS) model and the SATURN Assessment of London's Traffic (SALT) model.

Projections of the traffic impact of charging were based on "lower" and "higher" sensitivity demand assumptions, based on the range of predicted responses from drivers to the proposed scheme – their willingness to pay the charge or to alter travel behaviour in response to the charge.

The following findings were reported by TfL in its 2002 Report to the Mayor of London, based on the LTS mode, for the AM peak (from 7:00 to 10:00):

- Inbound traffic to inner London was predicted to reduce by 5 - 9% (low sensitivity) or 8 - 14% (high sensitivity) – the range of impacts dependent on the exact inbound approach;
- Traffic on the inner ring road (a possible diversion for traffic outside of the charging zone) was predicted to rise by 10%; traffic activity was predicted to reduce by 12 - 17%;
- Congestion was predicted to reduce by 18 - 26%; at that time, the time spent delayed in traffic queues was 2 minutes per kilometre and, hence, was expected to fall to 1.5 minutes;
- Traffic speeds were predicted to rise by 8 - 12% within the charging zone.

The same report (TfL, 2002) describes the results of analysis with the SALT model, which are roughly in line with the LTS model findings reported above, for example a predicted reduction in traffic movements in the charging zone of 9 - 13 % (slightly smaller than the 12 - 17% predicted by the LTS model). The SALT Model is based on SATURN and therefore incorporates greater microsimulation detail of traffic movements in precise locations, response to signal timings and traffic management measures.

3.2.2 Impact on Public Transport

The LTS model was also used for predictions of increased bus, underground and rail use to examine the effects of the congestion charge on public transport. The most net shift was expected to be from car drivers to bus passengers. Bus patronage was expected to increase further as some current rail and underground passengers would shift to buses as the congestion charge improved bus journey times and reliability in the charging zone. A net increase of up to 5,000 extra inbound underground and rail passengers and up to 15,000 extra inbound bus passengers in the 7:00 to 10:00 morning peak was predicted (TfL, 2002).

3.2.3 Impact on Accidents

Lower traffic volumes resulting from the charge were predicted to lead to a reduction in accidents, however the increased use of two-wheeled motorcycles and bicycles and increases in traffic speeds were predicted to offset this benefit to some degree (TfL, 2003). On balance, a reduction in accidents across London of between 150 and 250 (from a total of 34,000 accidents in Greater London, 1,900 inside the charging zone) were expected, with reductions of about a third of this total within the charging zone.

3.2.4 Impact on the Environment

The expected environmental impact of the introduction of the charge is outlined in TfL's *First Annual Impacts Monitoring Report* (June 2003). It was noted that the relationship between traffic and air quality is complex, so it was predicted that the expected reduction in traffic volumes in the charging zone (of up to 15 - 20%) would only have a "modest" impact on air quality. Predicting the environmental impact of congestion charging is complicated by factors such as weather, by the differential effects of the charge on commercial traffic (vans and lorries are more polluting than cars), by the increase in bus traffic and the absence of charging during certain hours of the day and on non-charging days. The change in pollutant concentrations was expected to be less than 1 or 2% and difficult to detect.

3.2.5 Economic Impact

As reported by TfL, the introduction of the congestion charge in central London was not expected to significantly affect the economy of central London (TfL, 2003). The congestion charge was expected to have an overall neutral effect on London's economy. The city's economy is very complex and subject to many short-term and long-term outside influences, so that identifying economic effects as attributable to the charge would be very difficult.

3.2.6 Results from Ex-ante Surveys on Acceptability of the Scheme

The ROCOL report (Government Office for London, 2000) presents details of surveys undertaken before the introduction of charging (and before details of the type of scheme were finalised) based on attitudes to a £ 5 charge to enter central London. A small majority responded that such a charge would be a "good thing", with car drivers generally less in favour and bus users generally more in favour. Given a number of choices on how money raised by a charge should be spent, most respondents favoured improvements to underground and rail services, lower bus fares and improved bus routes.

3.2.7 Overall Expected Impact of the Scheme

TfL's *First Annual Impacts Monitoring Report* (June 2003) summarises the expected impacts of the charging scheme that was introduced in February 2003:

- Congestion reduced by 20% to 30% within the charging zone;
- Volume of traffic within the charging zone reduced by 10 to 15%;
- Increase in public transport patronage of 1 to 2%;
- Estimate there will be between 150 and 250 fewer accidents per year (one third within the zone);
- Not expected to "alter significantly the overall economy or competitive position of London";
- Modest impact on air quality.

3.3 OBSERVATIONS AFTER SCHEME IMPLEMENTATION

3.3.1 Acceptability and Understanding of the Scheme

Surveys were undertaken, before and after the introduction of the charge, to assess the attitude of London residents to the congestion charge. TfL's *Second Annual Impacts Monitoring Report* (April 2004) presents the results of a series of telephone surveys in which respondents were asked, for example, whether they supported the scheme, whether they were affected by the scheme, how aware they were of the payment methods available, and whether they believed the charge would reduce / was reducing congestion. Seven questionnaire surveys were performed between December 2002 and October 2003, three before and four after the introduction of the charge in February 2003.

The results of these surveys suggest that attitudes towards the charge became more positive after its introduction. In the three surveys before the introduction of the charge an average of 39% of respondents indicated support for the charge; in the four surveys after introduction of the charge this figure had risen to 53.5% of respondents in support of the charge. Awareness of the various payment methods was also generally higher after the introduction of charging, although awareness of paying via text message was generally quite low. Before introduction of the charge 53% of respondents agreed that the charge would reduce congestion; after the charge was implemented an average of 74% of respondents believed the charge had reduced congestion.

There has been some opposition to the charge in general, and specifically to the price rises in July 2005 by business groups. The London Chamber of Commerce and Industry (LCCI) did not oppose the initial introduction of the charge; at that time LCCI welcomed the attempt to address congestion problems in central London. However LCCI subsequently expressed the belief that the three essential conditions that would allow the charge to be successful (significantly improved public transport, smooth practical running of the scheme, no adverse effects on business) were not in fact achieved. LCCI was opposed to the July 2005 price rises, and to the February 2007 western extension (LCCI 2005b, 2005c).

It is widely accepted and reported in the UK media that the congestion charge in London has been a political success, generally popular among residents in London. Mayor Ken Livingston was re-elected in June 2004 against a conservative challenger, Steven Norris, who pledged to scrap the charge and was vocal in his opposition to the charge during his election bid. By the time of the mayoral election in May 2008, scrapping the charge was not proposed by any of the three main candidates. However, as noted before, the election was won by conservative candidate Boris Johnson, and the new Mayor does propose to reform the congestion charge. The exact nature of this proposed reform has not yet been announced, although it seems certain the proposed new CO2 charge will now not be introduced, and that other aspects of the charge, such as the 2007 western extension, current charging tariffs and the administration of penalty charges will be reviewed.

3.3.2 Traffic Impact

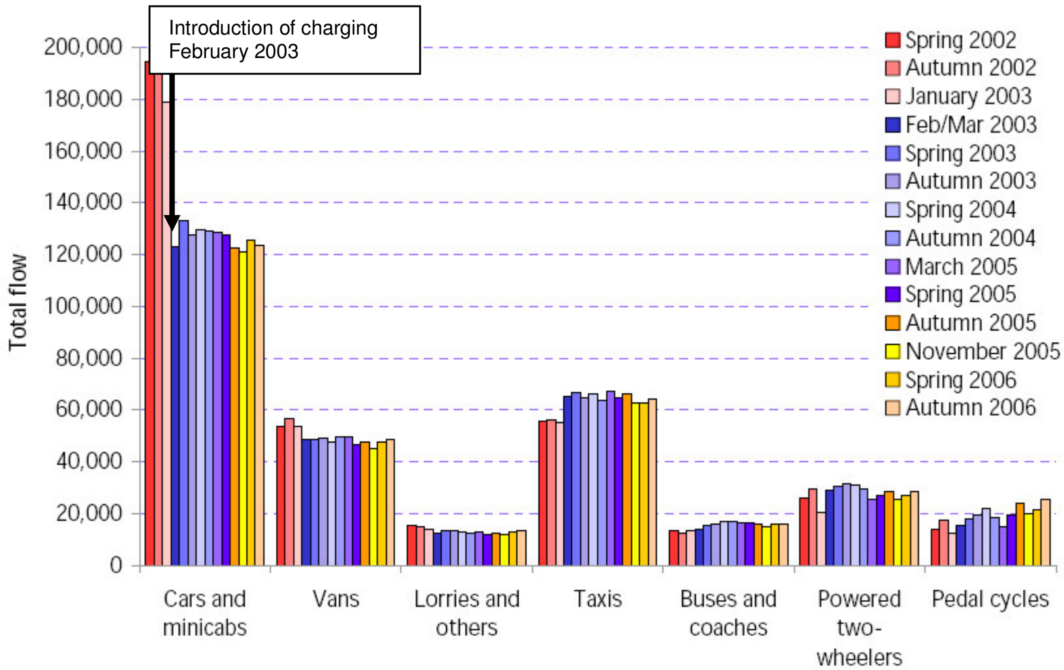
The aforementioned annual monitoring reports issued by TfL detail the traffic impact of the congestion charge in central London, specifically:

- Traffic patterns, that is volumes of traffic entering the zone, leaving the zone, circulating within the zone, on the inner ring road (that forms an obvious diversion for drivers wishing to avoid the charge), and on certain routes approaching the zone;
- Congestion, defined as an excess delay (in minutes per kilometre) over and above the delay that would be experienced in uncongested travel conditions, measured within the zone, on the inner ring road and on certain routes approaching the zone.

Volume of Traffic Entering the Charging Zone

As reported above, analysis undertaken using the LTS model (and backed up by SATURN analysis) before the implementation of the charge produced a range of predictions that inbound traffic to central London would fall by 5 - 9% (low sensitivity) to 8 - 14% (high sensitivity) – the range of impacts dependent on the exact inbound approach.

Figure 3-4 shows data from manual classified traffic counts of vehicles inbound to the charging zone, taken at a number of points in time (spring and autumn annually, plus extra counts at critical times) before and after the introduction of charging in February 2003. The shift from red to blue coloured bars corresponds to the introduction of the original £ 5 charge in February 2003, and the shift from blue to yellow colour bars corresponds to the timing of the pricing variations (increase from £ 5 to £ 8) in July 2005. Figure 3-4 shows a dramatic decrease in the number of cars and vans entering the zone after the introduction of the charge, alongside increases in the numbers of taxis, buses and two-wheeled vehicles (all exempt from the charge) at the same time. There is a smaller discernable immediate impact from the charging variations in July 2005.



Source: TfL, 2007a

Figure 3-4 Traffic Entering the Charging Zone during Charging Hours

The volume of traffic entering the charging zone has been comprehensively monitored using automatic and manual classified counts. TfL's *Second Annual Impacts Monitoring Report* issued in April 2004 – just over 12 months on from the introduction of the charge – reported an overall traffic reduction of 14%, and a reduction of 18% in four-wheeled traffic entering the zone when comparing data from 2003 (after implementation of the charge) against data from 2002 (before the charge). Comparing this against the pre-charging predictions suggests that the higher sensitivity predictions were quite accurate.

TfL's *Third Annual Impacts Monitoring Report* issued in April 2005 – two years on from the introduction of the charge – reports that comparing 2004 against 2003 there was no significant measurable change in the total number of vehicles (or in the number of four-wheeled vehicles) entering the charging zone. There was a small decrease (1%) in the number of cars and vans entering the zone and a larger decrease (5%) in the number of lorries entering the zone. The number of buses and two-wheeled vehicles (no charge) entering the zone each rose by 8%.

TfL's *Fourth Annual Impacts Monitoring Report* was issued in June 2006 – three years on from the introduction of the charge and nearly a year on from the July 2005 price variations. The preliminary data available at this time showed an immediate decrease of up to 6% in potentially chargeable vehicles entering the charging zone. However, further counts taken in the months after this report was issued, and using analysis consistent with that undertaken for previous years, showed very little change in vehicles entering the charging zone in 2006 compared against 2005.

The *Fifth Annual Impacts Monitoring Report* was issued in July 2007 and summarises the traffic impacts measured in all years since 2002. Overall, since the introduction of the congestion charge there has been a measured 16% decrease in all traffic entering the charging zone – a 30% decrease in potentially chargeable vehicles and a 16% increase in non-chargeable vehicles. These figures are summarised in Table 3-3.

Table 3-3 Year on Year Changes in Traffic Entering the central London Congestion Charging Zone

Vehicle Type	Change in Inbound Traffic during charging hours (7:00 to 18:30)					
	2003 vs 2002	2004 vs 2003	2005 vs 2004	2006 vs 2005		2006 vs 2002
All Vehicles	- 14%	0	- 2%	0		- 16%
4+ wheels	- 18%	0	- 3%	0		- 21%
Potentially Chargeable	- 27%	- 1%	- 3%	+ 1%		- 30%
Cars and minicabs	- 33%	- 1%	- 3%	0		- 36%
Vans	- 11%	- 1%	- 3%	+ 2%		- 13%
Lorries	- 11%	- 5%	- 4%	+ 6%		- 13%
Non-Chargeable	+ 18%	+ 1%	- 4%	- 1%		+ 16%

Source: TfL, 2007a
Note: Data is from manual classified counts taken in autumn and spring, complemented by automatic traffic counter data

Congestion Levels in the Charging Zone

As reported above, congestion was predicted to reduce by 18 - 26% during the morning peak (from 7:00 to 10:00). Congestion is defined as an excess delay (in minutes per kilometre) over and above the delay that would be experienced in uncongested travel conditions, for example during times of very low demand in the early hours of the morning. The uncongested travel time has been quantified as 1.9 minutes per kilometre. This was initially measured by floating cars and is now updated with panel surveys of regular journey times and data from ANPR cameras.

In TfL's *Second Annual Impacts Monitoring Report* (April 2004) reductions in congestion throughout the charging zone of up to 30% were reported, which is in line with the top-end of the estimate before charging was introduced. Before charging, average delay was measured as 2.3 minutes per kilometre. After charging, average delay of 1.7 minutes per kilometre was measured, with the average network speed during charging hours now 17km/h. The most recent congestion measurements available for that report (Jan/Feb 2004) gave average delays of just over 1.5 minutes per kilometre (leading to the reported 30% reduction). This suggests that congestion benefits measured immediately after the introduction of charging were sustained throughout the year.

Higher traffic flows were measured on the inner ring road (boundary of the zone, no charging), with lower measured congestion, suggesting better management of traffic (and also attributed to the end of roadworks in that location). Using the same definition, congestion reduced from 1.9 minutes per kilometre to between 1.5 and 1.7 minutes per kilometre, with about a 4% increase in traffic (low end of estimate).

TfL's *Third Annual Impacts Monitoring Report* (April 2005) reported that during the second year of charging reductions in congestion of around 30% were sustained, although in recent months the picture had become more varied. Measured congestion levels were now between 1.4 and 1.8 minutes per kilometre of delay (against 2.3 minutes per kilometre before charging). This represents a reduction in congestion of approximately 22% when compared against pre-charging levels of congestion. At the same time congestion on the inner ring road was measured as being very nearly back up to pre-charging levels.

The *Fourth Annual Impacts Monitoring Report* (June 2006) reported that, since the start of charging, the average congestion delay had been 1.7 minutes per kilometre, 26% down from the congestion levels measured pre-charging. Congestion measured during 2005 was 1.8 minutes per kilometre, that is a little up from 2003 and 2004. After the charge was raised in July 2005, there was no immediate noticeable change in measured congestion. However, in Jan/Feb 2006 a small fall in congestion was measured, to 1.75 minutes per kilometre. On the inner ring road at this time there was month to month fluctuation in measured congestion, with average measured congestion nearly back to pre-charging levels.

The *Fifth Annual Impacts Monitoring Report* (July 2007) reported that levels of congestion within the charging zone increased during 2006, although traffic volumes entering and circulating within the zone remained stable compared against the previous year. TfL attributes this “background trend towards increased congestion” to two main factors: traffic management programmes that reduce available roadspace, but enhance the environment for pedestrians and cyclists and allocate more space for buses; and increased roadwork and streetwork activity. Analysis of the incidence of congestion and the presence of roadworks suggests some evidence for this. Further investigation is being undertaken by TfL and may lead to tighter regulation over the timing and coordination of roadworks within the zone in the future.

Impact of the July 2005 Charging Variations

In July 2005, the charging variations came into effect. The charge went up from £ 5 to £ 8 per day for private vehicles, from £ 2.50 to £ 4 per week for residents with registered vehicles (90% discount), and from £ 5.50 to £ 7 per day for vehicles paying via the automated fleet system. TfL’s *Fourth Annual Impacts Monitoring Report* (June 2006) presents some initial findings from the charging variations. In addition, it is possible to calculate the impact of the new differentiated levels of payment between standard charge payers and vehicles in the automated fleet scheme from reported revenue data (see section 3.4.2).

Only interim data was available on the effect of the July 2005 charging variations at the time of the *Fourth Annual Impacts Monitoring Report*, issued in June 2006; the most recent data analysed in this report is from January/February 2006. At this time there was only six or seven months of “after” data, and this data has to be analysed against a background of seasonal variation and the effect of the 7 July 2005 terrorist bombings on the London Underground and no. 30 bus, which affected public transport usage and traffic patterns (the congestion charge was itself suspended for two days following the 7 July bombs).

Predictions of the impact of the charging variations formed part of the public consultation undertaken before the price increases in July 2005. It was predicted that there would be a reduction in four-wheeled vehicle traffic entering the zone of between 3% and 7% and a reduction in four-wheeled traffic circulating in the zone of between 2% and 6%.

Comparing spring 2006 against spring 2005, there was a 6% reduction in traffic volumes (four-wheeled traffic) inbound to the charging zone. At the same time there was a measured reduction of 3 - 4% in the volume of traffic (four-wheeled) circulating within the zone. As mentioned above, in TfL’s *Fifth Annual Impacts Monitoring Report*, with longer term data available, very little change in traffic was measured when comparing data collected in 2006 against data collected in 2005.

Data on charge payments, reported in the *Fifth Annual Impacts Monitoring Report*, shows that there was a decrease of between 11% and 12% in the number of charge payments made, when comparing the first six months after the July 2005 variations against the equivalent periods one year previously. This breaks down to different payment categories:

- Residents registered for the 90% discount reduced payments by 1% following the increase from £ 2.50 to £ 4 per week.
- There was a 9% increase in payments from registered vehicles in the automated fleet scheme. Although the charge for vehicles in this scheme went up from £ 5.50 to £ 7 per day, the scheme generally became more accessible and £ 7 per day is lower than the £ 8 paid by private drivers.
- Standard charge payments, that is individual drivers paying £ 8 per day, fell by 16%.

Clearly some vehicles that had been previously paying the charge as private drivers became part of the automated fleet scheme. This is further discussed in section 3.4.2.

Impact of the Western Extension, Effective from February 2007

The original congestion charge, introduced in February 2003, and with some subsequent minor amendments, was considered to have been successful in achieving the objectives set out: reducing traffic congestion, improving bus services, improving the reliability of journey times and improving the reliability and efficiency of the distribution of goods and services. Only one year after its original implementation the Mayor committed to investigate possible geographical extensions to the zone. Expanding to the west was considered the best option – with serious congestion to address, good existing public transport and suitable diversion routes outside the zone.

Following a period of consultation, the western extension shown in Figure 3-2, came into effect on 19 February 2007. The original zone plus the western extension now form one larger zone; charging is consistent throughout the extended zone. The 90% residents' discount is now available to residents throughout the extended zone; residents in the western extension, who previously had to pay the full charge to enter the original zone, can now register and receive a 90% residents' discount.

Preliminary findings reported in TfL's *Fifth Annual Impacts Monitoring Report* (July 2007) with data available for the first three months since charging was introduced in the western extension reveal:

- 52,400 applications for residents' discounts were received from within the western extension. This followed an extensive and successful public information campaign and was a higher number than expected by TfL.
- The number of charge payments made per day has increased from 97,000 to 150,000 (all charging groups – standard, fleet and resident), an increase of 55%.
- The volume of traffic entering the new western extension to the charging zone during charging hours fell by 10 - 15% when compared against traffic conditions before this area became part of the charging zone. TfL's estimates before introduction of the western extension were that the volume of traffic entering the zone during charging hours would fall by between 13% and 17%. Traffic data will continue to be monitored to assess longer-term impacts.
- Early data available shows an increase in traffic entering the "central zone" (that is, the original charging zone in operation since 2003) during charging hours of up to 4% (against TfL's predictions of a 2% increase), but with a lot of fluctuation in the data covering only a short period of time. Again this will continue to be monitored. Increases in traffic entering the central zone may be explained by western extension residents now able to drive in the central zone at the 90% discount rate.

3.3.3 Impact on Public Transport

Bus patronage has increased in London since the introduction of the congestion charge, attributable to mode change in response to the congestion charge and also in response to improved bus services and fare structuring. Surveys of bus patronage were undertaken by TfL in autumn 2002 (before charging) and in Autumn 2003 (after charging) and the results are described in TfL's *Second Annual Impacts Monitoring Report* (April 2004).

In the morning peak from 7:00 to 10:00, TfL surveys measured 77,000 bus passengers travelling inbound across the charging zone boundary on a typical weekday in autumn 2002; in autumn 2003 this number had increased to 106,000. The number of buses travelling inbound across the zone boundary increased from 2,400 to 2,950 for the same time period (with an increased load from 32 to 36 passengers per bus). These figures exceed the pre-charging predictions of up to 15,000 additional inbound bus passengers from 7:00 to 10:00.

Comparable surveys have not been carried out since 2003, but other bus patronage surveys undertaken by TfL show that bus passenger numbers inbound to central London (an area larger than the charging zone) in the three-hour morning peak increased by 18% in the first year of charging and by 12% in the second year of charging (TfL 2007a). From 2005 onwards the number of bus passengers inbound to central London in the AM peak has stabilised, with no detectable impact, for example, from the July 2005 congestion charge price variations.

3.3.4 Impact on Accidents

In TfL's *Fourth Annual Impacts Monitoring Report* (TfL, 2006) the number of reported personal injury road accidents across London for all hours and days of the week was revealed to have fallen from a total of 33,754 in the year immediately before introduction of the charge (February 2002 to January 2003) to 31,445 in the year immediately following its introduction (March 2003 to February 2004) and to 28,396 in the year from March 2004 to February 2005. This 16% reduction in accidents has to be viewed against a background effect of significant reductions in accidents even before the introduction of charging.

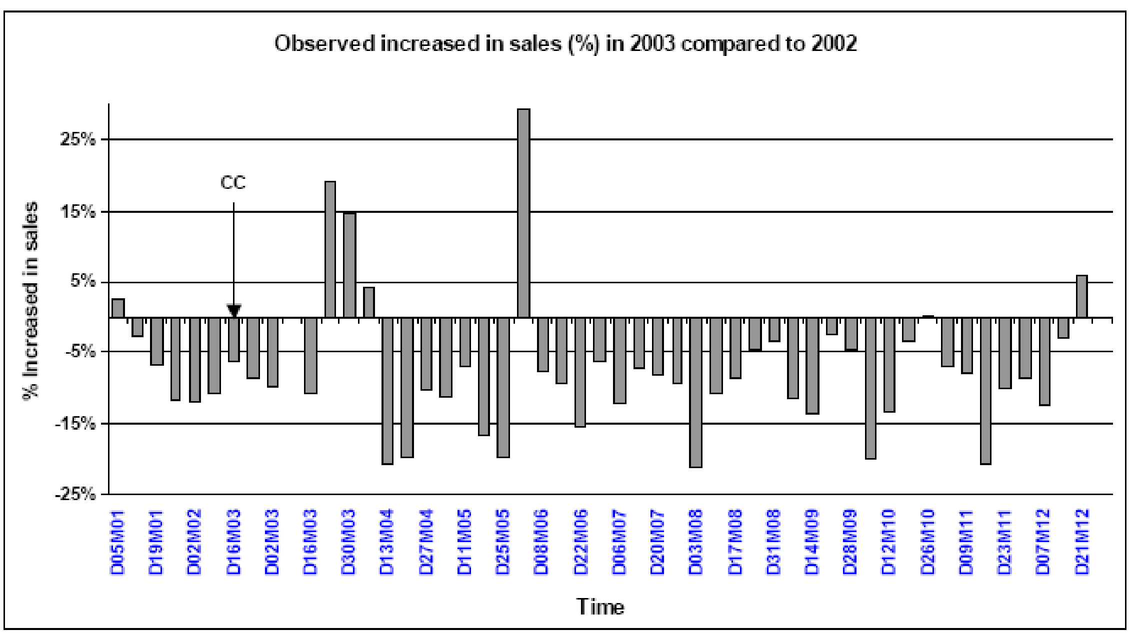
Within the charging zone, and during charging hours, the number of reported personal injury road accidents fell from 1,418 in the year immediately before introduction of the charge (February 2002 to January 2003) to 1,270 in the year immediately following its introduction (March 2003 to February 2004) and to 1,131 in the year from March 2004 to February 2005. Within the zone this is a 20% reduction in accidents.

TfL report that their analysis indicates that declines in accidents within the zone since the introduction of charging have been greater than would be expected according to background trends in improved accident rates. The "excess reduction" in accidents (attributable to the introduction of charging) has been between 40 and 70 fewer accidents per year, in line with predictions made before the introduction of charging.

3.3.5 Economic Impact

While the overall impact of the congestion charge on the London economy was widely regarded as either neutral or marginally positive, its effect on the retail sector was highly disputed.

John Lewis stores reported a fall in sales in their central London branch (Oxford Street) against a rise in sales in their other stores in the six months after the introduction of the charge, and commissioned a study (Bell et al 2004) that did come to the conclusion that this was directly attributable to the charge, even if their own data showed that a decline in sales in their Oxford Street branch had already started before the introduction of the charge (marked with 'CC' in Figure 3-5).



Source: Bell et al, 2004

Figure 3-5 Decrease in Sales in the John Lewis Oxford Street Store 2003 Compared to 2002

The London Chamber of Commerce and Industry also carried out a series of retail surveys to assess the impact of the congestion charge. In January 2005 they reported the findings of surveys carried out after 18 months of charging, with questionnaires sent to 2,159 randomly-selected retailers within the charging zone. The reported findings of this survey were that 84.2% of businesses responding had experienced a fall in takings since introduction of the congestion charge, and 62.7% reported a fall in customer numbers. Of those experiencing a fall in takings or in customer numbers 10% believed general background economic factors were all or mostly to blame and 62.1% believed the introduction of the congestion charge was all or mostly to blame. Overall 92% of retailers believed that the charge had not benefited their businesses (LCCI, 2005a).

However, while TfL in their *Second Annual Impacts Monitoring Report* (TfL, 2004) also show some decline in retail sales in early 2003, they attributed these to factors other than the congestion charge, suggesting the decline started before February 2003 when the charge was introduced – a suggestion that is in line with Figure 3-5. In any case, in their *Third Annual Impacts Monitoring Report* (TfL, 2005) TfL state that retail sales had recovered again from this fall.

Their view is supported by the *London Retail Sales Monitor*, published jointly by KPMG and The London Retail Consortium, which stated in June 2004: "Retail sales in Central London during June declined by 0.5% on a like-for-like basis compared with June 2003, when sales began to pick up after four months hit by the Iraq war, terrorist threats, the SARS virus and the Central Line closure." The clear implication of this statement is that the decline observed in early 2003 had a series of reasons, but that the congestion charge was not one of them.

As already indicated above, the overall economic impact of the congestion charge was less disputed. TfL's own surveys, based on quantitative figures plus the qualitative responses to questionnaires as reported in their *Annual Impacts Monitoring Reports*, show some positive findings regarding the impact of the charge on economic activity in central London, in particular with regard to jobs created, turnover and profits in businesses within the zone since introduction of charging in 2003, largely resulting from "decongestion" in the city – respondents to TfL's business survey report it is easier to get to business meetings, and easier for suppliers to deliver with more reliable journey times. On the other hand, there may be small negative effects, for example, on commercial property values inside the zone. Overall TfL conclude that the charge has had a broadly neutral effect on business in the zone.

Ernst and Young, in a review of the charge undertaken at this time (Ernst & Young, 2006), agree with TfL in concluding there is a broadly neutral impact of the charge on business and the economy within the zone.

3.3.6 Cost Benefit Analysis

The overall cost-benefit for the charging scheme, based on data collected within the first six months of its operation, was, according to TfL (TfL 2003b) and quoted in (Mackie 2005), in the range of 1.4, with annual benefits of around € 252 million and annual costs of € 182 million.

This was strongly disputed in a paper published in *Transport Policy* in April 2005, where Prud'homme and Bocarejo conclude "The London congestion charge, which is a great technical and political success, seems to be an economic failure". This conclusion is based on their finding that "the yearly amortisation and operation costs of the charge system appear to be significantly higher than the economic benefit produced by the system".

One thing that immediately stands out in the paper is that they estimate that the costs of congestion are reduced from € 75 million per annum by more than 90% to just € 6 million due to the charge, which is clearly totally unrealistic. A closer examination of their findings and underlying assumptions shows a number of critical issues in both TfL's and Prud'homme's calculations, but the biggest single issue is indeed the estimate of time savings (Mackie, 2005). While TfL only claim a reduction in congestion by 30%, they estimate that the absolute figures involved, with a saving of € 189 million, are substantially higher than Prud'homme's, in part due to the fact that they also take account of the reduction of congestion outside the charging zone. The fact that Prud'homme's calculations are based on a very simplified traffic volume and delay function with 24 hour flows sheds further doubt on his numbers, while TfL's figures are based on actual observations. Therefore, and in spite of the shortcomings in both approaches as described by Mackie, it appears likely that the overall resulting benefit-cost ratio for the six months of the scheme's operation is much nearer TfL's figure of 1.4 than Prud'homme's figure of 0.6.

However, given the increase in observed congestion in the charging zone since 2005, it would be appropriate - and very interesting - to update the cost-benefit analysis.

3.4 Some Effects of Differentiated Prices

3.4.1 Effect of Exemptions

As described in Section 3.1.7 before, several groups of vehicles/drivers are eligible for complete exemption or for different levels of discount (up to 100%) upon registration and payment of an annual registration charge.

Since the introduction of the congestion charge, the composition of traffic entering the charging zone has been affected by the existence of these exemptions from the charge (Table 3-4). Baseline counts were undertaken in 2002 before the introduction of the charge and can be compared against counts taken twice annually since then (spring and autumn) as part of TfL's extensive monitoring of the traffic impacts of the congestion charge.

Table 3-4 Composition of Traffic Entering the Congestion Charging Zone during Charging Hours

	2002		2003			2006	
	'000 veh	%	'000 veh	%		'000 veh	%
All Vehicles	378	100	324	100		316	100
4+ wheels	334	88	274	85		265	84
Potentially chargeable	**266**	**70**	**193**	**59**		**186**	**59**
Cars/minicabs	195	52	130	40		125	39
Vans	55	15	49	15		48	15
Lorries/other	15	4	13	4		13	4
Non-chargeable	**112**	**30**	**131**	**41**		**130**	**41**
Licensed taxis	56	15	66	20		63	20
Buses and coaches	13	4	16	5		16	5
Powered 2-wheelers	28	7	31	10		28	9
Pedal cycles	16	4	18	6		24	7

Source: TfL, 2007a

In 2002, "potentially chargeable" vehicles (including some minicabs that are exempt, but not distinguished in traffic counts) made up 70% of traffic entering the zone and "non-chargeable" vehicles made up 30%. In the year immediately after the introduction of the charge the proportion changed to 59% "potentially chargeable" and 41% "non-chargeable".

3.4.2 Standard Charge Payments and Fleet Payments

As already indicated in section 3.1.6, there is an "automated fleet scheme" that allows fleet operators to pay the charge in a different way to private drivers. Prior to the July 2005 variations, the daily charge in the automated fleet scheme was £ 5.50 (compared against £ 5 at that time for private drivers). In the July 2005 pricing variations the charge went up from £ 5 to £ 8 per day for private vehicles, and from £ 5.50 to £ 7 per day for vehicles paying via the automated fleet system. In this way being part of the automated fleet scheme became more attractive, relative to paying as a regular private driver, in July 2005.

Immediate Impact on Payments

Data on charge payments reported in TfL's *Fourth Annual Impacts Monitoring Report* (TfL, 2006) shows that there was a decrease of between 11% and 12% in the number of charge payments made, when comparing the first six months after the July 2005 variations against the equivalent period one year previously. This breaks down to different payment categories:

- There was a 9% increase in payments from registered vehicles in the automated fleet scheme. Although the charge for vehicles in this scheme went up from £ 5.50 to £ 7 per day, the scheme generally became more accessible and £ 7 per day is lower than the £ 8 paid by private drivers.
- Standard charge payments, that is individual drivers paying £ 8 per day, fell by 16%.

Both private drivers and those in the automated fleet scheme were subject to price increases in July 2005 (by 60% and 27% respectively). In response to absolute price rises some private drivers and some in the fleet scheme will have been deterred from driving in the charging zone. However, the number of payments made by drivers in the fleet scheme is up – vehicles that previously used the zone and paid as private drivers, but have now become part of the fleet scheme.

Analysis of Revenue Data

Taking the revenue data from Table 3-2 above for standard charge payments and fleet payments from 2004/05 (at the old £ 5 / £ 5.50 charging level) and from 2006/07 (new £ 8 / £ 7 charging level) it is possible to calculate actual numbers of charge payments and therefore percentage changes in charge payments from the two groups – standard charge payers and fleet vehicles (Table 3-5). Note that the period covered by financial year 2005/06 covers both charging levels, so is not analysed. For fleet vehicles there are no penalty charges and for standard charge payers it is not known how many paid the charge on time or paid a penalty charge, introducing some unknown error to this analysis. From 2004/05 to 2006/07 the number of charge payments made by standard charge payers fell by 20.3% while the number of payments made by fleet charge payers rose by 24.8%.

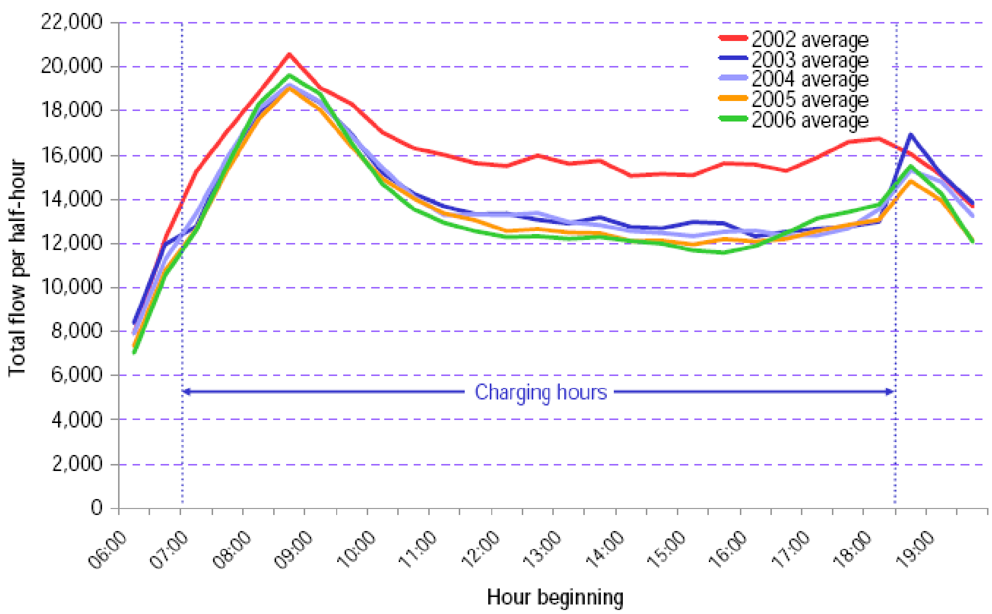
Table 3-5 Analysis of Standard Charge/Fleet Vehicle Payment Split

	2004/05	2006/07	% change
	£ 5 / £ 5.50	£ 8 / £ 7	2004/05 to 2006/07
Standard charge	£ 98m	£ 125m	
No. of payments	19,600,000	15,625,000	-20.3%
Fleet charge	£ 17m	£ 27m	
No. of payments	3,090,909	3,857,143	+24.8%

3.4.3 Differentiation by Time of Day

The charge is currently in operation from 7:00 to 18:00, Monday to Friday. As the London congestion charge is not simply a peak-time charge, driver response to the charge is fairly limited with regards to time of day. During the first four years of charging, the hours of operation ran from 7:00 until 18:30, but at the time the western extension came into operation (February 2007) the length of the charging day was shortened by 30 minutes. As the congestion charging zone contains London's west end theatre district and numerous restaurants and nightclubs, there had been some feedback that charging up to 18:30 was deterring trips into the area for evening entertainment. The 18:00 end to the charging day was a response to this feedback.

Figure 3-6 below shows annualised weekday figures for traffic entering the congestion charging zone for 2002 (before charging) and subsequent years up to 2006 (so before the new end time of 18:00). The major congestion problems in the area are experienced during the morning peak (from 7:00 to 10:00). Traffic volumes entering the charge zone are down in the morning peak, although it is clear from the figure that the greatest decrease in traffic entering the zone is during the off-peak after 10:00. The graph also clearly shows a definite peak in traffic entering the charging zone immediately after the end of charging hours at 18:30. This peak in inbound traffic, non-existent before charging was implemented, is most marked in 2003, the first year of charging. Clearly the timing of these trips is being delayed so that they fall just after charging has ended for the day. Morning peak inbound trips appear to be relatively inelastic, off-peak trips and especially those inbound to the zone in the early evening are more influenced by the charge. In fact this creates the opposite of peak spreading.



Source: TfL, 2007a

Figure 3-6 Traffic Entering the Central London Congestion Charge Zone by Time of Day

3.5 CONCLUSIONS CONCERNING ELASTICITIES

3.5.1 Short-Term Conclusions

In a paper published in *Public Works Management and Policy*, Santos and Sheffer calculated the price elasticity of demand, that is the responsiveness of the demand for trips into central London due to the change in travel costs following the introduction of congestion charging. The paper was published in October 2004, a year and a half on from introduction of the charge and based on data from its first year of operation.

In this calculation the generalised cost of making a trip into central London is made up of non-fixed motoring costs (from AA estimates) and time costs based on the value of travel time savings. The motoring cost increased following the introduction of the £ 5 charge, while the time costs fell with improved journey times. The percentage change in generalised cost of making the trip before and after the introduction of the charge was then compared against the change in the number of trips recorded, to assess the elasticity of the demand for those trips. A drop of 31% in car trips entering the charging zone was used as basis for the calculations and an increase in generalised cost of 23.5% was calculated, giving an elasticity of -1.3.

TfL's *Ex-Post Evaluation of Quantified Impacts of the Original Charging Scheme* (TfL, 2007b) quotes a calculated elasticity of -1.6. TfL's calculations used a slightly lower figure for the fall in demand for trips into the central area, and higher values of time, so that the change in generalised cost attributable to the £ 5 charge was not so great.

3.5.2 Response to Pricing Variations

In July 2005, a price rise of 60% for private drivers was introduced, so that the charge was now £ 8 per day. For drivers in the automated fleet scheme the price rose from £ 5.50 per day to £ 7 per day. Although this was still a price rise, in relative terms it was lower than for private drivers. At the same time the administration of the fleet scheme was streamlined, so that financially and otherwise the fleet scheme became more attractive.

Even without a precise breakdown of trips to who is paying fleet and who is a private driver, it is possible to say the response to the price rise is inelastic (less than 1). The immediate impact of the increase (autumn 2005 compared against spring 2005) saw a fall of 5% in “potentially chargeable” cars and minicabs, while standardised analysis with a full year’s data saw very little measured impact on vehicle entering the charging zone, against a price rise of 60%.

3.6 Overall Conclusions from London

TfL’s *Fifth Annual Impacts Monitoring Report* (July 2007) states “this ground-breaking traffic management scheme has operated successfully over four years”, and highlights “key success factors”, including political engagement and strong leadership, robust stakeholder and public consultation, thorough research and monitoring, and strong project governance and operational control – good communication with contractors and other partners.

The stated expectations for the congestion charge in London, to reduce volumes of circulating traffic and to reduce congestion in the zone, have been achieved, although recent trends show congestion increasing again. Other achievements outlined by TfL are increased patronage of public transport, reductions in traffic accidents, some impact on the emissions of pollutants, and revenues of around £ 100 million per year to re-invest in the city’s transport system.

4 STOCKHOLM

4.1 HISTORY AND MAIN CHARACTERISTICS OF THE CHARGING SCHEME

4.1.1 History of the Scheme

The possibility of introducing a congestion tax in Stockholm had been debated for a while, when in local elections in September 2002 a new Social Democratic Mayor was voted in with an election promise not to go ahead with the charging scheme. Nonetheless, the decision to introduce a congestion charge in Stockholm on a trial basis during the first half of 2006 was taken by the City Council in June 2003. In June 2004 the Swedish Parliament, under an – also Social Democrat – central government, passed a law that enabled Stockholm to levy this charge.

Several legal inquiries had established long before that the charge could only be treated as a tax, but the city still tried to find a way to treat the charge as a congestion fee, with the revenues being kept by the City. However, the Swedish government commissioned another formal inquiry, which presented its findings in June 2003 and confirmed that, since a Swedish law states that a charge can only be levied when the payer receives something in return, while the charge would only allow the use of existing infrastructure, the charge had to be a tax. Furthermore, since a municipality is only allowed to tax her own inhabitants, it had to be a state tax. Accordingly, the scheme and the trial were funded by the Swedish government.

The stated goals of the charging scheme were:

- A 10-15 per cent reduction in the number of vehicles that cross the inner city segment during morning and afternoon rush hours.
- Improved access on the busiest roads in Stockholm traffic.
- Reduced emissions of carbon dioxide, nitrogen oxides and particles in inner city air.
- Better street-level environment perceived by people in the inner city.

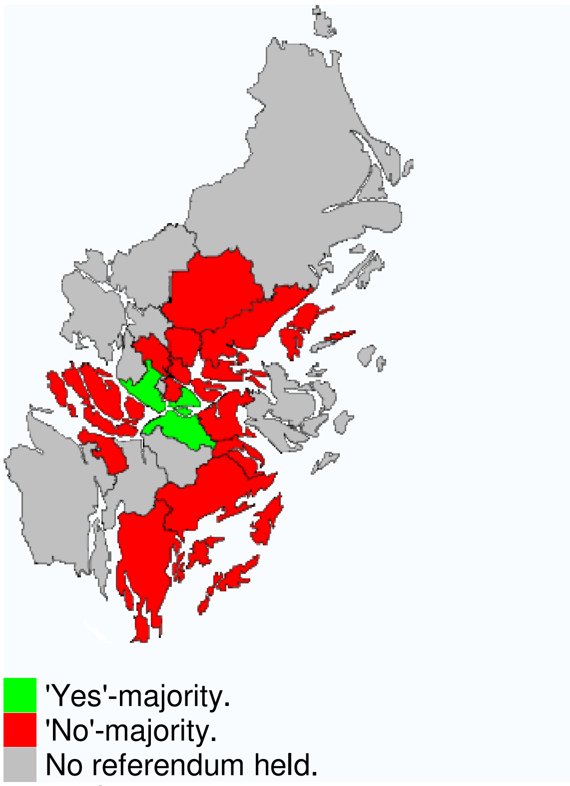
The trial started on 3 January 2006. The introduction of the tax was preceded by substantial improvements in the public transport system from late August 2005 onwards (marketed as “the largest public transport investment since the underground was introduced in the fifties” in SL 2006) and the implementation of additional Park & Ride sites in and around the city.

To plan and manage the charging system as well as to inform the public about the trial, the City set up a ‘Congestion Charge Secretariat’. The Secretariat also developed, in collaboration with the Swedish Road Administration as well as a range of other public and private bodies, a comprehensive evaluation programme to assess the effects of the trial and investigate to which extent the stated goals of the system have been achieved. The trial ended, as stipulated by the law, on 31 July 2006.

It had been planned throughout that after the trial a referendum would be held in Stockholm so that residents could decide whether they would want to make the charging scheme a permanent feature. However, similar to Edinburgh (see chapter 8), several of the neighbouring authorities, whose residents would be affected by the charge when they travelled into Stockholm, also wanted to give their residents a voice on this issue. The social democratic government, who ruled at that time, stated that they would base their decision only on the results of the Stockholm referendum, while the main opposition, the Alliance for Sweden, said that they would take all referenda into account.

So two and a half months after the trial, on 17 September 2006, referenda were held in Stockholm and 14 of the surrounding municipalities. In the other municipalities the question asked was simply whether the voters wanted the congestion tax to be made permanent, while in Stockholm, like in Edinburgh before, the question referred to the purpose of the scheme of reducing congestion and improving the environment and, furthermore, promised that the income would be returned to the region and invested in public transport and roads.

The results were very mixed (Figure 4-1). Only in the city of Stockholm a majority of the residents voted for the scheme, while in all 14 neighbouring municipalities the majority voted against it. But only in Lidingö the results, with 30% for and 70% against the scheme, very clear cut, while everywhere else the results were in the 40/60 range or even closer. In Stockholm itself it was as close as 53% for and 47% against the scheme, which meant that overall, although Stockholm has more residents than the other 14 municipalities together, there was a 52.5% majority against it.



Source: Wikipedia

Municipality	Valid Votes		
	#	Yes	No
Danderyd	16,962	32.5%	67.5%
Ekerö	13,528	39.9%	60.1%
Haninge	37,548	40.8%	59.2%
Lidingö	24,926	29.6%	70.4%
Nacka	44,785	42.9%	57.1%
Nynäshamn	12,588	41.2%	58.8%
Salem	7,563	39.6%	60.4%
Sollentuna	32,409	40.8%	59.2%
Solna	35,598	43.9%	56.1%
Stockholm	458,786	53.0%	47.0%
Tyresö	22,526	44.3%	55.7%
Täby	35,630	34.2%	65.8%
Vallentuna	14,884	42.5%	57.5%
Vaxholm	5,699	45.9%	54.1%
Österåker	20,140	40.9%	59.1%
Total excluding Stockholm	324,786	39.8%	60.2%
Total	783,572	47.5%	52.5%

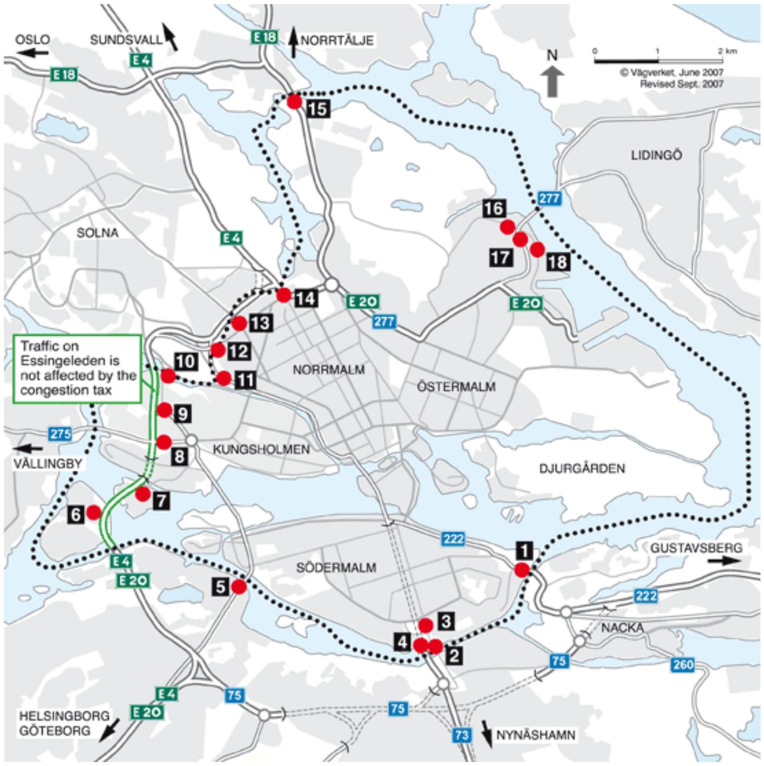
Figure 4-1 Results of the Stockholm Charging Referendum

However, on the same day as the referendum, also general elections were held and the Mayor of Stockholm, who had been against the scheme in the first place, was voted out, and, furthermore, the Social Democrats also lost their majority in the Swedish parliament. Since the now governing right-wing Alliance has stated beforehand they would take account of all referenda, if they were to be in government, and had anyhow always opposed the congestion tax in principle, it was widely expected that the scheme would be scrapped. But in a surprising U-turn the new government announced on 1 October 2006 that they would go ahead and introduce the congestion tax permanently, although the revenue would not go into public transport but entirely into new road construction. Parliament approved the congestion tax on 20 June 2007 and it was re-introduced on 1 August 2007.

4.1.2 Operation of the System

Charging Cordon

The congestion tax is levied when a vehicle passes, inbound or outbound, through one of 18 control points (Figure 4-2). The cordon is generally in line with the borders of the inner city, with the exception of the two islands of Lille Essingen and Stora Essingen, which are indicated through control points 7 and 6 respectively in Figure 4-2 and which, from outside the inner city, can only be accessed from the motorway E4 through those two control points. The E4/E20 Essingeleden is the main route by-passing Stockholm and since there is no viable alternative in the vicinity, no control points have been put onto the motorway and drivers passing through Stockholm on this route therefore do not have to pay the tax, while anybody leaving or going onto the motorway is being charged at control points 6 to 10.



Control points

1. Danvikstull
2. Skansbron
3. Skanstullsbron
4. Johanneshovsbron
5. Liljeholmsbron
6. Stora Essingen
7. Lilla Essingen
8. Fredhäll/Drottningholmsvägen Interchange
9. Lindhagensgatan Interchange
10. Ekelundsbron
11. Klarastrandsleden
12. Karlberg/Tomtebodavägen Interchange
13. Solnabron
14. Norrtull
15. Roslagsvägen
16. Gasverksvägen
17. Lidingövägen
18. Norra Hamnvägen

Source: Vägverket Website

Figure 4-2 Location of Control Points in Stockholm

Technology Used and Payment Modalities

The technical system was developed and operated by IBM Svenska and a number of subcontractors. At the 18 control points ANPR equipment registers the number plates of all passing vehicles inbound and outbound and DSRC transceivers for communication with those vehicles that have on-board units (Figure 4-3). The information from the control points is passed, via pre-processing units, to the central control system, which handles all payments, reminders and reports and is linked to the Swedish Traffic Registry, the National Tax Board, enforcement services as well as postal, bank and retail outlets that deal with one-off driver payments, direct debits and the distribution of the on-board units. A web portal provides a public website, which also offers the opportunity for on-line payment, as well as an intranet for customer services and the National Tax Board.

Source: Stockholm, 2006a

Figure 4-3 Typical Control Point in Stockholm

In contrast to London, the congestion tax can only be paid retroactively. The tax must be paid into the Swedish Road Administration's congestion tax account no later than 14 days subsequent to passage. It is the vehicle owner who is responsible for paying the tax. No invoice is sent out. There are several ways of paying the charge:

- Over-the counter payments can be made at banks, newspaper stalls and a chain of convenience stores.
- Internet payments can be made with a credit or debit card.
- Those car owners who have an on-board unit can pay by direct debit. In this case the tax is drawn automatically from the bank account specified, meaning the car owners do not have to keep track of when or how much to pay. Forms for the direct option can be obtained from the internet or by calling Customer Services.

Vehicle owners can see the tax amount they are liable to pay through logging into a website by using either an e-identity or the authorisation code found on every vehicle registration certificate, by calling Customer Services or when paying at the newspaper or retail outlets.

If the tax is not paid on time, a reminder is being sent by mail, and this adds a service charge of SEK 7 (approx. € 7) to the total bill. If this is not paid within 30 days, another surcharge of SEK 200 (around € 20) will be added. If the tax and charges still remain unpaid, the matter is referred to enforcement services.

Companies and other organisations can sign a special contract for paying the congestion tax through a collective account for all company/organisation vehicles by direct debit. In order to facilitate the administration of the tax, companies and organisations that pay via direct debit are sent daily lists of the taxes incurred.

Charging Levels and Exemptions

A congestion tax is only charged to vehicles registered in Sweden. The charge applies to vehicles crossing the cordon inbound as well as outbound on Monday to Friday between 6:30 and 18:29. No tax is charged on Saturdays, Sundays, public holidays, the day before a public holiday or during the month of July.

Each passage costs SEK 10, 15 or 20, depending on the time of day. The accumulated passages made by any vehicle during a particular day are aggregated into what is called a “tax decision”. The maximum amount charged per day and vehicle is SEK 60. 10 SEK equate roughly to € 1.00 and Table 4-1 shows the precise time periods when each level of charge applies. It should be noted that the official time periods all end at one minute before the half or full hour, e.g. ‘6:30 to 6:59’, rather than ‘6:30 to 7:00’, but since most of the results in the Swedish evaluation reports also refer to times like ‘6:30 to 7:00’, this will be also be used throughout this report.

Table 4-1 Stockholm Charging Levels

Congestion Tax	
Time	**Amount**
6:30 – 7:00	€ 1.00
7:00 – 7:30	€ 1.50
7:30 – 8:30	€ 2.00
8:30 – 9:00	€ 1.50
9:00 –15:30	€ 1.00
15:30 –16:00	€ 1.50
16:00 –17:30	€ 2.00
17:30 –18:00	€ 1.50
18:00 –18:30	€ 1.00

The following groups of vehicles are exempted from the congestion tax:

- Emergency service vehicles;
- Buses with a total weight of at least 14 tonnes;
- Diplomatic cars;
- Motorcycles;
- Foreign registered vehicles;
- Military vehicles;
- Vehicles that according to the Swedish Road Administration’s vehicle registry are equipped with technology for running
    - completely or partially on electricity or a gas other than LPG or
    - on a fuel blend that predominantly comprises alcohol.
- Vehicles granted an exemption by the National Tax Board of Sweden subsequent to an application by a person who has been granted a disabled persons parking permit. This exemption does not apply if the vehicle is used for commercial traffic purposes.

Furthermore, there are two exemptions relating to geographic location:

- Drivers using the E4/E20 Essingeleden (as indicated before) past Stockholm do not have to pay the tax.
- No tax is charged to vehicles that pass two separate control points within a time span of 30 minutes, providing that one of these is located on Gasverksvägen, Lidingövägen or Norra Hamnvägen (number 16, 17 and 18 in Figure 4-2), i.e. for vehicles coming from or going to Lidingö, since this island can only be accessed from the mainland through the city centre of Stockholm.

4.2 AVAILABLE DATA

A whole series of technical reports, together with various leaflets and brochures for general public information, are available on the trial's website: www.stockholmsforsoket.se. Of the technical reports, several have been produced by an advisory group (generally referred to as either Expert Group or Reference Group) that was constituted from two experts from consultancy, two from universities and one from the Swedish Ministry of Trade and Industry; other reports are from self-standing studies from various authors. These reports are:

- Six so-called "Reference Group Summary" reports, which are month-by-month updates on key findings concerning the impact of the trial from January to June 2006.
- The official Final Trial Report contains the overall conclusions drawn by Expert Group and summarises the findings from a series of evaluation reports with regard to:
  - Road traffic, travel patterns and parking,
  - Public Transport, pedestrian and cycle traffic ;
  - Road Safety;
  - Air quality, emission calculations, noise and Stockholmers' experience of the urban environment;
  - Sport for children and young people;
  - Trade and the region's economy;
  - Cost-benefit analysis;
  - Equity effects and
  - Knowledge of and attitudes towards the trial.
- For some of the issues listed above, there are also fuller individual reports on the website, more specifically on road traffic and travel habits, air quality and health, equity and the cost-benefit analysis.
- Furthermore, there is one report published by the public transport operator on their investment programme in preparation of the trial and the impact the trial had on their operations.

All of these reports provide a wealth of information about the effects of the trial charging scheme, but for the purposes of DIFFERENT they have a number of shortcomings, of which the most serious are:

- Most of the data is highly aggregated and therefore does not lend itself to more detailed analysis. Most importantly, there is hardly any data that is broken down into each of the nine intervals with different charging levels. It is obvious that the evaluation was totally focused on proving how far the stated objectives of the trial had been achieved and making sure that any disadvantages of the charging scheme were equitable; further use of the material for scientific purposes was not an objective of the data collection and processing.
- Different reports use different definitions, which can make it difficult to interpret results from different reports together. In particular, the morning and evening peaks are sometimes defined as the period from 7:00 to 9:00, i.e. the peak with the € 2.00 charge an both peak shoulders with the € 1.50 charge, and sometimes from 7:30 to 9:00, i.e. only the main peak and the post-peak shoulder; and worse, sometimes it is not entirely clear which of the two is presented.
- In many cases the available translation into English is rather poor and lacking accuracy, and is in some parts misleading.

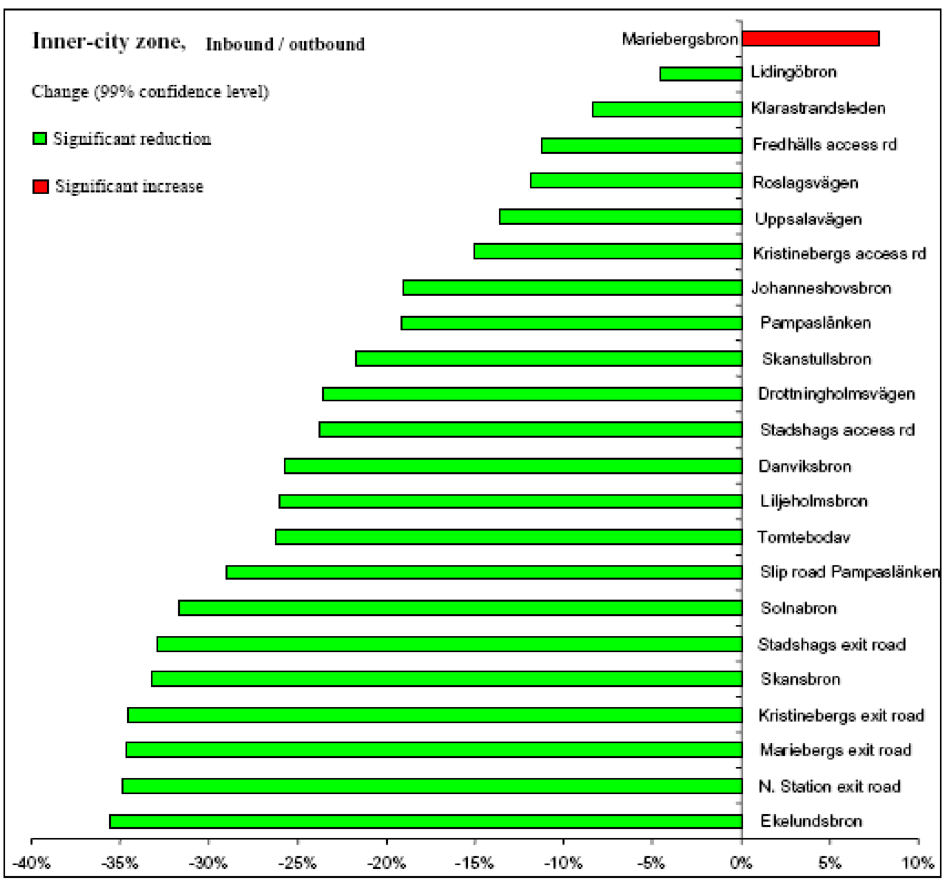
A limited amount of additional information could be obtained from consultants who had been involved in the trial, but most of this case study is based on the material available on the 'stockholmsforsoket' website.

Furthermore, by the time of writing this case study, the full final scheme has been in operation since five months, but its impact can so far only be assessed via various high-level summary statistics, which are updated monthly and are available from the website of the Swedish Road Administration www.vagverket.se.

4.3 RESULTS FROM THE TRIAL

4.3.1 Traffic Volumes

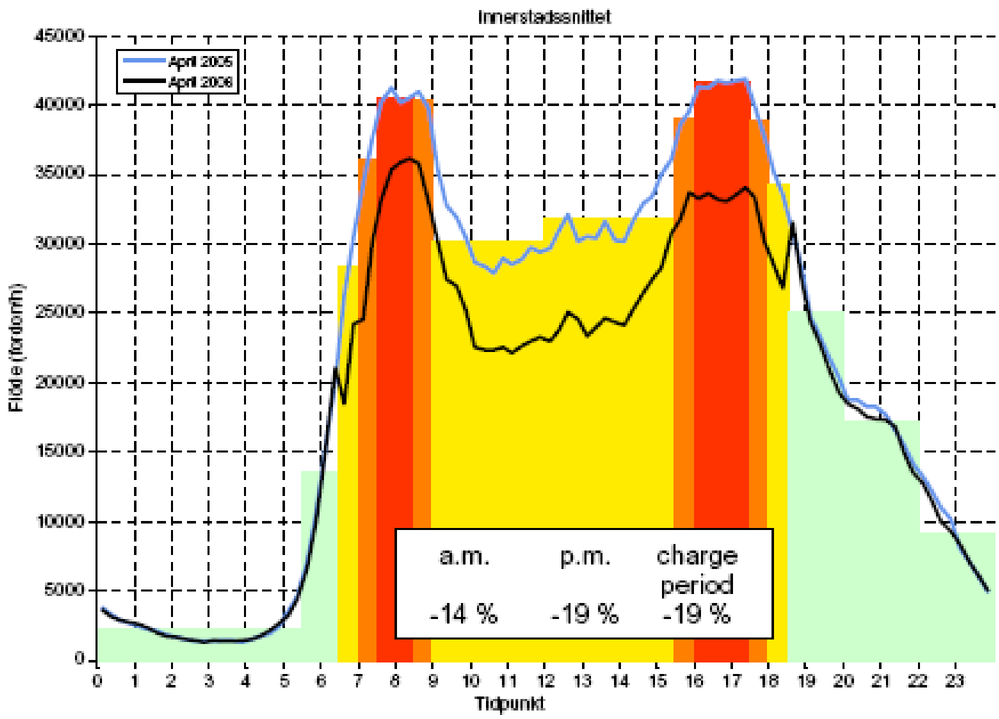
The most immediate effect of the congestion tax can be measured at the entry points to the inner city. Therefore, traffic volumes have been collected at 23 stations around the inner city. 22 of them are near the charging cordon, while one is located on the Mariebergsbron Bridge, which connects the inner city with the islands of Lilla Essingen and from there to Stora Essingen. As indicated before, both islands are included in the charging zone and are directly only accessible from the motorway E4; Mariebergsbron is therefore the only route to get to or from these islands that does not involve paying the congestion tax. Therefore, Mariebergsbron is the only entry to the inner city, where traffic has increased, while traffic volumes have fallen, in many cases very drastically, at all other 22 stations in spring 2006 compared with spring 2005 (Figure 4-4). The majority of these changes is certainly related to the congestion tax, although it should be noted that the fuel price went up by SEK 0.85 (approx. 8 to 9 eurocent) during this year, which could also have had some impact on demand for car travel.



Source: Stockholm, 2006b

Figure 4-4 Percentage Change in Traffic Flow at Entries to Inner City from 6:30 to 18:30

The average distribution from these 23 stations over the day is shown in Figure 4-5 for April 2005 and April 2006. This distribution is highly relevant for DIFFERENT, as it shows the relationship between charging level and traffic reduction. In this and the following similar figures for other areas the AM peak is defined as 7:30 to 9:00 and the PM peak as 16:00 to 18:00, i.e. both comprising the time where the € 2.00 peak charge is applied as well as the past-peak shoulder, where € 1.50 are charged, but NOT the pre-peak shoulder, where the same € 1.50 are applied.



Source: Stockholm, 2006b

Figure 4-5 Traffic Flow at Entries to Inner City

It could have been reasonably expected that the biggest traffic reductions were to be found during those periods where the charges are highest, but this is clearly not the case. It is well known that commuters have lower elasticities than, for instance, leisure travellers, but that the average reduction in vehicles entering the inner city in the middle of the day at a € 1.00 charge is significantly higher than the one in the morning peak at the € 2.00 charge is nevertheless surprising.

Some indications for the reasons behind this will become clear in the following sections, but only to a limited extent, and this key issue - not only from a DIFFERENT point of view - certainly warrants further research. Apparently, there is very rich data material, but it is currently not accessible to researchers. The Stockholm traffic unit in charge will in the near future come under new management, and they may make their data more accessible then; but even if this happened, this would unfortunately be too late in the lifetime of DIFFERENT.

Apart from the headline figures for the peaks and the overall charging period, Figure 4-5 also shows some very interesting effects of the congestion tax, when comparing the curves for 2005 and 2006:

- Up to 6:30, when the charging starts, the curves are exactly the same. If there is any effect at all of drivers starting their trip earlier to avoid the charge, as could have been reasonably expected, then it is at least negligible at the entries to the inner city.
- At 6:45 there is a sharp drop in traffic. This drop is only small compared with the volume at 6:30, but quite substantial compared with the 2005 curve.
- During the height of the morning peak, the traffic reduction is smaller than the average over the charging period, as indicated by the figures of -14% compared to -19%, but also as visually apparent. Between 8:00 and 8:30 traffic volumes for 2005 are just over 40,000 veh/h and in 2006 around 36,000; this means that during this main peak, the reduction is even only closer to -10%. This finding will be discussed further below.

- During the whole charging period the two flow curves appear to run roughly parallel, even if they are overall further apart during mid-day and afternoon than in the morning peak, and it is difficult to make out how big the changes between 2005 and 2006 really are throughout the day.
- In the same way, as the drop in traffic in the evening peak is larger than the one in the morning, so is the spike around 18:15 compared with the one around 6:45. But here the delay in traffic leaving Stockholm is slightly more visible than any early start in the morning. This is even more so the case around 20:30 and 23:00, after charging ended, when in 2006 more cars left the city than in 2005. This looks as if some people, who would have left the inner city after work in 2005 to go home, in 2006 spent longer days within the inner city, possibly to go to the cinema or for a meal, before returning home.

The above observations are all very relevant in the context of DIFFERENT, but most of it is qualitative and unfortunately not quantifiable from the published figures.

As explained before, Figure 4-5 shows the entries to the inner city, which are not precisely the same as the cordon crossing points, but headline figures for these are also given in the same report, again for the comparison between spring 2006 and spring 2005 (Table 4-2).

Table 4-2 Change in Cordon Crossings

	7:30 – 9:00	16:00 – 18:00	6:30 to 18:30
Cordon Crossings	-16%	-24%	-22%

Here, the drop in traffic is the same as for entry to the inner city during the morning peak, but even steeper in the afternoon peak and even more so during the total charging period. This shows, and will be confirmed with later figures further below, that the effects of the congestion tax decrease quite quickly once you move away from the actual cordon.

Breakdown by Charging Period

Table 4-3 to Table 4-7 are the only pieces of information in this case study that are not based on published data, but on a set of data obtained from the Chairman of the Expert Group (Jonas Eliasson). This data set consists of the average number of total cordon crossings for each 15-minute interval of the 24-hour day. But even with his help it was not possible to get the "before" data for spring 2005, but only for October 2005; this makes a difference, because there are regular seasonal variations in the traffic volumes.

Table 4-3 presents the average total number of cordon crossings for the three months in question for a 24-hour period. What this shows is that there is some oddity in the data, since in all three months there are more vehicles coming out of the city than have been going in.

Table 4-3 Total Number of Cordon Crossings (Raw Data)

	Inbound	Outbound	Difference
October 2005	253,725	263,036	9,311
April 2006	210,737	214,995	4,258
May 2006	222,502	230,256	7,754

Table 4-4 shows the cordon crossings broken down into three periods of the day: before charging, during charging and after charging. In principle, the trends showing here are as expected: more people going in than out early in the morning, roughly a balance during the charging period, and more going out in the evening. However, the surplus in the evening is so much larger than any differences earlier in the day that they account for the total outbound surplus already shown in Table 4-3.

Table 4-4 Breakdown of Total Cordon Crossings - Raw Data

		0:00-6:30	6:30-18:30	18:30-24:00	0:00-24:00
October 2005	cordon (inbound)	13,471	200,215	40,039	**253,725**
	cordon (outbound)	12,377	200,882	49,778	**263,036**
April 2006	cordon (inbound)	12,406	160,146	38,185	**210,737**
	cordon (outbound)	10,520	159,910	44,565	**214,995**
May 2006	cordon (inbound)	13,996	166,346	42,160	**222,502**
	cordon (outbound)	12,450	168,258	49,548	**230,256**

Since this is data for Monday to Friday, some of this unbalance can be explained with city dwellers, who leave on Friday afternoons to spend the weekend in the countryside and return on Sundays; however, in contrast to a city like Paris, where this is a well known phenomenon, the number of people doing this in Stockholm is relatively low. Moreover, this will be counterbalanced by the fact that only very few people will return home from the city in the early hours of Monday morning, while more people would spend long Friday nights in the city, which leads to a net increase in in-flow.

The reason behind the outbound surplus can therefore only be detector problems and, since these will in all likelihood occur all over the day, the picture shown in Table 4-4 is somewhat misleading. Table 4-5 and Table 4-6 show the cordon crossings after the 'missing' in-flow has been added back in proportionate to the detected flow, first in the same summary figures as in Table 4-4, then broken down further for each charging period. Table 4-5 shows that, after the adjustment, the outbound flow is still larger than the inbound flow in the evening, but the in-flow is now larger than the out-flow both in the early morning and during the charging hours for all three months.

Table 4-5 Breakdown of Total Cordon Crossings – Adjusted for Detector Failure

		0:00-6:30	6:30-18:30	18:30-24:00	0:00-24:00
October 2005	cordon (inbound)	13,965	207,562	41,508	**263,036**
	cordon (outbound)	12,377	200,882	49,778	**263,036**
April 2006	cordon (inbound)	12,657	163,382	38,957	**214,995**
	cordon (outbound)	10,520	159,910	44,565	**214,995**
May 2006	cordon (inbound)	14,484	172,143	43,629	**230,256**
	cordon (outbound)	12,450	168,258	49,548	**230,256**

Table 4-6 Cordon Crossings per Charge Period

		0:00-6:30	6:30-7:00	7:00-7:30	7:30-8:30	8:30-9:00	9:00-15:30	15:30-16:00	16:00-17:30	17:30-18:00	18:00-18:30	18:30-24:00
Oct 2005	cordon (inwards)	13,965	8,629	10,197	22,459	10,869	101,264	8,726	28,020	9,164	8,234	41,509
Oct 2005	cordon (outwards)	12,377	5,592	7,166	17,705	8,638	97,146	11,402	33,841	10,183	9,210	49,778
Apr 2006	cordon (inwards)	12,656	6,334	7,650	19,436	9,366	78,355	6,707	22,066	7,300	6,167	38,957
Apr 2006	cordon (outwards)	10,520	3,943	5,520	14,677	7,574	78,494	8,887	26,129	7,825	6,861	44,565
May 2006	cordon (inwards)	14,484	6,922	8,392	19,553	9,394	83,020	7,126	23,458	7,586	6,691	43,629
May 2006	cordon (outwards)	12,450	4,286	6,052	15,227	7,736	82,722	9,273	27,480	8,227	7,256	49,548

Table 4-6 confirms that the adjusted crossings now conform to reasonable expectations:

- Up to 9:00 the in-flow is larger than the outflow in all three months and all time periods.

- During the mid-day period the flows are roughly balanced: in-flow is slightly larger in October and May and marginally smaller than out-flow in April.
- From 15:30 onwards, out-flow dominates throughout.

But more important for DIFFERENT are the changes between the 'before' and 'after' period shown in Table 4-7. The first two rows show the changes calculated from the crossings as shown in Table 4-6. However, it has been mentioned before that it is problematic to compare data from autumn and spring, because there are regular seasonal variations in traffic volumes. Therefore, the last two rows show the results after adjusting the data a second time, in this case for the average traffic volumes that in 2005 were 2.3% higher in April than in October and 6.3% higher in May.

Table 4-7 Change in Cordon Crossings per Charge Period

		0:00-6:30	6:30-7:00	7:00-7:30	7:30-8:30	8:30-9:00	9:00-15:30	15:30-16:00	16:00-17:30	17:30-18:00	18:00-18:30	18:30-24:00	0:00-24:00
Oct v Apr	Both directions, adjusted once	-11%	-27%	-23%	-14%	-12%	-20%	-22%	-22%	-21%	-25%	-8%	-18%
Oct v May	Both directions, adjusted once	2%	-21%	-17%	-13%	-12%	-16%	-18%	-18%	-18%	-20%	2%	-12%
Oct v Apr	Both directions, double adjusted	-13%	-29%	-25%	-16%	-14%	-22%	-24%	-23%	-23%	-26%	-10%	-19%
Oct v May	Both directions, double adjusted	-4%	-26%	-22%	-18%	-17%	-21%	-23%	-22%	-23%	-25%	-4%	-18%

It is the 'double adjusted' rows which contain the most relevant information:

- The first thing to observe is that the traffic reduction with the congestion tax occurs through all periods of the day, including those outside the charging period.
- Within the charging period, the lowest traffic reductions can be found during the morning peak as defined for Figure 4-5, i.e. during the main peak and the post-peak shoulder.
- Both in the morning and in the afternoon, the reduction is larger in the pre-peak shoulder with the € 1.50 charge than in the main peak with the € 2.00 charge.
- What was not easily recognisable in Figure 4-5 is that the biggest reductions occur during the first charging period in the morning and the last in the afternoon, when the charge is only € 1.00.

Observation number 1 stands in contrast to the impression given by Figure 4-5, where it looks as if there is not difference in traffic flow between before and after in the early morning and, even more contrary, where it looks very clearly - as was mentioned before - as if there is an increase in traffic after 18:30. The fact that the counting stations used as a basis for Figure 4-5 are not directly at the cordon could only account for minor differences. Another explanation would be that Mariebergsbron has a different pattern over the day, since it is on a route that avoids the congestion tax; however, it seems very unlikely that this could account for the size of the difference of close to a thousand vehicles, or more than 10% of the total traffic volume, during the evening period and, moreover, there is no apparent reason why this route should be used more in spring 2006 in the evening, when no tax would be charged on the alternative routes.

The second observation confirms what the visual impression that Figure 4-5 had already suggested. The official final evaluation report comments on this: "That the reduction in traffic was less marked during the morning peak period than during the remainder of the charge period is probably due to the fact that the majority of journeys made during the morning peak period are travel to work, which is generally subject to more rigid time restrictions than other forms of travel." (Stockholm 2006c). This is certainly plausible, and the fact that the drop in travel is smaller in the morning than in the afternoon would also imply that for commuters and for business travellers on the way to their first appointment the € 2.00 charge is only a more limited deterrent to car use than for other travellers.

However, the third and the fourth observation are both truly surprising. This would be true in any case, but even more so in the light of the above. Surely the majority of trips 6:30 and 7:30 are also trips to work and, therefore, the same considerations as above should also apply for these. That this is not the case means that there are differences in travel behaviour for different groups of 'travel to work' journeys. One difference that appears plausible is the one between commuters and business travellers: the latter group is likely to have the lowest likelihood of changing behaviour among all user groups for several reasons:

- They are most likely to be tied to specified and precise times for their appointments.
- They are most likely to need their car to get from one appointment to another.
- They are most likely to be able to pass the congestion tax either on their employers or claim it as a business expense.

However, the possible total number of business travellers in the overall group of cordon crossings from 7:30 to 9:00 is unlikely to be large enough to account for all the differences in trip reduction compared to the earlier time windows.

Therefore, there must be also strong differences between different groups of commuters. The most likely explanation is that there is a link between travel behaviour and income: people on low incomes will see the congestion tax as a greater financial burden and are therefore more likely to switch to public transport for their journeys to work. It seems possible that those with the lower paid jobs, for instance shop assistants or small shop keepers, have to be at their place of work earlier than the higher paid professionals have to be in their offices. This could explain the differences in trip reduction between the different morning hours, but it is a pure hypothesis, since the author of this case study does not know the structure of the Stockholm job market.

If income were indeed the explanation for the difference in travel behaviour for the different morning hours, there could be two ways of interpreting this phenomenon:

- Travellers on lower incomes will have a lower value of time, and the congestion tax therefore increases the overall generalised cost for any trip across the cordon by a higher percentage than for people on high incomes. Therefore, even if the same elasticity is assumed for all commuters, then those on lower will react more strongly.
- However, although the above is likely to play at least some role, it is also possible that commuters on different incomes have different elasticities.

None of the results within the Stockholm reports, nor within the DIFFERENT Workpackage 4, shed any further light on this question, but since it appears to be a crucial issue, it would certainly be worth further research and investigations.

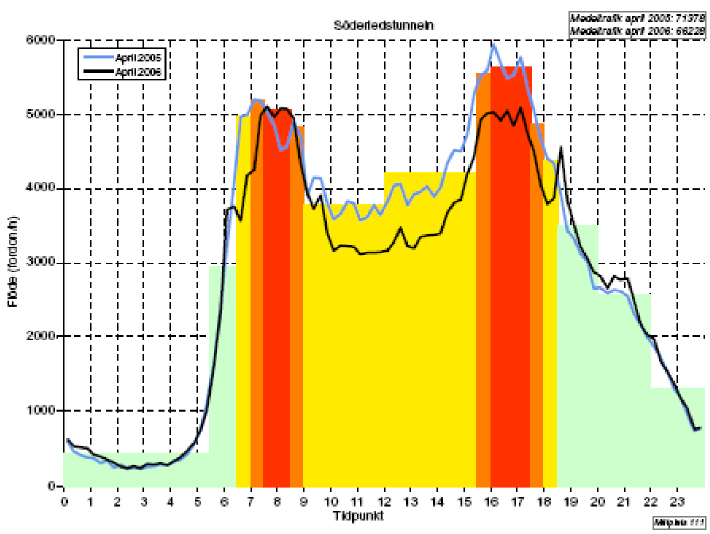
Effects in other Areas of the City

As was already indicated before, the effect of the congestion tax becomes lower the further away from the cordon you move (Table 4-8). It should be noted that in this table, which also shows data from the final evaluation report, the morning peak is for some unknown reason now defined as 7:00 to 9:00, so now includes the pre-peak shoulder, while the afternoon peak still only contains the main peak and post-peak shoulder.

Table 4-8 Decrease in Traffic in Different Types of Roads

	AM Peak 7:00-9:00	PM Peak 16:00 – 18:00	Charge Period 6:30 – 18:30	Full Day 0:00 – 24:-00
Cordon crossings	-16%	-24%	-22%	-19%
Inner city through-routes	-2%	-10%	-12%	-8%
Major inner city streets	-7%	-10%	-10%	-7%
Minor inner city streets	-8%	-13%	-10%	-8%
Outer approach roads	-3%	-4%	-5%	-5%
Other outer city roads	-5%	-4%	-5%	-5%

For the inner city streets, the reductions during the PM peak are, overall, slightly above the average over the whole charging period, while on the outer city roads, the PM peak reduction is less pronounced. Throughout, the lowest reductions are again found during the morning peak, most notably on the inner city north-south through-routes, where also the PM peak reduction is lower than the reduction during the off-peak hours. The evaluation report explains this small reduction with a reduction of congestion on these through-routes, which then attract more cars from other inner city roads. At a net traffic reduction of just 2%, any major congestion reduction seems unlikely, but the blue line for 2005 in Figure 4-6 shows a breakdown in traffic around 8:00, which results in increased congestion, as will be shown later on. In 2006, the peak period is shorter and traffic levels hold up at around 5,000 veh/h throughout, as traffic flows more easily.



Source: Stockholm, 2006b

Figure 4-6 Traffic Flow in Central Section of North-South Passage

The flow curves for other classes of roads listed in Table 4-8 follow the general pattern of that at the entries to the inner city as shown in Figure 4-5), albeit obviously at different traffic levels.

It had been expected that on the tax free passage through the city on the E4 Essingeleden as well as other orbital routes traffic levels would increase as drivers would reroute to avoid paying the charge. But, as in London, this only happened to a more limited extent than anticipated (Table 4-9).

Table 4-9 Increase in Traffic on By-Pass and Orbital Roads

	AM Peak 7:00-9:00	PM Peak 16:00 – 18:00	Charge Period 6:30 – 18:30	Full Day 0:00 – 24:-00
Outer orbital roads	4%	4%	1%	0%
E4 Esselingleden	0%	4%	5%	Not known
Södra Lanken	21%	12%	19%	Not known

The only significant increase in traffic levels occurred in Södra Lanken, a tunnel which by-passes the inner city in the south, but this tunnel had only been opened in October 2004 and traffic levels had been steadily rising in it all the time, from April 2005 to October 2005 alone by 7%, so that it is not clear how much of the further increase to early 2006 can be attributed to the congestion tax.

Finally, the evaluation in Stockholm has also looked into possible changes in weekend traffic, but any changes found were fairly marginal with a very small decrease in the inner city streets and on Södra Lanken and a small increase on the approach roads and the E4 Esselingleden, and it was not clear how far any of these could be attributed to the congestion charge being levied on weekdays.

Breakdown by Type of Vehicle

Manual traffic counts were carried out on 16 approach roads during the charging hours in 2004 and 2006. The overall reduction in traffic found there was even higher than in the main investigation, but this should be ignored since the manual counts were only carried out on three occasions and in this case there were two years between the two counts. However, what is relevant is that these manual counts recorded the breakdown of vehicles into different types and this should not vary too much from day to day and month to month (Table 4-10).

Table 4-10 Breakdown of Traffic Reduction by Vehicle Type during Charging Period on 16 Approach Roads

Mode of Transport	Change	
	Absolute	Relative
Car	-89,167	-30%
Light goods vehicle	-10,136	-22%
Lorry	-1,465	-13%
Motorcycle / Moped	-545	-54%
Total	**-101,313**	**-28%**

Source: Stockholm 2006c

The biggest traffic reduction, both in absolute and relative terms, comes from private cars, but also light goods vehicles have come down substantially, while lorries have reacted to a much lesser extent.

The relative reduction in motorcycles and mopeds is very large, but their absolute number was with 1,000 per day very small in the first place. The reduction can hardly be attributed to the congestion tax, since these vehicles are exempt from the tax; instead the reason is thought to be the more than average amount of snow in spring 2006, and this is certainly a deterrent for motorcyclists.

It should be noted that the snowy weather conditions are only mentioned in this context, which presumably means that the authors believe the snow had no bearing on the behaviour of car drivers.

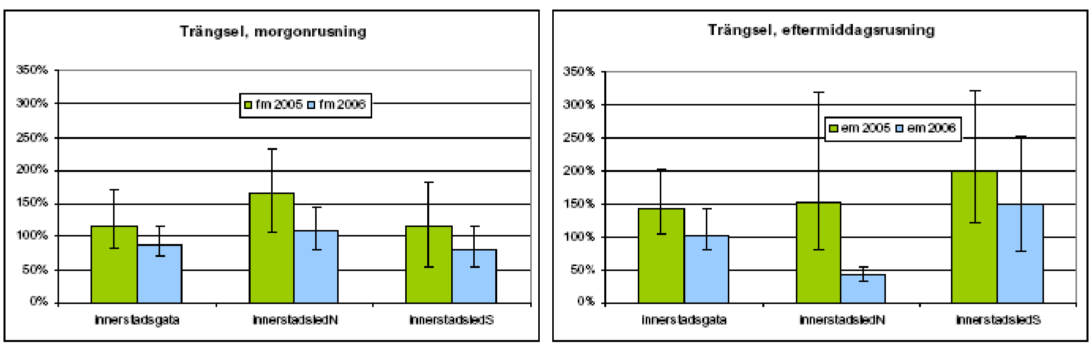
None of the reports provides a breakdown into the types of vehicles that cross the cordon, but assuming that the breakdown on the 16 approach roads mentioned above is typical for all cordon crossing, then this breakdown can be deducted from Table 4-10 from the absolute changes and the percentage they represent (Table 4-11). The report does not mention in which months they were done, but it appears likely that they were made in autumn in 2004 and in spring in 2006, i.e. during the same periods as the data that is the basis of Table 4-3 to Table 4-5 has been collected, and the total of 207,562 plus 200,882 vehicles (inbound and outbound together) from Table 4-5 is therefore used as the 100% value of cordon crossings in Table 4-11. (It should be noted that for ease of reference the term “cordon crossings” is also used for crossing the envisaged cordon in the ‘before’ period, when the cordon does not yet physically exist.)

Table 4-11 Estimated Breakdown of Cordon Crossings from 6:30 to 18:30 in 2004

Mode of Transport	Total Crossings		
	16 Roads	Share	Cordon Crossings
Car	297,000	84%	342,000
Light goods vehicle	46,000	13%	53,000
Lorry	11,000	3%	12,000
Motorcycle / Moped	(1,000)	(< 1%)	1,000
Total	**355,000**	**100%**	**408,000**

4.3.2 Congestion and Travel Times

Figure 4-7 shows the percentage to which the real travel time exceeds the ‘ideal’ travel time, which is used as a measure of congestion, in the inner city, on he left for the morning and on the right for the afternoon peak. The bars indicate the 90% and 10% percentile, and the green and blue blocks represent the average additional travel time.



Source: Stockholm 2006b

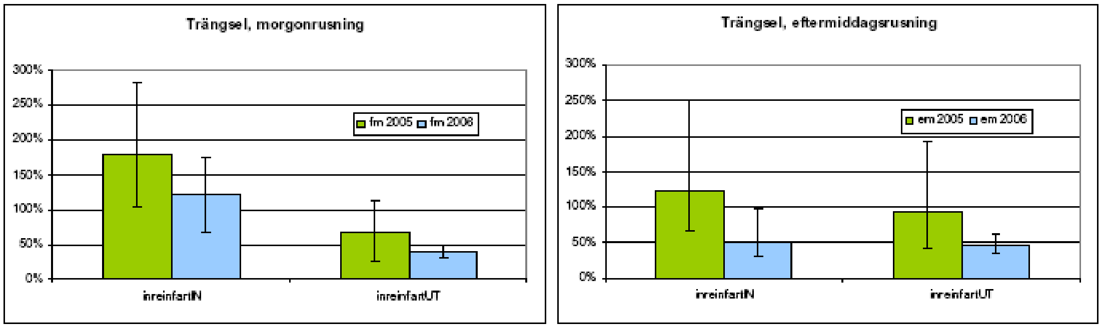
Figure 4-7 Congestion in the Inner City during Peak Hours

The two right-hand sets of columns show the northbound and southbound through-routes. For northbound travel on these roads during the morning peak, the average travel time of around 265% of the ideal time in spring 2005 went down to 210% of the ideal travel time in spring 2006, which equates to a reduction in travel time of 21% and a reduction in congestion of 33%. The respective figures for southbound travel are 18% for travel time and 33% for congestion. That all this could be achieved while traffic levels only dropped by 2% is surprising, but there is no specific reason to doubt this data.

On the other inner city streets, the level of congestion in 2005 was roughly the same as on the southbound through-routes, but the congestion reduction was slightly lower.

During the afternoon congestion in 2005 was significantly larger than in the morning on the southbound through-roads and also by about 20% on the other city streets, and the congestion tax could reduce congestion on both by about one third. Northbound traffic on the through-route experienced about 10% less congestion than in the morning, but congestion tax could reduce congestion here by three quarters, so that traffic is flowing here now very smoothly.

Severe congestion can also be found on the approach roads into the inner city around the charging cordon (Figure 4-8), most of all during the morning (left-hand diagram) for traffic travelling into the city (left set of columns). The tax managed to reduce this congestion by around 30% and the respective travel times by around 20%. For outbound traffic, congestion was much smaller in the first place, but the tax could reduce this further by 40% and the travel items by around 20%, which means in effect that traffic was flowing quite freely. Unfortunately it is not possible to compare the congestion reduction directly with the reduction in traffic volumes, since only the figure of -14% for the sum of in- and outflow is available.



Source: Stockholm 2006b

Figure 4-8 Congestion on the Approach Roads during Peak Hours

4.3.3 Changes in Travel Habits

To establish changes in travel habits, a dedicated 'before and after' study had been commissioned by the city of Stockholm (Trivector 2006). 77,000 questionnaires were sent out to residents in Stockholm County between the ages of 12 and 84, and another 7,500 were sent to commuters, who live outside the charging zone, but work inside. The questionnaires requested some personal information about the interviewees and a travel diary for a specific monitoring day. From both of the panels around one third returned the questionnaire for both the before and after period.

The before data was collected during September and October 2004, when it was thought the charging scheme would be in place at the same time in 2005, but delays in the scheme implementation meant that the after data could only be collected in March 2006. This meant that there were the normal seasonal variations to be taken account of in the interpretation of the results, but, furthermore, the weather during the before period had been generally nice and sunny, while March 2006 was unusually cold, which would certainly have an influence on the use of cycling and motorcycling as travel modes.

Unfortunately, the English translation of the report suffers from some poor definitions, which make is sometimes difficult to understand how certain data hangs together, and from a series of typing errors for key numbers in the text and several tables. In this context, it should also be noted that the English version of the report uses the terms 'journey' and 'trip' as synonyms, both meaning what is more usually referred to as 'trip', i.e. a trip into one direction only, and not a round-trip. Furthermore, it appears that corrections have been made to some of the data between the publication of the original Trivector Report and the final evaluation report.

But most crucially, and this will shown later on repeatedly, from the key figures derived from the travel diaries many match up well with information obtained from elsewhere, but some do not. Figure 4-9 shows the number of car trips that cross the cordon at least once.

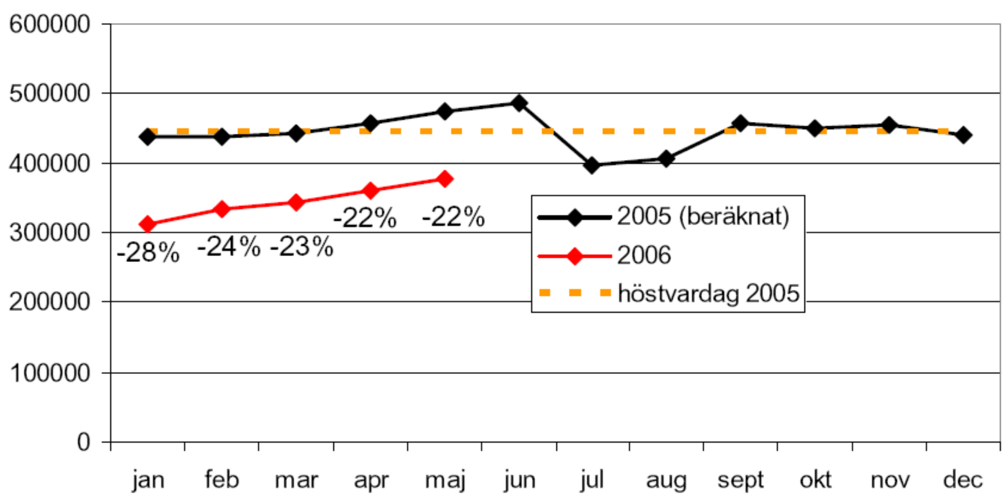
Total number of car journeys passing charging zone at least once			
	24-hour weekday period during the charging period	24-hour weekday period during charge-free period	24-hour weekday period
RVU 2004	304,000	73,000	377,000
RVU 2006	228,000	56,000	284,000
Percentage change	-25 %	-24 %	- 25 %
Statistically significant difference	-76,000	-17,000	- 93,000
Traffic monitoring across charging zone reduction 2005 to 2006			*- 22 %*
Seasonal variation according to traffic monitoring across charging zone			*- 5 %*

Source: Trivector 2006

Figure 4-9 Number of Car Trips Crossing the Cordon at Least Once in a 24-Hour Period

The figure of 22% for the reduction over 24 hours quoted as the result from the traffic monitoring investigation is not correct, since the final evaluation report claims a 22 % reduction for the charging hours, but only a 19% reduction for the 24-hour day.

The figure of -5% shown in the table as average seasonal variation stands in contrast to the figures shown in the context of the traffic volumes, but this is due to the fact that they are based on different months: the traffic volumes have been shown for October, April and May, while the travel habits have been investigated in March and September/October. Figure 4-10 shows that cordon crossings were in September higher than in October, and in March much lower than in April and May, which explains the reversal of the seasonal variation between the two studies. This then means that the -5% have to be deducted from the -25% shown for the whole day in Table 4-11, and the resulting figure of -20% then aligns well with the -19% figure from the traffic study.



Source: Reference Group, 2006

Figure 4-10 Vehicle Passages over Charging Cordon from 6:00 to 19:00

If the seasonal adjustment of 5% is applied to the figure of 304,000 trips during the charging period, this brings the expected traffic in March down to 289,000, to which the calculated 228,000 then compare as a further reduction of 21%, which is in line with the -22% from traffic study.

The reduction of 25% to spring 2006 also matches up well with the data from Table 4-5, which is adjusted for detector failure, but not yet for seasonal variations. In Table 4-5 the reduction in crossings is 21% to April and only 17% to April 2006, i.e. somewhat lower than the reduction derived from the travel diaries, but this includes lorries and vans, which had lower reductions according to Table 4-10.

But where the difference really becomes substantial is the crossings during the charge free period. The reduction to April 2006 for these hours is, after the seasonal adjustment, per Table 4-7 only 11%, and to May 2006 even only 4%. The Trivector figure of -24%, even after a seasonal adjustment of 5% brings it down to -19%, is much higher than that data. Also a look at Figure 4-5 confirms that the difference between before and after outside the charging hours is very small. If the decrease in reduction from April to May were part of a general spring trend of traffic reductions outside the charging hours becoming smaller as drivers get used to the congestion tax and its operating hours, then the 19% Trivector figure would fit into the picture. However, even then it would not be representative of the actual number of cordon crossings after traffic patterns settled. The question is therefore, whether some of the differences between the travel habits study and the findings of the traffic and other studies could also be due to the fact that travel behaviour in March was not yet representative of that in the later months of the trial.

It should also be noted that the Trivector report admits explicitly that there are some differences in the travel habits between those who responded to the survey and those who did not. Telephone interviews with a sample of those who had not responded to the survey led to the conclusion that the respondents were more mobile and made more trips than the non-respondents and had a more positive attitude to the congestion tax.

The final aspect to be considered before assessing the central findings of the study is the travel pattern found in a control group of 578 people, whose travel habits were recorded in September and October 2004, October 2005 and April 2006 (Figure 4-11).

Total for county population	Proportion of respondents who have not made any journey			Number of journeys per person		
	24-hour weekday period	24-hour weekend period	All journeys	24-hour weekday period	24-hour weekend period	All journeys
RVU 2004	14.8 %	29.6 %	20.1 %	2.90	2.12	2.70
RVU 2005	19.5 %	34.2 %	23.4 %	2.61	1.82	2.40
RVU 2006	22.8 %	36.8 %	26.5 %	2.41	1.99	2.30
Statistically significant difference between.04 and.05*	No	No	No	-0.29	No	-0.3
Statistically significant difference between.05 and.06*	No	No	No	No	No	No
Statistically significant difference between.04 and.06*	+8.0 %	No	+6.4 %	-0.49	No	-0.4

Source: Trivector, 2006

Figure 4-11 Travel Habits in the Control Group

This shows already from 2004 to 2005 an increase of 4.7% of people who did not make any journey on a given weekday and a decrease from 2.9 to 2.61 journeys that each person made in average per day. During this period, the petrol price increased by 10%, which is thought to explain at least some of this travel reduction. But the petrol prices then stabilised and there is no obvious explanation for the further decrease to April 2006. It should be noted that neither the decrease from 2004 to 2005, nor from 2005 to 2006 is statistically significant, but it could mean that not only the effects of the congestion tax in this study are somewhat overestimated, but that also traffic reductions shown earlier from the traffic study are not all entirely due to the congestion tax alone.

Breakdown by Mode

Table 4-12 breaks all trips that are, based on the travel diaries, estimated to cross the cordon down by mode.

Table 4-12 Number of Trips Crossing the Cordon at Least Once on 24-Hour Weekday by Mode

	By foot	Cycle	Car	PT	Other	Total
Autumn 2004	21,000	40,000	377,000	709,000	41,000	**1,188,000**
Spring 2006	22,000	9,000	286,000	734,000	27,000	**1,078,000**
Change	6%	-78%	-24%	4%	-34%	**-9%**
Statistically significant difference	No	-31,000	-92,000	25,000	-14,000	**-110,000**
Seasonal variation	-	-	-5%	-1%	-	**-**

Source: Stockholm, 2006c[2]

The sums in this and other tables do not quite match up, but this is probably only due to rounding. The change in travel on foot is not significant, while the steep drop in cycle trips is. However, it has already been mentioned in the context of motorcycles that during spring 2006 weather conditions were particularly bad with cold temperatures and much snow, and the change in the use of cycles or motorcycles is therefore certainly related to the weather and not to the congestion tax.

The drop shown for car traffic is, as mentioned before, after the reduction of the seasonal variation in line with other data (after the update or correction now even matching the 19% from the traffic study precisely), but what becomes evident here for the first time is that car trips only account for less than a third of all trips across the cordon.

It is not stated anywhere in the report what the category of 'other' modes includes, and neither is it clear anywhere how far trips made by delivery vehicles or by tradesmen in vans are covered by the travel diaries. But given that according to Table 4-11 motorcycles account for less than 1 % of the motorised traffic across the cordon, it appears that the 'other' category must mainly consist of trips made by light goods vehicles. But if this is the case, then the reduction of 34% between 2004 and 2006 is not in line with other data, more specifically the figure of 22% based on manual traffic counts in Table 4-10.

With around 60%, the by far biggest share of trips into and from the inner city was already in 2004 made by public transport. As was to be expected, and had indeed been anticipated with the increased investment in, and provision of, public transport from autumn 2005 onwards, the total number of PT passengers rose in 2006, and PT increased its share of trips into the city from 60% to 68%.

However, when looking at the net balance of all trips, it becomes apparent that this increase only matches less than 20% of the trips that have no longer been made by the other modes. 110,000 trips into and from the inner city have 'disappeared'.

Breakdown by Trip Purpose

To investigate this further, both all trips and then also car trips only were broken down by trip purpose (Table 4-13). For 'all trips' seasonal variations are shown from a regular Swedish travel survey.

As it turns out, there were reductions in trips for all travel purposes, and not only that, but the relationships between them are as surprising as the relationship between some the seasonal variations. Furthermore, that the reduction levels for car traffic only range from 21% to 33%, is much narrower than conventional wisdom would suggest.

2 Updated / corrected data from Trivector 2006.

Table 4-13 Number of Trips Crossing the Cordon at Least Once on 24-Hour Weekday by Trip Purpose

	Work / School	Business Trip	Purchase / Service	Leisure	Going Home	Other	Total
				All Trips			
Autumn 2004	381,000	84,000	117,000	138,000	411,000	53,000	**1,184,000**
Spring 2006	361,000	64,000	98,000	117,000	385,000	43,000	**1,068,000**
Change	-5%	-23%	-17%	-15%	-7%	-19%	**-10%**
Statistically significant difference	-20,000	-20,000	-19,000	-21,000	-26,000	-10,000	**-116,000**
Seasonal variation acc. to RES	-7%	-16%	-9%	-17%	-	7%	**-10%**
				Car Trips only			
Autumn 2004	100,000	51,000	44,000	43,000	110,000	29,000	**377,000**
Spring 2006	78,000	36,000	32,000	33,000	87,000	19,000	**286,000**
Change	-22%	-30%	-27%	-23%	-21%	-33%	**-24%**
Statistically significant difference	-22,000	-15,000	-12,000	-10,000	-23,000	-9,000	**-91,000**
Seas. Var. acc. to traffic monitoring	-	-	-	-	-	-	**-5%**

Sources: Trivector, 2006 and Stockholm, 2006[3]

The highest of all reductions for car travel was for 'other' purposes with 33% and for all trips it has the second highest reduction with 19%. What is particularly remarkable is the fact that the reduction of 19% is set against the only case, where the seasonal variation is positive (unless this is a typing error), which would mean a net reduction of 26%. But unfortunately the report does not fully explain what these 'other' purposes are, only "fetching and dropping off individuals and groups" is given as one example for this category, and no further interpretation of the 33% figure is therefore possible.

But the second highest reduction can be found for business travel by car with 30% and for all trips it is even the highest overall reduction with 23%. This is very surprising indeed, and that it is thought that there are even regular seasonal variations of 16% is even more remarkable, even if this means that the net effect of the congestion tax is then 'only' a reduction of 7%. Some of these 7% will probably be an effect of simple rerouting of trips that had previously gone through the cordon and are now diverting around it, but it seems doubtful whether this can account for such a relatively high percentage. Furthermore, the study found that there is a marked difference in travel behaviour between drivers of company cars and private cars: the latter show a gross reduction in trips during the 24-hour day of 30%, but the former only of 4%. Since it appears likely that business travellers have above average use of company cars, this makes the 30% even more perplexing.

In the context of car travel, no possible reason for this is provided in the report and all the report offers there is a general statement that "different reasons for journeys show great differences in seasonal variations" and that "this means that it is not possible to state with certainty precisely how the Stockholm Trial has affected different reasons for journeys — work/school journeys excepted". However, while it is plausible that there are differences by journey type, it is not very plausible that business travel should be among the categories with particularly high seasonal variations. Earlier on in this chapter it was argued that low differences in traffic volumes during the main morning peak may in part be related to the fact that business travellers a) have fixed deadlines, b) depend on their car to get to multiple destinations in one day and c) can often pass the charge on to their company or as business expense. All this is in complete contrast to the 30% figure in the Trivector study, for which there is simply no obvious explanation.

In contrast, the 17% and 27% figures for shopping and services are much more in line with the expectation that they would be among the highest reductions, since a loss of customers was the complaint of many London shopkeepers and was also the great fear in Edinburgh, even if the actual statistics in London did not confirm that the loss in business was very substantial, although the charge, with initially around € 8.00 and now € 12.00, is there very much higher than in Stockholm.

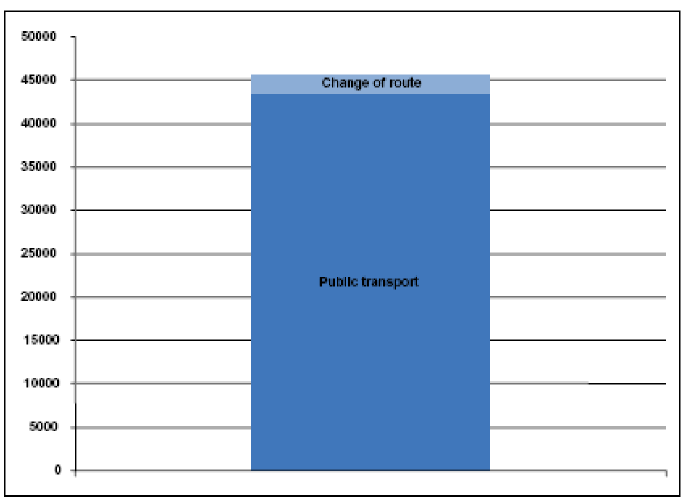
3 The data for all trips is from Trivector 2006, and the totals do not match the totals in Figure 4-11 precisely. The data for car trips is updated / corrected data from Stockholm 2006c.

That pure leisure trips only show a reduction of 15% for ‘all trips’ surprises, however, in the comparison with other trip purposes, and even more so in the light of the seasonal variation of -17%, which would mean that there was a net increase in leisure trips. Furthermore, even the 23% reduction in car trips for leisure purposes is only marginally larger than those for work and home trips. It will be later shown in chapter 7 for the modelling carried out for Rome that also there leisure trips have lower elasticities than work and shopping trips, which is explained there by the fact that late in the evening, when leisure travellers return home, they have few alternatives to travel by public transport. Nevertheless, this stands in complete contrast to the assumptions made in the traffic study that leisure traffic would have been particularly affected by the trial.

Finally, Table 4-13 shows for “all trips” to work or school and trips home reductions of 5% and 7%, but for work trips also a surprisingly high seasonal variation of 7%, which would mean that the trips to work have even increased by 2%. If this is the case, then it is also obvious why the final evaluation report comes to the conclusion that there “was no increase in telecommuting”. Both the Trivector study and the traffic study also found that there was no increase in the use of car pools.

However, the reduction for car travel for work and home trips shown in Table 4-13 is 22% and 21% respectively. These in themselves are very high figures, and, especially together with the claimed 30% reduction in business travel, do not match up at all with the reduction of just 10% in cordon crossings during the height of the morning peak from 8:00 to 8:30 found from the results of the traffic study.

Furthermore, the report contains another figure (Figure 4-12), which explains where the trips that are no longer made by car to and from work or school have gone. The total shown there is the sum of the 22,000 and 23,000 cars from Table 4-13, and from these around 43,000 are shown to have switched to public transport and only just over 2,000 are supposed to have changed their route, presumably by no longer crossing the cordon twice, but going around it instead, since both home and place of work or school are outside the cordon. These 2,000 are a very small number, equating to just 4% of the ‘disappearing’ cars and only 1% of the base figure of 210,000 trips that fall into these two categories. If this is typical for all the overall percentage of diverted trips, then this can clearly not help to explain the reduction in business travel discussed before.



Source: Trivector 2006

Figure 4-12 Trips across the Cordon to and from Work/School which Are No Longer Made by Car during the 24-Hour Period

Overall: conventional wisdom suggests that business travel has the lowest elasticities, followed by travel to work and back to home, followed by shopping trips, and with leisure trips having the highest of all elasticities. The Trivector study makes the startling suggestion that, except for travel to work and to home, it is the other way round, with business travel having the highest elasticities and leisure travel the lowest. If the data base were smaller, the findings would suggest a random bias, but with more than 24,000 returned travel diaries as a basis for the findings, this is not plausible.

It should be noted that the authors of the study also do not have any explanation for some of the results in their study, which they as well found to be counterintuitive or surprising; unfortunately they had no opportunity to investigate those issues further, but this is clearly an area that merits further research.

Commuters

As indicated at the beginning of this section, a separate part of the study had been investigating the travel behaviour of people, who lived outside the charging cordon, but were working inside in October 2005 and March 2006. Figure 4-10 shows that there is hardly any seasonal variation between those two months: travel in October is only marginally higher than in March. The responses of this group were weighted by age, gender and background, so that the total represented the total population of the county.

The commuters had not only been asked about their travel to work, but all of their trips across the cordon, and the overall trip reduction was 8% on weekdays (Table 4-14). The underlying reduction of 7% for trips to work is already surprisingly high, but even more remarkable is the fact that the reduction was even higher during the charge-free hours. For car trips the reduction figures for the charging hours and the 24-hour day are understandably quite high, while for the charge-free hours and the weekend the percentage reduction is similar to the one for all trips, although the absolute numbers of trips involved are much lower.

Even if the changes are not statistically significant, it still raises the question why there was such a reduction during the non-charging period. Some of the weekday trips can be return journeys, where the other leg of the journey would have happened during the charging hours and the tax affected both directions of travel, even if only one of them would have been chargeable, but this is not an explanation for the weekend trips. Lack of knowledge can hardly be the reason for shunning travel during charge-free periods, since these commuters travel into the city every day and will surely be well informed about the charging hours. So the question remains: why did they not travel, even if they did not have to pay? If this data is correct, then there are three possible explanations: this could be either:

- A sign of irrational travel behaviour or, alternatively,
- The plausible reaction of car drivers, who do not like the idea of the congestion tax and therefore either
  - behaved during the trial in a way that was aimed at screwing the evaluation results against the charge or
  - reported their travel pattern wrongly in order to influence the research outcome.

If one of the latter were the case, then it could also explain some of the other implausible outcomes of the survey shown elsewhere in the travel habit study. Against this theory, however, stands the fact that both respondents and non-respondents were asked about their attitude to the congestion tax, and the respondents claimed that their support for the scheme was above average (although it cannot be ruled out that this claim was untruthful either).

The alternative explanation would be that the data is not correct and something went wrong in the evaluation process, but while small corrections were made to the data later, as mentioned before, it does not appear likely that an evaluation error could change the outcomes to such a substantial extent.

Table 4-14 Number of Trips Crossing the Cordon Made by Commuters

	Weekday during charging period	Weekday during charge free period	24-hour Weekday	24-hour Weekend day
		All Trips		
Autumn 2004	222,000	43,100	265,100	104,600
Spring 2006	206,600	38,000	244,600	100,600
Change	-7%	-12%	-8%	-4%
Statistically significant difference	No	No	-20,500	No
		Car Trips		
Autumn 2004	52,900	12,900	65,800	43.300
Spring 2006	40,900	11,300	52,200	40,900
Change	-23%	-13%	-21%	-5%
Statistically significant difference	-12,000	No	-13,600	No

Source: Trivector, 2006

To understand the reduction in trips better, the next step is again to break the trip down by mode (Table 4-15).

Table 4-15 Number of Trips Crossing the Cordon Made by Commuters at Least Once on 24-Hour Weekday by Mode

	By foot	Cycle	Car	PT	Other	Total
Autumn 2004	2,200	13,300	65,800	179,000	4,800	**265,100**
Spring 2006	2,800	1,100	52,500	184,300	4,200	**244,600**
Change	29%	-92%	-21%	3%	-13%	**-8%**
Statistically significant difference	No	-12,200	-13,600	No	No	**-20,500**

Source: Trivector, 2006

The changes in travel by cycle and on foot can be again explained with the weather, with the snow in March making cycling a very unattractive proposition; and most of the increase in trips by foot is likely to be in replacement of short cycle trips. The changes in car, PT and other trips are in line with previous data.

To explain the apparent trip reductions, the breakdown by travel purpose should again be most enlightening (Table 4-16).

There are reductions in trips for all purposes for both all and car trips only and for both the charging period and the 24-hour day, with the one single and somewhat puzzling exception of all trips to home during the charging period. Most of these reductions are fairly substantial, but only very few are thought to be statistically significant, which is another surprising fact. With more than 2,200 respondents the sample is very large, and the range of possible answers is with ‘none’, ‘one’ or in very few cases maybe also ‘two’ or ‘three’ very narrow; so how then a reduction in leisure trips by car by 1,600 trips or 40% cannot be statistically significant is hard to understand.

From all the reductions shown, the ones for purchase and leisure trips are again the highest, as was to be expected. Furthermore, it can be suspected that the time spent for purchasing goods or services of for leisure in the city has not been reduced by anything like the same percentage, since the prospect of paying the congestion tax three of four times instead of once or twice would certainly deter many commuters from going home after work and then returning for shopping or leisure later in the day and many would instead stay in town after work to shop or go to the cinema straightaway.

Table 4-16 Number of Trips Crossing the Cordon Made by Commuters at Least Once on 24-Hour Weekday by Trip Purpose

	Work / School	Business Trip	Purchase / Service	Leisure	Going Home	Other	Total
				All Trips during 24-Hour Day			
Autumn 2004	113,400	9,500	12,400	15,200	95,000	19,600	**265,100**
Spring 2006	106,300	8,100	10,000	11,300	92,500	16,400	**244,600**
Change	-6%	-14%	-20%	-26%	-3%	-17%	**-8%**
Statistically significant difference	No	No	No	-3,900	No	No	**-20,500**
				All trips during Charging Period			
Autumn 2004	103,700	8,500	11,600	10,800	68,800	18,600	**222,000**
Spring 2006	94,900	7,900	9,200	9,700	70,700	14,300	**206,700**
Change	-9%	-7%	-21%	-10%	3%	-23%	**-7%**
Statistically significant difference	No	No	No	No	No	No	**No**
				Car Trips during 24-Hour Day			
Autumn 2004	24,300	4,300	5,300	6,200	19,100	6,600	**65,800**
Spring 2006	20,200	3,600	3,900	3,300	15,700	5,500	**52,200**
Change	-17%	-15%	-26%	-48%	-18%	-16%	**-21%**
Statistically significant difference	No	No	No	-2,900	No	No	**-13,600**
				Car Trips during Charging Period			
Autumn 2004	21,600	4,200	4,900	3,900	12,600	5,700	**52,900**
Spring 2006	17,100	3,500	3,100	2,300	10,100	4,800	**40,900**
Change	-21%	-15%	-37%	-40%	-20%	-17%	**-23%**
Statistically significant difference	-4,500	No	No	No	No	No	**-12,000**

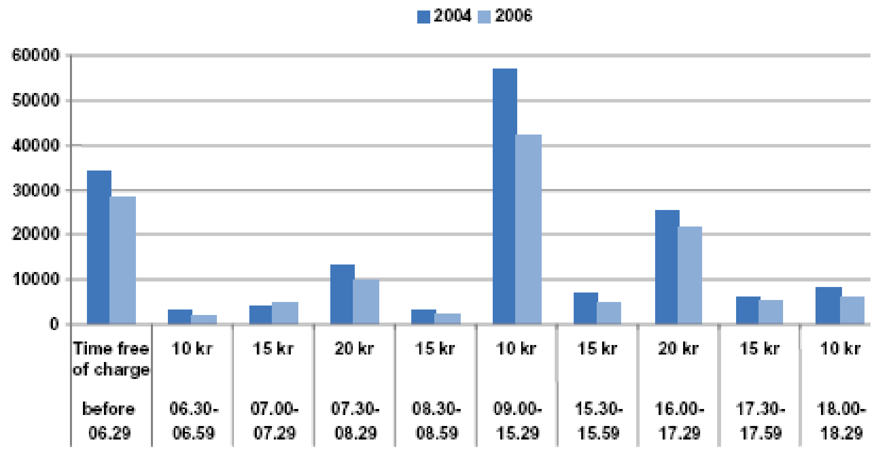
Source: Trivector, 2006

But puzzling is again the high reduction in business travel and also the reduction in work trips. The Trivector report shows in a dedicated section that the sample of respondents and their circumstances has not changed in any significant way between the 'before' and 'after' period, and it was said in several places that telecommuting did not increase. Neither can these commuters have changed route, since they have been selected so that they live outside and work inside the cordon. Furthermore, a different section in the report shows that travel to work by all commuters in the county has even marginally increased during the same time, and that the reductions shown in Table 4-16 are therefore not part of some general trend. The question still remains: what did the 7,100 people, or 6%, who no longer went to work at any time during the 24-hour day do instead?

Breakdown into Charging Periods

Finally, Figure 4-13 and Figure 4-14 show the breakdown of trips according to the charging time periods. In theory, these are highly relevant graphs in the context of DIFFERENT, but unfortunately they do not show during which time interval these trips crossed the cordon, and therefore which charge they incurred, but instead in which time period these trips started. Furthermore, only these figures are available and no tables with more precise numbers.

There is also no information available how long it took those who started their trip in the inner city to get to the cordon, but given the 'Lidingö' rule, whereby people travelling through the city within 30 minutes do not incur a charge, it appears likely that the average time to reach any cordon crossing point from anywhere in the inner city is below 15 minutes. Therefore, the breakdown in Figure 4-13 should show a time lag of approximately 10 to 15 minutes.



Source: Trivector 2006

Figure 4-13 Trips across the Cordon Starting within the Zone during Specific Time Intervals

In an attempt to interpret Figure 4-13, the size of the columns was translated into estimates of the numbers of trips, and the results are shown in Table 4-16.

The report compares the average reductions for the morning and afternoon peak and the entire charging period of -24%, -22% and -25% respectively against the equivalent figures of -16%, -24% and -22% from the traffic study. The report states then that "traffic measurements show a greater reduction in car traffic across the charging zone during the morning, whilst the [Trivector figures show] a greater reduction in the afternoon", although it is clearly the other way round. But while this is probably just a translation error, the report also ignores the seasonal variation of -5% that needs to be applied to their own figures, which then means they estimate a 3% greater reduction in the morning, a 7% lower one in the afternoon and 2% lower one the whole charging period than the traffic study.

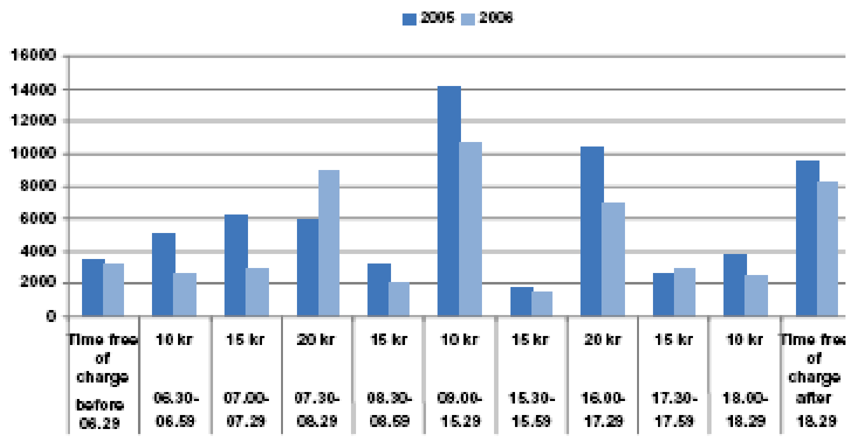
This somewhat questions the absolute numbers presented, but since here the only interest lies in the relative relationship between the time periods and not in their absolute size, it is still worth having a look at.

Table 4-17 Estimated Number of Trips across the Cordon Starting within the Zone during Specific Time Intervals

Time	Before 6:30	6:30–7:00	7:00–7:30	7:30–8:30	8:30–9:00	9:00–15:30	15:30–16:00	16:00–17:30	17:30–18:00	18:00–18:30	
Charge [€]	**0**	**1.00**	**1.50**	**2.00**	**1.50**	**1.00**	**1.50**	**2.00**	**1.50**	**1.00**	**Total**
Autumn 04	34,000	3,000	4,000	13,000	3,000	57,000	7,000	26,000	7,000	9,000	163,000
Spring 05	28,000	2,000	5,000	10,000	2,000	42,000	5,000	21,000	6,000	7,000	128,000
Difference	-6,000	-1,000	+1,000	-3,000	-1,000	-15,000	-2,000	-5,000	-1,000	-2,000	-35,000
Difference	-18%	-33%	+25%	-23%	-33%	-26%	-29%	-19%	-14%	-22%	-21%

The percentage figures for the reductions are obviously only indicative, but the first thing that is noticeable is the increase in traffic starting their trip between 7:00 and 7:30, which is not only already in the medium charged € 1.50 period, but also means that it is likely that many of them will only reach the cordon by the time the peak charge of € 2.00 applies. This is startling, but there is no particular reason to doubt this finding. But the main impression from this table is a confirmation of the finding from the traffic study that there is no direct relation whatsoever between the size of the charge and the size of the traffic reduction.

Figure 4-14 shows the same sort of breakdown, but this time based on the results of the commuter survey. This one even shows an increase in traffic starting between 7:30 and 8:30, when the highest charge applies. However, in this case it appears likely that the average gap between the starting time of the trip and the time of the cordon crossing is even bigger than for the inner city residents who were the basis of the previous figure. A later part of the report states that the average commuting journey in the county is 37 km in 2004 and 34 km in 2006. It is not entirely clear whether this should also apply to the commuters in this study, but it seems likely that their average is, if anything, even higher since it probably excludes a larger number of shorter commuting trips and a smaller number of longer one that go all the way across the county. It is therefore very difficult to relate the columns in Figure 4-14 to the time of the cordon crossing, and the figure is therefore shown here only for completeness rather than for drawing any further conclusions.



Source: Trivector 2006

Figure 4-14 Commuter Trips across the Cordon Starting during Specific Time Intervals

4.3.4 Public Transport

Another issue the Trivector study tried to investigate was the change in trips by public transport through the cordon and, again, the results were startling (Table 4-18).

Table 4-18 Number of Trips Crossing the Cordon by Public Transport on 24-Hour Weekday by Trip Purpose

	Work / School	Business Trip	Purchase / Service	Leisure	Going Home	Other	Total
Autumn 2004	252,000	25,000	64,000	83,000	267,000	18,000	**709,000**
Spring 2006	174,000	22,000	59,000	78,000	283,000	18,000	**734,000**
Change	9%	-10%	-7%	-7%	6%	-1%	**4%**
Statistically significant difference	22,000	No	No	No	No	No	**25,000**
Estim. seasonal / weather variation	-	-	-	-	-	-	**-1%**

Source: Trivector 2006

The only increases in public transport use were found for trips to work and school and for trips back home. For all other purposes the number of trips by public transport appears to have fallen, and even if these falls are not statistically significant, this is certainly not the counterbalance to the reduction in car trips, that could have been expected. This would mean a very substantial loss in attractiveness of Stockholm's inner city as travel destination.

Data from SL, the public transport operator, shown in the final report, paints a slightly more positive picture, since they report 45,000 more passages made on the approach roads to and from the city per day, i.e. nearly twice the figure shown in Table 4-18; but even this still only counterbalances half of the reduction of 93,000 car trips shown in Table 4-13 and still only 63% of the net reduction of 72,000 after accounting for the 5% seasonal variation in car trips.

During the main peak from 7:30 to 8:30, when the € 2.00 charge is in operation, the increase on the approach roads is 8% in average and 10% in the inbound direction alone, which means that during this period the increase in public transport is above the day's average, while the decrease in car traffic is very much below the day's average.

Overall, for the whole county SL reports a 6% increase in PT use with 140,000 more boarding passengers (even if only for partial journeys), which equate to 80,000 more trips and 40,000 more passengers during an average weekday compared to spring 2005. On the inner city trunk bus routes the increase is also 6%, but on the inner city local bus routes even 14%.

To isolate the effect of the improved public transport provision from that of the congestion tax, data has also been compared between autumn 2004 without and autumn 2005 with all improvements in place, and it was found then that passenger numbers had increased by 2%. Therefore not all of the increase in public transport found in spring 2006 can be attributed to the congestion tax alone, but are the combined effect of the PT improvements and the tax together.

Park&Ride provision by SL sand Stockholm Parkering AB in the county had been increased by 2,900 new spaces between spring 2005 and spring 2006, while the number of parked vehicles in these sites increased by 23% from 7,750 to 9,560 "in average per month" (Stockholm 2006c), presumably meaning "per day as average during the month", i.e. roughly in line with the additional spaces provided. Again some of this increase is already attributable to the provision of PT and P&R rather than the congestion tax (Table 4-19).

Table 4-19 Number of Parked Vehicles in P&R Sites

		Change			
	Total	**To Apr-May 05**	**To Sep-Oct 05**	**To Oct-Dec 05**	**To Jan-March 05**
April - May 05	7,751	-	-	-	-
Sep - Oct 05	8,418	+9%	-	-	-
Oct - Dec 05	8,542	+10%	+1%	-	-
Jan - Mar 06	8,764	+13%	+4%	+3%	-
Apr - May 06	9,559	+23%	+14%	+12%	+9%

For public transport, the seasonal variation from March to September has earlier been given as just 1%, but there is no indication whether the variation is that low all through the year and neither how far this applies to the use of P&R. Taken at face value, the data shows that, following the implementation of the PT and P&R improvements in August 2005, there was a stark climb in the take-up of P&R services right at the beginning that then levelled out towards the end of the year, while then with the start of the congestion tax the speed of the climb increased again.

But using the seasonal variations in car use, one would expect April and May to be highest, followed by September/October, and January/March and October/December both at the lower end. In that logic the initial reaction to the tax would have been an increase of 3% of P&R take-up, while of the additional take-up of +9% in April and May probably half would be attributable to seasonal variations and half to the congestion tax.

4.3.5 Other Impacts

Air Quality

Changes in air quality have been measure before and during the trial at around 20 stations in the Greater Stockholm area, but the main findings come from calculations that have been made for two 2006 traffic scenarios, one with and one without the trial (Figure 4-15).

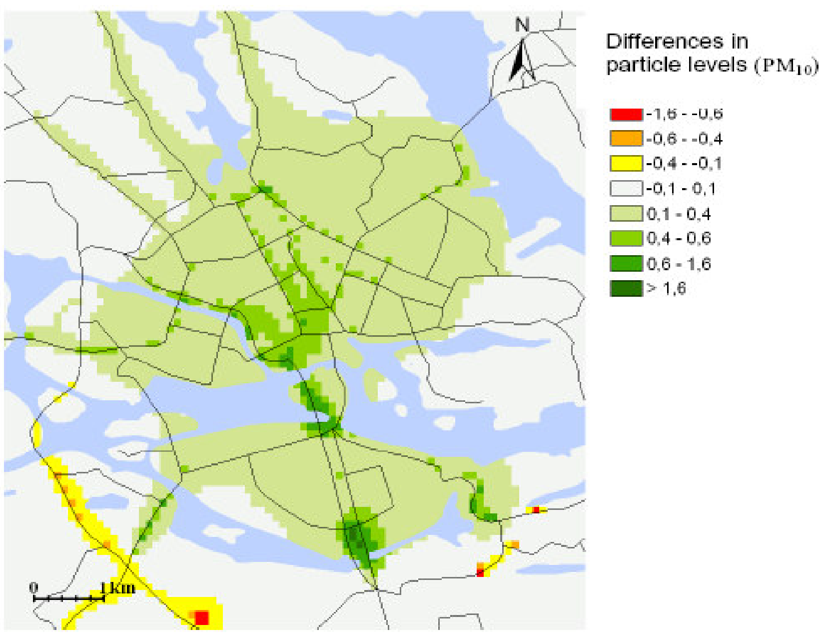
	Inner city: tons/year	per cent	City of Stockholm: tons/year	per cent	Greater Stockholm*: tons/year	per cent
Nitrogen oxides. NOx	45	-8.5%	47	-2.7%	55	-1.3%
Carbon monoxide. CO	670	-14%	710	-5.1%	770	-2.9%
Particles. PM_{10} total	21	-13%	23	-3.4%	30	- 1.5%
"road wear particles"	19	-13%	21	-3.3%	28	-1.5%
"exhaust particles"	1.8	-12%	1.8	-4.4%	2.1	-2.4%
Volatile organic compounds, VOC	110	-14%	120	-5.2%	130	-2.9%
benzene. C_6H_6	3.4	-14%	3.6	-5.3%	3.8	-3.0%
Carbon dioxide. CO_2	36,000	-13%	38,000	-5.4%	41,000	-2.7%

** defined as an area of 35 km x 35 km across central Stockholm.*

Source: Stockholm 2006c

Figure 4-15 Calculated Emission Reduction from Road Traffic

The strongest reductions are obviously found within the inner city and become smaller the larger the area under consideration is. For the inner city, Nitrogen Oxides have come down by 8% to 9%; all other indicators have come down by 12% to 14%. As a result, assuming the charge became a permanent feature and these reductions could continue, it is estimated that 25 to 30 premature deaths due to poor air quality can be prevented in the inner city per annum, and a similar number again for the wider Stockholm area. Figure 4-16 shows for the reduction in particles, how this is strongest along the main roads, but that this can also be felt in the entire inner city, while any increases are much more limited and confined.



Source: Stockholm, 2006c

Figure 4-16 Differences in Particle Emissions in Central Stockholm

Noise

Reduction in levels of noise could be achieved in the range of 1 to 3 dB(A), but this is within a limit that is not recognisable to the human ear.

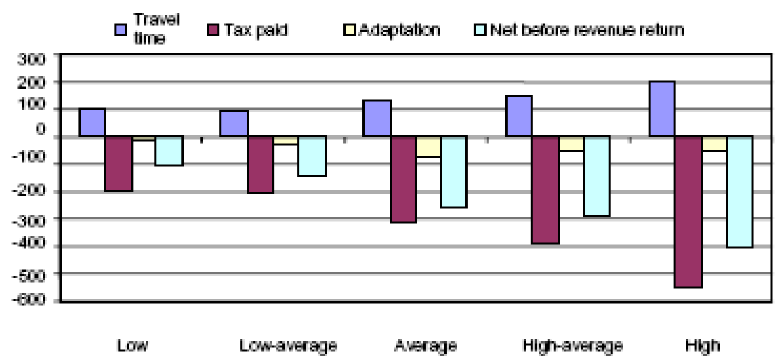
Urban Environment

A survey was conducted which tried to establish how Stockholmers felt about the urban environment as a results of the trial, but the results were not quite what had been hoped for. People felt that car access had become better, air quality had been improved and traffic speeds had increased. But, in part as a result of the higher speeds and improved car access, people also felt that pedestrian and cycle access had decreased, and, although a large majority of 80% stated before and after that it was pleasant to be in the city, in 2006 the average score given for this had been slightly lower than in 2005. Furthermore, access to public transport was also perceived as having become worse. Whether all of this is solely attributable to the trial, or whether other factors may have played a role as well, is not known.

Equity Effects

A dedicated study (Transek, 2006) had investigated the equity effects of the Stockholm trial. The concluded that “statistically, one is ... ‘hardest hit’ by the congestion tax if one is a well-to-do, gainfully employed male living in a household with two adults and children in the inner city or in Lidingö”.

Two particular figures of general interest show for households with different spending capacities the direct effects of the congestion tax (Figure 4-17) and the overall net effect depending on how the congestion tax is spent (Figure 4-18).



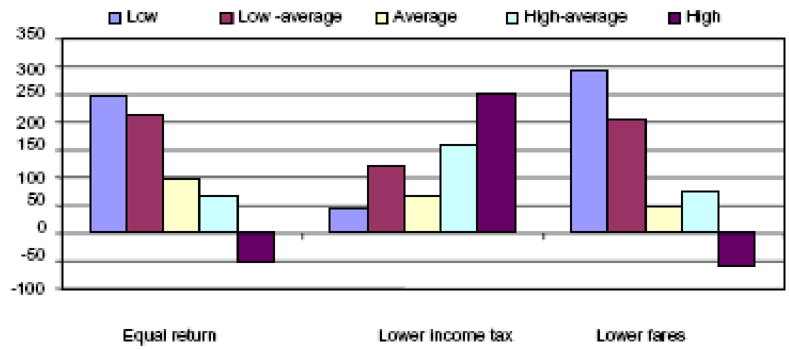
Source: Transek, 2006

Figure 4-17 Direct Effects of the Congestion Tax for Households with Different Spending Capacities

From Figure 4-17 it becomes clear that households with higher incomes pay the highest tax and also have the highest benefit from travel time reductions, but that the tax payments far outweigh the travel time advantage, resulting in the highest net loss for the households with the highest disposable income. What is also interesting to note is that the ‘adaptation cost’, defined as “the sacrifice involved in changing personal or commercial/business travel habits due to congestion tax” is highest for households on middle incomes; why this is the case is not explained though.

The report also notes: “The cost increase expressed as a *percentage* also co-varies with discretionary income: implementation of congestion taxes entailed a cost increase for journeys by car of 6% for the two groups with the lowest discretionary income, 8% for the group with average discretionary income and 9% and 11% respectively for the groups with the highest discretionary income.”

However, these are only the direct effects of the tax, and a crucial aspect is how the income generated by the tax is then spent. Figure 4-18 shows how the outcome differs for three options: an equal return to all households, a reduction in income tax and lower public transport fares.



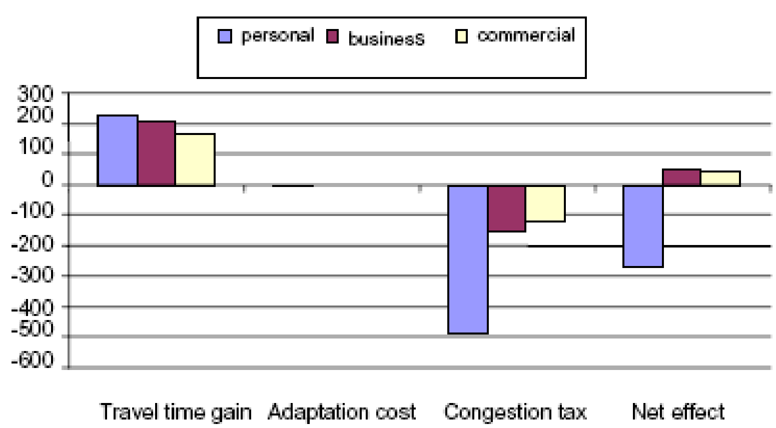
Source: Transek 2006

Figure 4-18 Net Effect for Households with Different Spending Capacities under Different Revenue Uses

The first option of 'equal return' appears rather hypothetical, but it would lead to a steady sequence from highest benefit for households with the lowest incomes to lowest benefit, respectively even a disbenefit, for those with the highest incomes. Reducing the income tax has the opposite effect, since low income earners only pay relatively little income tax in the first place; the benefit for middle income families is relatively low through the combined effects of benefiting only marginally more from the reduction of income tax while at the same only suffering slightly less than higher income groups from the congestion tax.

Similarly, with the reduction in public transport fares, mid-income households benefit relatively less than other groups, since they are the lowest public transport users, while the higher income groups are very mobile and make a large number of trips both by car and by public transport. Therefore the overall profile is similar to the one for equal return, but more accentuated at the top and bottom end.

It was mentioned earlier that middle income households have the highest adaptation costs, but Figure 4-19 shows that these costs are negligible in the wider scheme of things. Personal travel accounts for 64% of all car trips, while business trips only account for 20% and commercial travel for 16%; they all have similar levels of travel time gains, since personal trips across the cordon tend to go straight to one destination and later back out again, while business and commercial travellers are more likely to have a whole chain of trips once they are in the inner city. Since personal travel incurs by far the highest tax, the net effect for this group is a substantial loss before the use of the revenue is accounted for, although they also have the highest travel time gains. But for business and commercial travel the picture is different: although their travel time gains are slightly lower, they pay, as a group, substantially less congestion tax, so that on balance they already directly benefit from the introduction of the congestion charge before any use of revenue is taken into account.

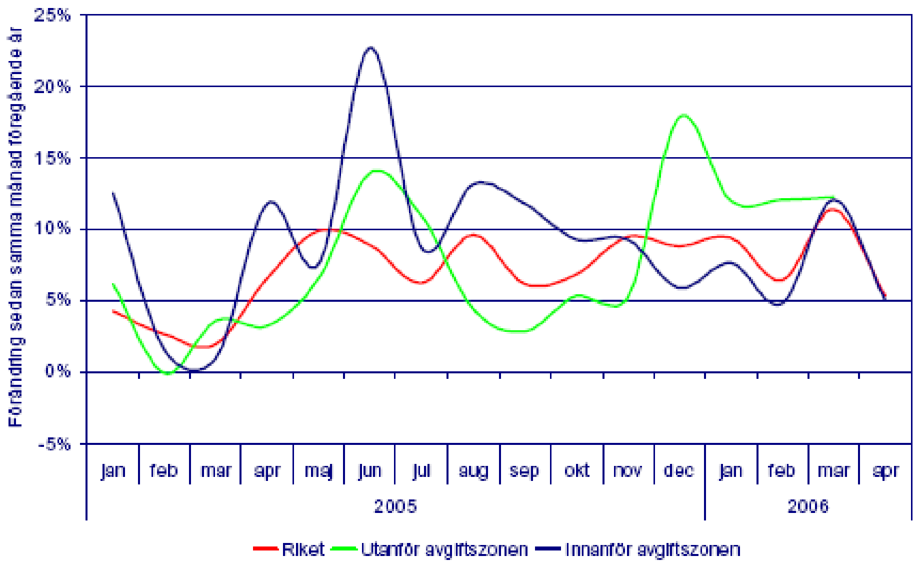


Source: Transek, 2006

Figure 4-19 Direct Effects for Personal, Business and Commercial Travel

Impacts on Economy and Trade

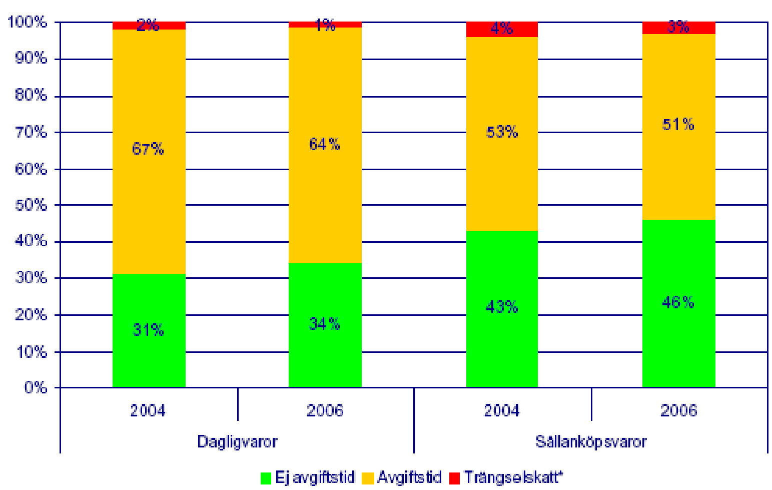
The possible impact of the congestion tax on trade had been investigated through a number of surveys. Figure 4-20 shows a typical finding. In this figure the national trend for trade in consumer durables is represented through the red line, the trend in a number of selected major retail centres outside the charging zone in green and the trend inside the charging zone in blue. It is obvious that there are not only very strong seasonal variations, but that dips and highs do not concur for much of the three lines, so that no conclusion can be drawn from the way these trends developed in early 2006.



Source: Stockholm, 2006c

Figure 4-20 Trends in Sales of Consumer Durables

Moreover, a consumer survey found that only a minute percentage, between 1% and 4%, of all shopping trips made by the inhabitants of Stockholm, would actually be affected by the congestion tax, which further confirms that if the congestion tax had any overall impact on the retail sector in the city, it would be only very minor (Figure 4-21).



LEGEND:

DAGLIGVAROR = *NON-DURABLES*
SÄLLANKÖPSVAROR = *CONSUMER DURABLES*

EJ AVGIFTSTID = *CHARGE-FREE PERIOD*
AVGIFTSTID = *CHARGE PERIOD*
TRÄNGSELSKATT = *CONGESTION TAX*

Source: Stockholm, 2006c

Figure 4-21 Congestion Tax Incurred for Shopping Trips

Similarly, no clear or major impact could be found for a range of other trade sectors.

Results of land use modelling indicated that the population in the inner city would fall by 1% over 25 to 30 years and the number of workplaces in areas surrounding the city by just under 3%, while more workplaces would be created within the city. However, given the long time horizon and the small level of changes involved, this all sounds highly speculative and is not conducive to any major conclusions.

Cost-Benefit Analysis

The cost-benefit analysis carried out as part of the evaluation included the factors shown in Table 4-20.

Table 4-20 Costs and Benefits, excluding Operating and Investment Costs

	Congestion tax	PT improvements	Total
	€ million / a	€ million / a	€ million / a
Shorter journey times	52.3	15.7	68.0
More predictable journey times	7.8	0	7.8
Change in mode of travel	-1.3	2.4	1.1
Congestion tax payments	-76.3	0	-76.3
Total: road user effects	**-17.5**	**18.1**	**0.6**
Reduced climate gas emissions	6.4	0	6.4
Health and other environmental benefits	2.2	0	2.2
Improved traffic safety	12.5	0	12.5
Total: other effects	**21.1**	**0**	**21.1**
Congestion tax revenue	76.3	0	76.3
Public transport revenue	18.4	0	18.4
Fuel tax revenue	-5.3	0	-5.3
Wear and tear on infrastructure	0.1	0	0.1
Maintaining public transport standards	-6.4	0	-6.4
Total public sector income and expenses	**83.1**	**0**	**83.1**
Total social cost-benefit surplus	**86.7**	**18.1**	**104.8**

Note: Calculated as SEK 10 = € 1
Source: Stockholm 2006c

The two largest figures in there by far are the congestion tax itself, which costs the car drivers € 76.3 million per annum, but counts in positive terms as public sector revenue, and the savings of € 52.3 million annually from the reduction in car and bus travel times caused by the congestion tax. To be added to that are the time savings which are due to the improvements made to the public transport system in autumn 2005, the total benefits from time savings are € 68 million.

Given the total costs of the trial, which were in the range of € 180 million, plus taking into account € 70 million of opportunity costs, which both stand against the benefits shown in Table 4-20, the part of the trial directly related to the congestion tax only produced a very substantial cost-benefit deficit to society. However, since most of the costs were coming from the initial set-up, which depreciates over the years, the estimate was that the permanent system would produce a net benefit of € 76 million per annum for the direct effects of the congestion tax, and € 42 million per annum if the costs and benefits of the PT improvements are taken into account as well.

Some of the above figures were revisited in later publications, and some were revised upwards, others downwards, but in every version there was a substantial total welfare gain.

However, as already for London, Prud'homme, this time together with Kopp (Prud'homme et al, 2006 and then in a revised version in 2007), derided these figures and claimed that, based on the congestion levels at the time of the trial, "the Stockholm experiment does not appear economically justified, and can be considered as a waste of scarce resources."

Using the latest figures from Prud'homme et al (2007) and Eliasson (2008), a comparison of their estimates looks as per Table 4-21.

The comparison is not straightforward, since there are some items that only appear in one column and others that treated entirely differently by the different authors. For instance, the table contains four different figures for Marginal Costs of Public Funds (MCPF), three separate ones by Prud'homme and a single one by Eliassson, which in his case covers the sum of gross charge revenues, operations costs, increased public transit fare revenues, increased transit operating costs and decreased fuel tax revenues.

Table 4-21 Two Cost and Benefit Estimates

	Loss/gain [SEK million]	
	Prud'homme	**Eliasson**
Consumer surplus		
Shorter and more reliable travel times	174	614
Loss for evicted car drivers, gain for new car drivers	-61	-74
Paid congestion charges	---	(-804)*
Increased public transport crowding	-168	-15
Welfare gain for new bus users	*49*	---
Consumer surplus excl. PT expansion	**-55**	**525**
Consumer surplus, total	**-6**	**525**
Externalities		
Reduced greenhouse gas emissions	14	64
Health and environmental effects	67	22
Increased traffic safety	16	125
Externalities, total	**97**	**211**
Government costs, revenues and tax effects		
Toll implementation costs / Investment costs **	-512	-220***
Operational costs for charging system (incl. reinvestment and maintenance)	---	-220
Paid congestion charges	---	(804)
Increased public transport capacity	*-559*	*-64*
Increased public transit revenues	102	136
Decreased revenues from fuel taxes	---	-53
Marginal costs on fuel taxes foregone	-21	---
Marginal costs on increased PT subsidies	-31	---
Marginal cost of toll revenues	234	---
Marginal cost of public funds	---	182
Correction for indirect taxes	---	-65
Government costs, revenues and tax effects excl PT expansion	**-228**	**-240**
Government costs, revenues and tax effects, total	**-787**	**-304**
Net social benefit, excl. costs and gains from PT	**-186**	**496**
Net social benefit, incl. costs and gains from PT	**-696**	**432**

Notes:

Items listed in italics relate to the costs and gains from the increased public transport supply.

* *Since the revenue is shown as a surplus for the consumer and a deficit for the public funds by Eliasson anyhow, but not considered on either side by Prud'homme, it is not used in the totals here to facilitate comparisons between the two authors' results.*

** *Prud'homme only lists "toll implementation costs" as one item, while Eliasson distinguishes between investment and operational costs.*

*** *This figure is calculated by this author on the basis of the total direct and opportunity costs for the trial (congestion charge only) of € 2,529 million (Stockholm 2006c) and a depreciation period of 15 years, and includes an MCPF of 1.3.*

Sources: Prud'homme et al (2007) and Eliasson (2008) and author's own calculation based on Stockholm (2006c)

Table 4-21 shows clearly that there is hardly one figure where Prud'homme and Eliasson agree. The most important differences directly related to the congestion charge and not to the additional investment in public transport are the following:

- First of all, as already for London, Prud'homme uses again an oversimplified model for calculating the congestion. Prud'homme comments on this: "The large discrepancies [between the two calculations for time gains] … come from differences in approaches. Our approach uses a relatively standard economic methodology, that mimics the behavior of car users by means of demand and supply curves. Transek's approach uses transport-engineering techniques to model, in a link-by-link fashion, flows and speeds in the entire county in 2005 and 2006. This makes it possible to capture the rich diversity of reality, including the role of traffic lights (something our simplified economic approach does not do). Physical changes are afterwards translated into economic gains and losses. In short, ours is an economic approach producing speeds and flows as a by-product, whereas Transek's is an engineering approach producing economic gains and losses as a by-product. In principle, both approaches are legitimate." (Prud'homme et al, 2007). The author of this case study disagrees with the last sentence in the above statement: if you want to know the economic value of a time gain, then you must first be sure that the physical time gains you calculate are correct; and since even Prud'homme admits that Eliasson's approach does this better, Eliasson's resulting figure appears much more credible.

- The large difference between the two figures for the cost of increased PT crowding is the second important one. Eliasson does not really explain how he calculates his figures, while Prud'homme shows how he arrives at figures between SEK 162 and 250 million using three different approaches, which would give some credence to the figure of SEK 168 million in the above table.

  One issue, where Prud'homme certainly overestimates the value of crowding, is that he uses the average value of time of SEK 98 per hour, while on public transport there are in all likelihood a far below average number of business travellers, for whom he uses a value of time of SEK 282, and far above average private travellers, who, in his own assumptions, only have a value of time of SEK 52. Assuming the share of business travellers on public transport were 5% (still a conservative estimate) instead of the overall average of 20%, the average value of time for PT users would be SEK 63.5, which would already bring his total down from SEK 168 million to SEK 109 million, although this is still more than 7 times Eliasson's figure.

  But, furthermore, in Stockholm (2006c) there is the following passage: "During spring 2006 the proportion of standing passengers on SL services totalled an unchanged 5% compared with spring 2005. The underground had an increase of 2 percentage points, rising to 9%, while suburban rail services also rose by 2 percentage points, to 4%. Inner city bus services increased by 1 percentage point to 8% and the proportion of standing passengers on commuter trains had decreased by one percentage point, to 2%." Prud'homme has used the figures from the second and third sentence in the one of his three calculations, which at first glance looks the least speculative one, and weights them with the number of passengers involved to derive an average increase in crowding of 1.3%. But the statements in this passage contradict each other: according to the first one, there should be no need to include any costs for increased overcrowding at all, while the figures in the second sentence, when weighted with the number of travellers involved, obviously do not add up to anything like a zero increase. Since there is now way of knowing how much rounding was involved in any of the percentages in this quote, they are a very unreliable basis for any calculation of social costs.

  A more reliable figure can be derived from Figure 4-22 below, which comes from the official report of SL, Stockholm's public transport operator (Casemyr, SL 2006). If the total of an extra 150,000 passenger standing minutes per day is multiplied with 200 working days and SEK 63.5 per hour, then the resulting total is SEK 31.75 million, now only twice Eliasson's figure. However, a closer look at Figure 4-22 shows that 95% of the 150,000 minutes come from just two Underground lines, and the SL report comments on that: "The increase between spring 2005 and spring 2006 has primarily taken place on the Red line but also on the Blue. The reason … is that many departures had to be cancelled and that many trains had to run with fewer carriages than normal." While the impact of these cancellations cannot be quantified here, it becomes clear that even the above figure of additional crowding costs of SEK 31.75 million is by far not all a result of the congestion charge, and Eliasson's figure of SEK 15 million appears in this light now to be even a conservative estimate.

	Spring 2005 StandMin	Spring 2006 StandMin	Difference StandMin	Difference %	Share of increase
New direct buses		1 800	1 800	100%	1%
Other bus routes to the inner city	46 800	48 500	1 700	4%	1%
Inner city trunk routes	59 000	58 400	-600	-1%	0%
Inner city local routes	33 400	37 600	4 200	13%	3%
Commuter trains	69 000	55 000	-14 000	-20%	-9%
Underground, green line	253 000	265 100	12 100	5%	8%
Underground, red line	226 400	335 500	109 100	48%	73%
Underground, blue line	35 800	68 200	32 400	91%	22%
Local trains	4 700	8 000	3 300	70%	2%
Total, inner city traffic	**728 100**	**878 100**	**150 000**	**21%**	**100%**

Table 7.3. Increase of the number of standing minutes per 24-hour period between spring of 2005 and spring of 2006 and the distribution of the summed up increase by means of transport/line/route group.

Source: Casemyr, SL 2006

Figure 4-22 Passenger Standing Minutes

- Concerning externalities, the costs resulting from emissions are relatively small, and although they differ in detail between the two estimates, they total in both cases to SEK 81 respectively 86 million. More significant is the estimate of accident costs, but this is difficult to comment on, because the prediction of accident numbers, in particular for severe accidents, is always problematic. This difference is therefore here only noted.
- The next important difference is that concerning the investment and running cost of the system. Eliasson shows the operating costs, in accordance with official estimates by the National Road Administration at SEK 220 million, and it needs to be noted that this included costs of replacement of components. Therefore, the depreciation period for the initial investment needs to consider the expected lifetime of the overall system, and not the average lifetime of its components. Given the Norwegian experience, where systems have been running for more than 15 years and are still expected to run on, a depreciation period of 15 years, as assumed in Table 4-21, seems a reasonably conservative estimate, and therefore also the total assumed investment and operating costs of SEK 440 million per annum.

  In contrast, Prud'homme assumes a depreciation period of only 8 years, which according to his research, is roughly in line with the period used by other toll operators. This is the main reason for his much higher estimate of the annual "implementation costs" of SEK 512 million.
- Finally, the individual figures concerning taxes and marginal costs for various items also very widely between the two authors, but they add up to totals in a vaguely similar range (except for the PT investment, which will be discussed separately below) with SEK 284 million for Prud'homme and SEK 200 million for Eliasson. Although these figures certainly merit further investigation and discussion, it is beyond the scope of this case study to research their origins and background in any further depth. In this instance, Prud'homme's total figures are anyhow even more positive for the charging scheme than Eliasson's, and therefore contain a potential bias against - rather than for - his overall conclusion that the system is an economic failure.

Overall, looking at the three subtotals for consumer surplus, externalities and government costs for the gains and losses directly related to charging scheme, the latter of the three is very similar for both authors, the difference in the second is more substantial, but the really divisive factor is undoubtedly the size of the consumer surplus. Since within this category, Prud'homme's figures for the two main elements, namely the travel times and PT crowding, have been rejected above, the author of this case study comes to the conclusion that there is indeed a clear and substantial net social benefit from the Stockholm congestion tax.

The issue that remains to be discussed is how to account for the costs for, and gains from, the increased public transport capacity that was implemented in autumn 2005. It is undisputed that this was a large loss-making operation, and that the costs, by any way or definition, far outstripped the benefits. This is shown by Prud'homme as an explicit welfare gain for new bus users and a heavy cost on the government side. In contrast, Eliasson, in his cost-benefit analysis, only accounts for the extension of train services and not for the around 200 extra buses that were laid on from autumn 2005 onwards. There are certainly arguments for both views:

- Eliasson argues that, since out of the 14,000 new bus users only 4% were former car users, there was no noticeable impact of the congestion charge on the use of the new buses and, the other way round, neither was there any noticeable impact of the availability of these buses on the behaviour of car drivers when the congestion tax came in; therefore the assessment of the two should remain separate.
- However, the increase in bus provision was explicitly announced as 'the carrot' that should sweeten 'the stick' of the congestion tax and enable drivers to abandon their cars. That they were, in the end, introduced at different times was not in the master plan for the congestion tax, but due to delays in the system implementation. Hence there is an argument for saying the two were parts of the same parcel and have to be considered together.

The latter view would be the one that should probably be taken by an economist who wants to establish what actually happened in Stockholm at the time. The former one, on the other side, is certainly the one that is more relevant for anybody looking for the potential of a congestion charge in future applications.

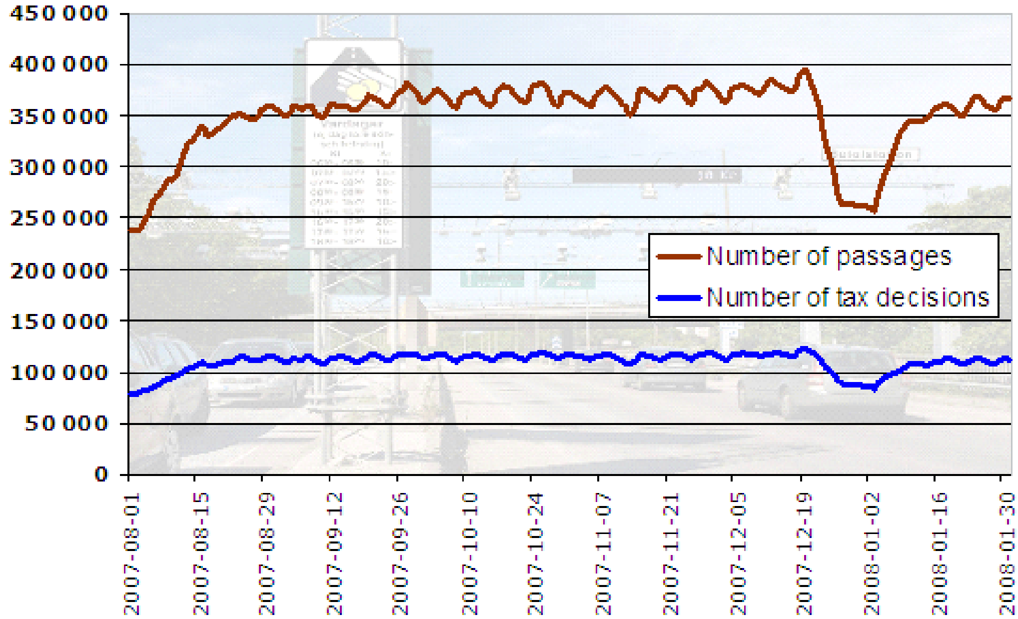
However, there is one other reason for not including the entire investment package of 2005 in any socio-economic analysis: SL realised following their own assessment of the situation that the new services were totally uneconomical and, as a result, cancelled most of them, keeping only some of the most frequented ones, and these (according to Eliasson in a non-published note) "even at a smaller cost, since there was time to achieve better bids from the subcontractors".

Unfortunately, there are no figures in the public domain that would allow quantifying the current costs and gains from the remaining new bus services; but, obviously, even if they were included in the overall cost-benefit analysis, they would not reduce the overall benefits by anything near the SEK 510 million (49-559) shown by Prud'homme.

4.4 RESULTS FROM FULL CURRENT SCHEME

On 1 August 2007 the Stockholm congestion has been introduced as a permanent feature. Since then the Swedish Road Administration has been updating some key statistics of the scheme on a monthly basis.

Figure 4-23 plots the number of vehicle passages across the cordon as well as the tax decisions (i.e. the numbers of vehicles that had to pay the tax on that day) over time from the start of the scheme to the end of January 2008. On 1 August the total number of passages was only under 250,000, but climbed then very quickly and steadily over the next four weeks; however, most of this increase was certainly not due to more drivers accepting the charge and deciding to carry out their usual trip in spite of this, but simply the effect of more and more holiday makers coming back home and resuming their normal daily life. Similarly, the big dip at the end of 2007 is simply an effect of the Christmas holidays and not of the congestion charge.



Source: http://www.vv.se/templates/page3wide____22611.aspx

Figure 4-23 Number of Passages and Tax Decisions per Day, 1 August 2007 to 31 January 2008

Between the end of September and mid December the weekly pattern and the average level per week had been very steady and had returned for most of January 2008, after the end of the Christmas break, to a level close to October 2007. If this is compared to Figure 4-10, then it becomes clear that the cordon crossings since the introduction of the tax no longer follow the expected seasonal variation entirely, more specifically: in Figure 4-10 traffic levels are higher in September than for any of the following months until April, while in 2007, they were below the average of the following months. This looks as if during September still more drivers refrained from their usual trips as a result of the tax, but then, two months after its introduction, many of them decided to return to their usual travel pattern.

Table 4-22 summarises the key statistics for each month of the permanent scheme next to the monthly average of the trial.

Table 4-22 Key Statistics of the Charging Scheme

	Trial		Permanent Scheme					
	Total	Average per month	Aug	Sep	Oct	Nov	Dec	Jan
Number of passages in and out [million]	46.5	8.0	7.3	7.3	8.5	7.8	6.2	7.5
Number of days with congestion tax	-	-	23	20	23	21	17	22
Passages per “congestion tax day” [‘000]	-	-	316	363	371	371	366	341
Number of tax decisions [million]	14.5	2.4	2.3	2.3	2.6	2.4	1.9	2.3
Percentage of non-taxed passages	-	30%	24%	24%	24%	24%	24%	24%
Average tax [€]	-	2.80	2.75	2.82	2.84	2.84	2.81	2.83
Total Revenue [€ million]	39.9	6.7	6.4	6.4	7.5	6.8	5.5	6.6

Sources: Stockholm, 2006, and http://www.vv.se/templates/page3wide____22611.aspx

The first thing that needs to be explained is the obvious difference in the percentage of non-taxed passages. There are two clear principal reasons for this:

- During the trial taxis were exempt and accounted for 8% of all passages, while they now incur the full charge.

- During the trial the percentage of 'green' cars ('green' as per definition by the national road administration's vehicle registry) was only 3%, while in August and September 2007 their share had risen to 8%, to 9% in the following months and to 10% in January 2008.

It would be clearly very interesting to find out how far the increase in the share of green cars was a result of the congestion tax having induced more people to buy new green vehicles in the run-up to the permanent introduction of the charge, or how far this is simply a result of county residents trading in their old cars against green cars from other parts of Sweden. If it is the latter, then it is still positive for the air quality in the Capital, but if it were also the former to a substantial extent, then this would be a highly desirable outcome of the congestion tax from a wider perspective.

When comparing Table 4-22 and Figure 4-23, it looks at first glance as if the numbers of passages in both do not fit together, in particular, August shows no fewer passages than September in the table, and October shows no particular spike in the figure. However, the number of days where the charge applies differs significantly from month to month, with 23 'tax days' in August and October and only 17 in December. Once the number of passages is calculated per taxable day, the picture changes, and the number of passages for August is indeed by far the lowest per taxable day, while October is no higher than November, and both are only little higher than September or December. The lower 'per day' figure for January can be explained by the fact that during the first days of the month, there were several days that were chargeable, but where commuters would have still been on a post-Christmas break.

The average tax that each driver who crosses the cordon at least incurs has also been very stable over the six months of the permanent scheme and generally slightly above the one of the trial, apart from August 2007 where it appears likely that the number was slightly lower, because

- more of the traffic was caused by visitors, who would only go into and out of the inner city once per day,
- there were fewer business and commercial travellers, who might be forced to cross the cordon more often, and
- fewer commuters were tied to the peak charge periods.

Furthermore, it seems plausible that in the very first phase of the charge being introduced more people might have made a conscious effort to either combine trip purposes and avoid crossing the cordon more than once, or to rearrange their departure times to avoid peak charges, while later relaxing in their effort to avoid peak charges.

The total revenue raised over the last six months is, in average, € 6.5 million per month, which is slightly lower than during the trial period, but when allowing for seasonal variations is again very much in line from what could have been expected after the trial.

Overall, the Stockholm congestion tax trial has to be regarded as a great success, since it

- very accurately predicted the effects that would eventually be caused by the permanent scheme as well as
- convincing the residents of the Stockholm municipality of the merits of the scheme, so that they changed in their attitude from their initial reluctance to a majority vote in favour of the scheme at the subsequent referendum.

4.5 CONCLUSIONS

During the six-months trial of the Stockholm congestion tax, which is, with its charging level varying in fine time slices and its various exemptions, the most differentiated urban scheme anywhere in Europe, traffic flows at the entries to the inner city during the charging hours were reduced by up to 35% in one location, and the average reduction of traffic crossing all cordons was 22%. Overall, and for all modes, it is estimated that 110,000 trips per day 'disappear', i.e. are diverted from the city centre or no longer take place at all. For the 24-hour day this still amounted to an impressive reduction of 19%. The effect away from the cordon was less strong with traffic reductions of around 10% inside the cordon and 5% outside, again for the charging hours. Among the chargeable vehicles, the strongest reduction in cordon crossings was found for cars, a smaller one for light goods vehicles and the smallest for lorries. It is possible, however, that not all of these reductions are due to the congestion charge, since one study found a general trend of decrease in travel between 2004 and 2006. Traffic increases on orbital roads from drivers trying to avoid crossing the cordon were, as in London, very limited.

The traffic reduction also reduced congestion significantly. During the morning peak, for traffic travelling into the city, congestion was reduced by around 30% and the respective travel times by around 20%. For outbound traffic, congestion was much smaller in the first place, but the tax could reduce this further by 40% and the travel times by around 20%, which means in effect that traffic was flowing quite freely.

All of these results are entirely in the logic of the scheme and not only fully meet, but even exceed the aims and objectives of the tax. But it is when these global figures are broken down further, that some of the results become surprising and in some cases even contradictory.

First of all, with the congestion tax, a reduction in traffic through all periods of the day, including those outside the charging period, is shown by some of the data, while in other figures it appears as if there may even be a very small increase during the early and mid evening. A small decrease could be certainly explained through round-trips in which one leg happens within and the other outside the charging period, so that, though not the single one-way trip, the overall journey is affected by the tax, while an increase could be due to vehicles shifting their trips into non-charging hours.

Within the charging period, the lowest traffic reductions are found again in the morning during the main peak and the post-peak shoulder. This finding is similar to the one in London, and the general assumption for explaining this phenomenon is that commuters as well as business travellers, who may be on the way to their first appointment during this time, have the lowest elasticities.

However, both in the morning and in the afternoon, the traffic reduction is larger in the pre-peak shoulder with the € 1.50 charge than in the main peak with the € 2.00 charge and, furthermore, the biggest reductions overall occur during the first charging period in the morning and the last in the afternoon, when the charge is only € 1.00. This is very difficult to explain since, at least in the early morning between 6:30 to 7:00, it is surely also mainly commuters who are travelling then. There are two ways of interpreting these differences in travel behaviour:

- Travellers on lower incomes people will have a lower value of time, and the congestion tax therefore increases the overall generalised cost for any trip across the cordon by a higher percentage than for people on high incomes. Therefore, even if the same elasticity is assumed for all commuters, then those on lower will react more strongly.
- However, although the above is likely to play at least some role, it is also possible that commuters on different incomes have different elasticities.

Neither the Swedish reports nor any of the work carried out within the DIFFERENT project can shed any light on this, and this is therefore an area that deserves further research and investigations.

But even more startling than the relationship between the level of charge and the traffic reduction during the different charging hours, are the results from the study based on travel diaries. According to this study, the biggest reductions in car trips crossing the cordon are found for business and "other" travel, while the reduction in leisure trips is only 1% higher than that for trips to work. For all trips for all modes it looks from this study as if, after seasonal adjustments, trips to work as well as leisure trips across the cordon even go up by 2%, while shopping/service trips go down by 8% and, most astonishingly, business trips also by 7%.

From this study it then looks furthermore as if business travel across the cordon has not only decreased for cars, but also by 10% for public transport and, similarly, trips for shopping and leisure made by public transport are also down by 7%.

All of this data raises far more questions than it answers and, again, there is a real need for more research into the background to these very puzzling findings.

Concerning the more global findings for the overall scheme: the most credible cost-benefit analysis shows that a very substantial net social benefit, in the range of € 40 to 50 million per year, can be expected for the permanent scheme, as long as only the costs and gains directly related to the congestion charge are concerned, and leaving the investment in additional buses aside. But even allowing for additional costs for those now bus services that were continuing into the permanent scheme, there should still be a substantial over net social benefit for the overall package.

The figures available so far from the permanent scheme show that the results from the trial, as far as traffic reductions and other headline figures are concerned, were very close indeed to those that so far emerged from the permanent scheme. Therefore the trial has to be considered as resounding success both in terms of predicting the effect of the congestion tax as well as in terms of persuading the Stockholm residents to vote for it in the public referendum.

5 MILAN

5.1 HISTORY AND MAIN CHARACTERISTICS OF THE CHARGING SCHEME

5.1.1 Background

In Milan, a pollution charge called *Ecopass* has been introduced on 2 January 2008 for vehicles entering the city centre. Some preliminary results were available at the time of writing this report.

Milan, the capital of Lombardia region, is situated in the north west of Italy at the core of a highly urbanised area. The population of Milan municipality is around 1.3 million inhabitants in a surface of 182 square kilometres, with a density of more than 7,000 inhabitants/km^2. During the last decades, Milan has experienced a radical process of de-industrialisation and a constant loss of population, which moved to the surrounding municipalities.

Some data describe the mobility of the city:

- Every day (from 7:00 to 21:00) almost 650,000 cars enter the city;
- About 160,000 car trips have as destination the inner part of the city, called "Cerchia dei bastioni" (see Figure 1), of which around 20,000 enter in the morning peak hour;
- On the whole, 47% of the trips have origins outside Milan and a destination in the city;
- The modal split between private vehicles and public transport shows that 51% of trips within the city occur by public transport; the public transport percentage increases up to 70% for trips with the "Cerchia dei Bastioni" (Figure 5-1) as destination;
- In the year 2000, with its 500,000 cars for 1,300,000 citizens, Milan was the Italian city with the highest number of vehicles per inhabitant (0.4 per person, 1.17 per family).

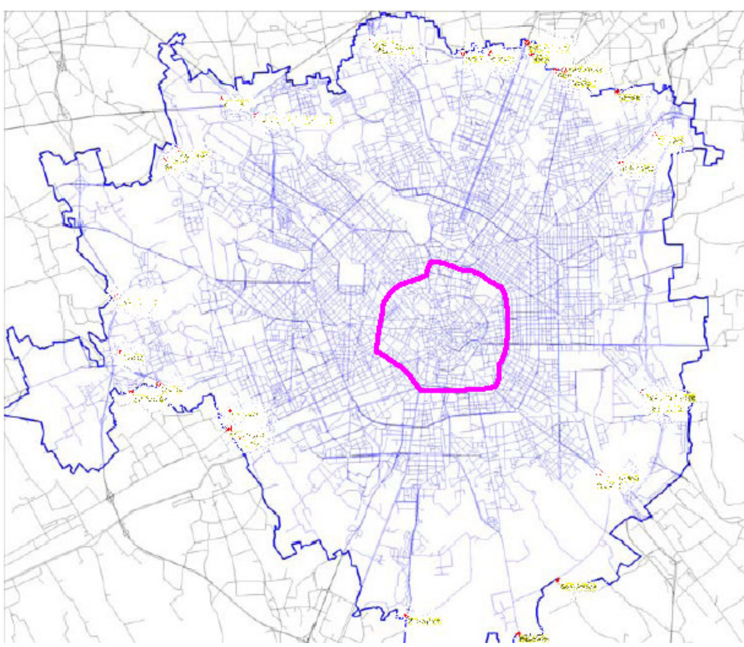


Figure 5-1 The Municipality Borders and the "Cerchia dei Bastioni"

Due to its geographical position and the very high number of motorised vehicles, Milan is one of the Italian municipalities at highest risk for human health as a consequence of road traffic pollution, which is responsible for 72% of total PM emissions in the urban area. During the last years, the daily average PM_{10} emission levels have been well above the threshold of 40 micrograms per cubic metre set by European Council Directive 1999/30/EC.

5.1.2 Aim of the Scheme

To reduce the level of pollution and intervene to face its causes, in the year 2002, there had been a first attempt to discuss the implementation of a road pricing scheme in the city ("Study for the introduction of Road Pricing in Milan ", carried out by the Agenzia per la mobilità e l'ambiente, i.e. the Municipality Agency for Mobility and Environment), but the issue was quickly cancelled by the agenda of the Milan local authorities.

Since the beginning of the debate, the objective of the future application of a road pricing scheme did not aim at reducing congestion but rather targeted at the most polluting vehicles ("the pollution charge"). The proposal entered officially the political arena in the year 2006. Since then, it became one of the controversial issues of the local elections, which were held in April of the same year. Although the scheme was one of the key points of the Action Plan of the newly elected Mayor, the preparatory steps for its implementation were delayed many times due to different views within the political majority in the Milan government. Indeed, the scheme was discussed and redesigned many times. No detailed feasibility study was made available for the public during such a preparatory period.

Ecopass came finally into force the 2nd of January 2008 and was designed with the aim to restrict access to the central "Cerchia dei Bastioni" area of Milan by charging the most pollutant vehicles. The *Ecopass* declared objectives are:

- To make the air cleaner by reducing PM emissions in the "Cerchia dei Bastioni" area by 30%, with a positive fallout on the surrounding area of the city as well;
- To relieve congestion by reducing the number of incoming cars by 10% and thereby speeding up public transport in the area;
- To boost public transport through the re-investment of the pollution charge revenues.

5.1.3 Description of the Scheme and Area Covered

The *Ecopass* scheme operates from 7:30 to 19:30 from Monday to Friday. One ticket allows for as many entries as needed during a single day.

Figure 5-2 The Milan *Ecopass* Tickets

The system is based on the ANPR (Automatic Number Plate Recognition) technology. Electronic cameras have been installed at each gate. They read plates' numbers and send them to a central database, where they are compared with a list of allowed plates. For each plate the corresponding pollution level is recorded and the charge is calculated.

Note: Red Dots are reserved to Public Transport

Figure 5-3 Entrance Points to the Milan *Ecopass* Area

The driver has to pay the charge within 24 hours. Charges can be paid in advance by buying tickets for single or multiple entrances. Payments can be done either by cash or through the internet.

The accessibility has been designed to allow the entrance through 43 streets as shown in Figure 5-3.

5.1.4 Level of Charges

Ecopass levels depend on the vehicle's Euro category and petrol/diesel engine. Euro categories are defined in EEC/EU directives and are grouped in pollution classes as shown in Table 5-1.

It is relevant to mention that pre-Euro (Euro 0) and Euro 1 diesel vehicles, pre-Euro (Euro 0) mopeds, scooters and two-stroke motorbikes are anyway barred from entering or circulating within the territory of the municipality of Milan, from 15/10/2007 to 15/4/2008, from 7:30 to 19.30 from Monday to Friday (except Public Holidays), in compliance with regional bylaw no.5291 dated 2/8/2007. There is no *Ecopass* charge for mopeds, scooters and motorbikes; vehicles carrying disabled passengers and/or bearing a disabled passenger badge.

Table 5-1 Pollution Classes in Milan

Pollution class	Vehicle EURO category	*Ecopass* (€/day)
I	gpl - methane - electric – hybrid	Free access
II	Euro 3, 4 or more recent petrol cars and goods vehicles Euro 4 diesel cars and goods vehicles without particulate filter (exempt for 3 months as from 2 JANUARY 2008) Euro 4 or more recent diesel cars and goods vehicles with approved particulate filter	Free access
III	Euro 1, 2 petrol cars and goods vehicles	€ 2
IV	pre-Euro (Euro 0)* petrol cars and goods vehicles Euro 1*, 2 and 3 diesel cars Euro 3 diesel goods vehicles Euro 4 and 5 diesel buses	€ 5
V	pre-Euro (Euro 0)* diesel cars pre-Euro (Euro 0)*, Euro 1* and 2 diesel goods vehicles pre-Euro (Euro 0)*, Euro 1*, 2 and 3 diesel buses mopeds, scooters and motorbikes*	€ 10

Table 5-2 illustrates the cost of the *Ecopass* Area for residents and the cost of the multiple entry daily *Ecopass* for passengers vehicles, which allows the access to the *Ecopass* area for 50 days – not necessarily consecutive – with a 50% reduction and for a further 50 days with a 40% reduction.

Table 5-2 Multiple Entry Price Reductions

Pollution class	*Ecopass* Area Residents (€/year)	Multiple Entry Daily Reduction (up to 100 days)
I	Free access	Free access
II	Free access	Free access
III	€ 50	€ 50 (first 50 days) - € 60 (second 50 days)
IV	€ 125	€ 125 (first 50 days) - € 150 (second 50 days)
V	€ 250	€ 250 (first 50 days) - € 300 (second 50 days)

5.1.5 Implementation Costs and use of Revenues

According to statements by local politicians interviewed in local newspapers, the implementation costs are somewhere between € 27 and 33 million (partly start up costs and partly operating costs).

Expected revenues should be between € 29 and 42 millions per year. *Ecopass* revenues will be reinvested in measures for public transport improvement and sustainable mobility.

5.2 PRELIMINARY RESULTS AFTER 3 MONTHS

5.2.1 Monitoring Activity

Since the beginning of the application of the measure, the Mobility Agency of the Municipality of Milan has published monthly monitoring reports, where data are compared with a “theoretical” average month based on real data of October and November 2007 (which is hereinafter called the “reference month 2007”):

- The first report has been carried out in January, but due to the fact that January is usually a month with less traffic than average, the collected data are slightly biased;

- At the beginning of March 2008 the Municipality has released a second report where data from February 2008 are compared with the reference period as described above;
- At the beginning of April a third report has been released.

The main results collected at this preliminary stage are described in the following.

5.2.2 Private Traffic

At the end of the first two months of the *Ecopass* activity, a decrease of **traffic volume** has been recorded, both for cars and delivery vans. The period considered is the daily validity time (from 7:30 to 19:30) compared with the same period of reference in 2007. Main results are:

- In the month of January, the trips directed in the urban areas decreased by 22.7% within the *Ecopass* area and of 12.5% outside the area;
- In the month of February, the trips directed in the urban areas decreased by 14% within the *Ecopass* area and of 8% outside.

In the following month of March, the decrease within the *Ecopass* area settled around 17%. The fluctuations occurred have to be linked to seasonal trends.

However, as shown by these first results, the *Ecopass* effect became lower in February and March, as a proof of a predictable over-effectiveness of the measure in the introductory period.

It is interesting to note that more than 60% of vehicles entering the *Ecopass* area can be considered non-usual users (having entered the area not more than 2 times within the 21 weekdays of operation). This proportion has remained stable in all the following reports.

Looking at the daily traffic development, it can be noticed that traffic volumes did not change significantly in the morning before the *Ecopass* validity period (7:30), while after the end (19:30) traffic reaches a clear peak, which is, however, lower than the evening peak of the reference period.

Concerning the **composition of the vehicle fleet entering the *Ecopass* area**, an increase of lower charged vehicles and a decrease of higher charged vehicles has been noticed and becomes more consolidated in the second month of the measure:

- In the month of January, the shares of passenger cars with emission class 3 went down from 15% to 9%, class 4 from 22% to 11% and class 5, for which the charge is € 10 per day, from 0.4% to 0%. Concerning Light Duty Vehicles the share of class 4 decreased from 49% to 39% and of class 5 from 22% to 15%. Detailed data on variations is shown Table 5-3.
- In February, after two months of application, the effect on the vehicle fleet composition seem to be more consolidated in favour of vehicles belonging to the first two classes not being charged. The decline is very marked for passenger cars, for which the share of vehicles belonging to the charged classes is almost halved (48.6%); also the reduction for commercial vehicles is very high (-21.9%). Vehicles belonging to the first two free classes increase both as a proportional share and in absolute terms, especially in the commercial segment, for which this trend is observable also in Class 3, subject to a small tariff. Overall, the phenomenon has to be put in relation with the capacity of private companies to use not charged vehicles to travel in the city centre.

Table 5-3 Passengers Cars and LDVs Entering the City Centre Before and After the *Ecopass*

Cars	Reference month 2007	January 2008	Delta	LDV	Reference month 2007	January 2008	Delta
Class 1	*1.8%*	*2.6%*	*44%*	*Class 1*	*2.0%*	*3.7%*	*85%*
Class 2	*60.8%*	*77.5%*	*27%*	*Class 2*	*25.2%*	*38.0%*	*51%*
Class 3	14.9%	8.6%	-42%	Class 3	2.7%	4.8%	78%
Class 4	22.1%	11.3%	-49%	Class 4	48.6%	38.5%	-21%
Class 5	0.4%	0.0%	-100%	Class 5	21.5%	15.0%	-30%
Total charged vehicle classes	**37.4%**	**19.9%**	**-47%**		**72.8%**	**58.3%**	**-20%**
Cars	**Reference month 2007**	**February 2008**	**Delta**	**LDV**	**Reference month 2007**	**January 2008**	**Delta**
Class 1	*1.3%*	*2.6%*	*103.5%*	*Class 1*	*0.7%*	*4.0%*	*468.5%*
Class 2	*60.0%*	*77.5%*	*29.1%*	*Class 2*	*25.8%*	*38.6%*	*49.6%*
Class 3	14.0%	8.6%	-38.4%	Class 3	2.7%	4.5%	67.3%
Class 4	24.7%	11.3%	-54.5%	Class 4	50.5 %	38.1%	-24.5%
Class 5	0.0%	0.0%	0.0%	Class 5	20.3%	14.8%	-27.1%
Total charged vehicle classes	**38.7%**	**19.9%**	**-48.6%**		**73.5%**	**57.4%**	**-21.9%**

5.2.3 Public transport

As a consequence of the reduced congestion within the *Ecopass* area, ATM, the Milanese public transport company, registered an increase of surface public transport commercial speed and of underground passengers.

- In the month of January, the commercial speed increased by 11.3%, from 8.67 to 9.64 km/h, and the underground passengers grew by about 9%;
- During the month of February, the surface public transport commercial speed has shown an increase of 3.7% (thus much lower than that registered in January), while the underground passengers increased by 9.8%.

The data for March confirmed the findings for February.

5.2.4 Revenues

The total revenues from the beginning of the *Ecopass* application to the end of February were almost € 4 Million (data for March was not yet available). Most of these were collected in January: more than 2.5 Million €, corresponding to more than 130,000 tickets of different types, as illustrated in Table 5-4.

Table 5-4 Numbers of *Ecopass* Tickets

Type	Number of tickets
Daily tickets	103,781
Multiple tickets	7,484
Multiple entry (>50) with price reduction	10,839
Yearly tickets	8,909
Total	131,013

5.2.5 Air Quality

Given the reduction in the number of the most polluting cars entering the city, benefits on the pollutant emissions have been recorded[4], in terms of PM_{10}, NO_2 emissions and CO concentration[5]:

- During January 2008, the average value of PM_{10} in the *Ecopass* area has been 60µg/m^3, which is better than the corresponding value of 75 µg/m^3 during January 2007 (-20%), but still above the threshold. The reduction of PM_{10} emissions was accompanied by a reduction of NO_2 emissions of 25%, carrying the value to 110 µg/m^3 average concentration against 126 µg/m^3 in the rest of the city. Finally, concentration of CO in the *Ecopass* area has been on average 1.6 mg/m^3 against 2.2 mg/m^3 in the rest of the city.
- In the month of February 2008, the effects of the *Ecopass* system are still positive although the decrease of PM_{10} and NO_2 compared to the reference period (February 2007) is lower than the decrease measured in January 2008 in comparison to January 2007: the average concentration of PM_{10} in the urban area has been 82 µg/m^3 against 84 µg/m^3 of the month of February 2007 (-2%)[6]. The reason of this lower effectiveness of the *Ecopass* application in February compared to January is the growth of the vehicles-km in February (+15% during the *Ecopass* time, +18% during the whole day). Concerning the CO concentration the average in the *Ecopass* area in February 2008 has been 1.3 mg/m^3 against 2.0mg/m^3 in the rest of the city.
- Concerning data from March 2008, is not easy to compare them with those of March 2007 and 2006. In March 2008 concentrations of pollutant have been about 35% lower than in 2007 and 2006 thanks to the weather conditions that in March 2008 have been exceptionally good from a "cleaning air" point of view. March 2008 has been very rainy and windy and these low concentrations have been registered outside the *Ecopass* area as well.

Consequently, although the above mentioned data seem promising, it is not easy to establish a correlation between emissions and pollutant concentrations because of the weather factor: for instance, January 2008 has been a very rainy month, with 115 mm against an average of 60 mm. For this reason more data and more time will be needed to fully understand the effects of the *Ecopass* scheme on air quality.

5.3 CONCLUSIONS

Only three months of results were available at the time of writing this case study. In the first month, the traffic reduction was 26% in the charging zone and 12.5% outside, while in February and March the traffic reduction was significantly lower with 14% to 17% inside the charging zone and 8% outside.

Since the tariff is differentiated on the basis of five pollution classes, with the lowest emitting cars not paying any pollution charge progressively higher charges for the other vehicle classes, a strong shift from higher to lower emitting cars as well as Light Duty Vehicles has occurred.

Air quality improved as well in the first two months, although the largest part of the pollution reduction could be explained by weather conditions, while in March the air quality improvements in the charging area were not better than in the rest of the metropolitan area. Therefore air quality will need to be monitored over a much longer period to allow any firm and quantifiable conclusions.

4 Source: ARPA Lombardia and AMA elaboration for the 'Rapporto Giornaliero di Qualità dell'aria della Città di Milano' (RGQA)

5 Emissions in the Ecopass area have been estimated following the COPERT 4 methodology:
- Vehicles passing through the Ecopass gates have been classified in 200 categories and than grouped in 100 COPERT classes;
- An average trips' length have been estimated using the results of an assignment model;
- Emission factors have been adapted to local conditions (fuels, driving cycles);
- Emissions have been calculated as product of average trip's length and emission factor for each COPERT class.

6 Outside the urban area the average of February 2008 has been 89 µg/m3 against an average of February 2007 of 82µg/m3 (+9%).

Finally, also the public transport drew some benefits from *Ecopass*: the number of Underground passengers increased by 9%, and the bus commercial speed, after an initially strong rise of about 11%, consolidated its gain at nearly 4%.

6 SINGAPORE

6.1 HISTORY AND MAIN CHARACTERISTICS OF THE CHARGING SCHEME

6.1.1 Political Background

Road pricing started in Singapore in 1975 and is regarded as an important component of Singapore's overall transport strategy which has reduced car ownership (relative to per capita income) below the levels prevalent in the 1960s and 70s. Christainsen (2006) explains that in 1972, policies to address worsening traffic problems came in the form of increasing the import duty on cars from 30% to 45% and introducing a separate registration fee equal to 25% (later increased to 55%) of a car's market value. However, these measures did not have much impact on traffic volumes and government remained concerned about the growing problems of congestion and environmental pollution and their possible impact on Singapore's economic prospects. Road pricing was therefore introduced by the Singapore Government's Land Transport Authority (LTA). Although road capacity continues to be increased to meet rising travel demand, the overall transport strategy calls for greater use of public transport and demand management measures. One of the goals set in Singapore's demand management strategy is to move away from the predominant reliance on vehicle ownership costs to one of better balance between the car costs and the usage costs, which would result in a fairer and more equitable system.

Christainsen (2006) emphasises that road pricing is only one part of the strategy and even in Singapore, where one political party dominates the government, there are some political barriers to effective pricing. Although Singapore is said to have done well in handling the politics of road pricing, it has not been completely unaffected by political pressures. For instance, the central expressway has not always been priced according to the government's own objectives, and decisions to change prices have to be approved at the ministerial level rather than being seen as technical matters that can be left to functionaries.

A manual road pricing scheme was implemented in 1975. Known as the Area Licensing Scheme (ALS), it covered the most congested parts of the central business district known as the restricted zone. In 1995, the ALS was replaced by the Road Pricing Scheme (RPS) which covered the major expressways as well as the restricted zone. Both schemes required paper licenses to be purchased before passing through control points set up on the roads. In 1998 the Electronic Road Pricing (ERP) scheme, based on the use of smart card technology to support a pay-as-you-use principle, replaced the manual schemes for the restricted zone and the expressways and, a year later, ERP was extended to arterial roads beyond the restricted zone.

Santos (2005) notes that Singapore complemented the ERP with other transport measures such as high ownership taxes and import duties on cars, and that it also improved the public transport network creating viable alternatives to the private car by developing a mass rapid transit system, expanding the rail network, improving the quality of bus services, and achieving coordinated and integrated bus, rail and taxi services (e.g. via automated ticketing).

6.1.2 Aims of the Scheme

The LTA state that the main objective of the ERP is to make motorists more aware of the true cost of driving, thereby optimising road usage and reducing congestion. Other aims are to provide better journey times for those users paying the charge and to encourage use of public transport, car pooling, alternative routes and alternative times of travel.

Luk (1999) points out that the objective of the ALS scheme was to reduce commuting trips by private cars into the restricted zone. The objective changed in 1989 to improving travel speeds on the road network. The LTA set target speeds for an expressway in the range of 45-65 km/h and for an arterial road in the range of 20-30 km/h.

6.1.3 Type of Scheme and Technology Used

The ERP system is a cordon based variable pricing scheme, where motorists are charged to enter the central business district (restricted zone), major expressways and arterial roads.

Keong (2002) explains that the ERP system has three major components:

- The in-vehicle Unit (IU) and the stored value smart card (CashCard). Prior to the launch of the ERP, IUs were installed on 680,000 eligible vehicles. It is mandatory for all Singapore vehicles to be fitted with an IU if they wish to use the priced roads. The IU installation programme took ten months starting from September 1997. IUs were fitted on 97% of the vehicle population and they were initially provided for free (Menon, 2000). After this period, IUs cost S$150. Different IUs distinguished by different colours were available for different classes of vehicles.
- On-site ERP gantries comprising of the antennae, vehicle detectors and the enforcement camera system which are linked to a controller at each site. Data is transmitted back to the control centre.
- Control centre which comprises of the various servers, monitoring systems, and master clock to ensure timing at all ERP gantries are synchronised. The financial transactions and violation images are processed at the control centre.

The ERP system uses a dedicated short-range radio communication system to deduct charges from CashCards. The CashCard is inserted in the IU before each journey and a diagnostic check is automatically done to ensure that both the IU and the CashCard are working. If there is a problem, the user will be alerted so that it could be solved. The IU also detects if the balance is low on the CashCard and alerts the user.

Each time the vehicle passes through the ERP gantry when the system is in operation, the appropriate charge is automatically deducted from the CashCard. If there is insufficient cash in the CashCard, or no CashCard in the IU, the enforcement cameras in the gantry will take a picture of the vehicle. The image is sent back to the control centre, where the vehicle's registration numbers are automatically read and the vehicle's owner is issued with a letter asking for payments. The outstanding charge plus an administration charge of S$10 must be paid within two weeks of the violation, failing which, a Notice of Traffic Offence is issued demanding S$70 to be paid within 28 days. If it is still not paid after this period, the matter is referred to court. If a vehicle does not have an IU installed and passes through the gantry, a fine of S$70 is immediately issued.

6.1.4 Hours of Operation, Charging Level, Exemptions and Discounts, Degree of Differentiation

The ERP operating hours for the restricted zone are Mondays to Fridays 7:30 to 19:00, and for the expressways and outer ring road areas are Mondays to Fridays 7:30 to 9:30.

Santos (2005) comments that the Singapore ERP is the most advanced pricing scheme in the world to date. The ERP differentiates charges according to vehicle type, time of day and location of the gantry. Vehicles are charged each time they pass the ERP area. This differs from the previous ALS charge which allowed numerous entries for that day after paying a daily charge.

In 2003, a graduated ERP rate was introduced. The charge rates are based on traffic congestion levels at the pricing points. The system allows more frequent changes to be made to the charges, and regularly reviews traffic conditions. LTA state that the ERP is intended to optimise road usage (ensuring that flows are near the maximum possible), therefore speed-flow curves were derived, and target speeds for an expressway in the range of 45-65 km/h and for an arterial road in the range of 20-30 km/h were set. If the speed is above the upper threshold, too few vehicles are thought to be using the roads and the road space is not being optimally used, therefore the charge could be reduced to allow more vehicles to use the roads. On the other hand, if the speed is below the lower threshold, this means that too many vehicles are on the roads and charge could be increased. Keong (2002) points out that other factors such as the effect of traffic diverting to other roads is also considered when deciding the final charge.

In order to discourage motorists from speeding up or slowing down to avoid higher charges, the changes in the ERP are more gradual in the immediate run up to a time/charge change point. LTA explain that graduated ERP rates are introduced for the first five minutes of the time slot with a higher rate. If the next period has a lower ERP rate, the new rate is introduced for the last five minutes. For example, where the charge for passenger cars was S$2 between 8:00 and 8:30 and S$3 between 8:30 and 9.00, it is now S$2 between 8:05 and 8:30, S$2.50 between 8:30 and 8:35, and S$3 between 8:35 and 8:55.

Charges also vary according to vehicle class. For example, Santos (2005) explains that charges for passenger cars, taxis and light goods vehicles vary between S$0.50 and S$3, charges for motorcycles vary between S$0.25 and S$1.50, charges for heavy goods vehicles and light buses vary between S$0.75 and S$4.50, and charges for very heavy goods vehicles and big coaches vary between S$1 and S$6. Exemptions apply to buses and emergency vehicles. Taxis, motorcycles and goods vehicles were originally exempt, but they were eventually charged.

Keong (2002) explains that foreign vehicles wishing to use the ERP priced roads can hire IUs and buy CashCards. However, due to the finding that not many IUs were hired out each day, most foreign vehicles travel to Singapore regularly and therefore find it more cost-effective to buy an IU that is permanently fitted to their vehicles. No discount is provided for residents.

6.1.5 Level of Income Generated and Use of Revenues

During the first year of operation, Goh (2002) states that the ERP revenues were 33% less than the combined revenues from ALS and RPS, not because of reduced traffic but due to the lower charges. Luk (1999) however puts the revenue decline down to the decrease in multiple entry trips and the 1998 regional recession.

Christainsen (2006) states that road pricing can be considered a success as it has not only been effective in controlling traffic volumes, but has also earned a healthy rate of return. The ERP infrastructure including the IUs was stated to have cost S$200 million in 1998. The annual gross revenues have recently been around S$80 million with annual operating cost of S$16 million (cost comprising of staff salary, administrative expenses to manage the system and department, and maintenance of the system). The operating profit was estimated to be around S$60 million. However, it must be noted that there have been some additional costs and revenues with the installation of new gantries.

6.2 OBSERVATIONS AFTER SCHEME IMPLEMENTATION

6.2.1 Acceptability and Understanding of the Scheme

The publicity for ERP was in place over a year before its implementation and started before the IU fitting programme. Keong (2002) explains that all vehicle owners were sent brochures explaining how ERP worked and the differences between ERP and ALS/RPS. Awareness of ERP was raised by adverts in the print media and television. There was a test phase that allowed motorists to test their IUs and experience the ERP charging process, which was regarded as an important awareness and confidence building programme. The publicity programme highlighted the fact that a key difference between ERP and ALS/RPS was that, unlike ALS/RPS, ERP imposed a charge each time the vehicle passed a gantry.

Potential lack of privacy was an issue with ERP because motorists were concerned that vehicle movements would be tracked. However, LTA took many steps to resolve these fears and emphasised that there was no need for the central computer system to keep track of vehicle movements since all charges were deducted from the CashCard at the point of use and the records of these transactions were kept in the memory chip of the CashCard belonging to the individual. Also, all transaction records required to secure payments from the banks were erased from the central computer system within 24 hours (Keong, 2002).

CfIT (2006) report that a survey found 75% of respondents felt it was fair to charge vehicles for congestion, and over 60% agreed with congestion management measures other than vehicle ownership taxes.

6.2.2 Traffic Impact and Economic Impact

Menon (2000) states that when ERP replaced the ALS, traffic speeds in the central business district were in the optimum range of 20-30 km/h. Menon also points out that even though the ERP charge was lower than the ALS charge, one year after the introduction of ERP, traffic volumes into the central business district fell by 15% during the whole day and by 16% during the morning peak, although there had been an increase between 18:30 and 19:00 (last hour of ERP operation). The reduction in the traffic volumes stemmed from the fact that drivers changed their behaviour when the charge became applicable for each passing as opposed to the previous ALS charge which allowed multiple entries into the central business district having paid a daily charge. Keong (2002) states that these multiple-entry trips were estimated to be around 23% during the ALS days, many of these multiple trip makers cut down their number of trips following the introduction of the ERP, for instance, office workers no longer used their cars during the day for lunch etc and became more reliant on public transport. Traffic volumes had increased in the pre-ERP operation period 7:00 to 7:30 mainly due to vehicles avoiding the charge. There was also an increase in traffic in post-ERP operation period 19:00 to 19:30 in some months.

It was reported that 95% of people driving into the central business district before the ERP continued to do so after it was introduced, 2% cancelled their intended trips and 3% were new entrants (Menon, 2000).

CfIT (2006) point out that the ERP led to a decrease of nearly 25,000 cars during the peak period and an increase of around 20% in average traffic speeds. Total vehicles in the restricted zone fell from 270,000 to around 235,000. Other impacts noted were that car pooling had increased, and there has been a shift of many trips from the peak to the off-peak.

LTA found that after the implementation of the ERP, motorists were making greater use of semi-major roads just outside the central business district in order to avoid paying the charges in the central business district. This led to increased congestion on these roads; therefore gantries were then added on some semi-major roads, but the charges for using these secondary gantries were not as high as for using the central business district (Santos, 2005).

6.3 Conclusions Concerning Elasticities

Menon and Chin (2004) estimate short-term price elasticities for driving into the central business district between 7:30 and 9:30 on weekdays to be in a range between 0.0 and -0.42. For travel on the expressways during the morning rush hours, the elasticity estimates range from -0.16 to -0.44. Christainsen (2006) points out that not an elaborate econometric model has been used to obtain these estimates, but that they have been measured by looking at the traffic volume before and after price changes affecting half-hour periods.

7 ROME

7.1 HISTORY AND MAIN CHARACTERISTICS OF THE CHARGING SCHEME IN ROME

7.1.1 The History of Rationing and Pricing Policies in Rome's Historical Centre

The general law regulating land use planning in Italy is the National Act 1150/42 (*Legge Urbanistica*). It introduced for the first time the *Masterplan* as an instrument to control planning starting from the *zoning* principle.

When private vehicle traffic became a serious problem, more specific measures were gradually set up to regulate it and integrate land use development and transport issues: the National Act 393/59 came first, assigning power to local administrations to limit parking time and/or car traffic in their area of competence "in order to safeguard human health, public order and environmental and cultural city heritage".

The Ministerial Decree 1444/68, related to the National Act 765/67, officially acknowledged for the first time in Italy the particular environment and cultural value of the historical core of Italian cities, defining the historic centre as *area A,* and in this area the main goal is the preservation of environmental and built heritage.

Afterwards a sequence of specific measures, instead of a systematic policy in favour of the safeguard of historic centres, was carried out starting from contingent needs, such as oil crisis (1970s) or environmental emergencies, i.e. pollutant concentration peaks related to weather conditions (1980s). Specifically in Rome, in the period from 1980s to 1990s, provisions were made aimed at reducing traffic congestion and promoting public transport.

Only recently the City Council began to consider the opportunity to impose a charge to access the historic centre, and a specific zone called *blue area* was identified: this area was defined in 1989 according to the National Act 122/89 (an integration of the above mentioned Act 393/59), but the real application started only in 1992, when the real extension of the area and time restriction segments were defined. The National Act 122/89 empowered city councils to define instruments such as the Urban Parking Plan (*PUP, Piano Urbano Parcheggi*) to increase and regulate public as well as private parking supply.

The definition of instruments to coordinate medium-term low-cost interventions to improve traffic became only later a real need and from 1992 Municipalities had to prepare their Urban Traffic Plan (*PUT Piano Urbano Parcheggi*) that is intended as an "immediate feasibility plan" that is aimed at maximum restraint of urban critical issues. This instrument, ratified by the National Act 285/92, must be developed according to the dispositions contained in the National Transport Plan (*PGT, Piano Generale dei Trasporti*). The PUT first level document is the Urban Traffic General Plan (*PGTU, Piano Generale del Traffico Urbano*), which is a general program to coordinate all interventions aimed at optimising global transport supply and regulating private vehicle traffic and restrictions, such as Restricted Access Zones (*LTZ, Zona a Traffico Limitato*) and on-street paid parking.

LTZ and parking fees in Rome were adopted in a systematic way in 1994, when PUT was implemented and permits to enter the LTZ were distributed: these permits were granted by the municipal offices and were *given free of charge* to residents and other users falling into specific categories. From 1998 some authorised non-residents were required to pay yearly in order to obtain the permit.

Furthermore, parking is free for residents near their home or within their designated neighbourhoods, while destination parking is burdensome for both residents and authorised non-residents.

The regulation reference framework that made the introduction of the automatic access control system possible is listed in the following:

- The Italian Parliament, with law 193/99, delegated the Government to emanate the regulation for the discipline of distance traffic control systems;
- The Presidential Decree 250/99 approved the regulation that allows municipalities to obtain the authorisation from the Ministry of Public Works for installing and operating access control systems to historic centres and areas restricted to traffic;
- The authorisation of the Ministry of Public Works enabled the assessment of violations to limitations in the traffic of determined user categories, in absence of police officers and by means of an automatic control system, which sends information to an operative centre managed by urban police.

The official approval request for the Rome system was presented by the equipment manufacturer in July 1999; the SIRIO.VES 1.0 system was approved on 26 June 2000. According to the national regulation, the approval for service operation was released by the Ministry of Public Works at the end of March 2001. Difficulties in obtaining all necessary authorisations show an extremely cautious attitude of national authorities, with Rome being the first example in Italy. From October 2001 access control with a flat-rate Road Pricing (RP) scheme in the area east of the Tiber, called 'Historic Centre LTZ', is operated through an automatic control system.

Other LTZs have been implemented in the last years. One was implemented in the San Lorenzo Area that is Rome's University Zone, and is located just outside the City Walls on Tiburtina Road. The San Lorenzo area has a very important night life and many clubs are present in this area. Unfortunately, because of the vehicles' entrance during the night, high levels of noise pollution had been experienced by the residents, and to reduce this noise pollution the San Lorenzo Night LTZ has been implemented in 2003 using an automatic control system.

In 2004 an automatic control system was implemented for the Trastevere LTZ, on the west side of the Tiber and, since 2005, the Historic Centre LTZ is operating also during night.

7.1.2 The Current Situation

Aims of the Scheme

The implementation of LTZs in Rome is strictly linked to the general transport policies defined by the Rome Municipality in last ten years. The main objective at the base of the City Council policies consists of the achievement of a sustainable development as outlined in the European Council Program "For a durable and sustainable urban development".

This main objective comprises two general goals:

- Improve mobility conditions, while increasing traffic safety and decreasing air and noise pollution;
- Re-organise urban spaces, by rationalising public space use, safeguarding citizens' health and preserving historical and architectural heritage.

With the intention to achieve the above objectives, the City Administration has developed a strategy aimed at obtaining a balance of modal split through the adoption of specific measures to decrease private car use and convert a significant part of this mobility to public transport, at the same time by enforcing transit supply and promoting alternative means of transport.

This strategy is developed as an extremely flexible instrument, susceptive to being adapted to typological and dimensional characteristics of the urban fabric; the transport policy is aimed at discouraging private vehicle usage in the central areas with high residential and activity densities, and allowing its usage with increasing distance from the historic centre.

The integrated transport solutions, identified by the Administration, aimed at speeding up the urban transformation processes through the implementation of two transport management instruments: the long term instrument focused on the planning and design of transport new infrastructures and improvement of the existing ones, the short term instrument oriented towards the definition of private traffic regulation and control.

The long-term instrument is the Integrated Mobility Program (*PROIMO, Programma Integrato della Mobilità*), setting up the synthesis of a global process already started from the first years of the past decade. The main objective of the program is to define a planning tool that gives coherence to all private as well as public urban mobility issues, defines timing for the implementation of new transit infrastructures and states functional, physical and financial requirements supporting the ongoing new General Masterplan.

According to local planning strategies, and following national legislation asking all the medium and large towns for the preparation of the Urban Traffic Plan (*PUT, Piano Urbano del Traffico*), in 1997 the City Council adopted the General Urban Traffic Plan (*PGTU, Piano Generale del Traffico Urbano*) as the first step towards the PUT; after a consultation process with citizens and public technical offices, the PGTU was approved in 1999 and revised in 2004. After this approval, the Administration has started in 2000 the planning phase, and is producing detailed traffic plans to implement on the territory of the PGTU directives.

The PGTU subdivided, from a functional point of view, Rome in five areas (Figure 7-1), four internal to the Great Ring Road (GRA, Grande Raccordo Anulare), while the fifth is external to the GRA and extends to the city border; all of them have been identified on the base of their general characteristics and the planned modal shift between public and private transport.

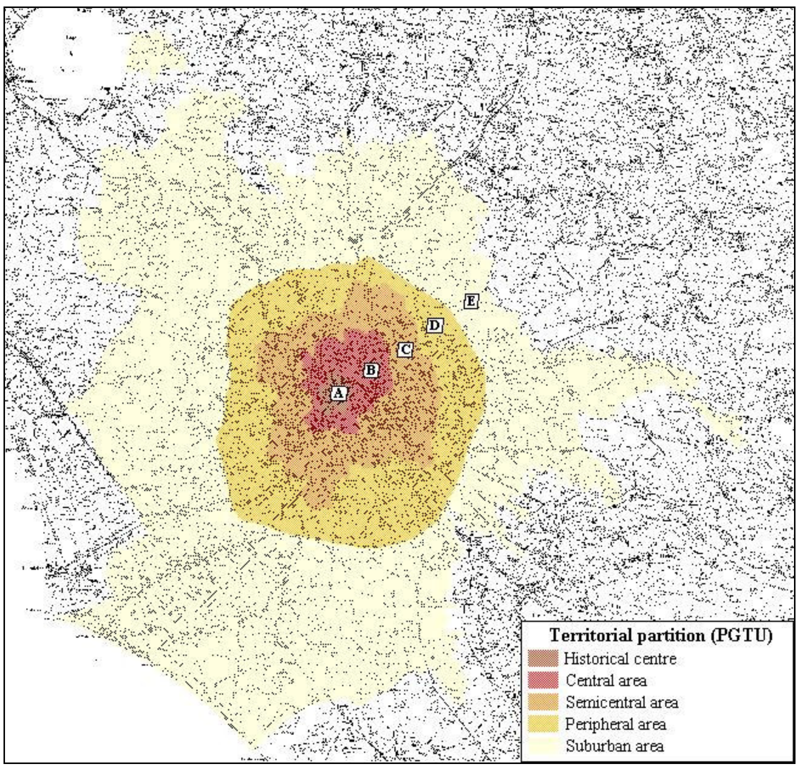


Figure 7-1 Territorial Partition of the Rome Municipality (PGTU)

The historical centre (A), corresponding to the historic centre LTZ (ZTL, Zona a Traffico Limitato), has an area of about 6 km^2 and shows the highest concentration of business activities. The central area (B) stretches from the outer edge of the historical centre to the railway ring. The area is densely populated and presents a great deal of business activities. The semicentral area (C) stretches from the border of the central area to a line which is approximately identified by the inner ring road (still not completed). The peripheral area (D) covers the rest of the urban settlement within the GRA. Finally the suburban area (E) outside the GRA presents the lowest business and residential densities. The general implementation strategy foresees that radial corridors will serve traffic to and from the central areas (A and B areas); this function can be guaranteed only by strengthening and redesigning radial railway systems. Towards this objective, the Administration has started from the early 1990s a financing policy for the development of the rail network (urban railways as well as metro and tram lines) supported by a very high budget.

In concomitance with the development of infrastructures designed by PROIMO, the redesign of road public transport is in progress: new high speed radial lines served by tram, trolleys and electric vehicles will be added to the existing ones, which will be strengthened and extended in the A and B PGTU areas. This will give to the radial road system the function of public transport main axes, in order to satisfy, jointly with rail lines, a greater part of transport demand to and from the historic centre.

These measures will be accompanied by the redesign and development of the road network aimed at an effective adjustment of the network to the city structure. The road tangential system in particular will be redesigned to allow easy access to the radial public transport system, especially from external areas. The above scheme will only work correctly if accompanied by complementary restrictive measures for traffic regulation and management:

- Articulation of parking fares (about 150,000 paid parking places at constant hourly price are now available) increasing while approaching the central areas, aimed at encouraging citizens to use peripheral intermodal nodes;
- Access control system to historic centre already implemented together with pricing policies, applied with equity to residents and non-residents, aimed at discouraging private vehicle usage.

In addition, the Administration has during the last years sped up a thorough innovation in the local public transport (*TPL, Trasporto Pubblico Locale*) organisation, giving licences to private partners and calling for tenders for 30 million bus*km per year in peripheral areas. Parallel actions are foreseen, i.e. mobility management, car pooling, car sharing and taxibus.

Finally, public funds have been allocated to develop surveys for specific sectors such as freight distribution in the central areas and plans to improve general conditions in the historic centre.

Taking into account the general objectives reported above, the main LTZs goals are to reduce the number of vehicles accessing them to the strictly necessary ones, and promote public transport and intermodality along rail lines far from the historic centre through the adoption of a fully integrated public transport fare system. Furthermore, road pricing within the LTZs and parking pricing are expected to be increased, getting more and more expensive approaching LTZs (see Figure 7-2).

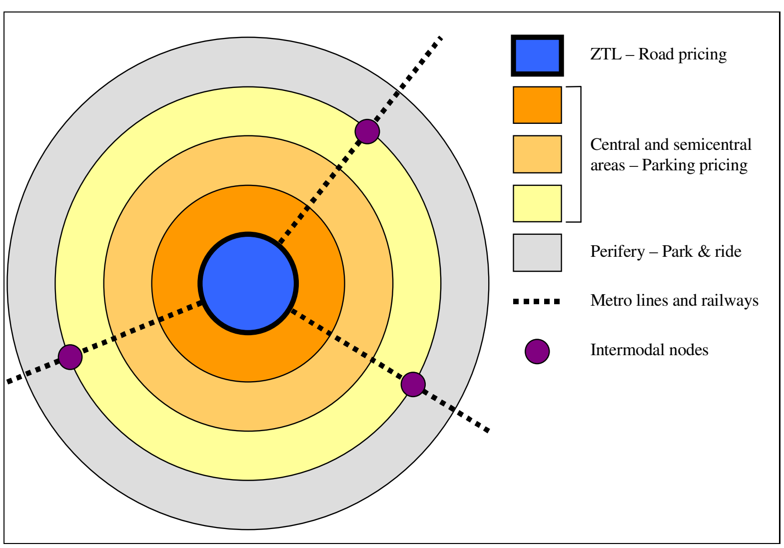


Figure 7-2 General Asset of the Pricing Policies in Rome

Type of Scheme

The LTZs have a flat-fare pricing scheme. Only authorised categories can access the LTZs paying an annual charge. The amount of the charge depends on the category.

Technology Used

The system developed in Rome consists of two independent systems: the access control system (SVU, Elettronica Santermo S.p.A.), operating the identification of number plates for applications in the Restricted Access Zone and already adopted in Bologna, and the payment system (TVU, Autostrade S.p.A.), based on the automatic toll collection system applied to motorway users (TELEPASS). The integration between the above mentioned systems generated the IRIDE system.

The generic process at the gate is shown in Figure 7-3. When a vehicle approaches the gate (the approach is captured by inductive loops), the on-board unit communicates information to a local gate control system. In case the smartcard in the on-board unit is invalid or the vehicle does not have the on-board unit, the video cameras are activated and a photo is shot at the vehicle back number plate (the position for capturing the image is again determined by the inductive loops). Data and images are then communicated to the central access control system and processed.

Video cameras at the gates capture images that undergo an automatic procedure to identify the plates of vehicles, which is based on OCR (Optical Character Recognition) software.

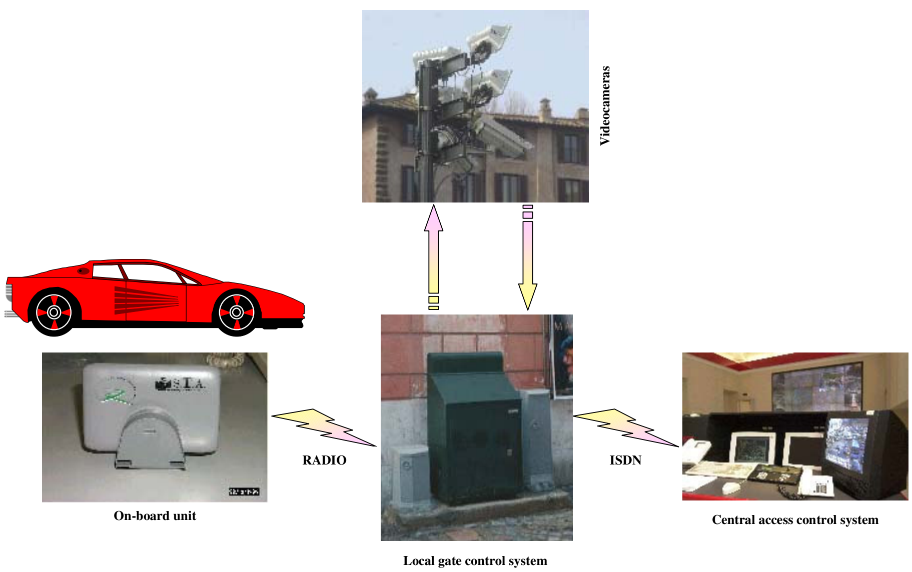


Figure 7-3 The Generic Process at the Electronic Gates

On-board unit (Figure 7-4) development and requirements were tuned to the necessity to produce them on a medium scale. It is now able to carry out two services: *LTZ pass* for the electronic permission in the access to the LTZ, and *TELEPASS* payment for the use on the highway network controlled by Autostrade S.p.A.

All the administrative functions of the system stay separated between Rome Municipality and Autostrade: the two only use the same technology. This model can be exported to other cities, either concerning the LTZ access or for the payment of on-street parking. If a Roman citizen has the permission of access to the LTZ of both Rome and Bologna, he will be able to use a single on-board unit and two smart cards.

Figure 7-4 On-Board Unit

Hours of Operation

Nowadays in Rome there are three different LTZs and each of them has different hours of operation. The historic centre LTZ is operating from Monday to Friday from 6:30 to 18:00 and on Saturday from 14:00 to 18:30. During the night the LTZ covers a smaller area than during the day (see Figure 7-5) and is operating from 23:00 to 3:00 on Friday and Saturday.

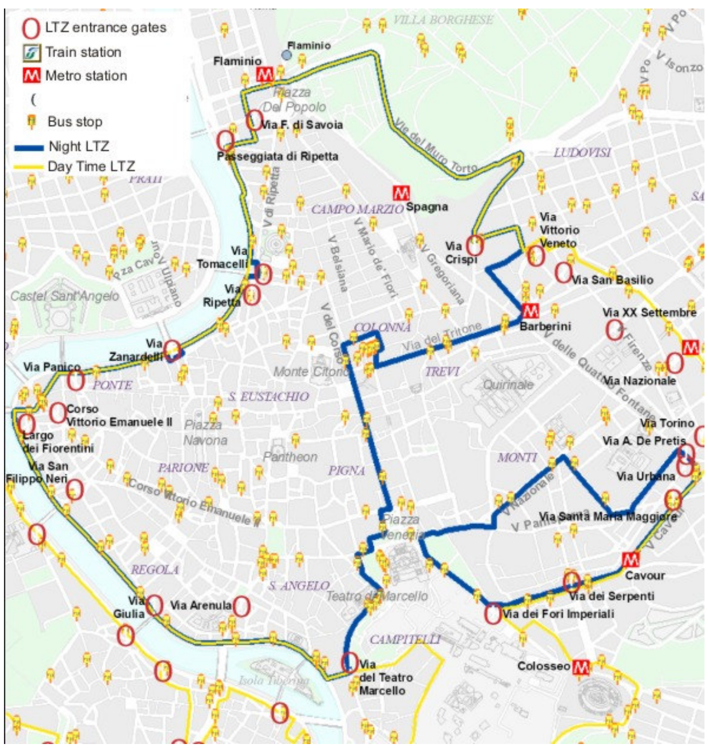


Figure 7-5 Historic Centre LTZ

San Lorenzo LTZ covers and area of 2.6 km^2 and has 7 entrance gates (see Figure 7-6). The LTZ is operating from May to October from Wednesday to Saturday from 21:00 to 3:00, and from November to April only on Friday and Saturday from 21:00 to 3:00.

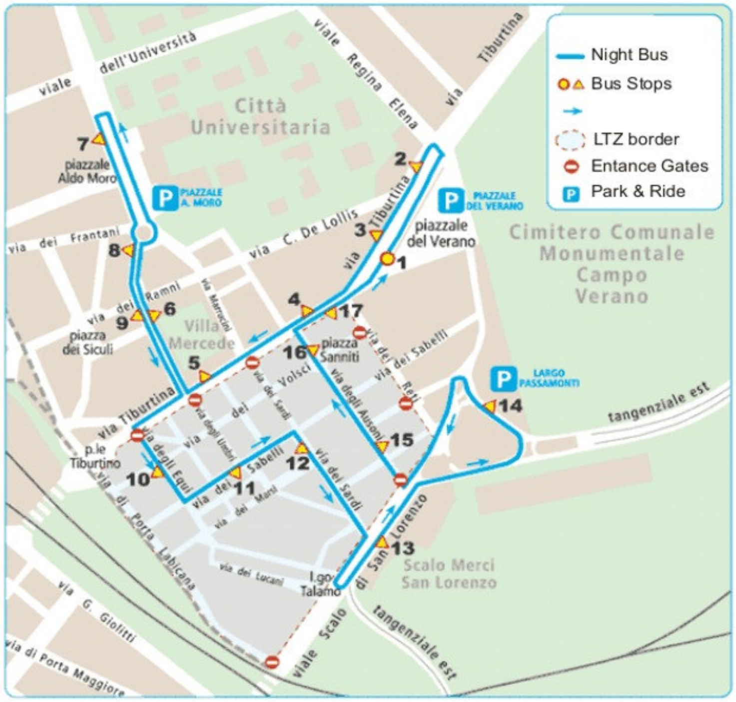


Figure 7-6 San Lorenzo LTZ

Trastevere LTZ covers 1.5 km^2 and has 12 entrance Gates (see Figure 7-7). The LTZ is operating from Monday to Saturday from 6:30 to 10:00 and on Friday and Saturday from 21:00 to 3:00.

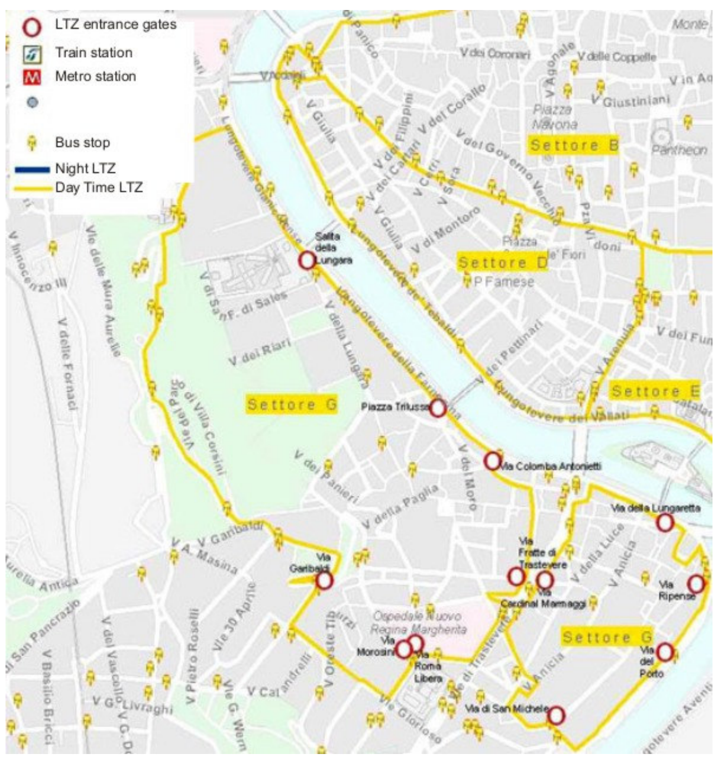


Figure 7-7 Trastevere LTZ

Charging Level, Exceptions and Discounts, Degree of Differentiation

The San Lorenzo LTZ is free for residents and for impaired people. The other categories are not allowed to enter the LTZ during the hours of operation.

The other two LTZs have the same prices and the same rules. The permit to enter the LTZ is strictly linked to the number plate of the vehicle and not to the person. Each family that lives inside the LTZ pays for the first car € 55 and € 300 for the second one and both permits last for 5 years, from the third car owned by the family the price is € 550/year.

All the other categories can have only a yearly permit and the prices are listed in Table 7-1.

Table 7-1 LTZs Prices

Category	Price	Duration of permit
Private vigilance company	550 €	1 year
Journalist	550 €	1 year
Banks or insurance companies	550 €	1 year
Parliament, Senate and National Government	550 €	1 year
Trade Unions, Parties and Firm Organizations	550 €	1 year
Doctors working inside LTZ	55 €	1 year
International Organizations and Embassies	550 €	1 year
Vatican City	55 €	1 year
Fright Transport operating inside LTZ	550 €	1 year
Craftsman working inside the LTZ - 1° permit	55 €	1 year
Craftsman working inside the LTZ - 2° permit	550 €	1 year
Night Workers	100 €	1 year
Hotels courtesy cars	550 €	1 year
National, Local and Justice Administrations	550 €	1 year
National and Local Health Administrations	550 €	1 year
Research Bodies	550 €	1 year
Temporary permit	20 €/day	Max 23 days

Categories that are not listed in Table 7-1 cannot have a permit.

Level of Income Generated and Use of Revenues

The Rome Municipality Commission has defined that the possible uses for LTZ revenues are:

- Control systems implementation for the enforcement of road law;
- Public transport improvement;
- Planning of new reserved lanes for public transport;
- Planning and implementation of private and public transport automatic control systems;
- Pollution monitoring and reduction activities.

At least for the moment, the total amount of LTZs revenues is not made available to the public by Rome's Municipality.

7.1.3 The Proposed New Charging Schemes

The proposed new charging schemes refer to two different timeframes: a daytime one and a night one. Particularly the night scheme has been subdivided in two other different schemes: one for the summer period, called summer scheme, and one referring to the remaining part of the year, the so-called winter scheme.

Short Description of the Daytime Scheme

The simulation activities focused on the results of the application of different road pricing schemes to the defined area in the current operational time of the LTZ (from 6:30 to 18:00). In most of the simulated scenarios the current application of the access restriction (LTZ) and road pricing has been assumed. A scenario assuming the complete substitution of the current access restriction with a "pure" road pricing policy has also been simulated, in order to check what price would have to be applied to have the same results currently achieved through the access restriction.

The following attributes were taken into account in the simulation scenarios:

- Level of charges for cars (different levels for residents and non-resident authorised car users);
- Level of charges for mopeds and motorcycles;
- Public transport supply (expressed in terms of average trip time).

Some scenarios focused on the separated effects of the single attribute variation, while in other scenarios the overall effects of integrated schemes were investigated. With reference to Table 7-2, the first case applies to scenarios 1, 2, 3 and 4, the second to scenarios 5 and 6. In order to better understand the characteristics of each scenario, it is useful to remember that in scenario 0 (i.e. in the current situation):

- Residents in the LTZ have a permit to drive into the area gratis;
- Non-resident authorised car users pay about 300 € for their annual permits, which works out to about 1.5 € per day (assuming one entrance per day, five days a week);
- Moped users can enter the area without restrictions.

The characteristics of the seven scenarios simulated can be described briefly as follows:

- Scenario 0 represents the current situation, with an annual charging structure.
- Scenario 1 aims at demonstrating the effects of a slight increase in the current charge levels for authorised car drivers (compared to the current situation, the price level for authorised car users is doubled), together with a slight improvement of the public transport supply.
- In scenario 2 the increase of the charge levels for authorised car drivers is higher than in scenario 1 and an annual price for residents is introduced as well. Moreover, a higher improvement of the public transport supply is assumed. Moped users are not charged in either scenario.
- Scenario 3 focuses on the introduction of a charging structure for moped users, accompanied by a slight improvement of the public transport supply. The charge levels for car drivers are very similar to the actual charges.
- Scenario 4 differs from scenario 3 only in a greater increase of the public transport supply. The comparison between the two scenarios shows the results achievable through an improved public transport system.
- In scenario 5 the results of an integrated approach, involving all the three considered attributes, is investigated. An annual price is applied for residents, the charge level for car drivers is bigger then the levels of scenario 3 and scenario 4, while the charge level for mopeds is the same of scenario 3 and scenario 4. The public transport supply is improved.
- Scenario 6 is very similar to scenario 5, except for the "time-based" charging structure for the authorised car users instead of the "per trip" one. The average price level for authorised car users in scenarios 5 and 6 is very similar, taking into account that, as emerged from the surveys, the average length of stay inside the LTZ for this category of users is about four hours.

Table 7-2 Summary of Charging Daytime Scheme

Category of user	Attribute	Scen. 0	Scen. 1	Scen. 2	Scen. 3	Scen. 4	Scen. 5	Scen. 6
Resident car user	charging structure	-	-	Annual permit	-	-	Annual permit	Annual permit
	Price level (€)	-	-	300	-	-	300	300
Non-resident authorised car user	Charging structure	Annual permit	Per trip[7]	Per trip	Per trip	Per trip	Per trip	Per hour
	Price level (€)	300	3	6	1,5	1,5	6	1,5
Moped user	Charging structure	-	-	-	Per trip	Per trip	Per trip	Per trip
	Price level (€)	-	-	-	1,5	1,5	1,5	1,5
Common	PT supply (average trip time reduction)	-	10%	20%	10%	20%	20%	20%

The level of prices assumed in the simulated scenarios was determined on the basis of:

- The current situation;
- The parking price (€ 1 per hour) in the area surrounding the LTZ;
- The current average length of stay inside the LTZ declared by the different categories of users.

In most scenarios the "per trip" charging structure is assumed for authorised non-residents; exceptions are scenario 0, with the annual permit, and scenario 6, in which the "time-based" (i.e. per hour) charging structure is used. Scenario 6 corresponds to scenario 5 in terms of average price levels: the comparison between the two simulation results allows drawing conclusions on the different effects of the two charging structures considered.

Beyond the seven described scenarios, additional simulations have been carried out in order to analyse what would be the effects of a complete substitution of the current rationing policy with a road pricing scheme (scenario 7). It is assumed that residents and moped users are not charged, while a common per-trip price is assumed for all the remaining categories of car drivers.

Short Description of the Night Scheme

In this second wave of simulation activities, the effects of a road pricing scheme application in the night period (from 18:00 to 23:00) have been assessed.

The two considered scenarios (the "daytime" one and the "night" one) are completely different for many reasons:

- In the first one, only selected groups of car drivers (residents, authorised car drivers and public utility vehicles) are allowed to access the area, while in the second one the access is completely free;
- As a consequence of the previous item, in the night hours a large number of car drivers just cross the area, without having their destination inside it;
- In the daytime hours regular trips are prevailing, while in the evening period most of the trips are for recreational or for shopping trips.

7 In the "per trip" charging structure it is intended that the car user is charged every time he accesses the LTZ (i.e. every time he passes through the electronic entrance gates).

This is why a new demand model has been calibrated and used: the travel behaviour and, particularly, the elasticity to prices of the (mainly regular) authorised users interviewed in the first phase of the work is significantly different from the (mainly non-regular) users interviewed in this second phase.

Given that the mobility pattern in the historic centre of Rome in the evening hours is significantly different between the summer time and the remaining part of the year, the surveys for the simulation model calibration have been subdivided into two parts: the first one has been carried out in July 2002, while the second one has been carried out in November 2002.

This has allowed calibrating two different models and to assess whether significant differences between the two situations can occur.

The following attributes were taken into account in the simulation scenarios:

- Level of charges for cars;
- Public transport supply (expressed in terms of average trip time).

In the summer scheme, some scenarios focused on the isolated effects of the road pricing scheme introduction, while in other scenarios the combined effects of both road pricing and complementary measures (i.e. PT supply increase) were investigated. With reference to Table 7-3, the first case applies to scenarios 1 and 2, the second to scenarios 3 and 4. Scenario 0 represents the current situation, without any charging structure.

In all the simulated scenarios a per-trip[8] charging structure is assumed. Levels of prices are common for all car users. Charges are not applied to residents, taxis and public utility vehicles.

The characteristics of the five summer scenarios simulated can be described briefly as follows:

- Scenario 0 represents the current situation, without any charging structure.
- Scenario 1 focuses on the introduction of a charging structure for car users.
- In scenario 2 the charge level for car users has doubled compared to scenario 1.
- Scenario 3 differs from scenario 1 only in a slight increase of the public transport supply.
- Scenario 4 differs from scenario 2 only in a great increase of the public transport supply.

All the summer scenarios are shown in Table 7-3.

Table 7-3 Summary of Charging Night Summer Scheme

Category of user **Attribute**	**Scen. 0**	**Scen. 1**	**Scen. 2**	**Scen. 3**	**Scen. 4**
Private cars					
Charging structure	-	Per trip[5]	Per trip	Per trip	Per trip
Price level (€)	-	3	6	3	6
Public transport					
PT supply (average trip time reduction)	-	-	-	10%	20%

In the winter scheme, some scenarios focused on the isolated effects of the road pricing scheme introduction, while in other scenarios the combined effects of both road pricing and complementary measures (i.e. PT supply increase) were investigated. With reference to Table 7-4, the first case applies to scenarios 1, the second to scenarios 2 and 3. Scenario 0 represents the current situation, without any charging structure.

8 In the "per trip" charging structure it is intended that the car user is charged every time he accesses the LTZ (i.e. every time he passes through the electronic entrance gates).

In all the simulated scenarios a per-trip charging structure is assumed. Levels of prices are common for all car users. Charges are not applied to residents, taxis and public utility vehicles.

The characteristics of the four winter scenarios simulated can be described briefly as follows:

- Scenario 0 represents the current situation, without any charging structure.
- Scenario 1 focuses on the introduction of a very cheap charge for car users.
- In scenario 2 the increase of the charge levels for car users is higher than in scenario 1, and a slight improvement of the public transport supply is assumed.
- In scenario 3 the increase of the charge levels for car users is higher than in scenario 2, and a higher improvement of the public transport supply is assumed.

Table 7-4 Summary of Charging Night Winter Scheme

Category of User Attribute	Scen. 0	Scen. 1	Scen. 2	Scen. 3
Private cars				
Charging structure	-	Per trip	Per trip	Per trip
Price level (€)	-	1	3	6
Public transport				
PT supply (average trip time reduction)	-	-	10%	20%

7.2 AVAILABLE DATA

The available data refers to activities carried out in October 2001, July 2002 and November 2002.

Two main groups of activities were carried out:

- Interviews with different categories of users, for the calibration of the demand model;
- On-site measurements and counts, for the calibration of the supply model and verification of the simulation result.

To simulate the effects of the introduction of a new option, a representative sample of users was asked about their hypothetical choices, if presented with the new choice set, as well as current user behaviour. For this reason, all questionnaires used to obtain the information that was the basis of the demand models have been subdivided in two parts: one concerning the current user behaviour (revealed preferences, or RP), and the other concerning users' hypothetical choices, if presented with the new choice set (stated preferences, or SP).

Moreover for the design of the experiments, in some cases, "simplification" techniques were used, since the Full Factorial Design would have required a single questionnaire to contain too many SP scenarios (beyond the level of the price, also the public transport trip time has been considered as an attribute in these scenarios). A "blocking" technique was used to separate the scenarios into blocks, so that the full choice set was completed by groups of respondents, each responding to a different sub-set of options (Pearmain, 1991). Dominated scenarios were removed.

In October 2001 surveys were carried out to calibrate the daytime scheme, and to obtain a detailed demand model that would permit accurate interpretation of user behaviour two groups of SP scenarios were defined:

- Scenarios in which the user was asked to choose his/her favourite transport mode (between car, moped, public transport and Park and Ride) given the introduction of a charge for cars, a charge for mopeds and an improvement (supply increase) in public transport service. This kind of questionnaire (called "modal") was delivered to users currently travelling in the LTZ and whose trips would be affected by the introduction of the pricing scheme and by the public transport improvement. Another group of users, currently not travelling in the LTZ but potentially interested in doing so by car, was interviewed by means of the same kind of SP scenarios to assess the consequences, if the current rationing scheme were to be entirely replaced by the road pricing scheme.

- Scenarios in which the user was asked to choose, for a hypothetical trip on a given transport mode, between two alternatives, each characterized by defined values of different attributes. This kind of SP scenario was intended to allow the model to take into account the different disaggregated attributes affecting user choice. These "focused" questionnaires were delivered to general users (not necessarily travelling in the LTZ) of different transport modes.

In both the "modal" and the "focused" questionnaires a common RP section was present. A synthesis of the survey structure is described in Table 7-5; two examples of questionnaires were used; one "modal" and the other "focused". With regard to measurements and counts, the following activities were carried out:

- Automatic counts of traffic flows at the 23 entrance gates of the LTZ and at 30 road sections, both inside and, mainly, outside the LTZ. The flows were counted through the monitoring system managed by STA in June and November 2001 (24 hours a day for the whole month), both before and after the automatic Access Control System became operational. These data were used to refine the O/D matrices and to verify the output of the simulation model, when simulating the current situation.
- Manual counts of traffic flows, vehicle categories and car and bus occupancy at five gates of the LTZ and the three internal road sections. The main aims of these manual counts, carried out in June and November 2001, were to estimate the exit flows at the gates in the different hours (the electronic gates can count only entrance flows), the moped flows (mopeds are counted by the automatic monitoring system) and the vehicle occupancy. As in the previous case, the manual counts were used to refine the O/D matrices and to verify the output of the simulation model.
- Since the model takes into account the parking supply and occupation level of different zones, manual measurements were carried out in June 2001 on a sample of roads inside the LTZ to estimate such indicators, together with the hourly turnover.

Also additional data (traffic flows, parking supply and occupation, public transport loads) already available were used.

In July 2002 surveys were carried out to calibrate the night summer scheme and a synthesis of the survey structure is described in Table 7-6. The number of interviews and the distribution among the different categories of users (some categories are more represented than others) were mainly determined by the available resources. Anyway, it must be considered that each respondent was interviewed with reference to several SP scenarios, thus determining an "artificial" increase of the number of interviews.

With regard to measurements and counts, a significant amount of activities has been carried out, due to the fact that, despite the situation of the morning/afternoon period, no reliable quantitative data (i.e. no reliable O/D matrices) were available for the evening period.

More precisely, the following activities were carried out:

- Automatic counts of traffic flows at the 23 entrance gates of the LTZ;
- Manual counts of traffic flows, vehicle categories and car and bus occupancy at a sample (five) of entrance gates of the LTZ;
- Interviews of a sample of car and moped drivers at the LTZ border, in order to determine and quantify the different categories of users accessing the area (residents; users with destination inside the area for shopping trips, recreational or work trips; users just crossing the area).

These measurements, counts and interviews did not allow, obviously, identifying the O/D matrices, but gave the necessary information on the total amount of users accessing the LTZ at each hour by each transport mode and on their categorisation in terms of trip purposes.

Table 7-5 Details of Surveys for Demand Model Calibration (Daytime Scheme)

Type of survey	Subject of interviews	Interviewed users	Place of interview	Questionnaire used (sample size)
Modal 1 400 car users)	Modal choice	50 car users living in LTZ	Inside LTZ	M1a-1 (12); M1a-2 (13); M1a-3 (12); M1a-4 (13)
		250 car users authorised to access LTZ	Inside LTZ	M1b-1 (62); M1b-2 (63); M1b-3 (62); M1b-4 (63)
		100 car users non-authorised to access LTZ / living outside LTZ	Outside LTZ (shopping centres)	M1c (100)
Modal 2 (400 PT users)		300 PT users leaving outside LTZ	Inside LTZ	M2a-1 (150); M2a-2 (150)
		100 P+R users living outside LTZ	Outside LTZ (interchange points)	M2b-1 (50); M2b-2 (50)
Modal 3 (400 moped users)		300 moped users living outside LTZ	Inside LTZ	M3a-1 (75); M3a-2 (75); M3a-3 (75); M3a-4 (75)
		100 moped users living in LTZ	Inside LTZ	M3b-1 (25); M3b-2 (25); M3b-3 (25); M3b-4 (25)
Focused 1	Perception of car trip attributes	150 car users	Outside LTZ	F1-1 (75); F1-2 (75)
Focused 2		50 PT users	Outside LTZ	F2-1 (25); F2-2 (25)
Focused 3		50 moped users	Outside LTZ	F3-1 (25); F3-2 (25)
Focused 4		50 P+R users	Outside LTZ (interchange points)	F4-1 (25); F4-2 (25)
Focused 5	Perception of PT trip attributes	150 PT users	Outside LTZ	F5-1 (75); F5-2 (75)
Focused 6		50 car users	Outside LTZ	F6-1 (25); F6-2 (25)
Focused 7		50 moped users	Outside LTZ	F7-1 (25); F7-2 (25)
Focused 8		50 P+R users	Outside LTZ (interchange points)	F8-1 (25); F8-2 (25)
Focused 9	Perception of P+R trip attributes	150 P+R users	Outside LTZ (interchange points)	F9-1 (75); F9-2 (75)
Focused 10		50 PT users	Outside LTZ	F10-1 (25); F10-2 (25)
Focused 11		50 moped users	Outside LTZ	F11-1 (25); F11-2 (25)
Focused 12		50 car users	Outside LTZ	F12-1 (25); F12-2 (25)

Table 7-6 Details of Surveys for Demand Model Calibration (Night Summer Scheme)

Type of survey	Interviewed users - trip purposes	Place of interview	Questionnaire used
1) Car drivers crossing the LTZ (126 users)	General car drivers (126)	LTZ border	S1
2) Car drivers with destination inside the area (361 users)	Shopping trips (44)	Inside the LTZ	S2a – S2b
	Recreational trips (235)	Inside the LTZ	S2a – S2b
	Work trips (82)	Inside the LTZ	S2a – S2b
3) Moped users with destination inside the area (155 users)	Shopping trips (48)	Inside the LTZ	S3
	Recreational trips (63)	Inside the LTZ	S3
	Work trips (44)	Inside the LTZ	S3
4) PT users with destination inside the area (90 users)	Shopping trips (32)	Inside the LTZ	S4
	Recreational trips (34)	Inside the LTZ	S4
	Work trips (24)	Inside the LTZ	S4

In November 2002 surveys were carried out to calibrate the night winter scheme.

Four different questionnaires have been used. The first concerning the users passing the LTZ with their car (S1), the second for the users which enter the LTZ with their car (S2A and S2B), the third for the users entering the LTZ with a moped (S3) and the fourth concerning the public transport users which enter the LTZ.

For the design of the experiment, the isolated cases in the stated preferences have also been considered.

847 respondents were interviewed, 126 passing the LTZ and 721 entering it. A synthesis of the survey structure is described in Table 7-7.

Table 7-7 Details of Surveys for Demand Model Calibration

Type of survey	Interviewed users - trip purposes	Place of interview	Questionnaire used (sample size)
1) Car drivers crossing the LTZ (126 users)	General car drivers (126)	LTZ border	S1
2) Car drivers with destination inside the area (450 users)	Shopping trips (58)	Inside the LTZ	S2a – S2b
	Recreational trips (287)	Inside the LTZ	S2a – S2b
	Work trips (105)	Inside the LTZ	S2a – S2b
3) Moped users with destination inside the area (181 users)	Shopping trips (45)	Inside the LTZ	S3
	Recreational trips (76)	Inside the LTZ	S3
	Work trips (60)	Inside the LTZ	S3
4) PT users with destination inside the area (90 users)	Shopping trips (26)	Inside the LTZ	S4
	Recreational trips (32)	Inside the LTZ	S4
	Work trips (32)	Inside the LTZ	S4

The available resources mainly determined the number of interviews and the distribution among the different categories of users (some categories are more represented than others). Anyway, it must be considered that each respondent was interviewed with reference to several SP scenarios, thus determining an "artificial" increase of the number of interviews.

In order to consider the current modal share and the number of interviews done (not precisely proportioned to the modal share), a weight variable has been introduced.

The interviews have been done both on the LTZ border (for users passing the LTZ) and inside the LTZ (for users entering it).

The check points adopted are: for the border survey, the gates in Via Nazionale and Via dei Fori Imperiali, for the inside LTZ survey Piazza San Silvestro bus station and Piazza di Spagna underground station for public transport users, and different zones in the historical centre near parking for car users and moped users.

With regard to measurements and counts, a significant amount of activities has been carried out, due to the fact that, despite the situation of the morning/afternoon period, no reliable quantitative data (i.e. no reliable O/D matrices) were available for the evening period.

More precisely, the following activities were carried out:

- Automatic counts of traffic flows at the 23 entrance gates of the LTZ;
- Manual counts of traffic flows, vehicle categories and car and bus occupancy at a sample (five) of entrance gates of the LTZ;
- Interviews of a sample of car and moped drivers at the LTZ border, in order to determine and quantify the different categories of users accessing the area (residents; users with destination inside the area for shopping trips, recreational or work trips; users just crossing the area).

As for the summer survey, these measurements, counts and interviews did not allow, obviously, identifying the O/D matrices, but they gave the necessary information on the total amount of users accessing the LTZ at each hour by each transport mode and on their categorisation in terms of trip purposes.

The automatic counting of the traffic flows, made through the Iride system, allowed establishing the number of vehicles which currently enter the LTZ area in the different hours.

The manual counting of the traffic flows on a sample of gates allowed to classify such vehicles in the different categories (cars, buses and commercial vehicles). Furthermore, it allowed estimating the number of mopeds entering the LTZ area, the average occupancy of cars and mopeds and the number of passengers entering the LTZ by bus.

The border interviews allowed verifying and quantifying the number of users passing or entering the LTZ, by car or by moped, and the different aims of their travels (work, recreational and shopping trips, and return to their homes).

7.3 MODEL USED

7.3.1 Outline of the Model

The pricing schemes to be simulated refer principally to persons' trips, whose access to the Limited Traffic Zone is regulated, depending on the person belonging to specific groups and the kind of private vehicle utilised. Hence, the consequences deriving from their implementation can be determined by applying a multiclass, multimodal, elastic demand, network equilibrium model developed from the one by Cantarella (1997). When employing such a model, the choice process is decomposed into the steps of choosing: whether making the trip altogether, to what destination, by what mode and along what route on the network; like in the classical four stages approach, but with the guarantee that submodels associated to each step are consistent.

The demand model utilised is a mode and route choice model where the mode choice, conditional to route choice, is given by a multinomial logit model, calibrated on RP-SP data while the route choice models are multinomial logit for the auto and moped and sequential logit, following again the definition of Nguyen, Pallottino and Gendreau (1998) for the transit mode.

The reason why RP-SP data has been deemed necessary is that the introduction of a road pricing scheme involves changing the choice set of road users, since the alternative of choosing certain routes by paying a price is given, possibly eliminating the alternative of choosing the same routes free. What matters, however, is that the new choice set provides to the users a new alternative, whatever happens to the other alternatives of the present choice set.

For this particular application, the LTZ has been delimited by a cordon of 23 access arcs where a different price is imposed on each class (actually the price is imposed also on the egress arcs in order to simulate the effects of pricing on residents, as the reference period is morning rush hour).

Users have been divided into systematic (regular) and non-systematic (non-regular). As the main purpose of the simulations performed is to evaluate the effects of pricing on the travel choices of users directed to the LTZ, a specific demand model for this class has been produced. The reference individual is a high-level-employed (including self-employed), young male, while the reference mode is car. The travel demand components are divided into eight user classes (see Table 7-8).

Table 7-8 Travel Demand Components

User Class	LTZ	Systematic
sys_RES	Yes	Yes
sys_AUT	Yes	Yes
sys_NAUT	Yes	Yes
sys_NLTZ	No	Yes
nsys_RES	Yes	No
nsys_AUT	Yes	No
nsys_NAUT	Yes	No
nsys_NLTZ	No	No

The surveys included both RP and SP. The RP was used to calibrate the whole utility model, except the price coefficient, which was obtained by calibrating the SP, where the results gathered from the RP were used for representing the utility of the current state (the SP were based on modifications of the current state obtained by imposing prices at different rates for accessing to the LTZ). The idea underlying the definition of two monetary coefficients, one for the fine, the other for the price, instead of a unique coefficient, was that the disutility of the fine is reduced in comparison with the one associated with a price, because the probability of being caught is less than 1.

As expected, calibrating mode choice for trips into the LTZ has yielded better demand models than those referring to the general case (the "Rho-Squared" is 0.5355/0.6021 for the LTZ models and 0.3071/0.4754 for the generic models). This is clearly the result of focusing the analysis on a specific type of trip, which reduces undesired averaging effects. On the other hand, mode choice for non-systematic trips appears to be easier to model than mode choice for systematic trips (the "Rho-Squared" is 0.4754/0.6021 for the non-systematic models and 0.3071/0.5355 for the systematic models).

7.3.2 Levels of Elasticity Assumed in the Modelling Process

Using the results from daytime scheme calibrated models it was possible to evaluate disaggregate and aggregate elasticities when a per trip price is experienced by the car's users.

To evaluate the aggregate elasticities for Systematic LTZ and Non-Systematic LTZ models has been used "sample enumeration". The others two models calibrated for the daytime scheme were not considered because they are not affected by the price.

To calculate the aggregate elasticities of each option considered in the models, the disaggregate elasticity of each user was first calculated, and then the aggregate elasticity was calculated for each level of car's price and for each option considered in the model.

The formulas used to evaluate disaggregate and aggregate direct and cross elasticity are shown below, and formulas 7.1 and 7.3 concern the direct car elasticity in respect to variation of own price while formulas 7.2 and 7.4 concern the cross elasticity of the other choices in respect of variation of the car's price.

Disaggregate Direct Elasticity

$$E_{x_{ink}}^{p_n(i)} = [1 - p_n(i)] \cdot x_{ink} \cdot \beta_k \qquad (7.1)$$

n index of individual
i index of transport mode
k index of attribute
E elasticity
p choice
x attribute
β parameter of the attribute in the utility function

Disaggregate direct elasticity is referred to car users, and $p_n(i)$ is the probability that user n uses the car when an x_{ink} car's price is experienced.

Disaggregate Cross Elasticity

$$E_{x_{jnk}}^{p_n(i)} = -p_n(j) \cdot x_{jnk} \cdot \beta_k \tag{7.2}$$

Disaggregate cross elasticity is referred to the other alternatives considered in the model where car's price is not a parameter of the utility function. In formula 7.2 $p_n(j)$ is the probability that user n uses the car when an x_{ink} car's price is experienced and, being the models used multinomial logit, the disaggregate cross elasticities are equal for all alternatives $i \neq j$.

Aggregate elasticity is the elasticity with respect to the expected probability of choice $\overline{p}(i)$ of a population of N individuals (who have different values of 1 or more attributes) where:

$$\overline{p}(i) = \frac{\sum_{n=1}^{N} p_n(i)}{N}$$

Under the hypothesis that the attribute with respect to which the elasticity is evaluated is equal across the population of individuals, there is for aggregate direct and cross elasticities:

Aggregate Direct Elasticity

$$E_{x_{ik}}^{\overline{p}(i)} = \frac{\dfrac{\partial \overline{p}(i)}{\partial x_{ik}}}{\dfrac{\overline{p}(i)}{x_{ik}}} = \frac{\sum_{n=1}^{N} p_n(i) \cdot E_{x_{ik}}^{p_n(i)}}{\sum_{n=1}^{N} p_n(i)} \tag{7.3}$$

Aggregate Cross Elasticity

$$E_{x_{jk}}^{\overline{p}(i)} = \frac{\dfrac{\partial \overline{p}(i)}{\partial x_{jk}}}{\dfrac{\overline{p}(i)}{x_{jk}}} = \frac{\sum_{n=1}^{N} p_n(i) \cdot E_{x_{jk}}^{p_n(i)}}{\sum_{n=1}^{N} p_n(i)} \tag{7.4}$$

$\overline{p}$ aggregate value of choice

Aggregate cross elasticity is different for all the alternatives because $p_n(i)$ the probability that user n uses the transport mode i when transport mode j is priced and x_{jk} is the level of price.

In the daytime scheme two different series of elasticities have been calculated according to the two different models calibrated for each category, which are:

- Systematic LTZ users;
- Non-Systematic LTZ users.

For each model the aggregate elasticities of the different transport mode choices were evaluated with the improvement of the per trip car's price using formulas reported above. The price increases from € 1 to € 6.

The results of the Systematic LTZ models are shown in Figure 7-8 and in Figure 7-9.

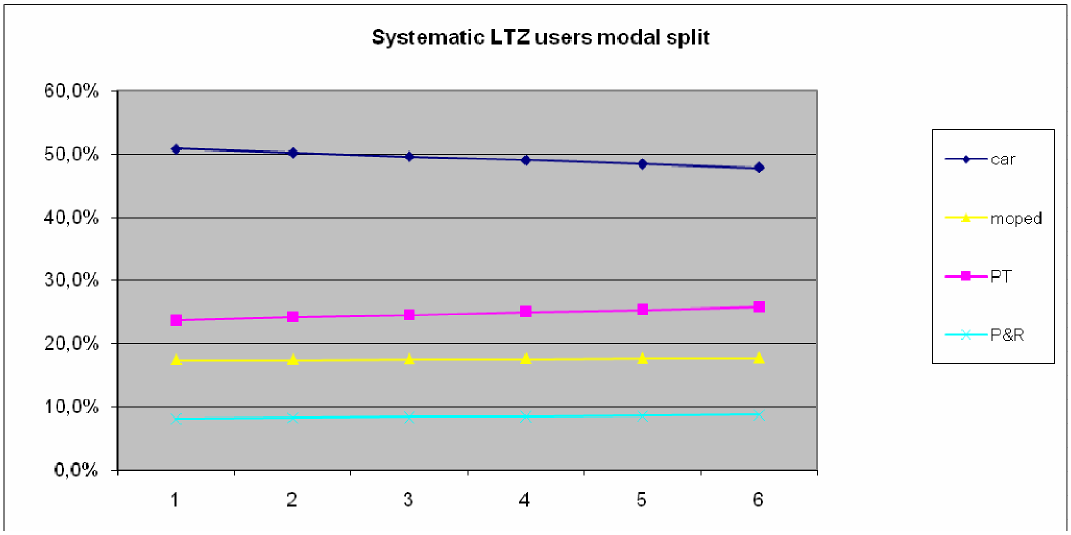


Figure 7-8 Systematic LTZ Users Model - Modal Share and Level of Price – Daytime Scheme

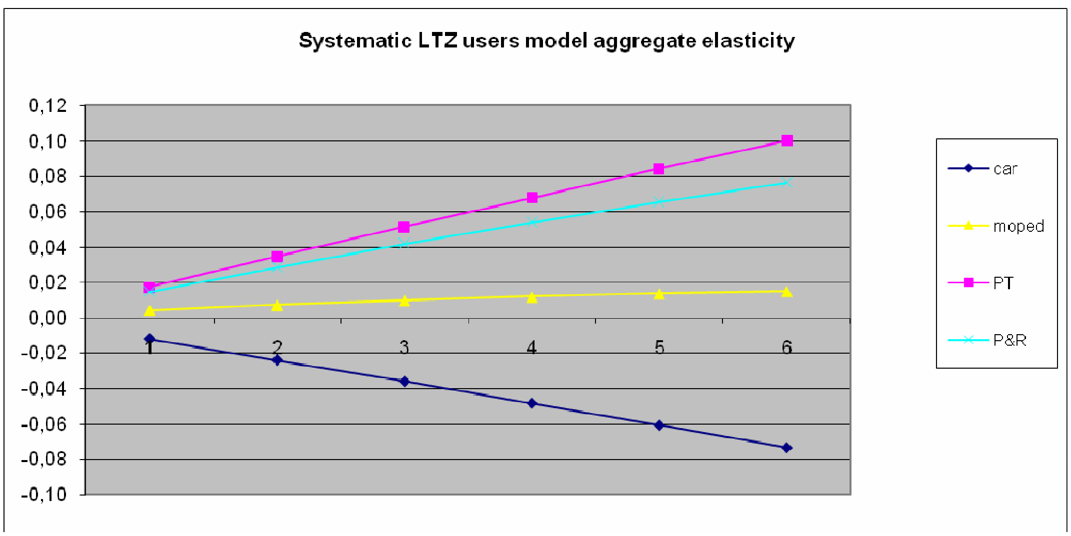


Figure 7-9 Systematic LTZ Users - Level of Price and Elasticity – Daytime Scheme

Concerning the car modal share, with the improvement of the price a slight reduction of its modal share is observed and its elasticities are negative but very low in absolute terms. PT shows a very slightly increase of modal share and a positive and low elasticities. P&R and Moped options do not show appreciable variations of modal share when an increase of the price is experienced, and the values of elasticities are lower than the PT ones but always positive.

The results of Non-Systematic LTZ users are shown in Figure 7-10 and in Figure 7-11.

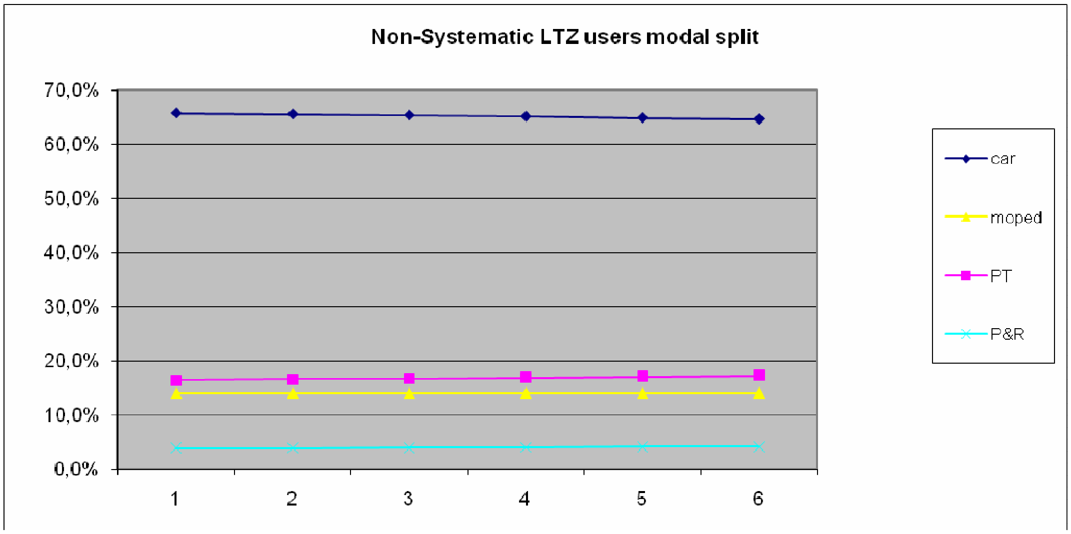


Figure 7-10 Non-Systematic LTZ Users Model - Modal Share and Level of Price – Daytime Scheme

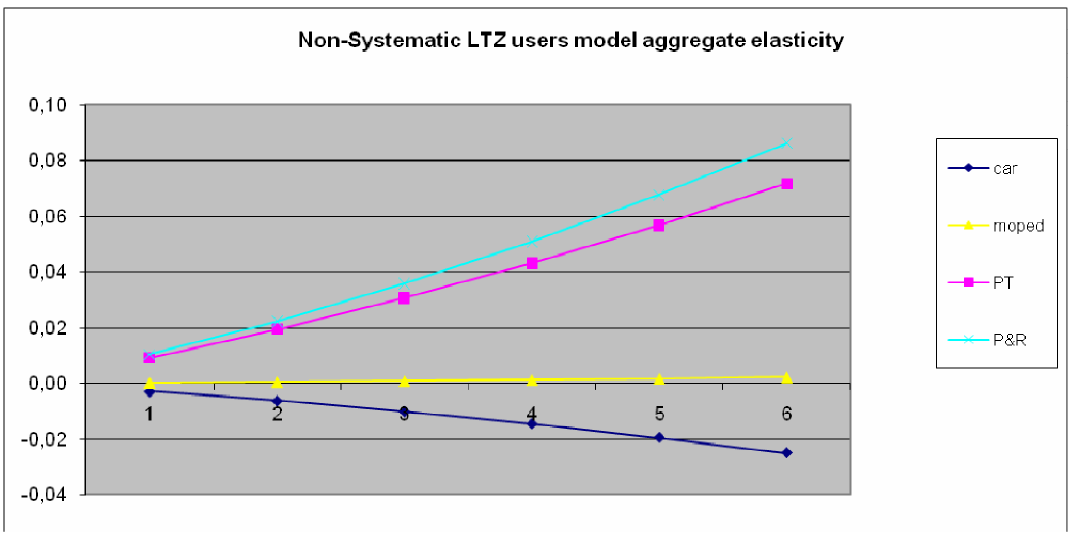


Figure 7-11 Non-Systematic LTZ Users - Level of Price and Elasticity – Daytime Scheme

Non-Systematic LTZ users do not show to be effected by an increase of the price to enter in the LTZ. The modal share of each option does not show an appreciable variation and also the elasticities (negative for car and positive for the other options) are very close to 0.

7.4 RESULTS FROM EX-ANTE MODELLING OF THE DAYTIME SCHEME

7.4.1 Traffic Impact

Traffic and Congestion Levels

The results, in terms of traffic and passengers flows, have been referred to six sectors (corridors) accessing the LTZ. Each sector includes some access gates and transit arcs:

- Sector 1: V01 – Ferdinando di Savoia, V02 – Passaggio di Ripetta, V03 – Tomacelli, V04 – Ripetta, V05 – Zanardelli; Metro A

- Sector 2: V06 – Panico, V07 – Corso Vittorio, V08 – Fiorentini, V09 – San Filippo Neri, V10 – Giulia, V11 – Arenula; Tram 8
- Sector 3: V12 – Teatro Marcello, V13 – Fori Imperiali
- Sector 4: V14 – Serpenti, V15 – Santa Maria Maggiore, V16 – Urbana, V17 – De Pretis
- Sector 5: V18 – Torino, V19 – Nazionale, V20 XX Settembre; Metro A
- Sector 6: V21 San Basilio, V22 Vittorio Veneto, V23 Crispi.

The number of passengers accessing the LTZ for each sector refers to each of the three transport modes (C = car, M = moped, T = transit), but only cars and mopeds are relevant for determining the traffic and congestion levels.

It must be noted that, in order to calculate the number of vehicles accessing the LTZ indicated in the figures, the number of passengers were divided by the vehicle occupancy coefficient: 1.5 for cars and 1.1 for motorcycles, in accordance with the conducted surveys.

Figure 7-12 and Figure 7-13 refer, respectively, to the morning peak and off-peak hours, when the road pricing scheme is applied together with the existing access restriction. With reference to the previous section, the results of scenario 0 to 6 are shown.

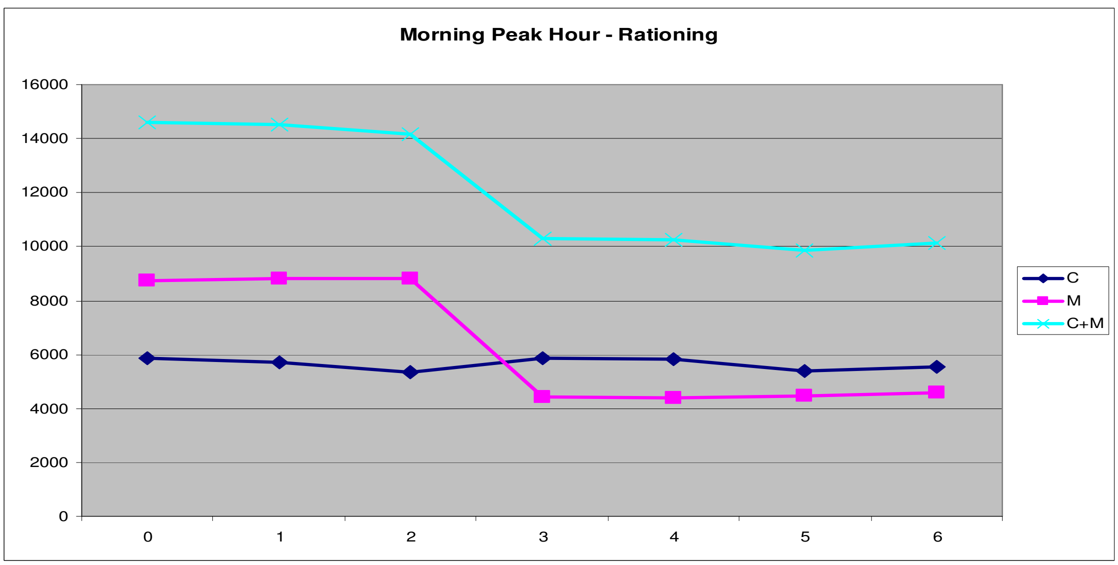


Figure 7-12 Road Pricing and Access Restriction (Morning Peak Hour)

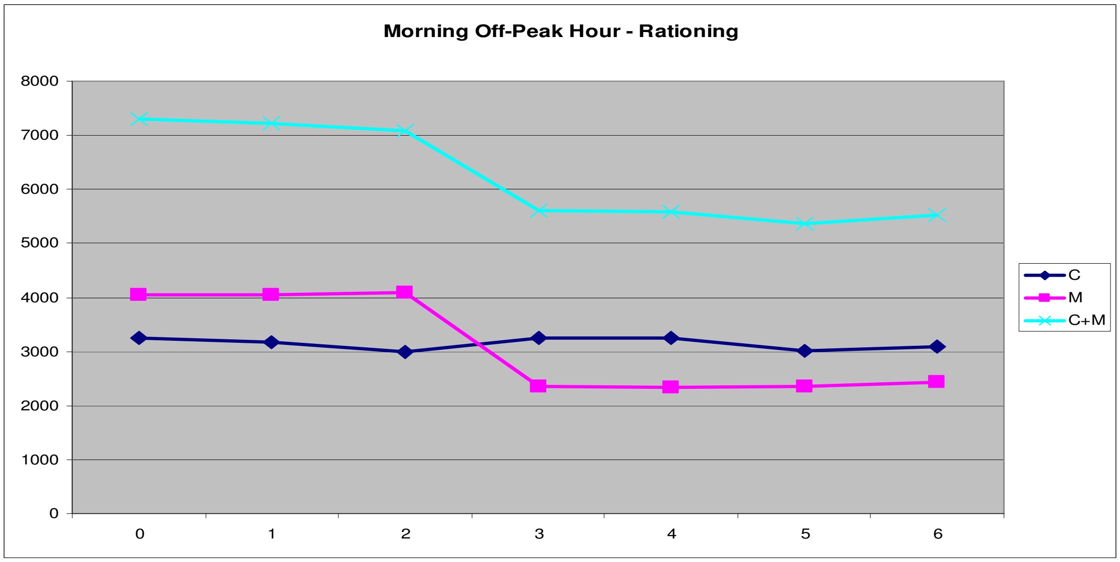


Figure 7-13 Road Pricing and Access Restriction (Morning Off-Peak Hour)

In particular, in the morning peak hour, passing from scenario 0 to scenario 1 and 2, there is we a car decrease, of 3% and 9% respectively, and a moped increase of 1% in each scenario. Introducing moped pricing in scenario 3, 4, 5 and 6, mopeds halve compared to scenario 0. In scenario 3 and 4, cars are the same as in scenario 0, but they decrease in scenario 5 and 6, with 8% and 5% respectively.

In total, in the morning peak hour, compared with scenario 0 (14,600 vehicles), there is a decrease of vehicles in scenario 1 of 1% (14,500 vehicles), in scenario 2 of 3% (14,150 vehicles), in scenario 3 of 29% (10,300 vehicles), in scenario 4 of 30% (10,250 vehicles), in scenario 5 of 33% (9,850 vehicles) and in scenario 6 of 31% (10,150 vehicles).

In particular, in the morning off-peak hour, passing from scenario 0 to scenario 1 and 2, there is a car decrement, respectively, of 2% and 8% and a moped increment of 1% only in scenario 2. Introducing moped pricing in scenario 3, 4, 5 and 6, mopeds decrease of 42% comparing to scenario 0. In scenario 3 and 4, cars are the same of scenario 0 but they decrease in scenario 5 and 6, respectively, of 7% and 5%.

Totally, in the morning off-peak hour, comparing with scenario 0 (7,300 vehicles), there is a decrease of vehicles in scenario 1 of 1% (7,200 vehicles), in scenario 2 of 3% (7,100 vehicles), in scenario 3 and 4 of 23% (5,600 vehicles), in scenario 5 of 26% (5,350 vehicles) and in scenario 6 of 24% (5,550 vehicles).

Figure 7-14 refers to the entire period from 6:30 to 18:00, i.e. the current operational period of the access restriction. Scenarios from 0 to 6 are again considered. The results are obtained by adding to the results of the two previous simulations an estimation of the traffic and passenger flows for the remaining hours, which are obtained through available variation coefficients based on the morning peak hour situation.

In particular, in the daytime, passing from scenario 0 to scenario 1 and 2, there is a car decrease of 2% and 8% respectively and a moped increment of 1% only in scenario 2. Introducing moped pricing in scenario 3, 4, 5 and 6, mopeds decrease 47% compared to scenario 0. In scenario 3 and 4, cars are the same of scenario 0 but they decrease in scenario 5 and 6, of 8% and 5% respectively.

In total, in the daytime, compared with scenario 0 (80,900 vehicles), there is a decrease of vehicles in scenario 1 of 1% (80,350 vehicles), in scenario 2 of 3% (78,400 vehicles), in scenario 3 of 27% (58,750 vehicles), in scenario 4 of 28% (58.450 vehicles), in scenario 5 of 31% (56,200 vehicles) and in scenario 6 of 29% (57,800 vehicles).

Finally, Figure 7-15 refers to the case of the full pricing scheme (scenario 7). The morning peak hour has been simulated, considering different price levels. That scheme assumes that residents and moped users are not charged, while a common per-trip price is assumed for all the remaining categories of car drivers.

In the morning off-peak hour with full pricing, compared to scenario 0, there is a decrease of cars and an increase of mopeds in all scenarios.

In total, compared with scenario 0 (35,150 vehicles), there is a decrease of vehicles in scenario 1 of 23% (27,100 vehicles), in scenario 2 of 32% (24,050 vehicles), in scenario 3 of 40% (21,150 vehicles), in scenario 4 of 49% (17,850 vehicles), in scenario 5 of 56% (15,400 vehicles) and in scenario 6 of 61% (13,800 vehicles).

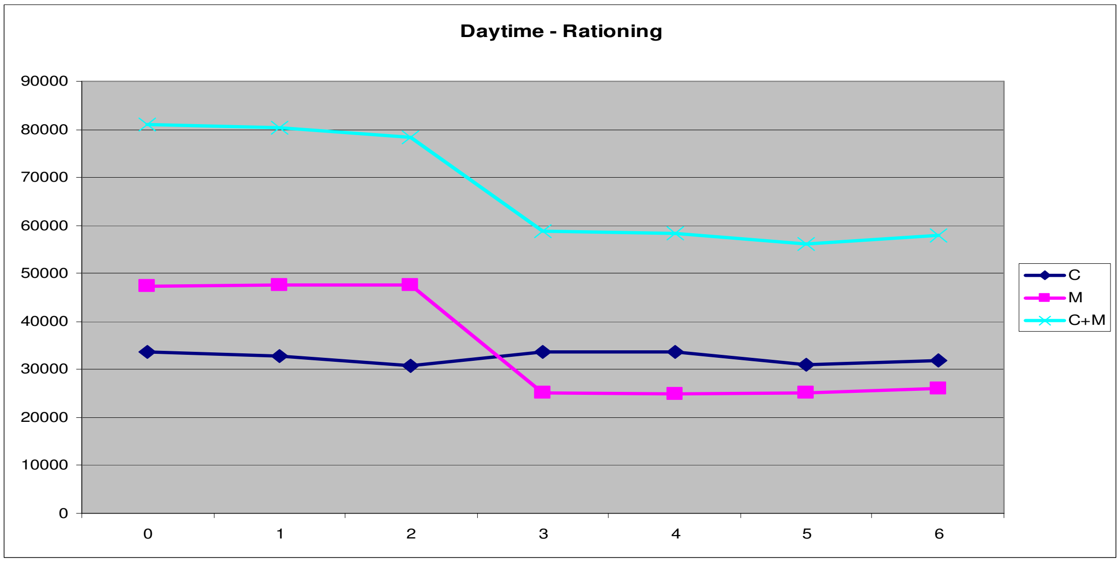


Figure 7-14 Road Pricing and Access Restriction (6:30 – 18:00)

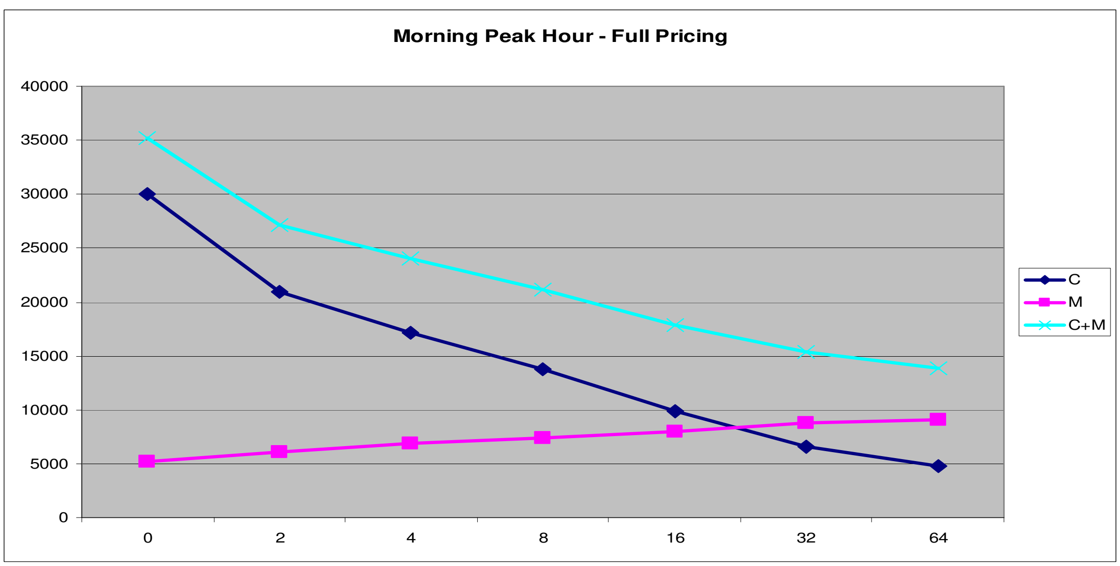


Figure 7-15 Road Pricing With Full Pricing (Morning Peak Hour)

Modal Shift

To evaluate modal shift, according to existing measurements, it has been assumed that a large part of the vehicles entering the LTZ (about 3,800 vehicles in the morning peak hour) is constituted by taxis, police, services, goods vehicles, i.e. vehicles that will not be charged after the road pricing scheme introduction. These vehicles have been considered as a base traffic in the simulations. It means that only a relatively small number of the vehicles currently accessing the area (about 2,200 in the morning peak hour) have been considered as possibly subject to charges.

This is why no substantial changes would be expected, in terms of overall modal split, moving from scenario 0 to scenarios 1 and 2, where only cars are still charged, even with a per-trip system instead of the annual permit system, as in scenario 0 (see Figure 7-16).

Focusing on the particular classes of charged car users, it emerges, however, that some 10% of the authorised car users switch to public transport when a € 3 per-trip price is imposed (scenario 1), while an additional € 3 charge (scenario 2) is required to move another 10%. With regard to residents, some 7% of them switch to public transport when a € 300 annual price is introduced.

In scenarios 5 and 6 the combined effects of car and moped charging are shown. No significant differences emerge between the two scenarios.

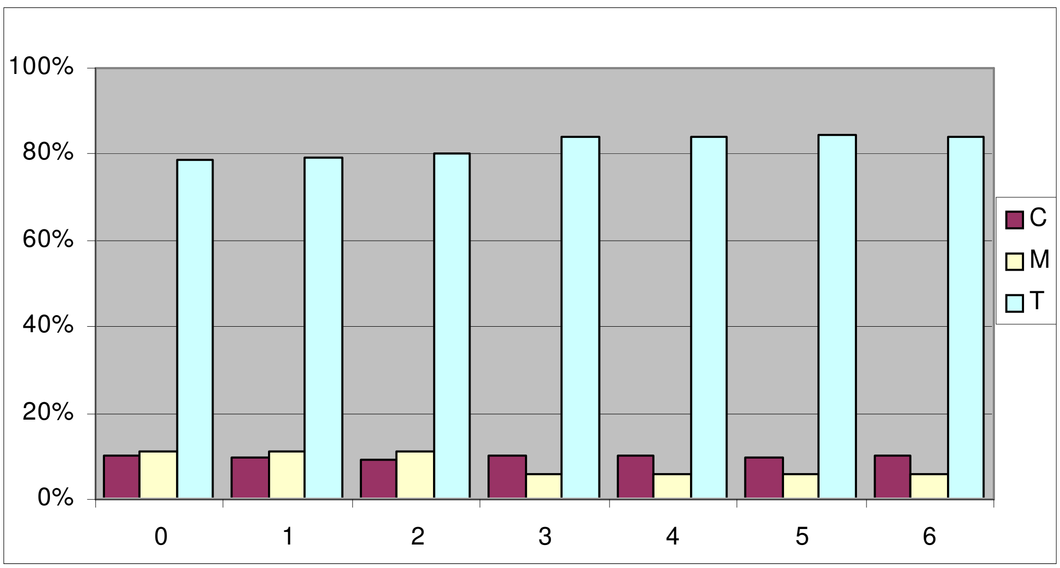


Figure 7-16 Modal Split in Scenarios 0 – 6 (Morning Peak Hour)

More relevant changes occur when mopeds are charged (scenarios 3 – 6). This is mainly due to the reduction of through-traffic for this category of users. The phenomenon is clearly shown in Figure 7-17 where the percentage of through-trips for each mode is indicated (the remaining trips have, obviously, their destinations inside the LTZ).

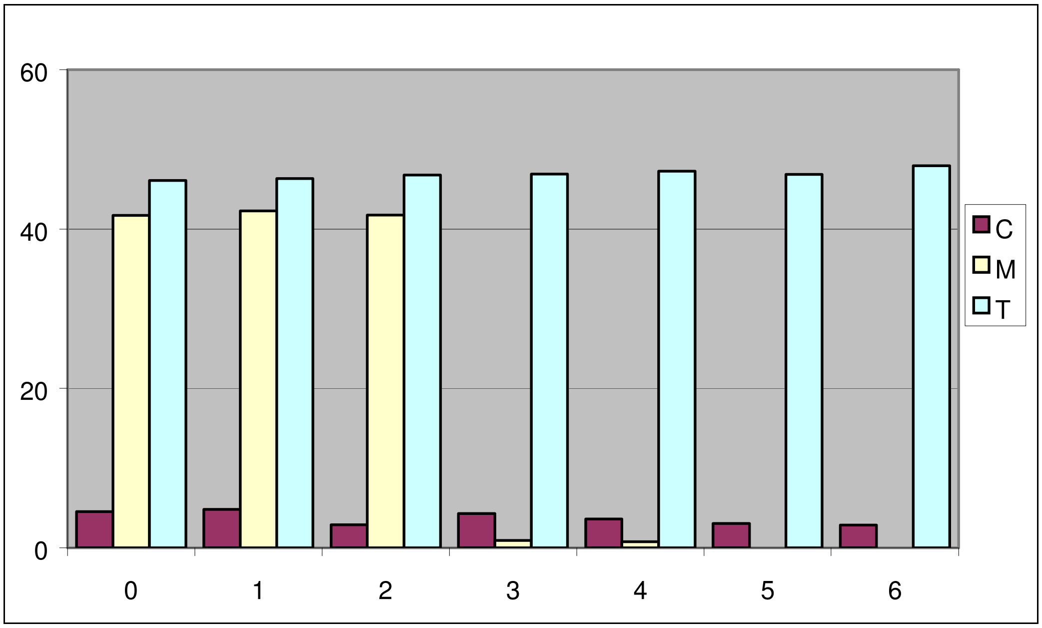


Figure 7-17 Percentage of Through Trips in Scenarios 0 – 6 (Morning Peak Hour)

Trip Diversion to Other Destinations

The destination choice has not been included in the simulation model. This variable, in fact, is relevant only if the access to the LTZ is regulated by means of road pricing policies, as an alternative to rationing. It is only in such case, in fact, that the availability of the car mode alternatives, corresponding to LTZ destinations, is likely to attract trips previously bound for other destinations, being otherwise only a second order effect. Moreover, decision-makers are not considering, at the moment, the adoption of a road pricing scheme allowing all auto users to enter the LTZ by paying a charge, so that most pricing schemes simulated refer to the charge being levied on accesses by already authorised users, such as mopeds. The scenario with the LTZ only regulated by means of road pricing policies has also been simulated, but just as a hypothetical reference case.

On the other hand, survey results showed that the introduction of a road pricing scheme in the LTZ would not induce a change of destination for users currently accessing the area.

Trip Suppression

Survey results showed that the introduction of a road pricing scheme in the LTZ would not induce a suppression of trip for users currently accessing the area.

7.4.2 Effects on Traffic Safety

The expected safety impact variations in scenarios 1 – 6 are shown in Figure 7-18 for the morning peak hour. The percentage variation refers to scenario 0. All trips with origin or destination inside the LTZ have been considered. Emissions, fuel consumption and accidents have been calculated using available functions and factors.

It should be noted that in the scenarios involving only car pricing the KSI (Killed and Seriously Injured) value increases, because some car drivers switch to moped, with mopeds being much more dangerous than cars.

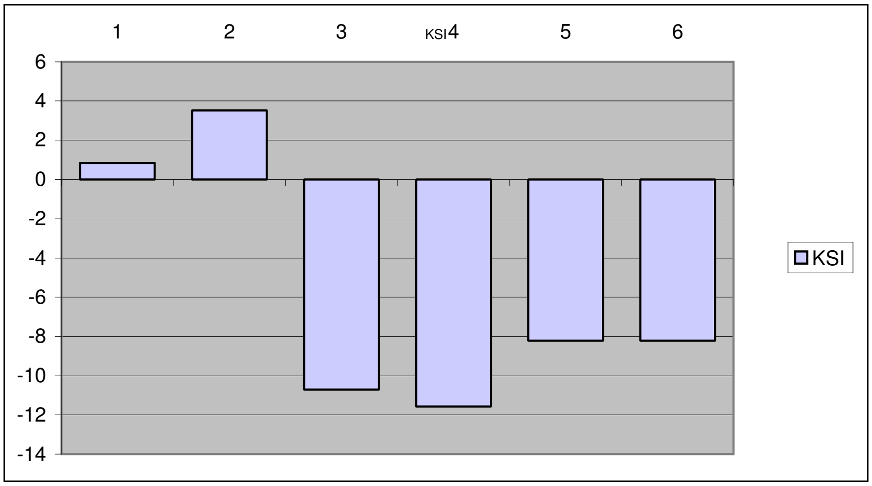


Figure 7-18 Percentage Variation of Safety Impacts in Scenarios 1 – 6 (Morning Peak Hour)

7.4.3 Environmental Impact

The expected environmental impact variations in scenarios 1 – 6 are shown in Figure 7-19 for the morning peak hour. The percentage variation refers to scenario 0. All trips with origin or destination inside the LTZ have been considered. Emissions and fuel consumption have been calculated using available functions and factors.

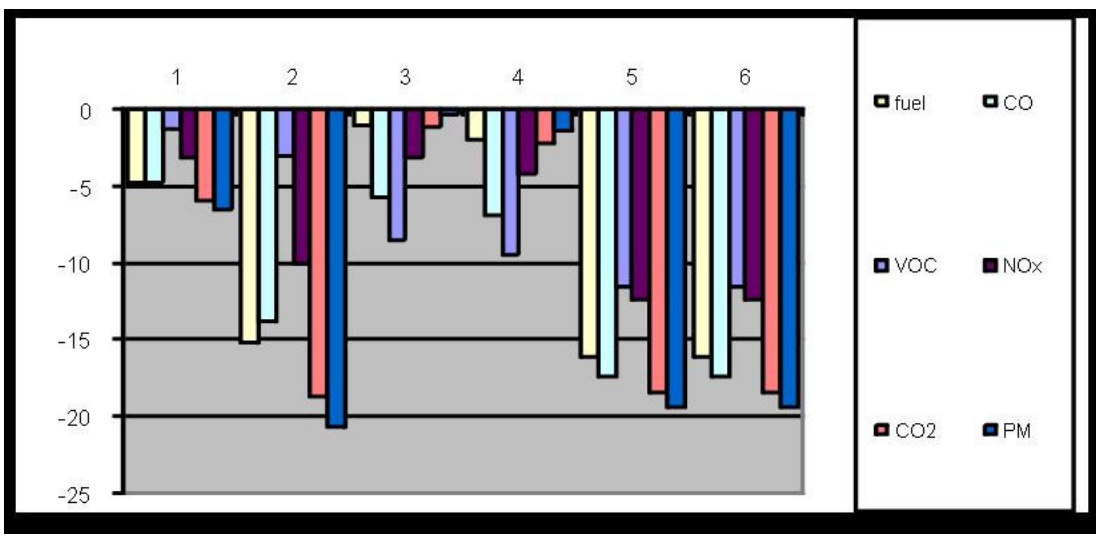


Figure 7-19 Percentage Variation of Environmental Impacts in Scenarios 1 – 6 (Morning Peak Hour)

As the production of pollution is non-linear with traffic speed, the effect on environmental indicators is much more relevant than on modal split.

With regard to PM emissions, the model underestimates the contribution of mopeds to such pollutant (the Meet Methodology does not consider PM emissions for mopeds) and, thus, the PM emission reduction in scenarios where mopeds are charged. A recent study (ENEA 2001), however, demonstrated the significant contribution of mopeds to PM emissions, estimating that some 82% of PM emissions in the historical centre of Rome are produced by mopeds.

7.5 RESULTS FROM EX-ANTE MODELLING OF THE NIGHT SCHEME

7.5.1 Model Used

In the night scheme, both in the summer scheme and in the winter scheme, multinomial logit models have been used. These models, calibrated on RP-SP data, have been used to assess the impacts on the user behaviour of the introduction of road pricing schemes in the night period. Beyond the introduction of the road charges, also the improvement of the PT service (expressed in terms of trip time) has been considered in the SP scenarios.

This assumption, although reducing the precision of the model, has been considered acceptable, since in the night hours the congestion level (for both private and public transport network) is lower than in the daytime hours and, thus, its influence on the higher level user choices (destination of the trip and used transport mode) is lower.

In the summer scheme, the demand models have been calibrated on the basis of 730 RP-SP interviews, in the night scheme on the basis of 847 interviews. The models were calibrated considering the scaling effect, in order to take into account the different variances of the RP and SP utility functions. Some corrections of the ASA terms determined by calibration of the demand models were needed in order to reproduce the current situation.

In the user choice sets of the summer scheme, not only the different modes (car, moped, public transport) were included, but also, according to the different classes of users, change of destination, postponement of the trip after 23:00 (i.e. when the charge would be no longer applicable), change of route (i.e. avoiding the charged area).

Four different models have been calibrated for four different classes of users:

- Users with destination inside the LTZ for work trips;
- Users with destination inside the LTZ for recreational trips;
- Users with destination inside the LTZ for shopping trips;
- General car drivers currently crossing the LTZ.

In every case only users directed to (or crossing) the LTZ have been considered. The case of new trips generated or diverted to the LTZ after the introduction of the road pricing schemes has not been considered realistic.

In the winter scheme, two different choice models have been calibrated: one for the users (car drivers) crossing the LTZ, and the other for the users entering the LTZ. Concerning this last group of users, differently from the summer scheme simulations, a division into three sub-groups according to the aim of the travels has not been done, because the number of users of each sub-group would be evaluated only after further precision verifications.

Multimodal logit models have been used, and three further choices have been considered inside the whole possible choices:

- Change of the destination of the travel;
- Postponement of the travel after the pricing period;
- Travel change (avoiding the priced zone).

7.5.2 Levels of Elasticity Assumed in the Modelling Process

Using the results from the night scheme calibrated models it was possible to evaluate disaggregate and aggregate elasticities when a per trip price is experienced by the car's users.

To evaluate the aggregate elasticities the "sample enumeration" (Ben Akiva 1985) method has been used, and to calculate the aggregate elasticity of each option considered in the models the disaggregate elasticity of each user was first calculated and then the aggregate elasticity was calculated for each level of price and for each option considered in the model.

The formulas used to evaluate disaggregate and aggregate direct and cross elasticities are reported below, and formulas 7.1 and 7.3 concern the direct car elasticity in respect to variation of own price while formulas 7.2 and 7.4 concern the cross elasticities of the others choices in respect to variation of car's price.

Disaggregate Direct Elasticity

$$E_{x_{ink}}^{p_n(i)} = [1 - p_n(i)] \cdot x_{ink} \cdot \beta_k \qquad (7.1)$$

n index of individual
i index of transport mode
k index of attribute
E elasticity
p choice
x attribute
β parameter of the attribute in the utility function

Disaggregate direct elasticity refers to car users, and $p_n(i)$ is the probability that user n uses the car when an x_{ink} car's price is experienced.

Disaggregate Cross Elasticity

$$E_{x_{jnk}}^{p_n(i)} = -p_n(j) \cdot x_{jnk} \cdot \beta_k \qquad (7.2)$$

Disaggregate cross elasticity refers to the other alternatives considered in the model where car's price is not a parameter of the utility function. In formula 6.2 $p_n(j)$ is the probability that user n uses the car when an x_{ink} car's price is experienced and, being the models used multinomial logit, the disaggregate cross elasticities are equal for all alternatives $i \neq j$.

Aggregate elasticity is the elasticity with respect to the expected probability of choice $\overline{p}(i)$ of a population of N individuals (who have different values of 1 or more attributes) where:

$$\overline{p}(i) = \frac{\sum_{n=1}^{N} p_n(i)}{N}$$

Under the hypothesis that the attribute with respect to which the elasticity is evaluated is equal across the population of individuals, there is for aggregate direct and cross elasticities:

Aggregate Direct Elasticity

$$E_{x_{ik}}^{\overline{p}(i)} = \frac{\dfrac{\partial \overline{p}(i)}{\partial x_{ik}}}{\dfrac{\overline{p}(i)}{x_{ik}}} = \frac{\sum_{n=1}^{N} p_n(i) \cdot E_{x_{ik}}^{p_n(i)}}{\sum_{n=1}^{N} p_n(i)} \qquad (7.3)$$

Aggregate Cross Elasticity

$$E_{x_{jk}}^{\overline{p}(i)} = \frac{\dfrac{\partial \overline{p}(i)}{\partial x_{jk}}}{\dfrac{\overline{p}(i)}{x_{jk}}} = \frac{\sum_{n=1}^{N} p_n(i) \cdot E_{x_{jk}}^{p_n(i)}}{\sum_{n=1}^{N} p_n(i)} \tag{7.4}$$

$\overline{p}$ aggregate value of choice

Aggregate cross elasticity is different for all the alternatives, because $p_n(i)$ is the probability that user n uses the transport mode i when transport mode j is priced and x_{jk} is the level of price.

In the summer night scheme, four different series of elasticities have been considered according to the four different models calibrated for each trip purpose, that are:

- Users with destination inside the LTZ for work trips;
- Users with destination inside the LTZ for recreational trips;
- Users with destination inside the LTZ for shopping trips;
- General car drivers currently crossing the LTZ.

For each model the aggregate elasticities of the different transport mode choices were evaluated with the improvement of the per trip price using formulas above reported. The price improves from € 1 to € 6.

7.5.3 Results

For work trips results are reported in Figure 7-20 and in Figure 7-21.

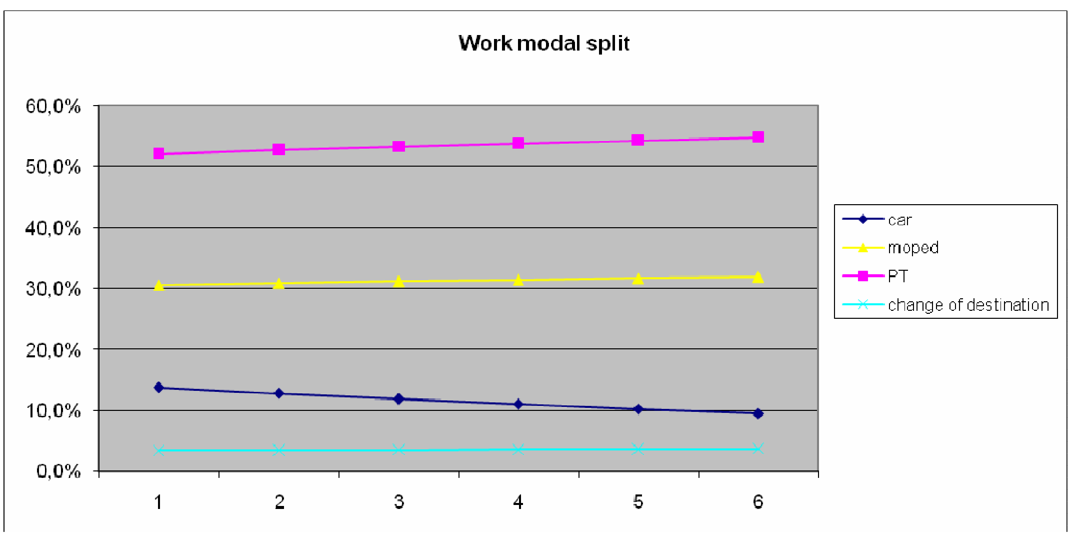


Figure 7-20 Work Trips - Modal Share and Level of Price – Summer Night Scheme

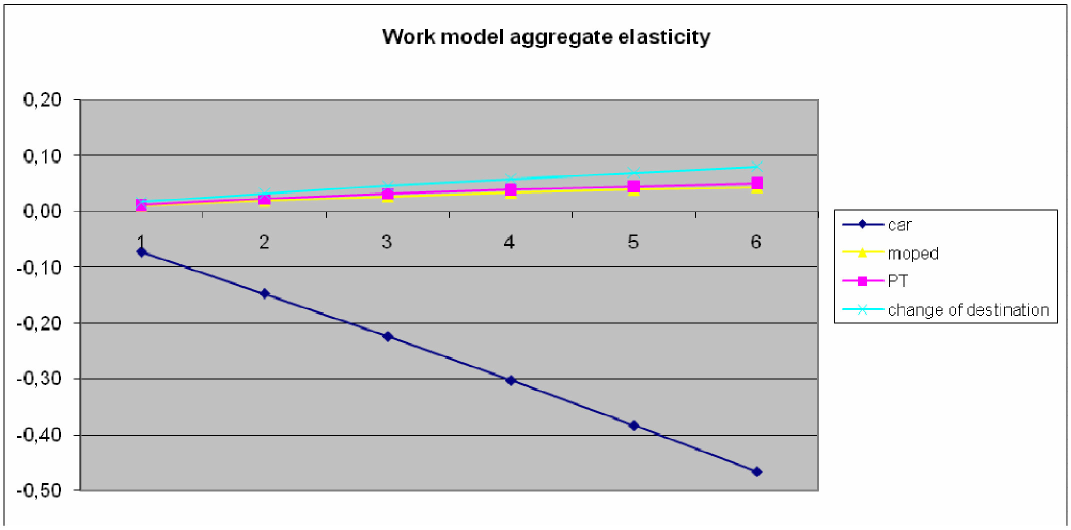


Figure 7-21 Work Trips - Level of Price and Elasticity - Summer Night Scheme

Concerning the work trips, with the improvement of price a slight change in user behaviour is observed. This matches with what was observed for elasticities that are always, in absolute terms, lower than one.

For shopping trips results are reported in Figure 7-22 and in Figure 7-23.

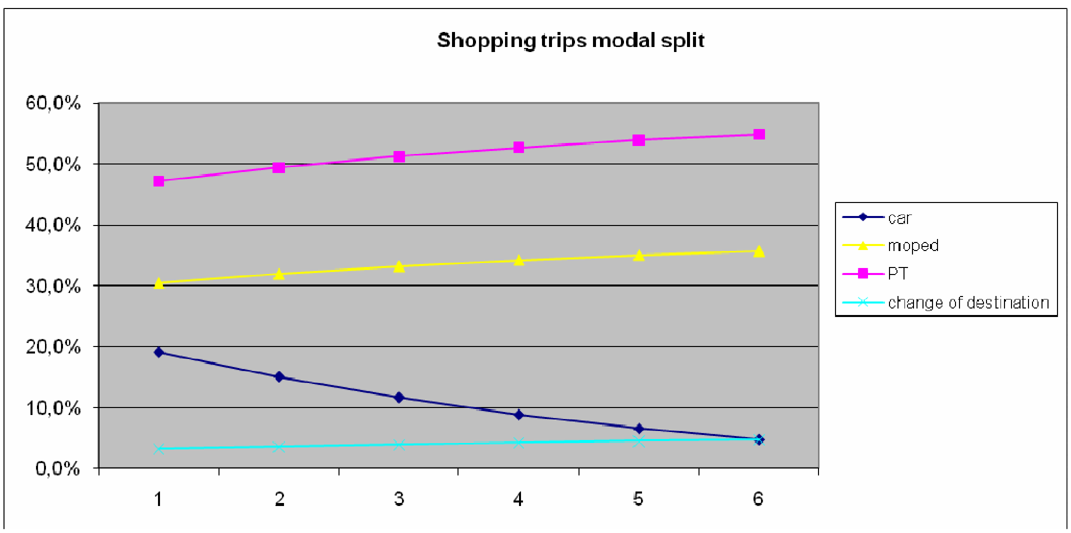


Figure 7-22 Shopping Trips - Modal Share and Level of Price – Summer Night Scheme

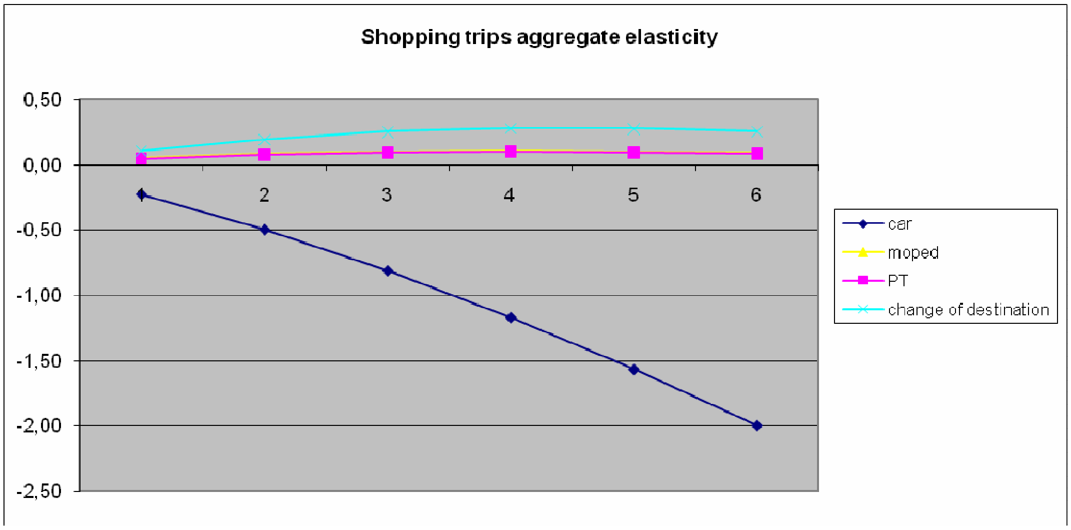


Figure 7-23 Shopping Trips - Level of Price and Elasticity – Summer Night Scheme

Concerning the shopping trips, with the improvement of the price, a change in user behaviour is observed. The car modal share decreases strongly by about the 14% when the price increases for € 1 to € 6. Also the public transport modal share experienced a rather strong increase of about 7% when the price increases from € 1 to € 6. On the other hand, the moped modal share and change of destination modal share do not show strong variations. The car shows a strong increase in elasticity, in absolute terms, and for a € 6 price the car's elasticity is about 2. The other alternatives show positive but low elasticities, and change of destination shows the highest elasticities, probably because for a car's price increase it is the alternative that has the greatest relative increase of modal share.

For recreational trips results are reported in Figure 7-24 and Figure 7-25.

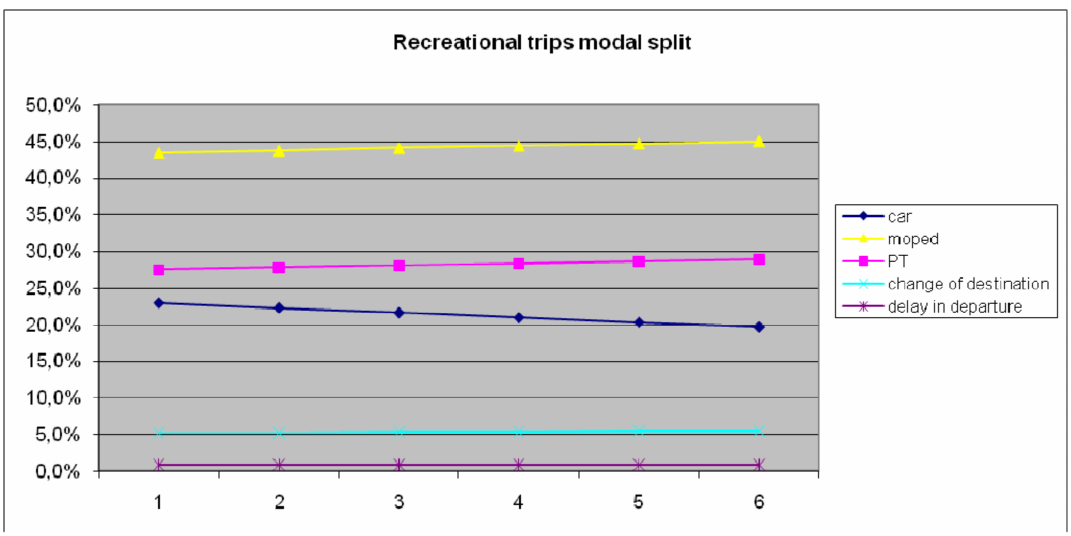


Figure 7-24 Recreational Trips - Modal Share and Level of Price – Summer Night Scheme

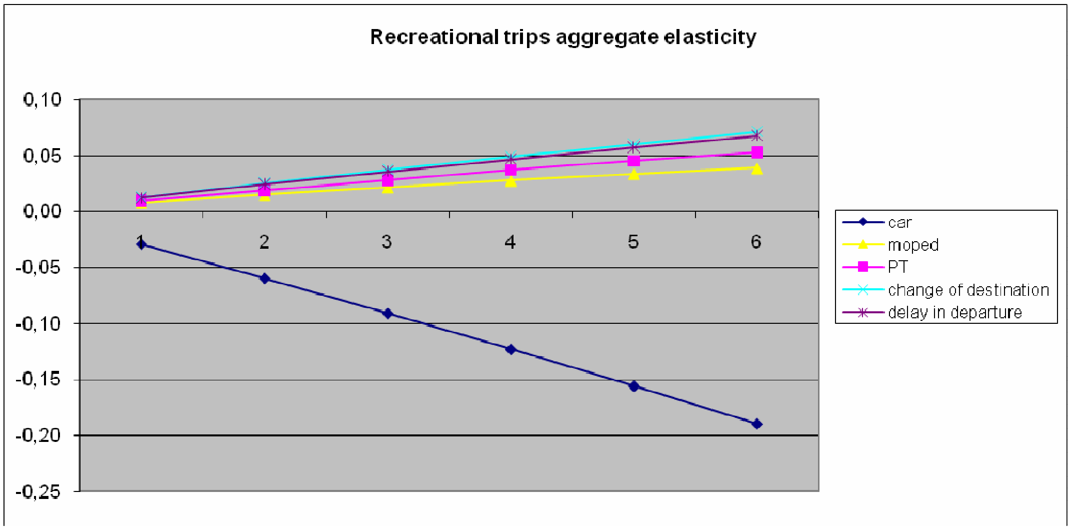


Figure 7.25 Recreational Trips - Level of Price and Elasticity – Summer Night Scheme

The recreational trips do not show appreciable modal shift when a car's price increase is experienced by users, and for this reason they show very low elasticities in absolute terms. Moreover, recreational trips elasticities are lower than work and shopping trips ones. It means that people moving for recreational reasons do not change their behaviour when a trip's price increase is experienced.

Results from crossing trips are shown in Figure 7-26 and in Figure 7-27.

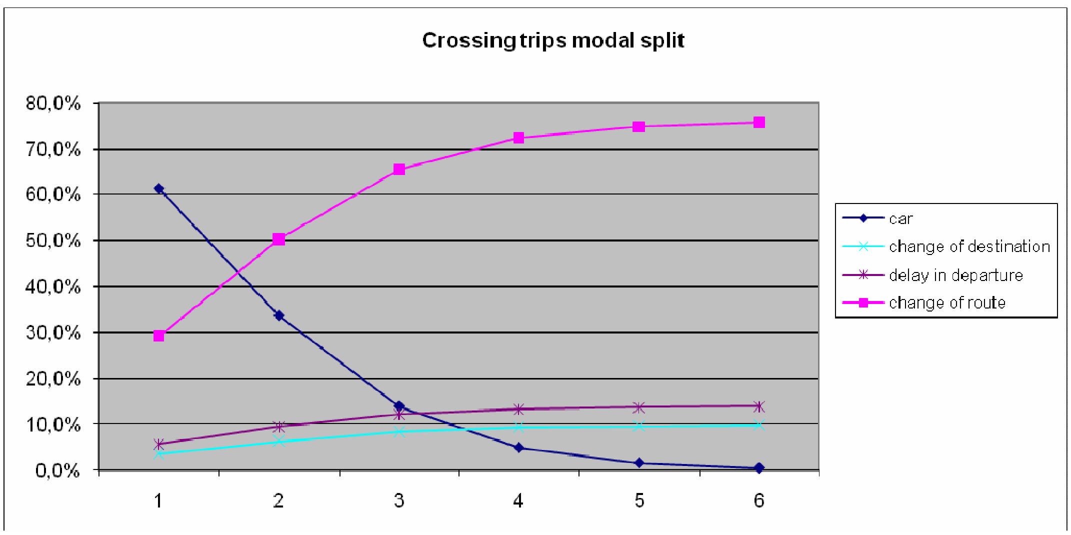


Figure 7-26 Crossing Trips - Modal Share and Level of Price – Summer Night Scheme

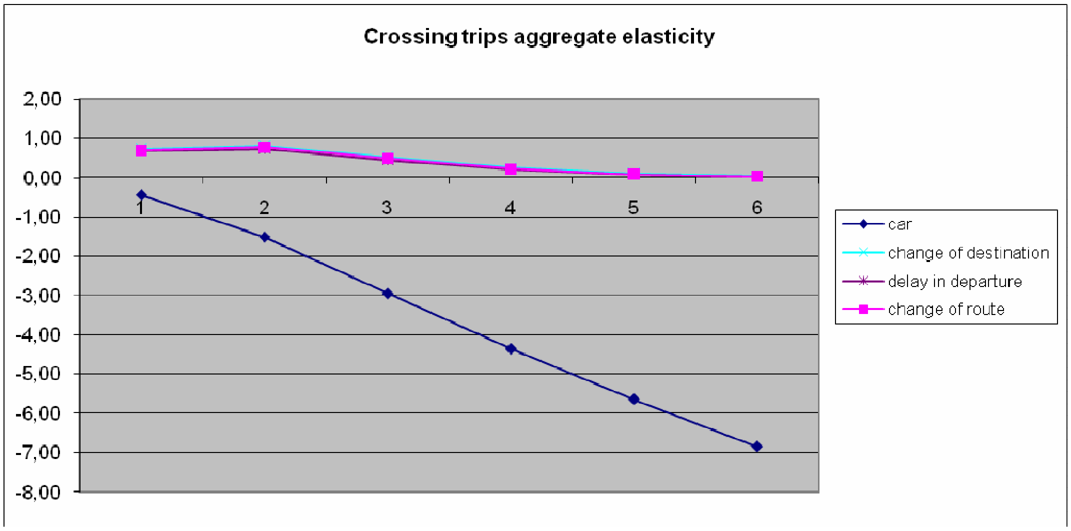


Figure 7-27 Crossing Trips - Level of Price and Elasticity – Summer Night Scheme

When car users experience a car's price increase, there is a strong change in behaviour. The use of a car to pass across the LTZ decreases strongly from 60% to about 0% while the other options increase strongly when an increase of the price is experienced by drivers. Elasticities have very interesting progression. The "car" elasticity is always negative and decreases strongly with the increase of the car trip's price. In contrast, the cross elasticities of the other options for a € 1 and € 2 price increase and then decrease slightly, because for prices over € 2 the variation of modal share is smaller than for a price under € 2.

In the winter night scheme two different series of elasticities have been considered according to the two different models calibrated for each trip purpose; they are:

- Users with destination inside the LTZ for work, recreational and shopping trips (briefly "winter model");
- General car drivers currently crossing the LTZ (briefly "crossing trips").

For each model the aggregate elasticities of the different transport mode choices were evaluated with the improvement of the per trip car's price using formulas above reported. Car trip's prices increase from € 1 to € 6.

Results from the winter model are shown in Figure 7-28 and in Figure 7-29.

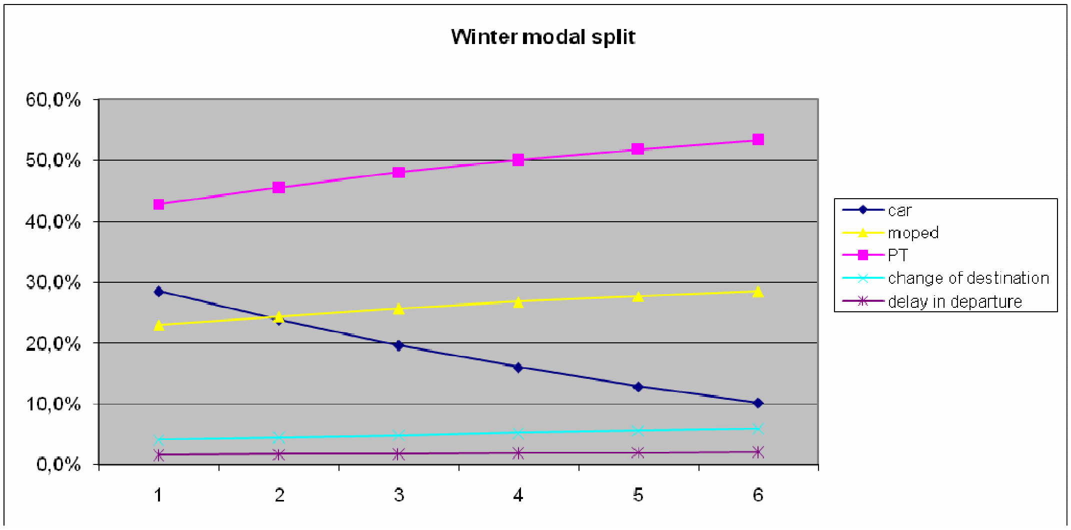


Figure 7-28 Winter Model - Modal Share and Level of Price – Winter Night Scheme

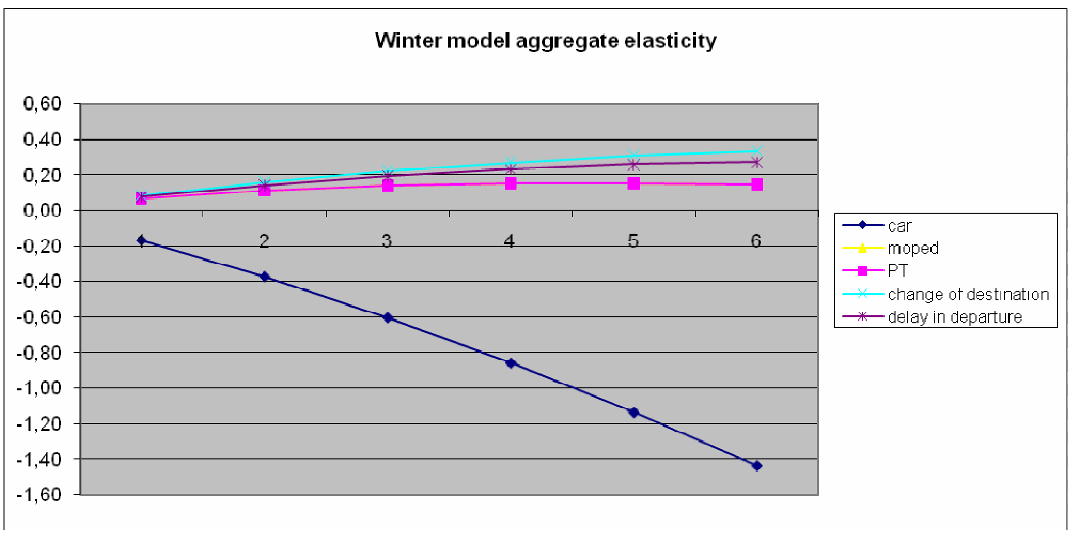


Figure 7-29 Winter Model - Level of Price and Elasticity – Winter Night Scheme

When an increase of price a strong reduction of car modal share is experienced, and an increase of the other options is observed. In particular, car users move to moped and to PT. The car elasticities are negative and decrease when an increase of price is experienced, and for a price of € 6 elasticities are around -1.40. In contrast, the other options show always positive elasticities, and for an increase of the price an increase of elasticity is observed. Change of destination and delay in departure options show elasticity values bigger than the moped and PT ones, probably because change of destination and delay in departure options have relatively bigger variations.

Results from crossing trips are shown in Figure 7-30 and Figure 7-31.

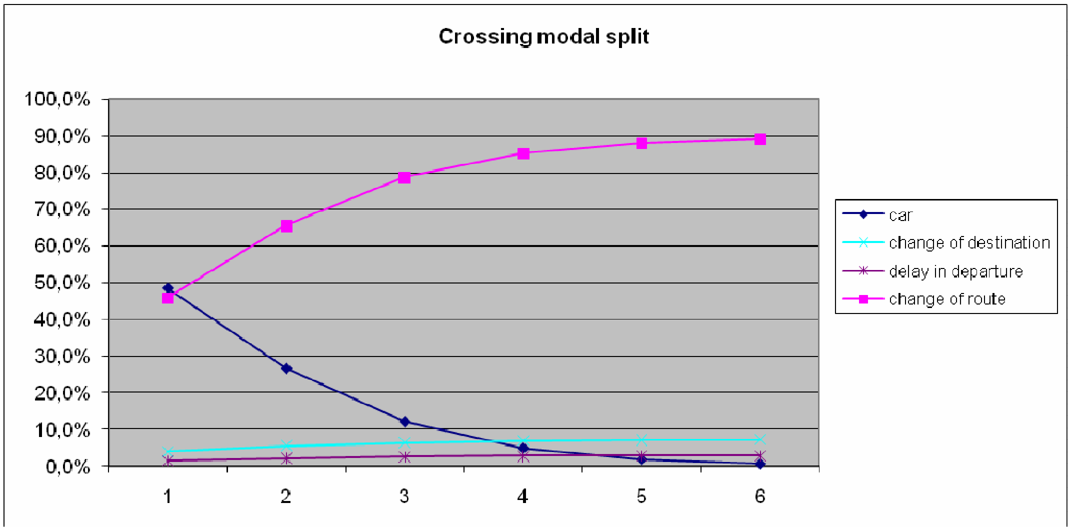


Figure 7-30 Crossing Trips - Modal Share and Level of Price – Winter Night Scheme

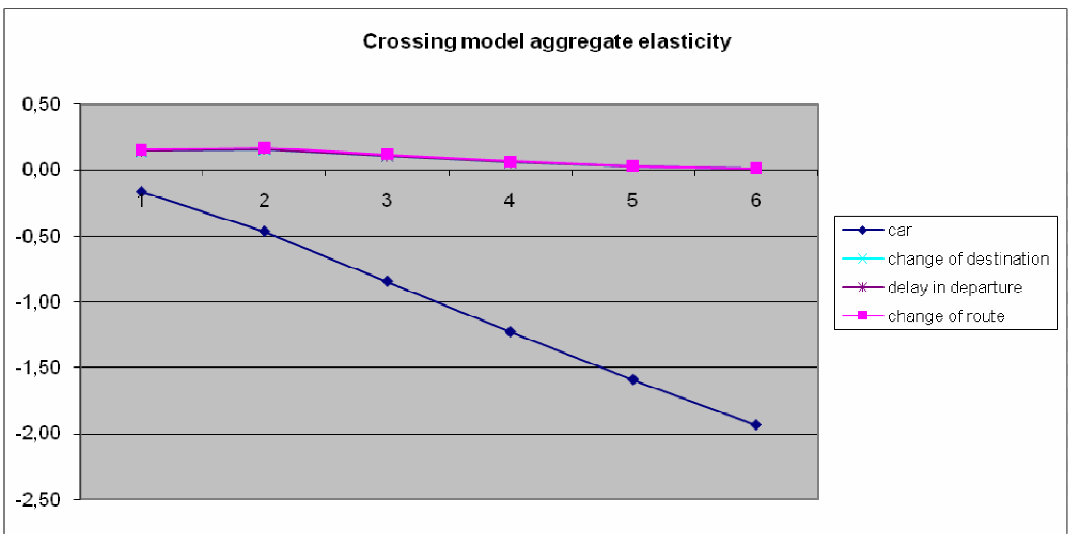


Figure 7-31 Crossing Trips - Level of Price and Elasticity – Winter Night Scheme

The car's modal share decreases strongly when an increase of car's price is experienced and for a € 6 charge for the car it is close to 0%. Change of route modal share increases strongly when an increase of the car's price is experienced. In contrast, change of destination and delay in departure s do not show strong variations when an increase of the car's price is experienced. The car elasticity is negative and decreases when an increase of the price is experienced. In contrast, the other options have positive elasticities, but they decrease when an increase of the car's price, of more than € 2 is experienced, probably because for a € 1 or € 2 car charge a bigger relative variation of modal share is observed.

Traffic and Congestion Levels

Figure 7-32 and Figure 7-33 show the overall effects of the road charges introduction on users with destination inside the LTZ and users crossing the LTZ. The former is about the summer scheme, the latter is about the winter scheme. Cars and mopeds include:

- Private cars and mopeds crossing the LTZ;
- Private cars and mopeds accessing the LTZ for work, recreational or shopping trips;
- Resident's private cars and mopeds accessing the LTZ.

This list excludes buses, cabs and service vehicles.

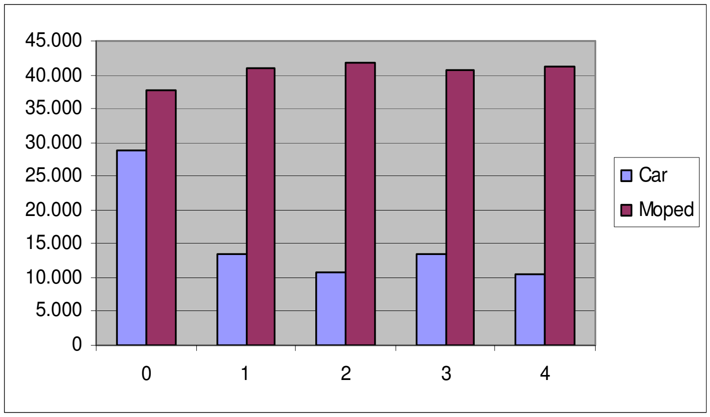


Figure 7-32 Cars and Mopeds from Charging Night Summer Scheme

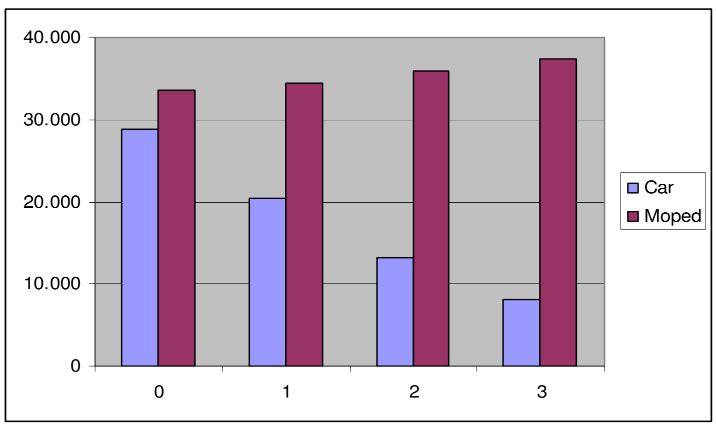


Figure 7-33 Cars and Mopeds from Charging Night Winter Scheme

Modal Shift, Trip Diversion to Other Destinations, Shift in Start-time of Travel, Rat-Running and Detours to Avoid Charges

The impacts of the night summer scheme introduction, combined, in some scenarios, with an increase of the public transport supply, have been simulated for each of the four identified classes of users (work, recreational or shopping trips and crossing).

Figure 7-34, Figure 7-35 and Figure 7-36 show what would be the results of the pricing schemes, in terms of modal split, change of destination and postponement of the trip, for the three classes of users with destination inside the LTZ. Some comments:

- The current modal split of the work and shopping trips classes is similar; in the third case (recreational-trips) the use of the private means (car and, particularly, moped) is much higher;
- In all the cases a significant reduction (around 50 % of the initial value) of the private car share occur, even with a € 3 charge;

- Most of the users leaving their car shift, in similar parts, to moped and public transport;
- The percentage of car drivers changing their destination is usually low; it is a bit higher (5.5 %) for the recreational-trips class;
- The percentage of car drivers postponing their trip is appreciable (1 %) only for the recreational-trips class;
- The additional effect due to the PT supply increase on the PT share ranges from 0.5 % (when a 10 % reduction of the PT average trip time is assumed) to 1.5 % (when a 20 % reduction of the PT average trip time is assumed).

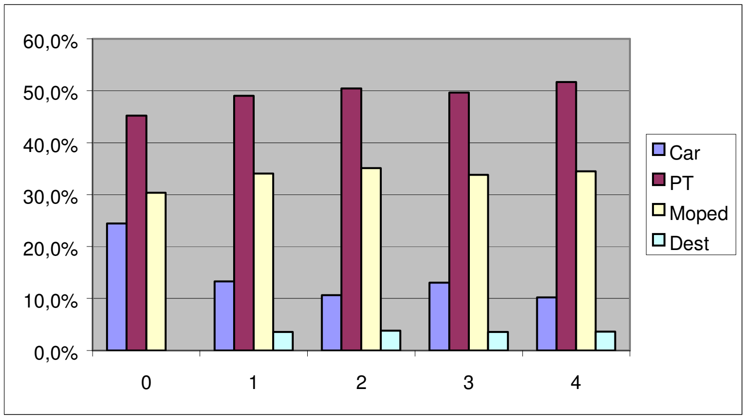


Figure 7-34 Impacts on Passengers Accessing the LTZ for Work Trips (Night Summer Scheme)

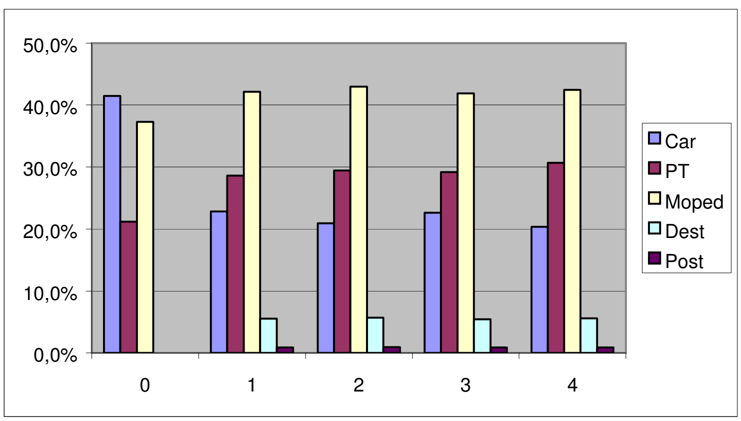


Figure 7-35 Impacts on Passengers Accessing the LTZ for Recreational Trips (Night Summer Scheme)

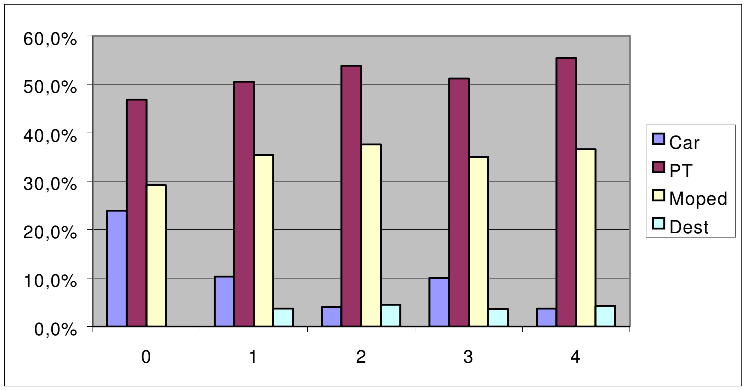


Figure 7-36 Impacts on Passengers Accessing the LTZ for Shopping Trips (Night Summer Scheme)

Figure 7-37 shows the overall effects of the road charges introduction on users with destination inside the LTZ. In this case, beyond the three classes examined above, also residents (whose modal split is not affected by the charges) are taken into account.

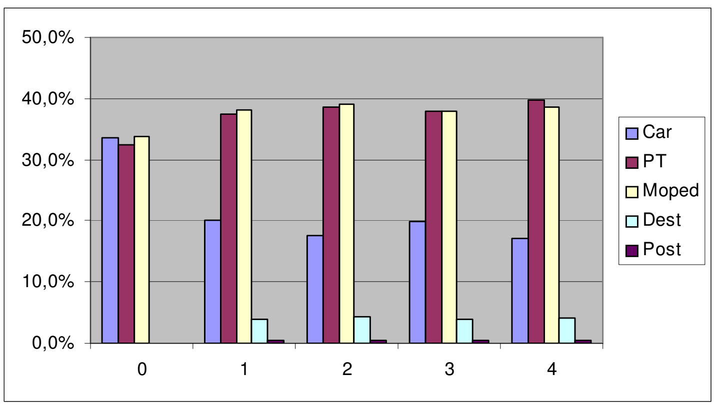


Figure 7-37 Overall Impacts on Passengers Accessing the LTZ (Night Summer Scheme)

Very interesting results arise from the analysis of the impacts that the road pricing scheme would have on car drivers crossing the LTZ (see Figure 7-38). Only some 14.5 % of the car drivers continue to cross the area with a € 3 charge, while they nearly disappear with a € 6 charge. Most of the car drivers would change their route, avoiding the charged area.

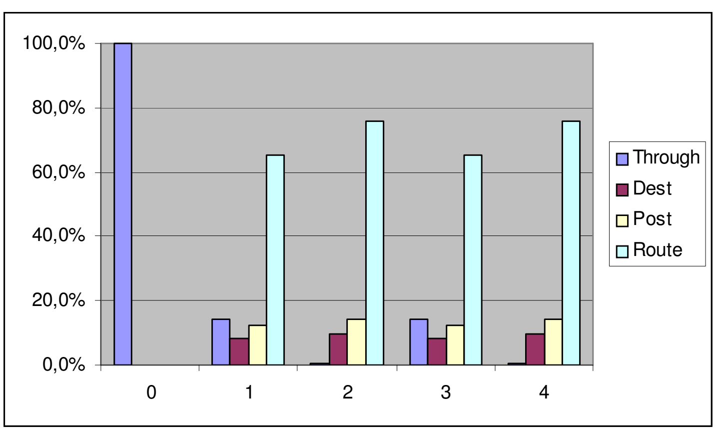


Figure 7-38 Impacts on Car Drivers Crossing the LTZ (Night Summer Scheme)

In absolute terms, Table 7-9 shows the overall number of vehicles (private cars and mopeds) accessing the area (including those just crossing it) or diverting their trips (destination, time, route) in the different scenarios.

Table 7-9 Vehicles Accessing the LTZ (18:00 – 23.00)

	Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Cars accessing LTZ	28,870	13,480	10,760	13,350	10,510
Mopeds accessing LTZ	37,690	40,890	41,670	40,710	41,240
Cars changing destination	-	3,130	3,420	3,100	3,340
Cars postponing trips	-	1,270	1,430	1,270	1,420
Cars changing route	-	5,400	6,250	5,400	6,250

Figure 7-39 shows the impacts of the night winter scheme introduction in terms of modal split, change of destination and postponement of the trip, only for the classes of users "chargeable" with destination inside the LTZ. Some comments:

- In all the cases a significant reduction of the private car occurs with an increase of the charge (around 38% in the initial scenario, around 30% in the scenario 1, around 20% in the scenario 2 and around 10% in the scenario 3);
- Most of the users leaving their car shift to moped and public transport (in the scenario 3 the public transport exceeds 50%);
- The percentage of car drivers changing their destination or postponing their trip is low.

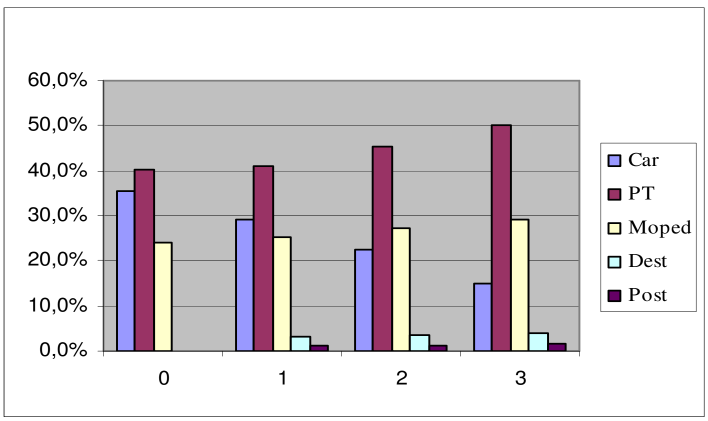


Figure 7-39 Impacts on Passengers Accessing the LTZ (night winter scheme)

A comparison between the summer results and the winter results shows:

- A different current situation;
- A substantial similarity in the users' behaviour for low charges (a € 3 charge halves the car modal dimension for both the cases);
- An appreciable difference in the users' behaviour for higher charges (in the summer scheme to pass from € 3 to € 6 does not produce appreciable changes, while in the winter scheme it halves the car modal dimension).

The simulations show that the crossing users (see Figure 7-40) are the most sensitive to price. Some 50% avoid the LTZ even with a € 1 charge. The percentage of those who would continue passing through the LTZ by car decreases to a little more than 10% in the second scenario and goes towards zero in the third scenario.

The most chosen alternative is the change of travel, which is preferred by 46% of the users in the first scenario, by 80% of users in the second scenario and by 90% of users in the third scenario.

The change of the destination and the postponement of the travel alternatives are less relevant; change of destination is chosen by 4% of the users in the first scenario and 7% of the users in the second scenario, whereas concerning the postponement of the travel 1.5% of the users choose it in the first scenario and 3% of them in the second scenario.

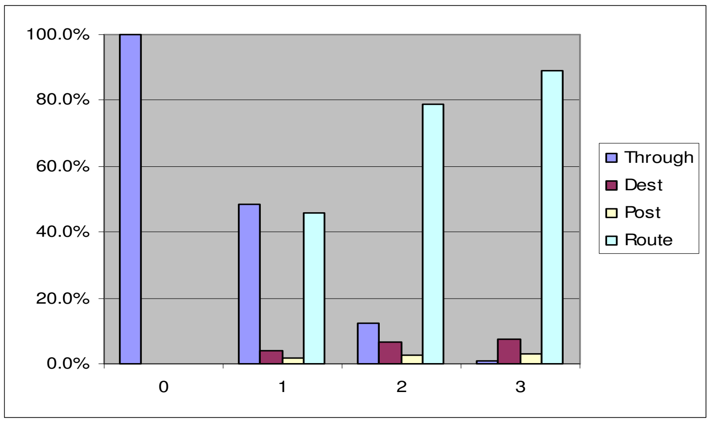


Figure 7-40 Impacts on Passengers Crossing LTZ (Night Winter Scheme)

The comparison with the summer scenario shows the same trend of the modal dimension of the users who continue to pass through the LTZ in the different scenarios. The trend of the alternatives is little different: in the summer scenario, the "change of travel" alternative is the most chosen, though less than in the winter scenario. This means that the alternatives "change of destination" and "postponement of the travel" in the summer scenario take a more important role than in the winter scenario. Such trend is maybe due to the higher share of the systematic trips in the winter scenario, for which such two alternatives are less significant.

Trip Suppression

Survey results showed that the introduction of a road pricing scheme in the LTZ would not induce a suppression of trips for users currently accessing the area, both in the summer period and in the winter period.

7.6 RESULTS FROM EX-ANTE SURVEYS

7.6.1 Acceptance of the Principle of the Charging Scheme

Before the implementation of IRIDE (automatic control system for entrance in LTZ) about 40% of the vehicles entering the Historic Centre LTZ had no permit. In 2000, just before the implementation of IRIDE, Rome Municipality run a survey to understand the degree of acceptance of the new automatic control system and the degree of acceptance of a per trip time based pricing scheme instead of a flat-fare pricing scheme.

The survey had a sample of 800 persons divided into 600 residents living inside the LTZ or close to it and 200 shopkeepers inside the LTZ.

One of the questions was "Which of these measures could be effective in reducing the impact of traffic and improving the life quality in the historic centre?". The measures proposed were:

- Use in the historic centre of low emission buses;

- Improvement of public transit system in the historic centre;
- Access control improvement to the LTZ;
- Pedestrian areas and PT improvements in the historic centre;
- Mopeds accesses limitation into the LTZ;
- Permits number reduction;
- LTZ operation hours improvement ;
- Restrictive law on car pollutant emissions;
- Per trip based pricing scheme of LTZ without need of permits;

Results are reported in Figure 7-41 and Figure 7-42.

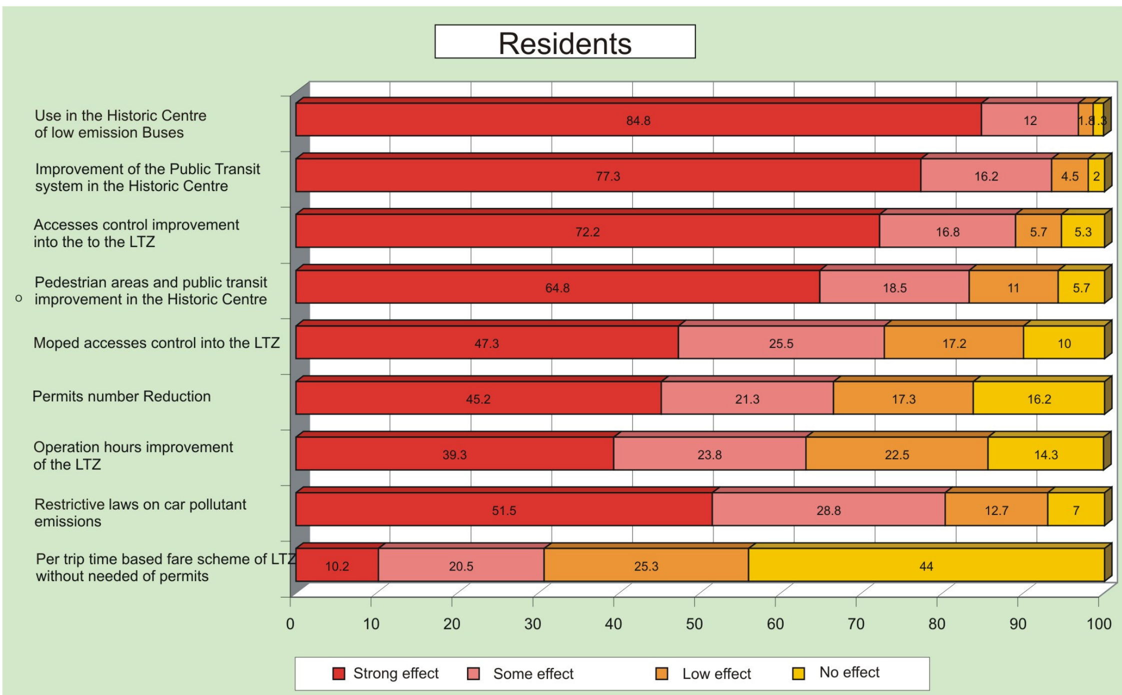


Figure 7-41 Degree of Acceptance of Different Measures – Residents

Looking at the results, 96.8% of residents believed that the use of low emission buses could be effective in improving the conditions in the historic centre and 93.5% felt that a general improvement of PT could be in some way effective. The large majority of residents also believed that a strengthening of the LTZ could be effective:

- 89% thought that an improvement in monitoring the access to the LTZ could be effective,
- 83.3% that an improvement of the pedestrian areas and an improvement of TP could be effective,
- 72.8% that a permits number limitation to enter the LTZ could be effective,
- 66.5% that an extension of the moped entrances limitation in the LTZ could be effective and
- 63.1% that an improvement of LTZ operational hours could be in some way effective.

The measure the residents considered not effective was a per trip time based pricing scheme. Indeed 69.3% of residents considered that this measure could be little effective or not effective at all.

Figure 7-42 Degree of Acceptance of Different Measures – Shopkeepers

Shopkeepers considered as effective the improvement of the PT, both using low emission busses, (97%) and improving the PT service (94.5%). Concerning LTZ strengthening shopkeepers were less supportive than residents although still 83% of them thought that an improvement in monitoring the access to the LTZ could be effective, 75% of them that an improvement of pedestrian areas with an improvement of PT could be effective, 52.5% that a limitation of number of permits to enter the LTZ could be effective. In contrast, the majority of retailers did not think that improvements in LTZ operation hours or a limitation of moped entrances would be effective.

62% of retailers did not consider a per trip time based pricing scheme as effective in reducing traffic impact and improving quality of life inside the historic centre.

In summary: the LTZ with a flat pricing scheme was well accepted, particularly by residents, who felt that a strengthening of LTZ with some kind of limitation and charging for entering the historic centre would be a good solution for historic centre problems. In contrast, a per trip time based pricing scheme, without any limitation to the LTZ access, was neither accepted by the residents nor the shopkeepers, who felt that this kind of scheme would not be not effective in solving the historic centre traffic problems.

The high degree of acceptance of an LTZ with a flat pricing scheme emerged also from another question of the survey. Both residents and shopkeepers were asked what they thought about the implementation of the new automatic control system for LTZ accesses and which impact they would have on:

- Reducing the pollutant emissions in the historic centre;
- Improving the modal share of the PT system.

The results are reported in Figure 7-43 and in Figure 7-44.

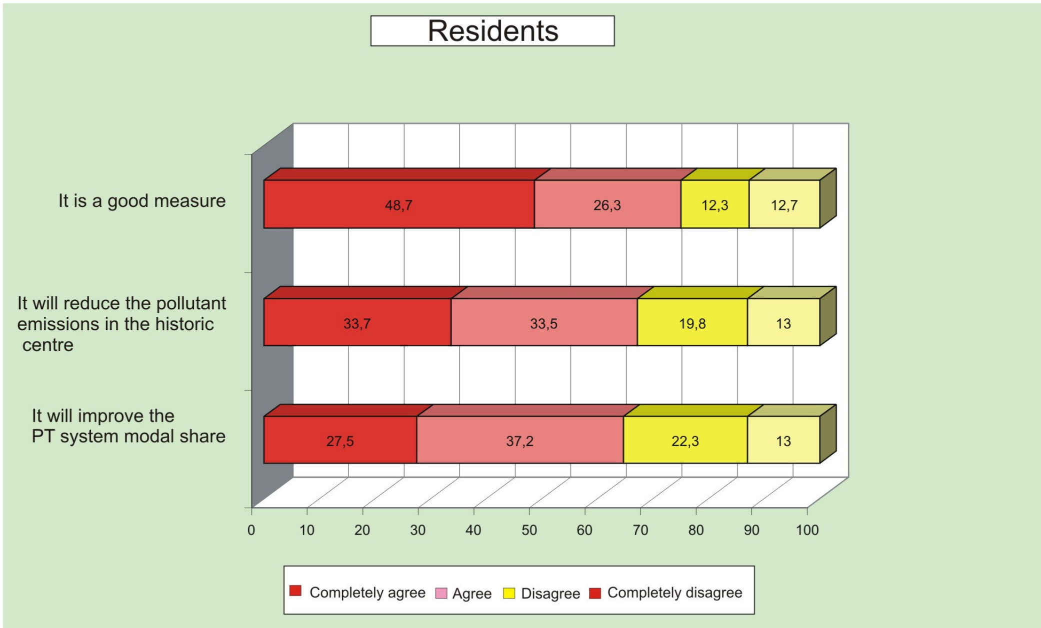


Figure 7-43 Degree of Acceptance of Automatic Access Control System – Residents

The majority of residents thought that the insertion of the automatic access control system was a good measure (75%), would reduce the pollutant emission (67%) and would improve PT modal share (64%).

Figure 7-44 Degree of Acceptance of Automatic Access Control System – Shopkeepers

Also in this case the shopkeepers were less supportive than residents, probably because they thought that an automatic access control system would reduce the number of costumers entering in the LTZ. Nevertheless, still 53% of shopkeepers thought that the access control automatic system was a good idea, 48.5% thought that it would reduce the pollutant emissions in the LTZ and 52.5% thought that it would improve the PT modal share.

7.6.2 Acceptance of the Planned Charging Scheme

Concerning the degree of acceptance of a time based per trip pricing scheme, the survey asked both residents and shopkeepers what they thought about the implementation of this scheme "only for already authorised non-residents" and which impact this would have on reducing the pollutant emissions in the historic centre and improving the modal share of PT.

The results are reported in Figure 7-45 and in Figure 7-46.

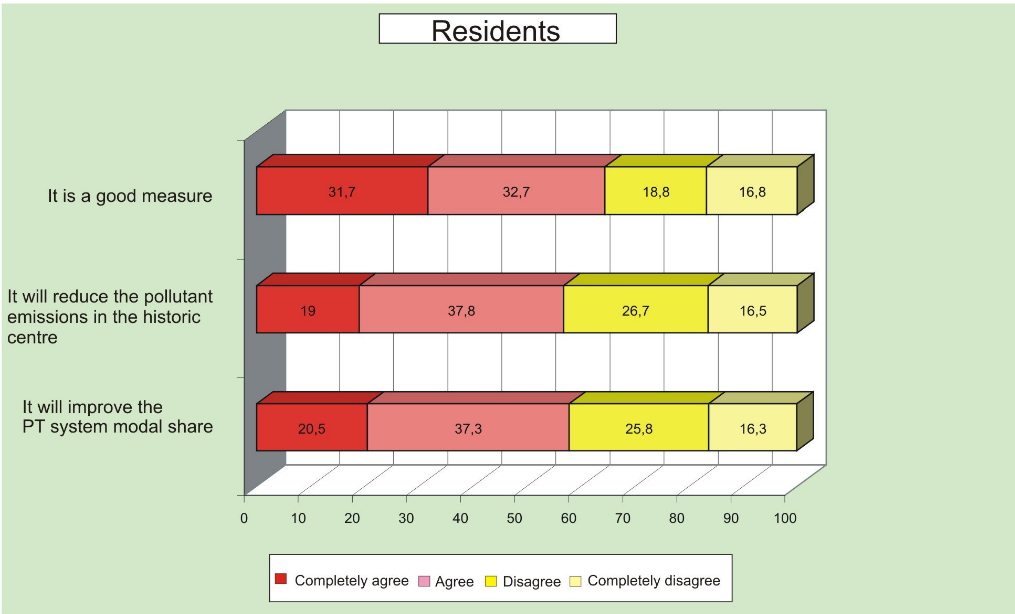


Figure 7-45 Degree of Acceptance of per Trip Time Based Pricing Scheme – Residents

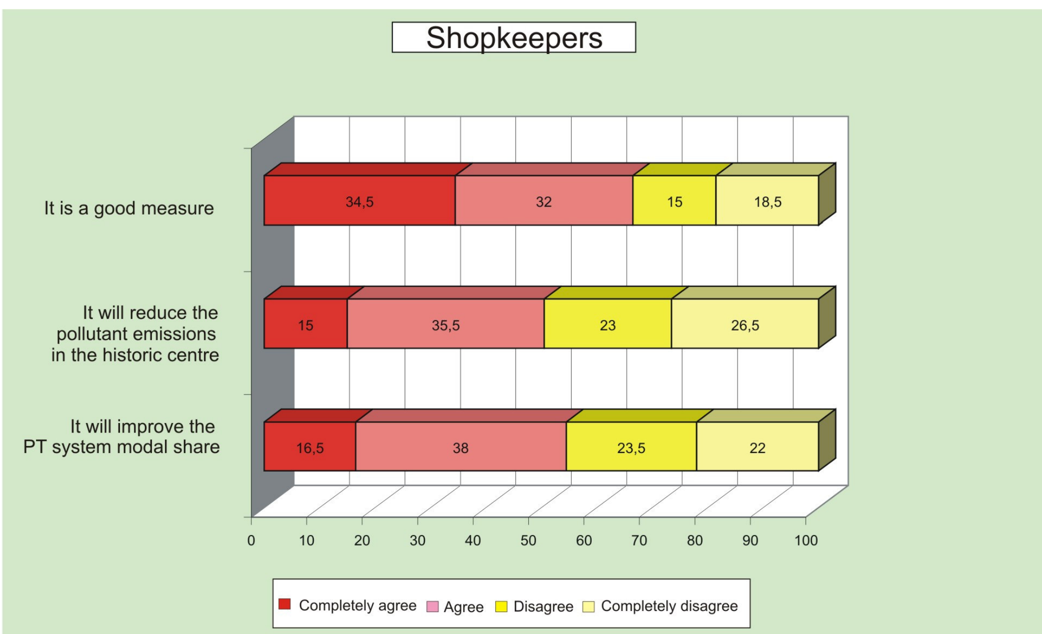


Figure 7-46 Degree of Acceptance of per Trip Time Based Pricing Scheme – Shopkeepers

The majority of residents thought that a per trip time based pricing scheme was a good idea (64.4%), 56% agreed that it could reduce the pollutant emission and 57% agreed that it would improve the PT system modal share.

The shopkeepers were slightly more supportive than residents for a per trip time based pricing scheme only for authorised non-residents, and 66% think that it is a good idea. On the other side, only 50% of shopkeepers thought that it would reduce the pollutant emissions in the historic centre and 54% thought that it would improve the PT modal share.

7.7 CONCLUSIONS CONCERNING ELASTICITIES

Using the results from calibrated models for daytime and night it was possible to evaluate the elasticities of the different options when a per trip pricing scheme, without any other limitation, is applied to cars entering the historic centre. The charge applied to the models varies from € 1 to € 6. The application of a higher charge was not considered politically realistic.

The results show some differences between the daytime and night scheme. In the daytime scheme, elasticity values are, both for systematic and non-systematic LTZ users, very low in absolute terms and non-systematic user behaviour is less elastic than the systematic users', probably because non-systematic users find it more difficult to plan their trips.

The mopeds (systematic and non-systematic) have behaviour almost inelastic for each car price and car drivers do not shift to moped (probably because who owns a moped already uses it), while the PT demand is most elastic for systematic LTZ users.

Systematic and non-systematic LTZ users' elasticities are close to zero due to lack of alternatives desirable for the car users. In fact, there are no significant variations of the modal split when the car price changes.

Concerning summer night scheme results, the PT share is the highest both for work and shopping trips. For work trips this may be due to socio-economic reasons, with many users probably not having access to a car or a moped. For shopping trips, it is necessary to consider the timeframe when such trips are made: they happen in particular in the early evening, before 20:00, and PT is still perceived as an alternative to the car in terms of frequency and safety. Overall, work trips show lower elasticities for all the alternatives considered compared to the shopping trips.

In contrast, for recreational trips the moped share is the highest followed by PT. It is also interesting to note that recreational trips show the lowest elasticities for all the alternatives considered compared to work and shopping trips, probably because these trips happen during the late evening when the PT is not perceived by users as a possible alternative.

The crossing trips have high car elasticities, and compared to the other trips, high values of cross elasticities, but it is necessary to evaluate such results in relation with the different dimensions of choice. In fact, the car users do not leave the car but they prefer changing destination, delaying the departure or changing the route (the highest modal share when a charge of € 2 or more is experienced by car users crossing the LTZ). The cross elasticities increase for a € 1 or € 2 price, then decrease for higher charges, probably because the increase in price does not go hand in hand with a proportional increase of alternative options.

For the winter night scheme, the model shows an appreciable increase of moped and PT trips and a reduction of car trips when a car price increase is experienced. In contrast, change of destination and delay in departure options are not effected by a car price increase, probably because they are not considered by users as possible options. Car elasticities increase strongly, in absolute terms, when an increase of car price is experienced. In contrast to the other options cross elasticities show very low elasticities that increase slightly when an increase of car price is experienced.

The crossing trips have shown the same behaviour as the summer night scheme.

The results show that during daytime users consider the car as the best way of moving in the historic centre and no major changes in user behaviour have been observed when a car price increase is applied. Night summer model results show that the level of elasticity values and the behaviour of users change with the trip reason. Shopping trips have a higher level of elasticity followed by work trips. In contrast, recreational trips have smaller elasticity values.

Winter model results show a strong reduction of car modal share when an increase of car price is experienced and car users shift to the moped or to the PT.

Concerning crossing modal split, both for the summer and night scheme, a strong variation is observed when a car price increase is experienced by users, but this is due to the different dimension of the choice.

Taking into account these general conclusions, it is possible to say that, probably, a per trip pricing scheme (time based or not) during daytime nowadays is not as effective in reducing the car use consistently as a mix between permits and flat-fare pricing scheme. This result matches with ex-ante surveys (see chapter 7.6) where both LTZ residents and shopkeepers consider a mix of measures such as improve of PT and reducing LTZ entrance permits more effective in reducing historic centre traffic and pollution problems than a per trip time based pricing scheme.

8 EDINBURGH

8.1 HISTORY AND MAIN CHARACTERISTICS OF THE CHARGING SCHEME

Discussion about the pros and cons of a possible road user charging scheme for Edinburgh go back to the early 1990s, but serious planning for a concrete scheme started within the 'New Transport Initiative' (NTI) that was launched by the City of Edinburgh Council in June 1999.

The Council's Local Transport Strategy for 2002 – 2004, which was published in October 2000 and described congestion charging as the only realistic alternative to 'do-nothing', set out a number of key aims (CEC 2000). These were:

- Making it easier to live without the car, or use the car less;
- Minimising the need for car travel;
- Reducing the amount of car use;
- Encouraging and facilitating walking, cycling and public transport use;
- Reducing the adverse impacts of travel including road accidents and environmental damage, particularly for those worst affected by these impacts;
- Reducing the dominance of streets by cars, both moving and parked;
- Improving the ability of people with low incomes or mobility impairments to use the transport system, especially by public transport, as pedestrians or by bicycle.

In October 2001, the City applied to the Scottish Executive for 'Approval in Principle' for a congestion charging scheme (CEC 2001). The rationale for this proposal was described as follows:

"The key conclusions of the New Transport Initiative are that if serious inroads are to be made into congestion problems, the transport policy framework has to support substantial new investment through sources of additional finance and that congestion charging is the only way to reduce the impact of traffic by both reducing demand for car use and funding substantial improvements to alternative forms of transport. It can act as both carrot and stick."

The implication of this rationale is that the scheme had not one but two main aims: cutting congestion and raising revenue for new transport investment. In line with this, it was a key feature of the proposal that the charging scheme was presented as part of a combined charging and investment package. The net revenue that was estimated to be around £ 50 million per year over 20 years was to be used exclusively for transport improvements. Some of the investment would go into improved road repairs, traffic calming and improvements for walking and cycling, but the lion share would be spent on public transport schemes, and in particular on light and heavy rail projects.

Approval in Principle (which had been expected to arrive within three months according to the original time table) was finally only granted in December 2002 (SE 2001). However, the approval letter crucially requested that "at the Approval in Detail stage [the Council] should be able to demonstrate clear public support for the scheme".

The range of charging options that had been originally investigated included a combination of area licence and cordon schemes either based on paper permits, electronic tags or ANPR. It should be noted that during this time also the London charging scheme was being developed, which was an Area licence with ANPR. The two schemes taken forward for further investigation for Edinburgh were

- An entry permit for the city centre based on ANPR, and
- A double cordon entry permit based on ANPR.

At the Approval in Principal stage it had already been decided that the charging scheme would involve a once-per-day maximum payment on weekdays only, and that any cordon scheme would operate inbound only. Further scheme characteristics like hours of operation, level of charges and number of exemptions were still to be investigated and to be included in further appraisal and consultation.

Eventually, it was decided to go for a double cordon, with the inner cordon around the city centre operating on weekdays from 7:30 to 18:30 and the outer cordon inside the city by-pass in the morning peak from 7:30 to 10:00. The charge would be £ 2 per day independent of how many times one or both cordons were crossed by that car in a single day.

Exemptions were to be given to disabled drivers with a 'blue badge', buses, taxis, private hire cars, motorcycles, bicycles, approved car club vehicles, approved breakdown and recovery vehicles and emergency vehicles.

The majority of Edinburgh citizens would have been affected by the inner cordon, if they wanted to take their car into the city centre: 80% of the cars crossing the inner cordon are actually coming from with in the city.

The outer cordon, in contrast, would have mainly affected people coming into the town from the surrounding local authorities, and only two groups of Edinburgh citizens would have possibly had to pay for crossing this cordon:

- At some stage of the scheme design process it was planned that the outer cordon would operate both in the morning and afternoon peak. This would have meant that people who live in Edinburgh, but work outside would have had to pay for coming back home at the end of their working day. Furthermore, they would be travelling against the main traffic flow without significantly contributing to congestion.
- Two of Edinburgh's suburbs lie outside the outer cordon, so that Edinburgh citizens living here would have had to pay to get not just into the city centre like everybody else, but to get to practically anywhere in their own city.

That people would have to pay for getting home without contributing to congestion was widely regarded as grossly unfair, and it was therefore decided very quickly that the outer cordon would operate only in the morning hours.

Having to pay for getting into their own city, understandably, incensed the people in the suburbs concerned and there was a massive outcry over this. As it happened, there was a by-election for the local council in one of these suburbs in September 2002; and, as a clear sign of protest among voters, the Labour party, who had at that stage a narrow majority in the City of Edinburgh Council, lost half of their share of votes. This led to two decisions that would both be main contributors to the eventual downfall of the charging scheme:

- The first decision was to hold a public referendum on the charging scheme. In fairness it has to be said that the Scottish Executive's request that the Council needed to demonstrate clear public support for the scheme put the politicians under pressure: survey results were indicating that public opinion started to turn against the scheme and, therefore, survey results alone could no longer be used to fulfil the Executive's demand for proof of support. However, there is little doubt that the by-election result was a major factor in this decision, as politicians tried to save their narrow majority in the Council by divorcing the charging issue from the local elections and making this not an election issue but the subject of a separate referendum.
- The second decision was that, in order to increase the chance to get a majority of Edinburgh voters supporting the charge in the referendum, politicians resolved to grant Edinburgh residents who lived outside the outer cordon an exemption from the outer cordon charge.

This may have pacified the voters in the suburbs concerned, but then caused massive protest from residents and politicians in the surrounding local authorities: why commuters from these areas would have to pay the charge, when cars travelling next to them and contributing to the same congestion had not, was deemed grossly unfair not only by those directly concerned but by a wide range of people inside and, in particular, outside the city, and the local press used this as further ammunition in their campaign against the introduction of the charge. Moreover, it was widely believed that this exemption would not stand up to any legal challenge.

The congestion charging scheme was then subject of a Public Inquiry in May/June 2004. The inquiry endorsed the principle of the scheme and most of its detailed features, but not all of them, in particular not the highly disputed exemption.

The politicians decided nevertheless to retain the exemption in the charging scheme which was finally put to Edinburgh voters in the referendum held in February 2005, arguing that this would create ‘equity of treatment’ for all Edinburgh Council Tax payers (CEC 2004). However, this did not convince a sufficient number of voters in these suburbs, in particular not since many feared that, once the scheme got a majority in the referendum, the exemption would be thrown out by a Court decision and they would end up paying the charge anyhow.

Opinion surveys carried out repeatedly over the years showed that the outer Edinburgh exemption was far from being the only concern people had about the charging scheme. Other principal concerns and worries among voters – many of them contradictory - were:

- Traffic reduction would be less than promised and the scheme would therefore not achieve its stated goal;
- Congestion would not be reduced at all, since more of the available road space would be given to public transport;
- Rat-running by people trying to avoid the cordons would increase the accident risk in residential streets and around schools;
- Congestion reduction was not the real reason behind the scheme and was only a pretext for raising more money from motorists by an anti-car Council;
- Traffic reduction would be higher than expected and, hence, the revenue generated by the scheme would be lower than expected;
- Shoppers would turn to other destinations in Glasgow and around Edinburgh, which would endanger city centre vitality and the viability of the retail sector in Edinburgh.
- The Council would not deliver on the promised improvements in public transport.

Moreover, the more the scheme was discussed in the public and the more details of the scheme became known, the more any support for the scheme faded, as shown in Figure 8-1 below (UoW, 2004). A net support of around 40% in 1999 turned into net opposition against the double cordon of nearly 20% in 2002, and the better result for 2003 does not amount to a real recovery. These findings are in line with survey results from Trondheim, London or later in Stockholm, where opposition to the charging scheme was always highest in the period leading up the its introduction, while in all of those three cities support was rising again when the scheme was actually introduced and residents could see the benefits of the scheme. So it was clear that the timing of the referendum in Edinburgh could not have been worse.

The result of the referendum was decisive and resounding: the turn-out was 61.8% and only 25.6 % voted ‘yes’ while 74.4 % voted ‘no’.

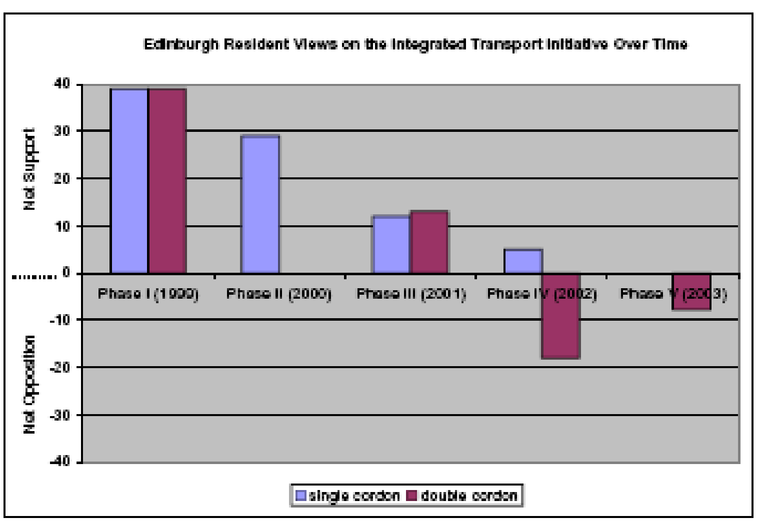


Figure 8-1 Change in Edinburgh Resident Views on the Charging Package over Time

8.2 AVAILABLE DATA

The two strands of work carried out in preparation of the charging scheme that provided data that is of direct relevance to DIFFERENT were

- Opinion surveys: data from some of these has been analysed in WP4 and the results are shown in DIFFERENT deliverable D4.2; and
- Modelling work with CSTM3 and LUTI: results available from two sets of modelling runs are the focus of the case study in this present chapter.

A huge amount of before-data had also been collected from the real world, but without any after-data, unfortunately, none of this would provide any conclusions for DIFFERENT.

CSTM3

An Inception Report for the "City of Edinburgh Road User Charging Study" was prepared by consultants MVA in November 1999 (MVA, 1999). This study compared the impact of a range of potential charging schemes through the use of CSTM3, which is version 3 of the Central Scotland Transport Model. CSTM3 is a nested logit model, which uses the generalised costs of the various alternatives for travel to calculate the proportions of travellers who will use each of these alternatives. To predict the resulting elasticities, knowledge of the parameters which go into the various logit-based formulae and the corresponding costs of the alternatives would be needed, but this knowledge is not in the public domain.

The impact assessment included traffic and environmental impact as well as economic impact. This economic impact was calculated from the benefits from savings in time and Vehicle Operating Costs (VOC) of users who still make the same car journeys after charging is introduced and disbenefits for those users who change mode or destination. The results of this study were presented in three reports between January and September 2000 (MVA 2000a, 2000b, 2000c).

These reports show the results for 20 charging schemes with different numbers of cordons, different cordon locations, different levels of charges and different charging structures. The second report also contains sensitivity testing for higher economic growth, greater improvements in public transport and road closures in the city centre.

The modelling results for the 20 alternative schemes are the most interesting for Edinburgh from the DIFFERENT point of view in so far as they compare such a wide range of scheme options, while all later modelling exercise only covered both a lower number as well as much more similar charging options. However, the 2000 study considered only a more limited number of indicators than the later LUTI model runs. Main findings from the CSTM3 model runs will be provided in section 8.3.

LUTI

In 2002 a Land-Use and Transport Interaction model (LUTI) was developed by MVA for Edinburgh combining a Traffic Restraint Analysis Model (TRAM) and the Land-Use model DELTA (MVA 2003), which allowed a more detailed and more encompassing impact analysis than CSTM3 had done. Like CSTM3, also LUTI is a nested logit model that does not use an elasticity based approach. LUTI was used for a series of tests between September 2002 and March 2004, but most of these were done for the combined charging and investment package.

The exception was the test programme for which the results were reported in January 2004 (MVA 2004). This programme comprised six tests, which were all based on the same (then current) Reference Case without an associated infrastructure package and with a common level of transport supply. However, for these test only the TRAM model has been used rather than the full LUTI package. Results reported therefore only cover number of cordon crossings, trips and trip km by mode, vehicle km and hours, average speed and time lost in congestion, and revenue generated and none of the wider economic or long-term effects. Main findings from these six tests will be presented in section 8.4.

8.3 RESULTS FROM EX-ANTE MODELLING WITH CSTM3

8.3.1 Test Programme

Initially, 18 different charging scenarios had been modelled, listed as T01 to T18 in Table 8-1 below (MVA 2000a). Cordon C1 lies within the city centre, encircling only a few core streets, C2 lies closely around the inner city centre, C3 describes a wider cordon around the centre, C4 lies just outside the city by-pass, and C5 just inside the by-pass (see Figure 8-2 and Figure 8-3). Schemes T11 and T12 have additional screen lines between the cordons (Figure 8-4). The area covered by the model is, however, not restricted to the City of Edinburgh, but encompasses the whole travel-to-work area.

Scenario T19 was introduced, when it became clear that the by-pass, as a dual carriageway trunk road, could not be included in the local Edinburgh charging scheme for legal reasons (MVA 2000b). Accordingly, the new cordon C5 just inside the by-pass was defined. Scenario T24 was finally added to check the effects of an outer cordon only, which had not been considered in any of the original tests (MVA 2000c).

Two sets of direct comparisons exist: one between all of T01 through to T18 and subsets for the different groups in accordance with the second column of Table 8-1, and another between T10, T19 and T24 only.

Table 8-1 Test Definitions

Test	Cordons	Cordon Crossing Charge
T01	C1	£0.50
T02	C1	£ 1.00
T03	C1	£ 2.00
T04	C1	£ 4.00
T05	C2	£0.50
T06	C2	£ 1.00
T07	C2	£ 2.00
T08	C2	£ 4.00
T09	C1, C3, C4	£0.50 for each cordon
T10	C1, C3, C4	£ 1.00 for each cordon
T11	C1, C3, C4 + screenlines	£0.50 for each cordon
T12	C1, C3, C4 + screenlines	£ 1.00 for each cordon
T13	C2	£0.50 peak, £0 off peak
T14	C2	£ 1.00 peak, £0.50 off peak
T15	C2	£ 2.00 peak, £ 1.00 off peak
T16	C2	£ 4.00 peak, £ 2.00 off peak
T17	C1, C3, C4	£0.50 peak, £0 off peak
T18	C1, C3, C4	£ 1.00 peak, £0.50 off peak
T19	C1, C3, C5	£ 1.00
T24	C5	£ 1.00

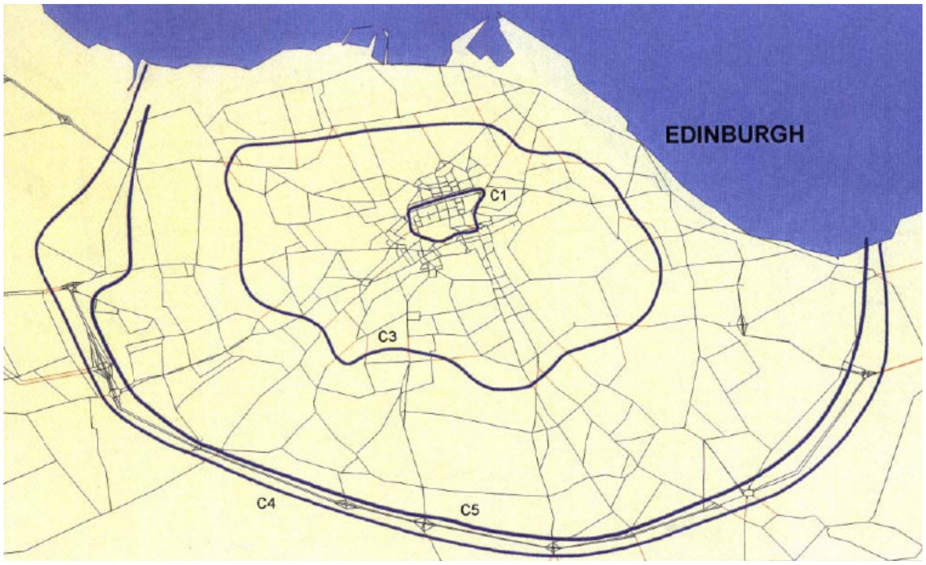


Figure 8-2 CSTM3 Cordons C1, C3, C4 and C5 (MVA 2000c)

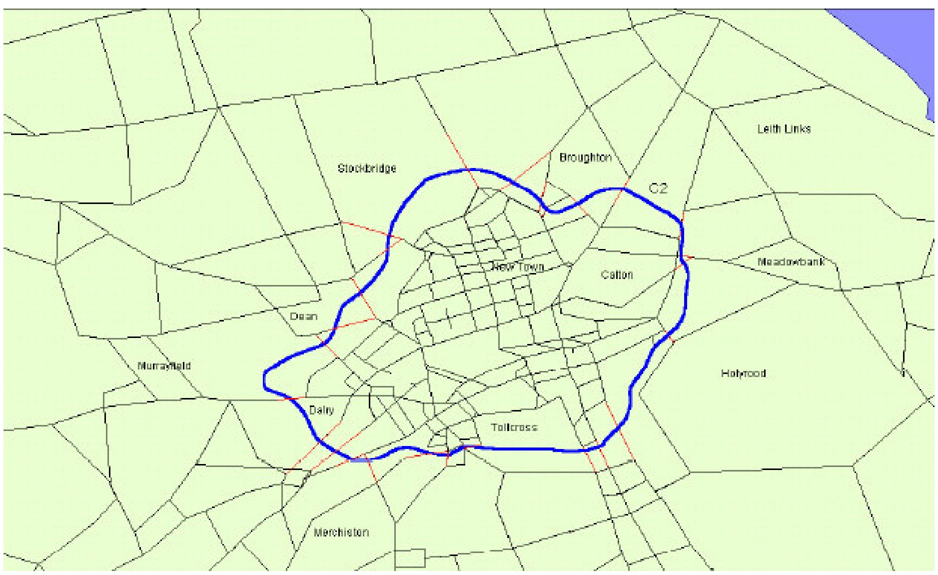


Figure 8-3 CSTM3 Cordon C2 (MVA 2000a)

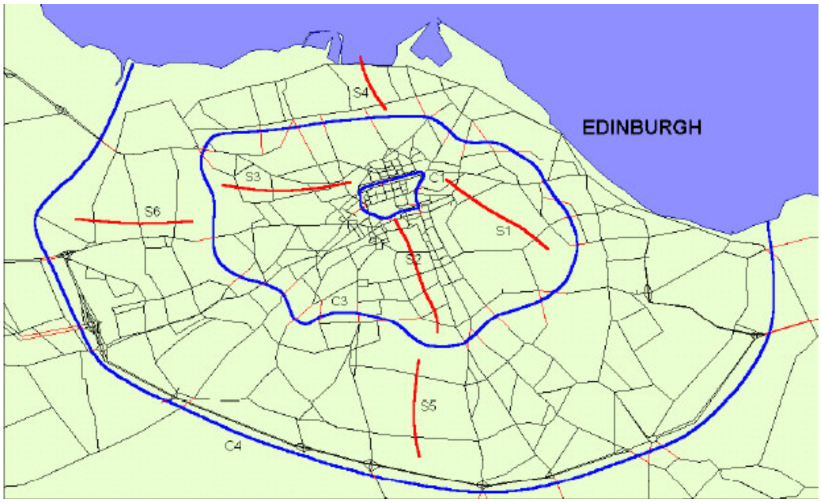


Figure 8-4 CSTM3 Cordons C1, C3 and C4 with Screenlines (MVA 2000a)

All of the monetary values used in the CSTM3 runs are annual values for the single prediction year of 2006, but are presented in 1997 prices.

8.3.2 Traffic Impact

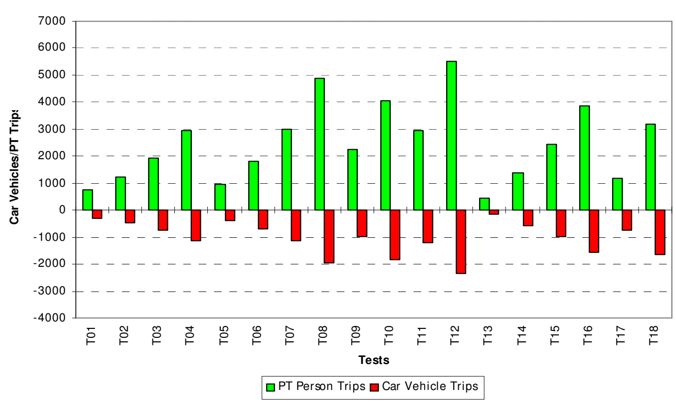
The traffic impact analysis focused on three issues:

- Changes in modal split,
- Traffic flow changes and rerouting, and
- Trip re-distribution.

Another possible major effect, namely re-timing of trips, could not be explicitly modelled with CSTM3.

Modal Split

One of the key effects of any charging scheme is the shift from car travel to public transport use. The trends for this are the same for AM peak, off-peak and PM peak, only the absolute values are different (see Figure 8-5, Figure 8-6 and Figure 8-7). The smallest changes occur during the off-peak and the largest in the PM peak. Therefore, in the following, all further analysis will focus on the AM peak only with the understanding that the same results would apply to the off-peak and PM peak in principle, just at a lower, respectively higher, level.



Note: The units used are not directly comparable: car vehicles versus public transport persons

Figure 8-5 Modal Shift in the AM Peak Hour (MVA 2000a)

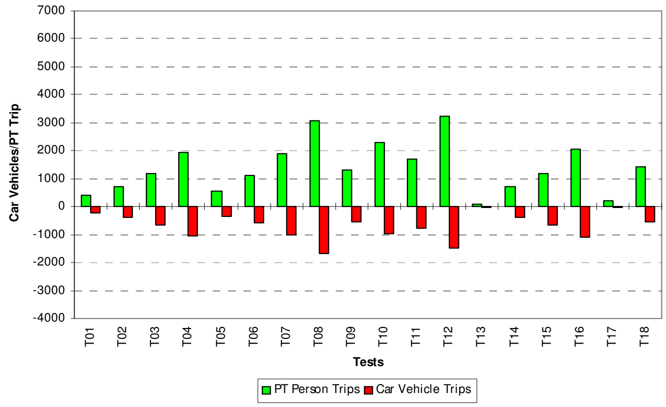


Figure 8-6 Modal Shift in the Off-Peak Hour (MVA 2000a)

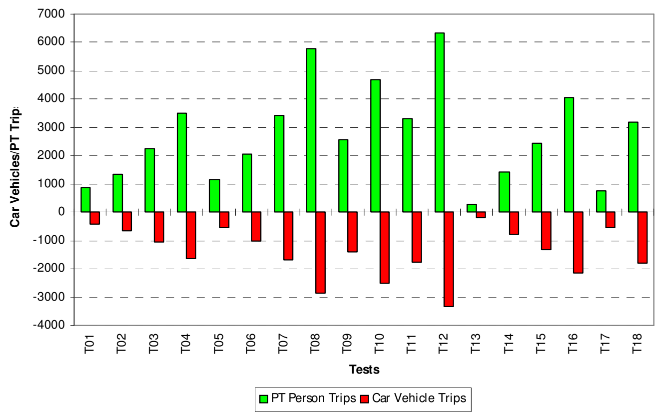


Figure 8-7 Modal Shift in the PM Peak Hour (MVA 2000a)

Tests T01 to T04 and T05 to T08 have simple all-day charges, the first four for the innermost cordon around the heart of the city and the latter four for a cordon through the inner suburbs. It is therefore evident that more drivers are caught in the second set of tests and, therefore, the modal shift is higher there.

It is noticeable that the gain in PT passenger trips is considerably higher than the loss in car trips. This is in part due to the fact that the average car carries more than one passenger, in part due to the reduction in bus travel times due to reduced congestion, which attracts additional passengers.

It is also obvious that the modal shift increases with the level of charges. However, the relationship between the charging level and the modal shift is not linear, as Figure 8-8 shows. The marginal effect of charge increases on modal shift decreases more and more the higher the charge becomes.

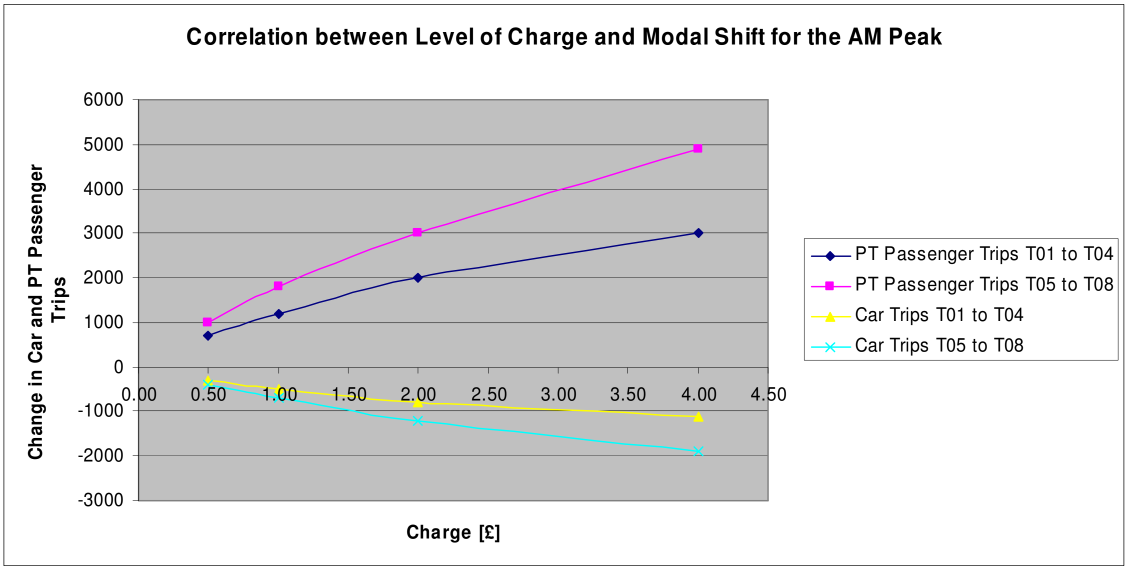


Figure 8-8 Correlation between Level of Charge and Modal Shift for the AM Peak

Tests T13 to T16, which are also based on Cordon 2 like T05 to T08, but with a differentiation between the level of charges at peak and off-peak periods, show obviously the same trends (Figure 8-5). Furthermore, it was to be expected that the modal shift is lower in T13 to T16 than in T05 to T08 during the off-peak, when the charges are lower.

However, although the level of charge during the AM and PM peak is the same for both test series, T13 to T16 show a significantly lower modal shift also in both peak periods.

Figure 8-9 shows the modal shift for Tests T10, T19 and T24. That the shift is much lower when there is only an outer cordon in T24 is entirely logical, since all car trips within the city are not charged in any way. That there is no noticeable difference between T10 and T19 may seem more surprising on first glance, but can be explained through the fact that cordons C4 and C5 equally catch all traffic coming into the city from outside while there are no public transport services using the by-pass for any significant length that would be influenced by the precise location of the outer cordon.

Figure 8-9 Modal Shift for the AM Peak Hour for Tests T10, T19 and T24 (MVA 2000c)

The increase in the number of PT trips for the full CSTM3 area is directly in line with the modal shift shown above for all tests (Figure 8-10). However, for bus use within Edinburgh there are some marked differences: the highest increase in bus trips is in test T8 for the middle cordon, while the highest modal shift is found in T12 for the three cordons plus screenlines. This indicates that cordon

C2 catches relatively more car trips that are entirely within the city area than any other cordon combination.

More surprising at first glance is the fact that moving the outer cordon from outside to inside the by-pass, while not affecting the overall modal shift or bus use, would increase PT patronage inside the city. That this happens is due to the fact that car drivers from within Edinburgh, who want to use the by-pass to get from one end of the city to the other, would have to cross C5 but not C4. The number of drivers who would decide to use the bus instead amounts to a 2% increase in bus patronage inside the city, but only to a negligible percentage within the whole CSTM3 area.

Cordon C5 alone still affects everybody entering the city from outside as well as anybody living in Edinburgh and either returning back home from outside the by-pass or using it indeed as a by-pass to get more easily from one end of the city to the other. However, out of these, only a very small proportion switches to public transport.

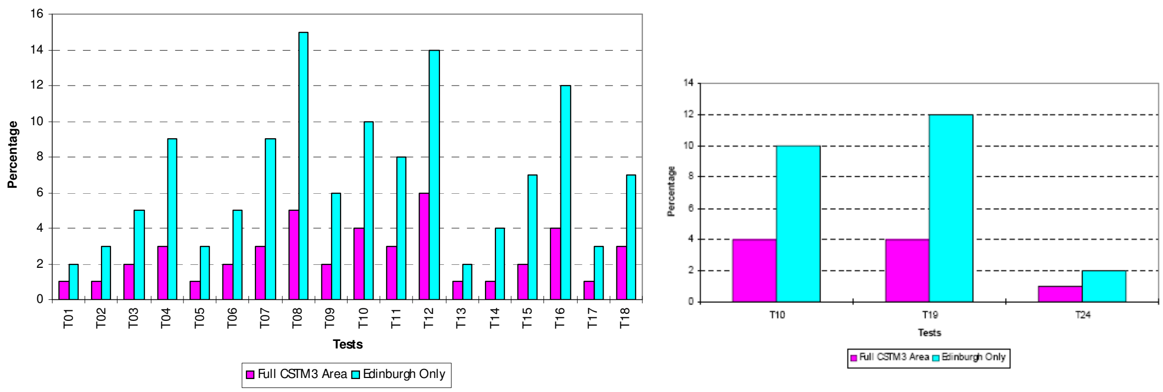
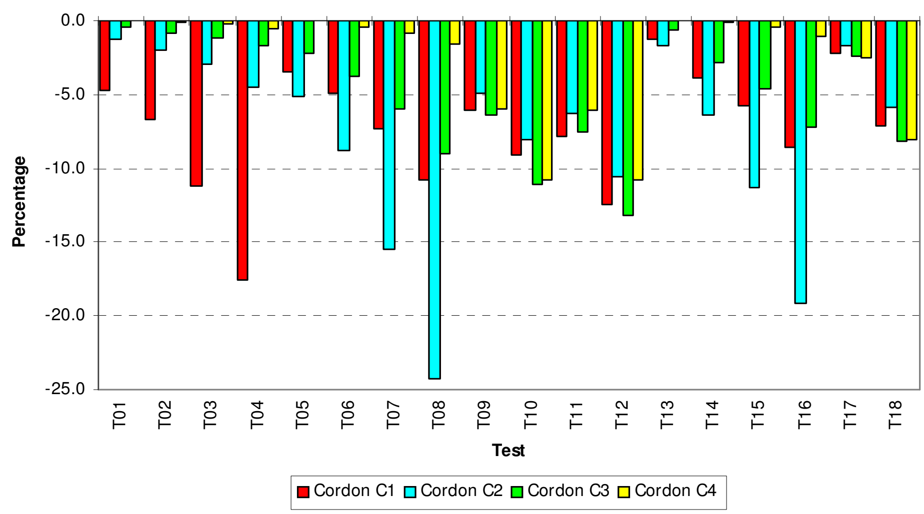


Figure 8-10 Percentage Increase in AM Peak PT Trips (MVA 2000a and 2000c)

Traffic Flow Changes and Rerouting

Figure 8-11 shows the reduction in the number of vehicles crossing each of the four cordons included in the initial modelling exercise for each of the 18 tests. There are obvious effects of different cordon locations on the number of crossings at these locations as well as the level of charge on the overall traffic reduction, but it is difficult to draw further conclusions from this picture due to its complexity.



Notes : 1. Analysis is for 2006 Central Growth Scenario
2. Values are percentage change in total vehicles (two-way) crossing each cordon

Figure 8-11 Percentage Reduction in 24 Hour Cross Cordon Flows (MVA 2000a)

However, when the results are shown in a different way that allows a more direct comparison between the different tests, they are easier to interpret.

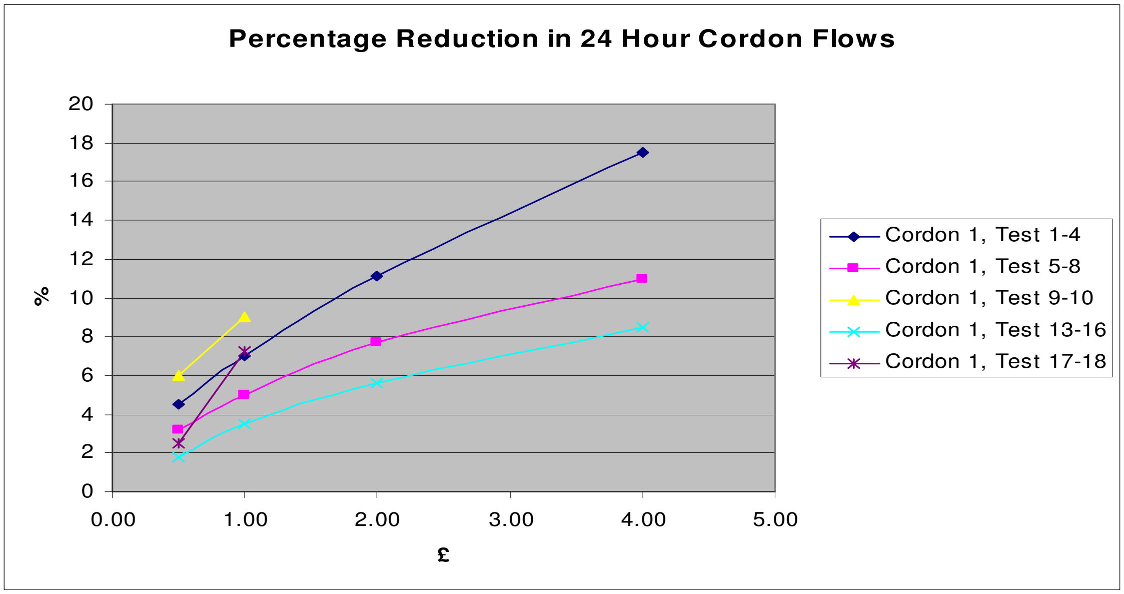


Figure 8-12 Percentage Reduction in 24 Hour Cross Cordon Flows, Cordon 1

Figure 8-12 shows obviously that a charge at C2 (Test 5-8) has less impact on C1 than a charge at C1 (Test 1-4), and also that a reduction of off-peak charges reduces the impact to an extent equivalent to the average level of charge. But it also shows is that a charge of only 50 pence for each of the three cordons (T9), implying a maximum payment of £ 1.50 per driver, has about the same impact on the inner city cordon as a £ 2.00 peak charge combined with a £ 1.00 off-peak charge levied at C2. A £ 1.00 charge for each cordon (T10) also has a very similar impact to a £ 4.00 peak and £ 2.00 off-peak charge at C2.

Furthermore, a comparison between Tests 9/10 against 17/18, all for the same triple cordons, but the former with an all day charge and the latter with lower off-peak charges, may look at first glance as if an increase of the charges has more impact when they are differentiated by peak and off-peak than an all-day charge would have. However, a simple look at the arithmetic mean cost shows that the difference is really simply due to average maximum prices, which are £ 1.50 for T9 and £ 3.00 for T10, while the difference is £0.25 for T17 and £ 1.25 for T18, i.e. a mere doubling of costs in the first case and a five-fold increase in the second case. And these multipliers are then again fully in line with the impact on traffic reduction.

This means that overall, so far no impact from any differentiation of charges on traffic reductions could be shown, neither by number of cordons nor by differentiation over the day. All differences in impact can be simply explained by the overall charging level.

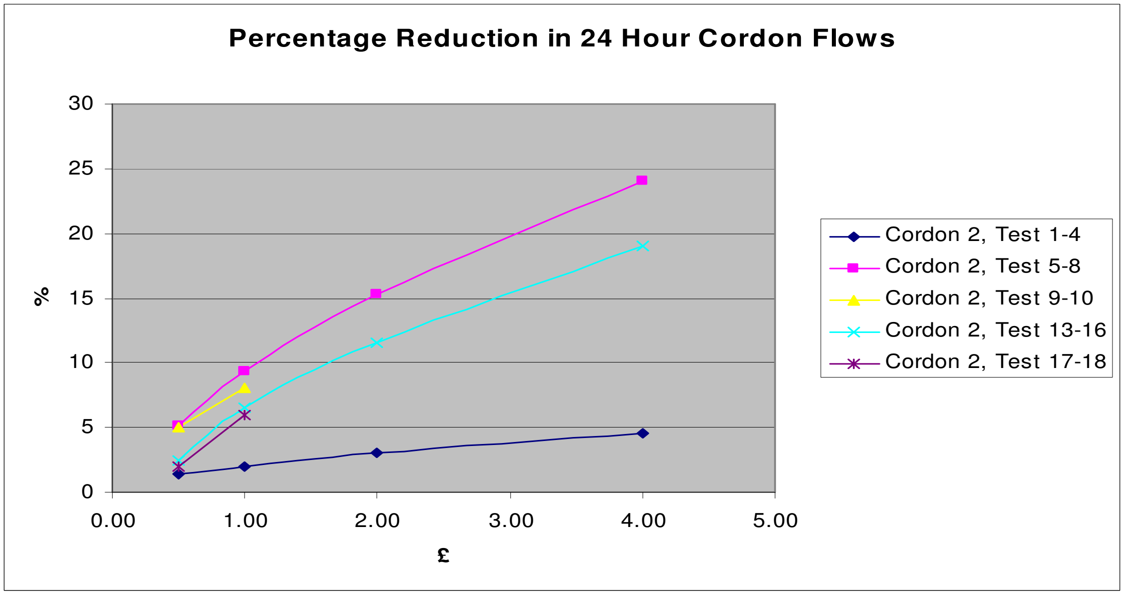


Figure 8-13 Percentage Reduction in 24 Hour Cross Cordon Flows, Cordon 2

Figure 8-13 shows the same comparisons for Cordon 2. The overall reduction in crossings is higher than at C1, and the main reason for this is probably that the area enclosed by the cordon is larger, and it is therefore more difficult for car drivers to park outside the cordon and reach destinations inside it on foot.

Obviously, the highest impact comes here from the charges directly levied at C2, followed by those for each of the three cordons, while the impact of charges at C1 is very low at C2, even at the highest charging level. A look at the map easily explains why charges at C1 have a much lower impact at C2 than the other way round: First of all, C1 is much smaller than C2 and catches much fewer vehicles, and second, there are plenty of destinations between C1 and C2 for people coming from outside C2 that are not affected by a charge at C1, while the vast of majority of those going into C1 come form outside C2 and are therefore affected by a C2 charge.

A comparison between T 5-8 and T 13-16 shows that the more differentiated charge in the latter set has no specific impact, since the main factor for the overall impact is the average level of charge; and, as shown before for the impact on C1, the same is also true for the comparison between T 9-10 and T 17-18.

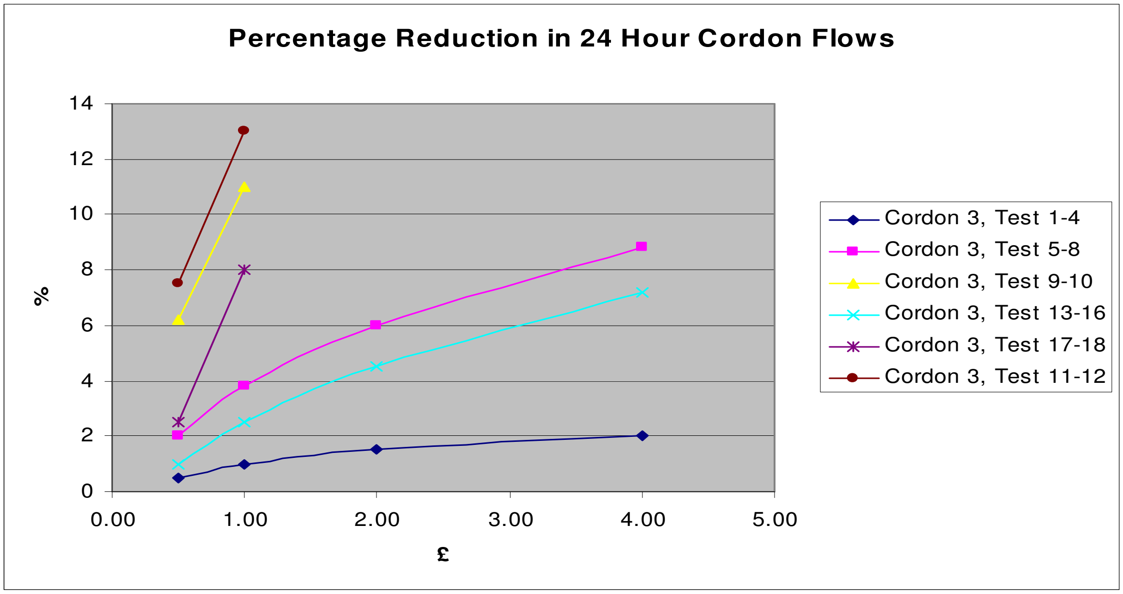


Figure 8-14 Percentage Reduction in 24 Hour Cross Cordon Flows, Cordon 3

In the comparison between the three inner cordons, the overall impact of the charges is lowest at C3 (Figure 8-14), which is obvious, since a substantial part of the traffic crossing C3 will not head for the city centre, and therefore not be affected by any charges at C1 or C2.

The highest impact here, with a maximum traffic reduction of around 13%, comes from T12, the £ 1.00 charge for each of the cordons C1, C3 and C4 plus the screenlines between them. But, again, the traffic reductions for T 11-12 are not an effect of more differentiation, but simply of average price that drivers have to pay in the network, and the same also holds for all the other tests.

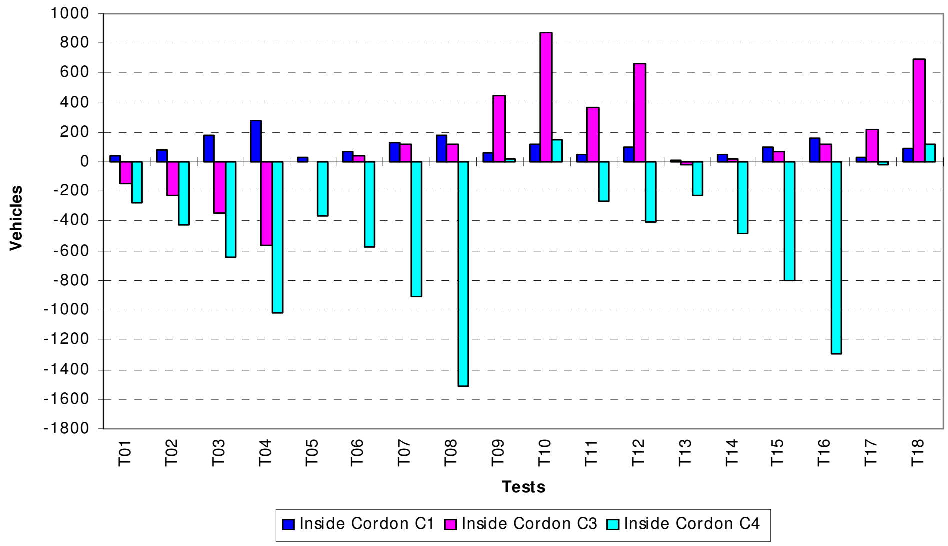
The results for C4 as well as those of the additional tests involving cordon C5 follow the same pattern and are therefore not shown here any more in detail.

Trip Re-Distribution Analysis

While the results shown above are based on changes in the traffic assignment model, the following are solely based on changes in the demand model. As stated in MVA 2000a, the re-distribution shows the same pattern for all periods of the day, and therefore, as for the modal shift presented earlier, only the results for the AM peak are shown in the following. Furthermore, although the re-distribution was calculated for the whole travel-to-work area, the re-distribution effect outside Edinburgh was very small, and the following graph therefore only shows the effects within the city by-pass (Figure 8-15).

The general assumption is obviously that charging at a cordon reduces the number of drivers who are willing to cross it, and that therefore any cordon charge increases the number of trips made wholly within or wholly outside it.

For tests T1-4 the results are within this logic: due to the charge levied at C1, the trips made wholly within C1 increase, even if at least at lower charging levels only by a small number. Trips made entirely within C3 decrease by the number of those trips suppressed by the charge at C1 that would otherwise have gone into the city centre, but that may now not take place at all or go to destinations outside C3, for instance to out of town shopping centres. This trip suppression is in absolute terms even larger within C4 due to the larger number of trips affected.



Note: Trips inside Cordons C3 and C4 include all trips inside, including those inside interior cordons

Figure 8-15 Trip Re-Distribution within Edinburgh in the AM Peak (MVA 2000a)

For T5-8, with a charge at C2, there is also an increase of trips inside C1, albeit smaller than for T1-4 since drivers have more possible destinations inside C2 and more trips will cross the non-charged cordon C1 now. Trips inside Cordon C4 decrease be a larger amount than for T1-4, since a larger number of trips from within C4 would have crossed C2 than C1, and this is also entirely logical.

But for C3 the MVA 2000a report says: "However, there is now a small increase in trips within C3 reflecting the costs of crossing C2." While the observation of a small trip increase inside C3 is in Figure 8-15 indeed obvious at least for T6-8, the reasoning given is less obvious: why should the cost of crossing C2 increase trips within C3?

- With the same logic with which for T1-4 trips within cordons C3 and C4 reduce because of charges at C1, it could be expected that also trips within C3 reduce as they also include trips that are charged at C2; moreover, this reduction should be even larger than for T1-4 since more destinations, and therefore trips, are affected by C2 than by C1.
- Moreover, the logic for the trip increases inside C1 for all of T1-8 does not apply for C3, since it is outside the charging cordon and drivers with origins between C2 and C3 therefore have no reason to increase trips within the C3 boundary.
- However, there will certainly be some increase through trips that now, with a charge at C2, stay entirely within C2, which would otherwise have gone to destinations outside C3.
- Furthermore, it is possible that the congestion reduction encourages some trips within C3 that would otherwise not have happened at all.

The two latter of the four causes of change must be very substantial indeed and more than outweigh the reduction of trips from the area between C3 and C2 into the city centre, if then, on balance, there is a net increase in trips inside C3.

What is also noticeable is that in all other test series the effect on any cordon becomes proportionally stronger with each increase in the level of charge, while in this case there is no increase in trips within C3 with an increase of the charge from £ 2 to £ 4 in T7 and T8, but no apparent reason is provided for this.

For T9-10 it is clear that charges at C1 as well as C3 and C4 will in a similar way increase trip making within C1 by a small amount as do charges at C1 only.

What may be surprising at first glance is that trips within C3 should suddenly increase by such a big amount, since there must be a trip reduction for travel across C1. However, this is obviously more than compensated by the trip increase, which is in the same logic as shown before for the increase within C1 for charges at C1: people staying inside the cordon and no longer go to destinations outside C3 in order to avoid being charged for coming back in again; and due to the different sizes of areas within the cordons, this affects more cars in the case of C3 than in C1.

A remarkable result is that even trips inside C4 increase, even if only by a small number. If it were C5 rather than C4, this would be more understandable, since trips from one end of the city to the other, which currently use the by-pass rather than going through the city, would have been discouraged from doing so. But C4 lies outside the city by-pass, and therefore the by-pass can be used freely by everybody from within. Furthermore, from the trip increases shown earlier for charges at C1 and C3 within those cordons, only those are still relevant, which would otherwise have gone entirely outside the city, i.e. only a relatively small share, since the rest would have been compensated in the sum total by the related reduction of trips across the C1 and C3. Since there are relatively few major destinations outside C4, the implication of the overall trip increase inside it is that the charges at C1 and C3 only have a relatively small effect on trip suppression.

In the comparison between T9-10 and T11-12, it is easily understandable that the screenlines introduced in the latter set reduce the number of trips within cordons C3 and C4.

The effects of charges, which are differentiated by time, i.e. T13-18, are overall very much in line with the resulting average level of charge. Data that may have shown differences over different periods of the day is unfortunately not available.

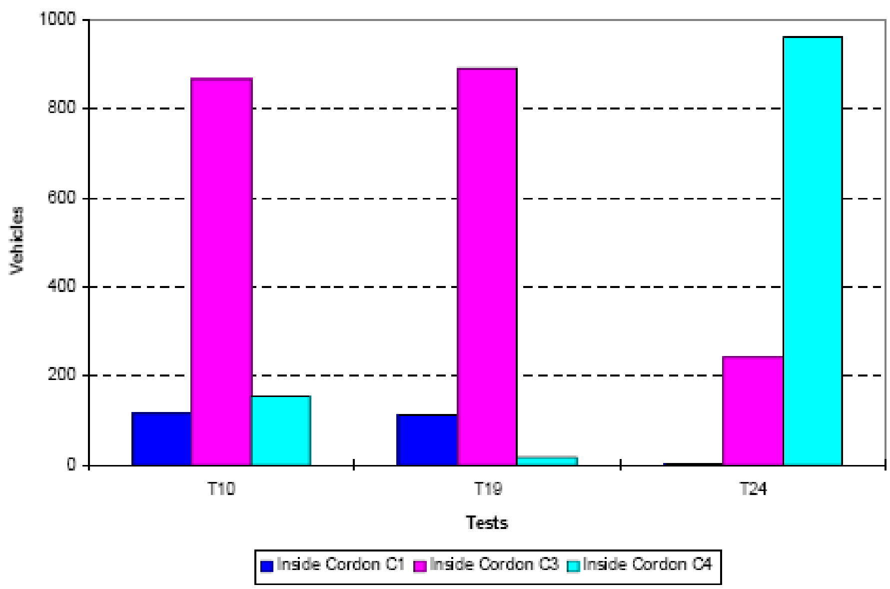


Figure 8-16 Trip Re-Distribution within Edinburgh in AM Peak for Tests T10, T19 and T24 (MVA 2000c)

Figure 8-16 shows T10 and T19 together, both with an all-day £ 1 charge per cordon, both with C1 and C3, but for T19 the outer cordon as C5 inside the by-pass instead of C4 outside. The differences for trips within C1 and C3 are understandably very small. The effect on C4 is less obvious, but there are probably two reasons behind this:

- First of all, there will be more trips suppressed, if people cannot use the by-pass to get to more distant destinations within the city without being charged.

- Second, and probably more significant, especially for shopping trips: for destinations outside the city, people would have to cross C4 and C5 equally, but if they can instead easily and comfortable reach the two large retail parks, which are located at the east and the west end of the city just inside the by-pass, without being charged, they will be more likely to change to these destinations than under cordon C5, where they would only have the choice between either using complicated inner city routes to get to the retail parks or pay the charge; and if have they to do that anyhow then they will be more likely to stick to their original destination.

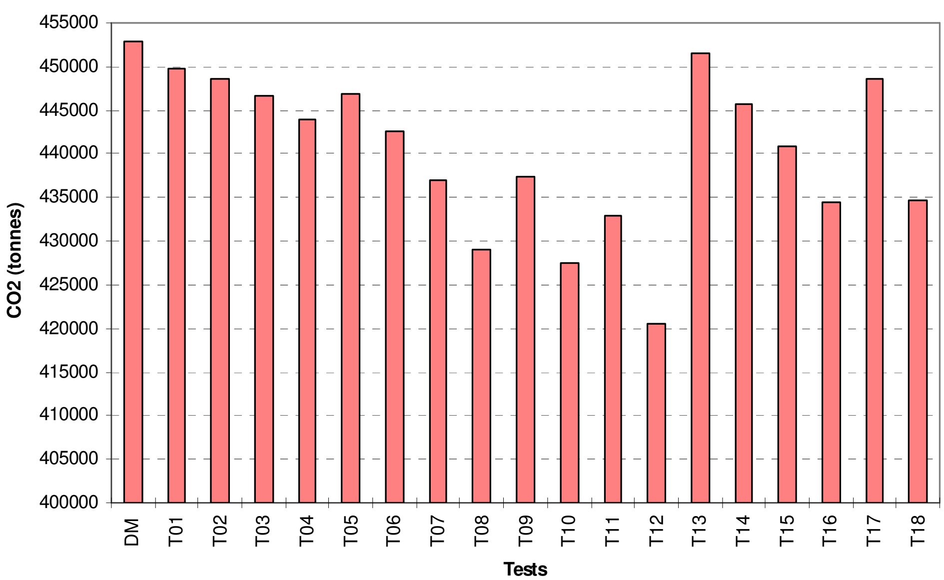
Finally, T24 which is a £ 1 charge at C5 only, shows the full extent to which trips are increased within C4 to avoid the charge at C5, without the opposite effect from trip suppression through the charges at C1 and C3.

Emissions

The reduction in emissions, and here only CO2 as the overall most important element, cannot be related directly to any of the traffic indicators shown above, since they result from a combination of trip re-distribution, modal shift and changes in cordon crossings.

The lowest CO2 reduction arises from a £ 0.50 charge at the most inner cordon C1, where the total CO2 output is around 453 ktons. By far the highest CO2 reduction can, according to this modelling exercise, be achieved with a £ 1 charge for each of the three cordon crossings C1, C3 and C4 plus a further £ 1 charge at each of the six screenlines with an output of just over 420 ktons. All other values lie between those two and are a direct result of the overall reduction of car travel within the Edinburgh area, and this in turn relates directly to the charging levels at each cordon on the one hand and the number of car trips affected by the cordon on the other.

Conclusions about the effects of either spatial or time differentiation of the charges cannot be drawn from these global figures.



Notes : 1. Analysis is for 2006 Central Growth Scenario - annual values
2. Values are for emissions within Edinburgh only

Figure 8-17 Carbon Dioxide Levels within Edinburgh (MVA 2000a)

8.3.3 Economic Impact

The economic impact has been calculated on the basis of the so-called “consumption” on the one hand and the “new user value” on the other. “Consumption” is defined by MVA as the benefit gained from the reduced congestion on their trip by those who pay the charge and stay on their original route and mode. “New user value” is the disbenefit of those who no longer travel on the route or mode that used to be optimal for them and are therefore suffering a disadvantage.

Figure 8-18 shows the results for the 12 tests with all-day charges. T5-8 with the charges at C2 show a substantially higher consumption than T1-4 with charges at C1, but only a much smaller increase in new user value, and therefore overall more than twice the net benefit.

The comparison between T9 and T11 (50p per cordon) and T10 and T12 (£ 1 per cordon) shows that the additional total benefit gained by charging for the six screenlines in addition to the three cordons is relatively small with around £ 10-12m.

What is most interesting about Figure 8-18 is that it demonstrates a different aspect of the effect already shown in Figure 8-8 and Figure 8-12 to Figure 8-14, i.e. that the effect of the charge increases is non-linear. In the case of Figure 8-18 it is clear that a spatial differentiation of charges is overall more effective than a mere increase in the level of charges at one particular cordon, i.e. ‘catching’ more people in the cordons has a stronger effect than charging fewer drivers more money. T9 is based on a £ 0.50 charge at cordons C1, C3 and C4, and the maximum charge that any driver coming from outside Edinburgh and travelling right into the city centre would have to pay is £ 1.50; but as T 24 in Figure 8-16 clearly demonstrates, the number of such trips is very small, and the average that would be paid by any driver coming into Edinburgh or driving within the city will probably be below £ 1.00. But as Figure 8-18 shows, the net benefit for T9 is substantially higher than for T6 with a £ 1.00 charge at C2, and even still higher than for T7 with a £ 2.00 charge. For T10, the £ 1 charge at each of the three cordons, and therefore an average charge of less than £ 2.00 per driver, the net benefit is on the same level as for T8, the £ 4 charge at C2.

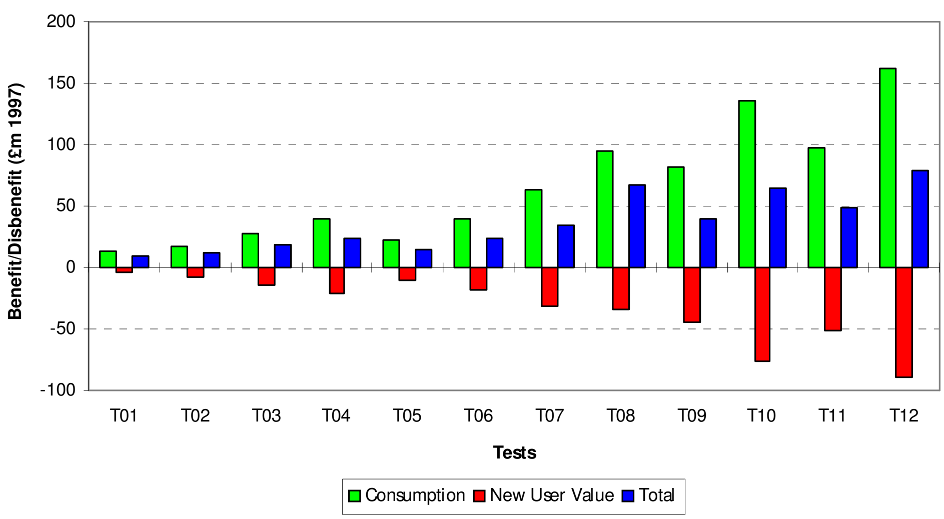
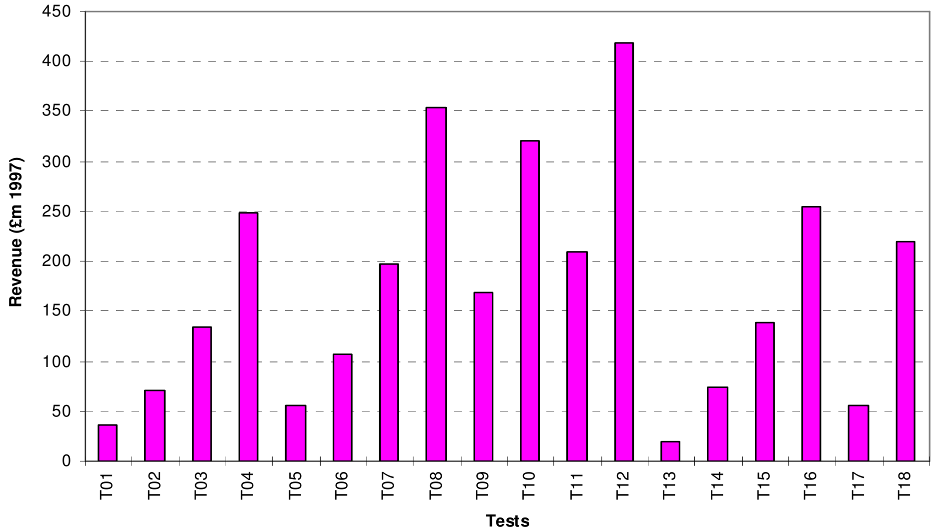


Figure 8-18 Economic Analysis of Tests 1-12 (MVA 2000a)

What is more is that this result is not just due to the number of vehicles caught out by each scheme. If that were the case, then the revenue raised should also be roughly in line with the net benefit, but Figure 8-19 and Figure 8-20 show that this is not the case: the net benefit for T9 and T10 rises faster with rising revenue than for T6-T8.



Notes: 1. Analysis is for 2006 Central Growth Scenario
2. Values exclude implementation and maintenance expenditure

Figure 8-19 Revenue Analysis of Tests 1-12 (MVA 2000a)

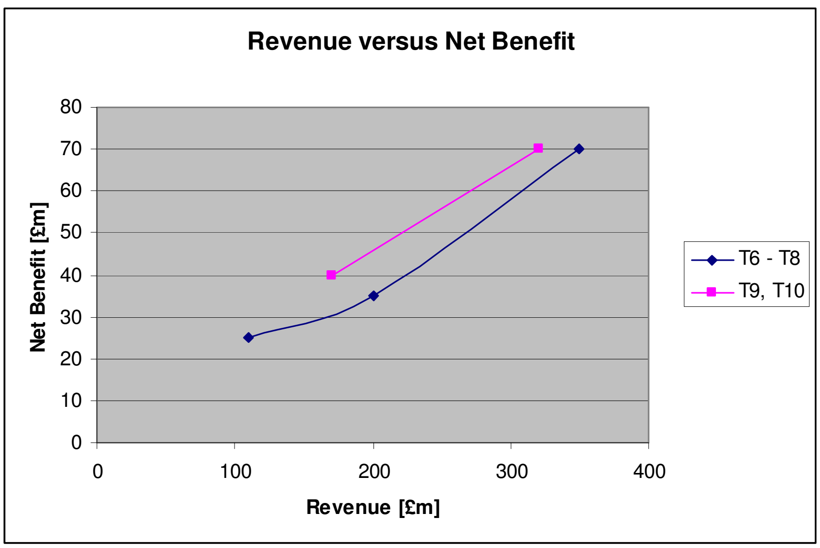


Figure 8-20 Revenue versus Net Benefit

Figure 8-21 shows the results for the charge differentiated for peak and off-peak (T13-16) alongside those for the all-day charge at C2 (T5-8). It is clear that the all-day charge creates greater net benefits, and that these increase (in line with previous results) with higher charges, but there is an exception with T16, which shows a lower benefit than T15. Both cases with the £ 4.00 maximum charge, T8 and T16, do not quite follow the usual pattern: in T8 there is hardly any increase in new user value from T7 to T8, while in T16 the increase is so large that it more than cancels out the increased consumption compared to T15. The MVA report offers no explanation for these phenomena, but merely states that the result for T16 suggests "that, if a differential toll was to be considered, the optimum level for it would be less than the £ 4 peak and £ 2 off-peak level used in that test".

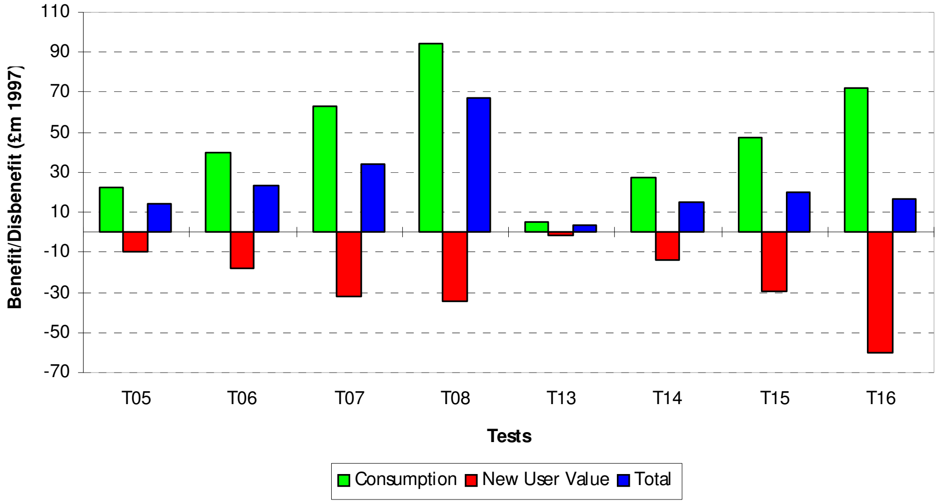


Figure 8-21 Economic Analysis of Tests 5-8 and 13-16 (MVA 2000a)

The comparison between T9-10, the all-day charge at the three cordons, and T17-18, with the lower off-peak charge (Figure 8-22), show as expected that the all day-charges produce much higher net benefits, but the differences between the four charging scenarios are in line with the average level of charge in each of them, and do not show any explicit effects of the differentiation.

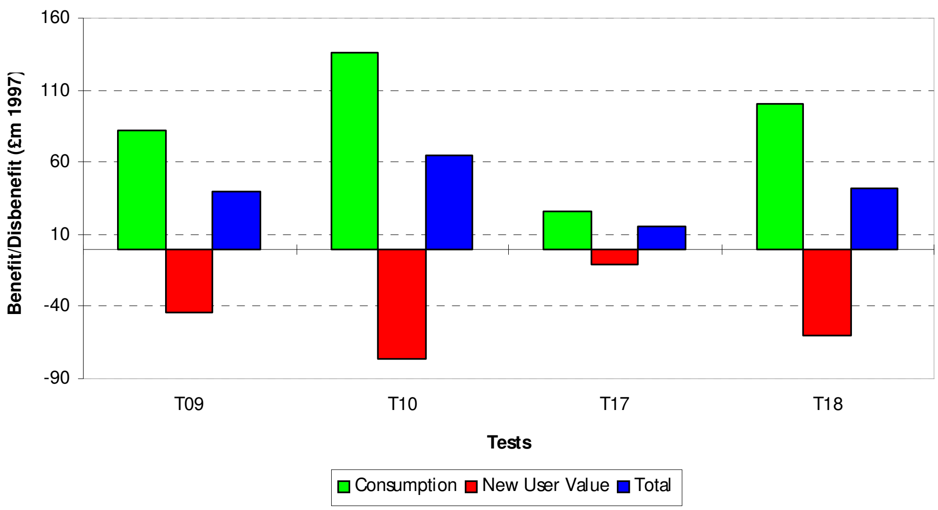


Figure 8-22 Economic Analysis of Tests 9-10 and 17-18 (MVA 2000a)

8.4 RESULTS FROM EX-ANTE MODELLING WITH LUTI

8.4.1 Test Cases

The LUTI modelling was no longer based on the same cordons as the CSTM3 tests, since in the meantime the decision process had advanced, and only two cordons were now investigated further as shown in Figure 8-23 as blue lines.

Figure 8-23 Map of Cordons Used in LUTI Modelling (tie 2002)

Other major differences to the CSTM3 tests were that charges were no longer assumed to apply on a 24-hour basis and that the LUTI could model:

- Change in trip frequency;
- Change in trip destination;
- Change in route of travel (e.g. avoiding charged cordons);
- Change in mode of travel; and
- Change in time of travel.

Forecasts have been made in this modelling exercise for 5-yearly intervals from 2006 to 2026, but for the purposes of DIFFERENT, it is sufficient to look only at one year, and the one for which the results are shown in the following is the year 2011. For this year, for most indicators, the effects of the congestion charging system are peaking: effects for 2006 are much lower, and from 2016 onwards they are dropping again slightly.

It should also be noted that in further LUTI modelling exercises that were carried out later, the positive impact of the congestion charge became generally smaller; therefore, the numbers shown below represent a "best assumption" scenario, and the total size of the impacts should therefore not be taken at face value. But since the main purpose of the discussion in the context of this DIFFERENT report is to look whether there are any effects of a differentiation of charges at all and, if yes, how important they are relative to the overall expected impacts, the absolute values are not so important here.

The six tests that were carried out in December 2003, for which the results were reported in MVA 2004, were as follows:

- T1 – Reference Case;
- T2 – As T1 with cordon charges as follows: Inner Cordon all day, Outer Cordon AM and PM peak only;
- T3 – As T2 with Outer Cordon exemptions modelled for City of Edinburgh Council area zones beyond Outer Cordon;

- T4 – As T1 with cordon charges as follows: Inner Cordon all day, Outer Cordon AM peak hour only;
- T5 - As T1 with cordon charges as follows: Inner Cordon all day;
- T6 - As T1 with cordon charges as follows: Inner Cordon AM and PM peak only.

In all cases the charge is only to be paid once per day and only for inbound crossings.

In the context of DIFFERENT, the direct comparisons between T2, T3 and T4 and between T5 and T6 are most relevant.

It should be noted that the 2004 MVA report only contains a series of figures and tables without any accompanying text discussing or explaining the results. Any explanations offered below are therefore the interpretation by the author of this case study and not by MVA.

8.4.2 Traffic Impact

Table 8-2 shows the number of inbound crossings at the inner and the outer cordon in terms of both numbers of vehicles and person-trips for each of the three time periods: AM peak from 7:00 to 10:00, PM peak from 16:00 to 18:00, and the off-peak period in between.

Table 8-2 LUTI Results by Time of Day for the Year 2011 – Cordon Crossings

	T1	T2		T3		T4		T5		T6	
			% T1		% T1		% T1		% T1		% T1
Inner C. crossing ['000 veh]											
AM 7:00 – 10:00	55	39	-29.7	39	-29.8	40	-27.7	40	-27.5	40	-26.4
OP 10:00 – 16:00	82	64	-22.1	62	-23.6	64	-21.2	63	-22.2	88	+7.9
PM 16:00 – 18:00	45	28	-38.5	28	-38.6	28	-37.5	28	-38.0	29	-36.3
Inner C. crossing ['000 PT p-trips]											
AM 7:00 – 10:00	72	77	+7.1	77	+7.1	77	+6.7	76	+5.8	75	+5.2
OP 10:00 – 16:00	52	60	+14.5	60	+15.2	59	+13.4	58	+10.3	54	+3.8
PM 16:00 – 18:00	31	33	+7.9	33	+7.4	33	+8.3	33	+7.6	33	+7.4
Outer C. crossing ['000 veh]											
AM 7:00 – 10:00	48	41	-14.5	41	-14.0	41	-14.0	48	+0.3	48	+0.4
OP 10:00 – 16:00	73	70	-3.2	71	-3.0	71	-1.9	72	-1.3	72	-0.6
PM 16:00 – 18:00	47	40	-15.4	40	-15.0	46	-2.1	46	-2.2	47	-1.5
Outer C. crossing ['000 PT p-trips]											
AM 7:00 – 10:00	22	23	+6.7	23	+6.4	23	+5.2	23	+2.3	23	+2.2
OP 10:00 – 16:00	13	14	+7.3	13	+6.9	13	+5.2	13	+2.9	13	+1.4
PM 16:00 – 18:00	6	6	+9.1	6	+9.2	6	+5.6	6	+3.0	6	+2.3

The first thing that is notable in T1 is that, although the size of the outer cordon is obviously much larger than the inner one, in the reference case the number of vehicles crossing is not. During the whole 13 hour period, the inner cordon is crossed by 182,000 vehicles and the outer by 168,000, i.e. by 8% fewer vehicles. Only during the afternoon peak there are more vehicles coming into the wider city area than into the city centre. But for person-trips made by public transport the difference between the two cordons is much larger, and exists in all three time periods. In total for the day 155,000 PT persons-trips are made across the inner cordon and only 41,000 across the outer cordon. In the morning, the ratio is 3.3 to 1, during the off-peak 4 to 1 and in the afternoon 5.2 to 1. Overall, the number of vehicle crossings is larger than the number of PT trips with the exception of the inner cordon during the morning peak, when 31% more persons cross the cordon by public transport than vehicles of all types.

This number increases, again in the morning peak, to between 87 and 97 % with all five charging schemes, i.e. with any charging scheme nearly twice as many PT trips are made across the inner cordon as vehicle journeys. That the differences between the schemes are relatively small is understandable since the inner cordon is charged during this time in all scenarios.

Although the number of vehicles crossing the cordon is reduced very substantially for most periods in all scenarios, and the number of person-trips goes up at the same time, there is overall a strong reduction in all cordon crossings together, e.g. from 337,000 in T1 to 301,000 in T2, indicating, in spite of the strong modal shift towards public transport, a 10% net loss in visitors to the city centre. It should be noted, however, that this figure turned round into a 10% net gain in later model runs, when not only the effect of the charging scheme itself was assessed, but the effect of the associated investment package was taken into account at the same time.

Nevertheless, as mentioned before, for the purposes of the DIFFERENT project, the model runs without parallel transport improvements are more relevant, since they are the only ones that show the pure effects of different charging schemes, even if they do not reflect how the scheme would have been eventually implemented.

For the outer cordon, most effects are less strong, since there is much less opportunity for those drivers who need to get into the city to change mode or stop travelling altogether than for those aiming for the city centre. If there are charges at the inner cordon only, the number of crossings at the outer cordon even increases slightly; the explanation for this would be that a number of drivers who need to get in the morning from one end of the city to the other would stop using the direct route through the city centre and make a substantial detour using the city by-pass instead in order to avoid the inner cordon charge.

During the off-peak period, when there are no charges at the outer cordon, there are still very small traffic reductions, even with scenarios where there are also no off-peak charges at the inner cordon. This is, on first glance, somewhat surprising, in particular in the light of the increase for T6 at the inner cordon. This could mean that any charging scheme works as a general deterrent for car drivers to enter the city, even if they would not actually have to pay the charge for that particular trip.

With regard to the specific comparison between T2 and T3, i.e. without and with the outer cordon exemptions for Edinburgh residents living outside the outer cordon, most differences are under 1 %, with the only exception of vehicle crossings at the inner cordon during the off-peak, where they are for some unknown reason slightly higher.

The comparison between T2 and T4 (with and without the outer cordon PM peak charge) shows the obvious effect during the afternoon at the outer cordon, where in T4 there is only a very small reduction against T1, while it is substantial in T2.

For T5 and T6, there is the expected effect that without off-peak charge at the inner cordon there is not only no decrease in crossings during this time, but even an increase as drivers can be expected to move from the charged peak into the non-charged off-peak. But there are other phenomena that are counterintuitive. If there are more crossings in T6 in the off-peak, why are there also more crossings during the peaks, and this not only at the inner cordon, but also at the outer one?

From the data available it is simply not clear whether some car drivers really show a somewhat irrational behaviour, where increased differentiation, which here always means relaxation, of charges has less effect than it should rightfully have on non-affected time periods.

Table 8-3 lists the changes in the Total Travel Distance (TTD) and congestion by sector, i.e. for the areas inside the inner cordon, outside the outer cordon and the ‘other city’ i.e. the area between the two.

Table 8-3 LUTI Results by Sector for the Year 2011 – TTD and Congestion

	T1	T2	% T1	T3	% T1	T4	% T1	T5	% T1	T6	% T1
TTD ['000 veh*km]											
In inner cordon	399	297	-25.5	289	-27.5	309	-22.7	302	-24.4	353	-11.5
Other city	3,751	3,543	-5.6	3,547	-5.5	3,658	-2.5	3,703	-1.3	3,715	-1.0
Outside city	10,502	10,326	-1.7	10,328	-1.7	10,383	-1.1	10,447	-0.5	10,462	-0.4
Total	14,653	14,167	-3.3	14,164	-3.3	14,350	-2.1	14,451	-1.4	14,530	-0.8
T. in cong. ['000 veh*h]											
AM in inner cordon	1,571	537	-65.8	561	-64.3	614	-60.9	617	-60.7	643	-59.1
AM other city	5,684	4,380	-22.9	4,403	-22.5	4,924	-13.4	5,343	-6.0	5,573	-2.0
AM outside city	248	180	-27.4	180	-27.4	185	-25.4	257	+3.6	256	+3.2
AM Total	7,503	5,097	-32.1	5,144	-31.4	5,723	-23.7	6,217	-17.1	6,472	-13.7
OP in inner cordon	2,426	897	-63.0	632	-73.9	928	-61.7	952	-60.8	2,372	-2.2
OP other city	4,867	4,779	-1.8	4,837	-0.6	5,102	+4.8	5,205	+6.9	4,824	-0.9
OP outside city	306	248	-19.0	254	-17.0	282	-7.8	300	-2.0	287	-6.2
OP Total	7,599	5,924	-22.0	5,723	-24.7	6,312	-16.9	6,457	-15.0	7,483	-1.5
PM in inner cordon	1,156	301	-74.0	285	-75.3	316	-72.7	310	-73.2	313	-72.9
PM other city	6,408	5,675	-11.4	5,681	-11.3	6,526	+1.8	6,617	+3.3	5,261	-17.9
PM outside city	661	546	-17.4	544	-17.7	593	-10.3	604	-8.6	625	-5.4
PM Total	8,225	6,522	-20.7	6,510	-20.9	7,435	-9.6	7,531	-8.4	6,199	-24.6
In inner cordon	5,153	1,735	-66.3	1,478	-71.3	1,858	-63.9	1,879	-63.5	3,328	-35.4
Other city	16,959	14,834	-12.5	14,921	-12.0	16,552	-2.4	17,165	+1.2	15,658	-7.7
Outside city	1,215	974	-19.8	978	-19.5	1,060	-12.8	1,161	-4.4	1,168	-3.9
Total	23,327	17,543	-24.8	17,377	-25.5	19,470	-16.5	20,205	-13.4	20,154	-13.6

The TTD is reduced in all five charging scenarios for all three sectors, albeit to different degrees. The reduction is strongest in the city centre and least significant outside the city. Overall, it is strongest in T2 and T3 with 3.3%, where the exemption in T3 has no noticeable effect at all; not charging at the outer cordon in the PM peak in T4 lessens the TTD reduction to 2.1%. An inner cordon all day charge (T5) leads to a reduction of 1.4% and least effective is T6 with a reduction of only 0.8 %. All of these results are entirely in line with the logic of the schemes.

In the city centre, the reduction is, again as could be expected, mainly determined by the inner cordon charge with TTD reductions for T2 to T5 all ranging from 22.7 to 27.5 %, while T6 with the peak hour only charge more than halves the benefits. But what is not immediately obvious is the effect that the outer cordon charge has:

- T4 and T5 both have an all day charge at the inner cordon and T4 in addition the AM peak outer cordon charge, but the TTD reduction in T5 is stronger than in T4, i.e. more drivers avoid the city centre when there is an inner cordon charge only than in the case of a double cordon charge. This probably implies that drivers from outside the city are more likely to drive right into the centre, if they have already paid the charge at the outer cordon than in the case where there is no outer cordon and they can avoid the charge altogether by not going into the city centre.
- The comparison between T2 and T3 follows the same logic: If the residents in Currie and Balerno, the suburbs outside the cordon, get an exemption for the outer cordon, they are more likely to cross it than without the exemption. And since they then can avoid the charge altogether, if they

stay within the inner suburbs, they appear to be more likely to avoid the city centre than if they had not exemption.

- However, since the TTD between the cordons is in T3 only 4,000 veh*km higher than in T2, but in the city centre 8,000 veh*km lower, something else must be going on here. Looking back at the number of vehicles that cross the cordons from Table 8-2, the trend is the same, even if the absolute differences are smaller: in T2 130,000 vehicles cross the inner cordon and 151,000 the outer one, and in T3 129,000 the inner and 152,000 the outer cordon. It is not obvious why an increase of 1.6% of vehicles travelling into the city centre should cause a 2.8% increase in traffic driving around inside it; but, more crucially, it is not at all clear why, with the exemption, 1,000 vehicles more should cross the outer cordon, but 2,000 less the inner one.

It could be expected that the reduction in congestion is roughly in line with the reduction in traffic, but this is not always the case:

- For the total over the whole day and all sectors, the traffic reduction is larger in T5 than in T6, but for congestion it is the other way round. This is largely due to the fact that in T5 congestion increases by 1.2 % between the cordons, compared to the reference case, although the TTD drops by 1.3%; this congestion increase occurs in both the off-peak and the afternoon, while during the AM peak, when the outer cordon is charged, congestion is reduced in all sectors. This could be explained if the traffic reduction in the morning is not sufficient to reduce congestion significantly, because congestion is so severe, while later in the day the network now runs just below the ‘tipping point’ and even a relatively small increase in traffic leads to traffic breakdown and sets congestion off. Unfortunately, a breakdown of the TTD into the three time periods is not available to confirm this assumption, and results discussed in the context of Table 8-4 below raise more questions for the comparison between T5 and T6.
- Within the inner cordon, the TTD drops, compared with T1, by 22.7% in T4 and 24.4% in T5, while congestion drops by 63.9% in T5 and 63.5% in T5. These differences are not huge, but nevertheless, the outer cordon in the AM peak leads to more traffic in the city centre for the overall day, while it reduces congestion there overall. The only period where this is different, is the afternoon peak. Any possible reasons for this are pure speculation.
- What happens during the AM peak outside the city is even more difficult to understand: in T5, with an inner cordon charge only, the TTD drops by 0.5% compared to T1, but congestion increases by 3.6 %; in T6 the drop in TTD is 0.4% and the increase in congestion 3.2%. This might still be understandable, if ‘outside the city’ meant just the immediate surrounding area, where even a relatively small amount traffic, that avoids travel across the city and uses the by-pass instead, can indeed aggravate the already existing congestion on the by-pass significantly. But ‘outside the city’ is the whole travel-to-work area of approx. 2,000 km^2, not including Edinburgh herself with 259 km^2, and even though congestion is not distributed over the whole area, but concentrated on a smallish number of black spots, a congestion increase of more than 3% so far away from the charged cordon around Edinburgh city centre is difficult to understand.

There are further times and locations, where the connection between TTD and congestion for different scenarios appears to be illogic, and it is therefore unfortunately impossible to draw any general conclusions from this data.

Table 8-4 summarises the overall results from the LUTI modelling.

The first thing that is noticeable from the screenline data is that traffic across the orbital screenlines increases compared to T1 in all scenarios without a PM peak charge on the outer cordon. Rat-running around the inner cordon is a logical consequence of drivers’ trying to avoid the cordon, and that in T2 and T3 this is outweighed by the reduction of cars coming in from the outside, is understandable.

It also hangs together that, compared to T2, which not only has the AM outer charge as T4, but also the PM charge, the number of vehicles heading into the city centre in T4 is only up by 2,000, while the orbital crossings are up by 14,000, and that therefore the TTD is up by 115,000 veh*km and congestion by 1.7 million veh*h.

In the comparison of T4 with T1, orbital crossings are up by 11,000, the number of cars heading into the city centre are down by 50,000 and, because the latter carries more weight, the overall TTD between the cordons is down 93,000 veh*km, and congestion by 407,000 veh*h.

For the comparison between T5 and T6, there are 26,000 more vehicles aiming for the centre in T6 while there are 18,000 less orbital crossings. The resulting difference in TTD is an increase of 12,000 veh*km, which is still within the logic of the crossings into the centre carrying more weight than the screenline crossings. But this overall increase in traffic now results in a congestion decrease of 1.5 million veh*h in T6 (Table 8-4). To maintain the 'tipping point' theory for the T5 v T6 comparison suggested earlier, it would be necessary that the big reduction of traffic on the arterials does not have any significant effect on reducing congestion there, while the smaller increase in orbital traffic has a very substantial effect on increasing congestion on the radial routes. Even if the arterials in Edinburgh are better designed for taking high traffic volumes than any radial connections, this is still a very startling result.

Table 8-4 LUTI Summary Results for the Year 2011

	T1	T2	% T1	T3	% T1	T4	% T1	T5	% T1	T6	% T1
Screenline data ['000 veh]											
Inner c. inbound	182	130	-28.5	129	-29.2	132	-27.2	131	-27.7	157	-13.4
Outer c. inbound	168	151	-9.9	152	-9.5	159	-5.5	166	-1.1	167	-0.6
Orbitals	368	365	-0.7	367	-0.1	379	+3.0	381	+3.8	373	+1.5
Total Area trips['000]											
Car trips	1,614	1,543	-4.4	1,544	-4.3	1,570	-2.7	1,576	-2.3	1,589	-1.5
PT	335	361	+7.8	360	+7.5	355	+6.0	349	+4.3	345	+3.1
Slow modes	588	618	+5.1	616	+4.8	608	+3.4	601	+2.2	597	+1.6
Total	2,536	2,522	-0.6	2,520	-0.7	2,532	-0.2	2,526	-0.4	2,531	-0.2
Trips to Z1 to Z12 ['000]											
Cars	127	120	-5.3	120	-5.4	121	-4.6	120	-5.3	123	-2.7
PT	76	83	+9.8	83	+9.5	82	+7.7	81	+6.2	79	+4.1
Total	273	279	+2.3	279	+2.1	277	+1.4	274	+0.4	275	+0.6
Total p trip km [million km]											
Car	21.4	20.7	-3.1	20.8	-3.0	21.0	-1.9	21.2	-1.2	21.2	-0.8
PT	4.6	4.9	+6.9	4.9	+6.7	4.9	+5.2	4.8	+3.1	4.7	+2.2
Total	26.0	25.7	-1.3	25.7	-1.3	25.9	-0.6	25.9	-0.4	26.0	-0.3
Mode share cars [%]	63.6	61.2	-	61.3	-	62.0	-	62.4	-	62.8	-
Time in congestion ['000 veh*h]	23.3	17.5	-24.8	17.4	-25.5	19.5	-16.5	20.2	-13.3	21.8	-6.7
CC Revenue [£ m]	-	74.1	-	72.2	-	64.2	-	50.7	-	28.2	-

Total area trips are reduced in all five scenarios with a reduction in car trips that is not fully compensated by the increase in trips made by public transport and slow modes. What is surprising here is that the exemptions in T3 only lead to an increase in vehicles crossing the outer cordon of 1,000 while at the same time reducing both PT trips by 1,000 and trips by slow mode by another 2,000 compared with T2, resulting in a total reduction in trip numbers by 2,000. That giving exemptions to a group of people should reduce overall trip numbers rather than increase them is entirely counterintuitive, and no explanation can be found for this result.

The comparison between T4 and T2 is more in line with expectations, since in T4 cordon crossings are up at both cordons, overall car trips are up and, in spite of some decrease in the use of PT and slow modes, overall area trips are up by 10,000; and the same is also true for the comparison between T5 and T6.

Zone Z1 to Z12 are not precisely the same as the area inside the inner cordon, since the model and its zoning were developed before the cordon boundaries were finalised, but they still represent the city centre overall. For trips to these zones overall trip numbers are up over T1 in all charging scenarios, with the gain in PT trips more than compensating for the loss in car trips. But again, consistent with the inner cordon crossings shown in Table 8-2 and discussed in that context, the comparison between T3 and T2 shows that the exemptions lead to a decrease in travel into the city centre.

In line with the area trips, also the total person trip kilometres are reduced by all five pricing scenarios, but the overall differences are all very small, and similarly, the mode share of cars changes only by a maximum of 2.5% absolute, or 3.9% relative, in T2 and even less in the other scenarios. It is therefore even more remarkable that these small overall changes have such a strong effect on reducing congestion, which is down by up to 25.5% in T3 and even in T6 still by 6.7% while the person trip km in T6 only go down by 0.3% (or 0.075 million km).

Finally, the revenue raised by the five charging schemes is in line with expectations, with the revenues increasing with increasing number of cordons and operating hours.

8.5 OVERALL CONCLUSIONS

When Edinburgh was included as a case study in the original proposal for the DIFFERENT project, it was expected that this would entail a full real-life charging scheme and the evaluation results surrounding this. However, the referendum that was held in February 2005 stopped the scheme in its tracks, and only much more limited data was available from the preparatory work for the scheme introduction. Much of this data concerns results from public surveys and the highlights of these are reported in the DIFFERENT deliverable D4.2, while in the context of this current report the only relevant information came from two sets of modelling runs.

From the first set of runs that were still conducted with the so-called CSTM3 model, when the final shape of any future charging schemes was still very uncertain, it was found that one of the key effects of any of the investigated charging schemes was the shift from car travel to public transport use, in particular during the PM peak. The reductions in flows across the cordons for the 24-hour day were up to a maximum of 24% for a £ 4.00 charge at the cordon across the inner suburbs, with charges of £ 2.00, £ 1.00 and £ 0.50 leading to reductions of 16%, 8% and 5 % respectively.

It was noticeable that the gain in PT passenger trips was considerably higher than the loss in car trips. This was in part due to the fact that the average car carries more than one passenger, and in part due to the reduction in bus travel times due to reduced congestion, which attracts additional passengers.

It was also obvious that the modal shift increased with the level of charges. However, the relationship between the charging level and the modal shift was not linear and the marginal effect of charge increases on modal shift decreased more and more the higher the charge became, as could be reasonably expected with standard elasticities.

The comparison between all-day charges and schemes with a lower off-peak charge show, as expected, that the all day-charge produces much higher net benefits; however, the differences between the charging scenarios are in line with the average level of charge in each of them, and do not show any explicit effects of the differentiation.

This means that overall, and at least in this modelling exercise, there is no impact from any differentiation of charges on traffic reductions, neither by number of cordons nor by time of day. All differences in impact can be simply explained by the overall charging level.

The analysis of the economic impact also confirms the non-linearity of the impact of higher charges: a “spatial differentiation” of charges is overall more effective than a mere increase in the level of charges at one particular cordon, i.e. ‘catching’ more people in the more cordons has a stronger effect than charging fewer drivers more money.

From the modelling exercise carried out with LUTI it is unfortunately not possible to draw any general conclusions. Differences in traffic reductions between different schemes are largely due to the simple question of whether the charging is operating at any cordon during the time period considered, without any obvious further effects of the time differentiation.

With regard to congestion there are a number of startling results, where the connection between traffic volume and congestion level is difficult, or even impossible, to explain, but without further insight into the details of the underlying modelling no conclusions can be drawn from this.

From the specific comparison between T2 and T3, i.e. without and with the outer cordon exemptions for Edinburgh residents living outside the outer cordon, it is clear that most differences are under 1 %, with the only exception of vehicle crossings at the inner cordon during the off-peak, where they are slightly higher. This means that, although these exemptions were an important political issue and obviously very relevant for the drivers concerned, the impact of the exemptions on the overall performance of the charging scheme would have been very small.

9 RESULTS FROM APPLICATION OF A CONCEPTUAL MODEL

9.1 AIMS OF THE MODELLING WORK

The aims of the modelling work carried out with a conceptual model are twofold:

- To assess the comparative merits of increasingly differentiated charging schemes in an urban network, in particular with regard to the marginal returns of increasing degrees of scheme complexity; and
- To assess how sensitive these results are to different assumptions concerning price elasticities and, therefore, how important a precise estimate of the elasticities is in the context of differentiated charges.

This will be done by using an elastic demand, user equilibrium traffic assignment model, which represents the main road network of a real city and assesses the short-term impact on private car traffic (in terms of rerouting, and trip suppression) of a variety of forms of charging schemes. The charging schemes to be tried are: complex (link-specific) marginal social cost pricing, cordons, distance-based, area-based and, as input to chapter 10, motorway charging.

Starting from the base case (with the network as it is, and with no charges), each of the different charging schemes will be imposed, and the user equilibrium assignment model applied to find the new equilibrium (giving link flows, OD travel times, and (when elastic demand assumed) equilibrium OD demands). From this, one can then calculate a variety of statistical measures to use to assess the impact of the scheme in terms of the changes in these measures from the base case equilibrium to the new equilibrium. The possible measures include:

- Total flow across each cordon, or total veh*km within each region (e.g. inner cordon, outer cordon etc), or on different road types;
- Total number of trips in the network, total veh-hours spent in network, average trip length, average trip duration;
- Total cost of delays, total cost of other externalities;
- Total toll revenue.

Other statistics could, of course, be calculated, but the ones above give a sufficiently full picture of the effects of any scheme, without going into excessive detail.

9.2 BASE NETWORK

The network used for the modelling is one that has been used before for modelling work, and is based on Edinburgh. The city itself covers an area approximately 10 km^2, but the modelled area is approximately 30 km by 20 km. The network consists of 175 (mainly) two-way links, and a total road length of 490 km (of which 143 km is of motorway or near-motorway standard). There are 25 zones, and a total demand (representing the morning peak) of approximately 110,000 movements in the base case, spread over 550 OD pairs. If all trips could be made at free-flow travel speeds, the total time spent in the network would be 19,987 veh*h and the average trip duration would be 10.9 minutes. The full network diagram is shown in Figure 9-1.

The modelling is carried out using a user equilibrium (Wardrop) traffic assignment model, with a single user class. Link performance functions are of the BPR variety, with travel times expressed in seconds and flows in veh/h. Once represented as separate, one-way links, there are 344 such links, and 52 zone centroid connectors.

The assignment software is written in Fortran95 and uses the Frank-Wolfe method to iterate through to the equilibrium solution. The results obtained have been compared, for the base case, with those from a different piece of software that uses the origin-based approach of Bar-Gera (Bar-Gera and Boyce, 1998), which is known to give extremely precise results. Close agreement was obtained, giving reassurance of the reasonable accuracy and good convergence of the results obtained from the Fortran code. It was not considered practicable to use Bar-Gera's origin-based assignment software in the rest of the work described here, as it would not have possible to make modifications to the source code to implement the various features required in the testing.

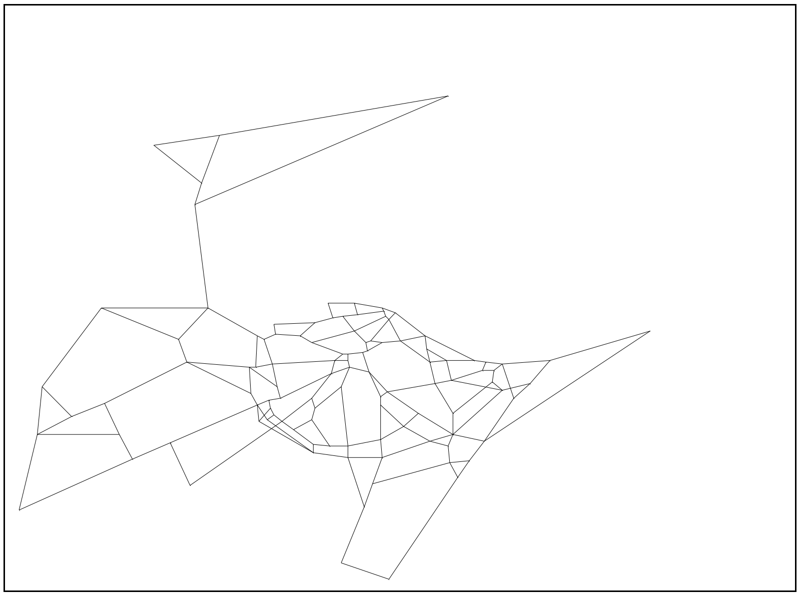


Figure 9-1 Diagram Showing Whole of Modelled Network

Two cordons are defined: an outer one, located just inside the city ring road, and an inner one encircling the central area of the city. As shown in Figure 9-2, the inner cordon is made up of seven links, and the outer cordon consists of 17 links. Of the 25 zones, three (zones 1, 2 and 12 – see Figure 1) are inside the inner cordon (Region 1), 11 are between the two cordons (Region 2), and the remaining 11 (zones 15 to 25) are outside the outer cordon (Region 3).

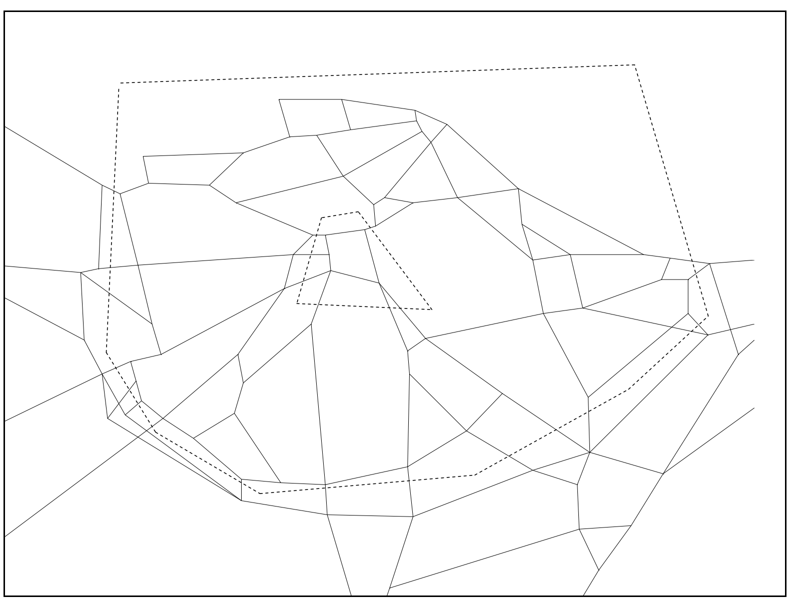


Figure 9-2 Central Part of Modelled Network, Showing Inner and Outer Cordons

9.3 EVALUATION PARAMETERS

Delay is valued at the resource value of time (assumed to be € 0.1413 per person minute – based on the assumption that the peak period matrix is 50% commuters, 10% workers and 40% other and using Webtag's resource values of time (in £ per hour) of 4.17, 22.11 and 3.68 for these three purposes respectively (see Webtag, 2007).

The assumed values of externalities shown in Table 9-1 are taken from Samson et al (2001), based on values for cars in outer metropolitan areas in peak periods and adjusted to reflect the different impact of smaller and larger cars.

Table 9-1 Assumed Values of Externalities (in € Cents per Veh*Km)

	Small cars		Large cars	
	Principal	Other	Principal	Other
Infrastructure wear and tear	0.071	0.141	0.047	0.094
Accidents	2.717	2.717	2.223	2.223
Local Air Pollution	0.517	0.517	0.423	0.423
Noise	0.032	0.032	0.026	0.026
Climate Change	0.210	0.210	0.172	0.172
Total	3.547	3.617	2.891	2.938

Given an assumption of 50% large cars (> 1600 ccs) and 50% smaller cars (< 1600 ccs), overall total values of 3.219 € cents/veh*km (for principal roads) and 3.278 (for other roads) will be assumed for the single vehicle class in this modelling work.

9.4 INITIAL TESTS – FIXED DEMAND

An initial set of runs was carried out, to check the operation of the software, and to illustrate the evaluation measures. In these runs, a fixed demand was assumed, and four versions of a two-cordon charging scheme were applied: (1) no tolls, (2) zero toll on the inner cordon, and € 5 on the outer cordon, (3) € 10 on the inner cordon, and zero on the outer cordon, and (4) a toll of € 10 at the inner cordon, and € 5 at the outer cordon. Table 9-2 shows the results.

Table 9-2 Results from Charges of (*x*, *y*) € at Inner and Outer Cordons (Fixed Demand)

Measure	(0, 0)	(0, 5)	(10, 0)	(10, 5)
Total vehicle trips ['000]	109.7	109.7	109.7	109.7
Total person trips ['000]	131.6	131.6	131.6	131.6
Total vehs crossing inner cordon ['000]	28.8	30.1	23.3	23.3
Total vehs crossing outer cordon ['000]	37.8	30.9	39.8	30.9
Total veh*km ['000]	1798.2	1783.5	1831.9	1814.7
Percentage veh*km on principal roads	58.9	58.1	58.9	56.8
Total veh*h ['000]	56.4	57.7	57.8	60.2
Percentage veh*h on principal roads	41.7	52.9	60.7	67.2
Total veh*km in Region 1 ['000]	77.0	80.0	66.3	66.5
Total veh*km in Region 2 ['000]	511.2	508.5	537.8	548.0
Total veh*km in Region 3 ['000]	1210.0	1195.0	1227.8	1200.2
Average trip length [km]	16.4	16.3	16.7	16.5
Average trip duration [min]	30.8	31.5	31.6	33.0
Total cost of delay [€ '000]	355.9	368.6	365.7	389.7
Total cost of externalities [€ '000]	58.3	57.9	59.4	58.9
Total cost of tolls charged [€ '000]	0.0	154.5	233.4	387.9
Benefit (measured from no tolls case)	0.0	-12.2	-11.0	-34.3

Delay here is defined as the excess of travel time over the free-flow travel time. The free-flow average trip duration is 10.9 min). The impact of a charging scheme can be measured in a variety of ways, as may be seen from the list of different measures in the table above. For the moment, however, to provide a simple economic measure, the scheme "benefit" is defined as the difference between the sum of the costs of the delays and externalities for the no tolls case and the sum of the costs of delays and externalities from the scheme. So, naturally the benefit for the base case is zero, and for any proposed scheme the benefit should hopefully be positive. However, the benefits of the three cordon schemes are all negative, although this is with the assumption of fixed demand, where rerouting is the only option available to users.

Other than that, the results are generally as would be expected, given that the imposition of the tolls gives rise only to rerouting (because fixed demand is assumed here). Note that in case 2, compared with case 1, there is an increase in veh*km in Region 1, when a toll is imposed at the outer cordon only. This is presumably due to some journeys with origin and destination both in Region 2, which previously would have taken a route that went out into Region 3 (e.g. to the by-pass) and then back in again, but now take a more direct route, avoiding Region 3 and the charge that would be incurred when passing back into Region 2.

9.5 INITIAL TESTS – ELASTIC DEMAND

As a further check on the software, the same four charging schemes were applied, but this time with elastic demand. The demand function is of the power law type, with a constant elasticity *e* such that the demand function looks like:

$$\frac{Q}{Q_0} = \left(\frac{C}{C_0}\right)^{-e}$$

where Q_0 and C_0 are the demand and travel cost for an OD pair in the "no charges" scheme. Q and C are the equilibrium demand and travel cost in any other scheme (i.e. when tolls are applied). An outer iterative process is applied to adjust the demand, starting from the base demands of Q_0 until convergence is obtained (that is, the demands applied are in balance with the travel costs, according to the demand function above). Good convergence (to within 0.1% of each OD's demand) was found to be obtained in around six or seven of these outer loops.

Using a value of elasticity of e = 0.3, the results from the same four cordon charging schemes are shown in Table 9-3 (in which the first column is identical to that in Table 9-2, of course). The changes (from the base case of no tolls) in terms of total veh*km, costs of delay and externalities, and tolls charged, are not quite additive: that is, the effect of a change from (0, 0) to (10, 5) is slightly less than the sum of the change from (0, 0) to (0, 5) plus that from (0, 0) to (10, 0). The changes themselves are broadly as would be expected:

- As tolls are imposed, demand falls; the larger the tolls imposed, the greater is this reduction in demand; this demand reduction will depend of course on the assumed value of elasticity: the greater the value of *e*, the greater will be the reduction in demand for any given charging scheme;
- When a toll is imposed on either the inner or outer cordon, the flow across that cordon is reduced;
- When a toll is imposed on the inner cordon, traffic levels in Region 1 fall, and average trip length rises slightly (because shorter trips within or into Region 1 are reduced in number);
- As toll levels increase and demand falls, the total delay in the network falls.

Now, under elastic assignment, the scheme "benefits" (the sum of the reductions in the costs of delays and externalities, measured from the base, no tolls, case) are all positive.

Table 9-3 Results from Charges of (*x*, *y*) € at Inner and Outer Cordons, (Elastic Demand, with *e* = 0.3)

Measure	(0, 0)	(0, 5)	(10, 0)	(10, 5)
Total vehicle trips [‘000]	109.7	104.3	102.9	97.8
Total person trips [‘000]	131.6	125.1	123.5	117.3
Total vehs crossing inner cordon [‘000]	28.8	28.5	16.3	15.7
Total vehs crossing outer cordon [‘000]	37.8	25.7	37.4	24.4
Total veh*km [‘000]	1798.2	1686.2	1756.1	1654.4
Percentage veh*km on principal roads	58.9	58.7	59.4	58.7
Total veh*h [‘000]	56.4	51.1	51.4	47.7
Percentage veh*h on principal roads	41.7	52.5	57.8	67.8
Total veh*km in Region 1 [‘000]	77.0	77.1	57.5	55.4
Total veh*km in Region 2 [‘000]	511.2	476.8	503.4	479.7
Total veh*km in Region 3 [‘000]	1210.0	1132.3	1195.2	1119.2
Average trip length [km]	16.4	16.2	17.1	16.9
Average trip duration [min]	30.8	29.4	30.0	29.3
Total cost of delay [€ ‘000]	355.9	313.9	312.0	284.5
Total cost of externalities [€ ‘000]	58.3	54.7	57.0	53.7
Total cost of tolls charged [€ ‘000]	0.0	128.4	162.9	279.4
Benefit (measured from no tolls case)	0.0	45.7	45.3	76.0

9.6 CHARGING SCHEMES TO BE MODELLED

9.6.1 Introduction

The aim was to model the effect of each of the following types of charging schemes:

- Cordon scheme: one-cordon and two-cordon schemes, with the locations as shown in Figure 9-2, and charges of € *x* and *y* respectively at the inner and outer cordons;
- Distance-based schemes, in which travel is charges at a constant rate per km, on links within each of the three regions: Region 1 is inside the inner cordon, Region 2 is between the inner and outer cordon, and Region 3 is outside the outer cordon;
- Area-based schemes, in which fixed amounts € *x* and *y* are charged respectively if a part (however large or small) of any trip is within Regions 1 and 2 respectively;
- Motorway-only schemes, in which a charge, per link, is made for any parts of a trip that use motorway links;
- Mixed schemes, which consist of an outer cordon plus per-link charges on all motorway links that are outside the outer cordon;
- First best schemes, in which separate charges are made on each link in the whole network (with different charges for the different directions of travel), also known as “optimal tolls” as the aim is to set the level of charge on each link to reflect the marginal costs imposed by each vehicle on all others, in terms of congestion and other externalities, or “fully complex” schemes as they are the most differentiated, or complex schemes, with separate charges made on each link (including separate charges for the different directions on the same two-way link);

The following sections will deal with each of these types of scheme in turn, giving more detail of the modelling, and providing results from example runs of that scheme, obtained from the traffic assignment model with elastic demand, with an assumed value of elasticity *e* = 0.3.

9.6.2 Cordon-Based Schemes

With the given network, and with the inner and outer cordon located as shown in Figure 9-2, charges of € x and y respectively are to be charged on vehicles crossing *in the inbound direction only*. Therefore the generalised cost on a link that crosses the inner cordon in the inbound direction is the sum of the travel time t plus x/β where β is the value of time. Similarly, the generalised cost on links that cross the outer cordon in the inbound direction is $t + y/\beta$. These charges apply to all vehicles.

Some sample results from this type of scheme have already been shown in Table 9-2 (for fixed demand) and Table 9-3 (for elastic demand). With charges of (x, 0) a single (inner) cordon with various levels of charge x can be clearly modelled, and with charges of (0, y) a single (outer) cordon at various levels of charge y.

9.6.3 Distance-Based Schemes

In a distance-based scheme, the toll charged on a link is proportional to the length of the link, with the rate per km being different for links in the three different regions. Each link is deemed to lie entirely within just one region. So, links that straddle the inner cordon are deemed to lie entirely within Region 1; whilst links that straddle the outer cordon are deemed to lie entirely within Region 2. Therefore, the generalised cost of travel on a link in Region j is the sum of the travel time and the charge on that link: $t + x_j L/\beta$ where L is the length of the link in km, and x_j is the charge per km in Region j.

Once the link costs are defined in this way, assignment is straightforward. Some example results are displayed in Table 9-4, for rates per km in Regions 1 and 2 of (0, 0) (the "no tolls" case, for comparison), (20, 0), (20, 10) and (40, 20) € cents/km.

Table 9-4 Results from Distance-based Charges of (x, y) € cents per km in Region 1 and Region 2, (Elastic Demand, with e = 0.3)

Measure	(0, 0)	(20,0)	(20,10)	(40,20)
Total vehicle trips ['000]	109.7	108.6	105.4	101.7
Total person trips ['000]	131.6	130.4	126.4	122.1
Total vehs crossing inner cordon ['000]	28.8	27.2	27.2	25.8
Total vehs crossing outer cordon ['000]	37.8	38.1	36.6	35.5
Total veh*km ['000]	1798.2	1797.0	1751.9	1719.1
Percentage veh*km on principal roads	58.9	58.8	59.9	60.7
Total veh*h ['000]	56.4	55.7	53.6	51.7
Percentage veh*h on principal roads	41.7	42.4	45.8	49.6
Total veh*km in Region 1 ['000]	77.0	68.8	71.1	65.9
Total veh*km in Region 2 ['000]	511.2	515.5	467.9	436.3
Total veh*km in Region 3 ['000]	1210.0	1212.7	1212.9	1216.9
Average trip length [km]	16.4	16.5	16.6	16.9
Average trip duration [min]	30.8	30.8	30.5	30.5
Total cost of delay [€ '000]	355.9	349.3	335.2	322.0
Total cost of externalities [€ '000]	58.3	58.3	56.8	55.7
Total cost of tolls charged [€ '000]	0.0	13.8	61.0	113.6
Benefit (measured from no tolls case)	0.0	6.6	22.2	36.5

It can be seen that, as would be expected, when a charge is made for travel within Region 1 only, the flow across the inner cordon falls and the total distance travelled in Region 1 falls, whilst the distance travelled in Regions 2 and 3 increases slightly. Also, it can be noted that the demand, and the total distance travelled, fall as the charge levels increase from (0, 0), through (20, 10) to (40, 20) and that these changes are approximately (but not exactly) linear: that is, the change from (0, 0) to (20, 10) is roughly the same as from (20, 10) to (40, 20).

9.6.4 Area-Based Schemes

In an area-based charging scheme, a charge is made for a part (however long or short) of any trip that involves the use of links within a specified area. In the simplest version of the scheme, only the innermost region, Region 1, is charged. So, any trip that originates in Region 1, or originates elsewhere but uses a route that crosses into Region 1, will be subject to the charge.

In general, there are charges τ_1, τ_2 and τ_3 associated with Regions 1, 2 and 3 respectively. Any trip originating in Region *k* will be charged τ_k and if the path used to reach the destination crosses into any other region *j*, then the link crossing that boundary have a toll τ_j added to its generalised cost. Therefore the link costs are origin-specific and once the charge at the origin has been imposed, the system is modelled in a similar way to a cordon-based system, except that the cordon tolls are specific to the region that the origin zone lies within. This is therefore a form of multiple user class user equilibrium assignment problem, where the user classes are associated with the three regions that the origin zone lies within.

Schemes are considered in which there is no charge made in the outer region, Region 3, but charges *x* and *y* made in Regions 1 and 2, with $x \geq y$. Table 9-5 shows some sample outputs for a variety of levels of the charges.

Table 9-5 Results from Area-based Charging Scheme, with Charges of (*x*, *y*) € in Regions 1 and 2 (Elastic Demand with *e* = 0.3)

Measure	(0, 0)	(5, 0)	(10, 0)	(10, 2)
Total vehicle trips [‘000]	109.7	100.1	96.6	88.4
Total person trips [‘000]	131.6	120.2	116.0	106.1
Total vehs crossing inner cordon [‘000]	28.8	18.6	16.3	15.7
Total vehs crossing outer cordon [‘000]	37.8	38.1	37.4	33.1
Total veh*km [‘000]	1798.2	1750.7	1719.4	1618.1
Percentage veh*km on principal roads	58.9	59.6	60.1	61.3
Total veh*h [‘000]	56.4	51.5	49.2	43.5
Percentage veh*h on principal roads	41.7	43.5	44.6	46.4
Total veh*km in Region 1 [‘000]	77.0	54.0	48.5	45.8
Total veh*km in Region 2 [‘000]	511.2	501.0	487.0	438.1
Total veh*km in Region 3 [‘000]	1210.0	1195.8	1183.9	1134.2
Average trip length [km]	16.4	17.5	17.8	18.3
Average trip duration [min]	30.8	30.8	30.6	29.5
Total cost of delay [€ ‘000]	355.9	314.2	295.8	251.6
Total cost of externalities [€ ‘000]	58.3	56.8	55.8	52.5
Total cost of tolls charged [€ ‘000]	0.0	144.5	250.5	392.3
Benefit (measured from no tolls case)	0.0	43.3	62.7	110.2

The results are broadly as would be expected. As the charge for trips in Region 1 increases, the number of trips crossing the inner cordon and the number of veh*km in Regions 1 fall appreciably whilst veh*km in the other two regions are reduced only marginally. The average trip length is increased, as it is predominantly the shorter trips that are eliminated. When additionally a charge is made for trips in Region 2, the number of trips crossing the outer cordon falls, as does the veh*km in Region 2.

9.6.5 Motorway-Only Schemes

Of the total road length of 490 km in the modelled network, 143 km are of motorway or near-motorway standard. These motorway links are shown in bold in the network diagram below in Figure 9-3. It can be seen that the motorway links are predominantly on the approaches to the city from the north, west and east, and on the southern city by-pass, and therefore almost entirely in Region 3. However, there is a short section of motorway leading towards the city centre (the Western Approach Road), and a section on the approach from the east that crosses the outer cordon.

In the motorway-only schemes, charges are made at a constant rate per km on all motorway links, whilst all non-motorway links are untolled. The generalised cost of a motorway link is then the sum of the travel time t and $\alpha L/\beta$ where L is the length of the link, α is the constant charge rate (in cents per km) and β is the value of time.

Figure 9-3 Network Diagram Showing Motorway Links as Thicker Lines

Some example results are shown in Table 9-6 for a range of values of the constant rate per km from zero through to 50 € cents per km.

Table 9-6 Motorway Only Tolls, for Constant Toll Rates α of 0, 10, 30 and 50 € Cents per Km

Measure	0	10	30	50
Total vehicle trips [‘000]	109.7	106.0	100.4	97.6
Total person trips [‘000]	131.6	127.2	120.5	117.1
Total vehs crossing inner cordon [‘000]	28.8	28.9	29.7	29.7
Total vehs crossing outer cordon [‘000]	37.8	34.3	30.0	29.8
Total veh*km [‘000]	1798.2	1713.6	1623.8	1570.6
Percentage veh*km on motorways	58.9	42.3	23.7	18.4
Total veh*h [‘000]	56.4	53.4	59.5	63.2
Percentage veh*h on motorways	41.7	44.1	37.5	37.9
Total veh*km in Region 1 [‘000]	77.0	77.6	82.2	83.9
Total veh*km in Region 2 [‘000]	511.2	509.5	521.7	545.8
Total veh*km in Region 3 [‘000]	1210.0	1126.5	1019.9	940.9
Average trip length [km]	16.4	16.2	16.2	16.1
Average trip duration [min]	30.8	30.2	35.6	38.8
Total cost of delay [€ ‘000]	355.9	323.2	383.0	422.0
Total cost of externalities [€ ‘000]	58.3	55.7	53.0	51.3
Total cost of tolls charged [€ ‘000]	0.0	72.4	115.3	144.5
Benefit (measured from no tolls case)	0.0	35.3	-21.8	-59.1

Here it can be seen that as the rate per km increases, the demand falls and the percentage of veh*km on motorway links falls dramatically, with a consequential increase in the veh*km in Regions 1 and 2. Because drivers are rerouting in order to avoid motorway links, congestion in the inner parts of the network increases. The total delay falls at first (for a rate of 10 cents per km), but then increases, even though the total demand is decreasing substantially. Naturally, the average trip duration increases substantially, from 30.8 to 38.8 minutes.

9.6.6 Mixed Schemes

In an attempt to counteract some of the clear disadvantages of the motorway-only schemes noted above, a "mixed" scheme was modelled. In a mixed scheme, there is a charge for crossing the outer cordon (in the inbound direction only), plus a charge at a constant rate per km on the motorway links that are outside this cordon.

Results are shown below in Table 9-7 for (i) the no tolls case, (ii) a charge of 10 cents per km on motorway links only (copied from Table 9-6), (iii) a charge of € 15 at the outer cordon only, and (iv) a combination of a charge of € 15 at the outer cordon, plus a charge of 10 cents per km on motorway links.

Table 9-7 Mixed Tolls (*y, z*): Outer Cordon Charge *y* €, and Outer Motorways Tolled at *z* Cents per km (Elastic Demand, with *e* = 0.3)

Measure	(0, 0)	(0, 10)	(15,0)	(15, 10)
Total vehicle trips ['000]	109.7	106.0	100.4	97.9
Total person trips ['000]	131.6	127.2	120.5	117.5
Total vehs crossing inner cordon ['000]	28.8	28.9	27.3	27.3
Total vehs crossing outer cordon ['000]	37.8	34.3	21.1	20.8
Total veh*km ['000]	1798.2	1713.6	1594.3	1531.0
Percentage veh*km on principal roads	58.9	42.3	59.1	40.3
Total veh*h ['000]	56.4	53.4	46.0	44.8
Percentage veh*h on principal roads	41.7	44.1	74.2	71.9
Total veh*km in Region 1 ['000]	77.0	77.6	75.2	75.7
Total veh*km in Region 2 ['000]	511.2	509.5	454.0	460.4
Total veh*km in Region 3 ['000]	1210.0	1126.5	1065.1	994.9
Average trip length [km]	16.4	16.2	15.9	15.6
Average trip duration [min]	30.8	30.2	27.5	27.5
Total cost of delay [€ '000]	355.9	323.2	272.8	257.1
Total cost of externalities [€ '000]	58.3	55.7	51.7	49.8
Total cost of tolls charged [€ '000]	0.0	72.4	316.9	368.8
Benefit (measured from no tolls case)	0.0	35.3	89.7	107.3

It appears that the effects of the two component parts of the mixed scheme are roughly additive: for example, the effect of the motorway charging alone is to reduce the cost of total delay from 356 to 323 (a drop of 32); the effect of the cordon alone is a drop of 83; whilst the combined effect of the mixed scheme is a drop of 99. So, it appears that the two components combine well.

9.6.7 The First Best Scheme

It is known that, for a given fixed demand matrix, the System Optimal (SO) solution gives the minimum value of the total network travel time (TNTT). The SO solution can be obtained, using UE assignment software, by providing as input the *marginal* link cost-flow functions $m(x)$ instead of the standard cost-flow functions $c(x)$. For the case of BPR-type cost-flow functions, there is:

$$c(x) = c_0\left(1 + k\left(\frac{x}{X}\right)^p\right) \qquad \text{and} \qquad m(x) = c_0\left(1 + k(p+1)\left(\frac{x}{X}\right)^p\right)$$

where c_0 is the free-flow travel time and X is the notional capacity. It is also well-known that the optimal marginal cost tolls can be found by obtaining the SO solution x^* and calculating, for each link, $m(x^*) - c(x^*)$. If this set of tolls is then charged on the links, the resulting UE solution (*with* tolls) will be the same pattern x^* as the SO pattern (*without* tolls). This is because the users are charged an equivalent amount to the difference between marginal cost and the standard cost on each link that they use, and therefore made to appreciate the external congestion effects their journey imposes. The optimal toll τ (for the given demand matrix) can therefore be calculated easily for any link, given the BPR form above, as:

$$\tau = \beta \frac{p}{p+1}\left(m(x^*) - c_0\right) + \gamma L$$

where β is the value of time, γ is the cost of other externalities (per km) and L is the length of the link (in km).

The aim is then to find the demand matrix T and tolls τ that are consistent under UE assignment with elastic demand (with the specified value of elasticity). To do this, the following iterative procedure has been implemented:

1. Set the iteration counter k to 1, and the demand matrix $T^{(1)}$ to the given initial matrix (representing the current set of demands under no charges)
2. For the current demand matrix $T^{(k)}$, run the assignment software in SO mode, and from the equilibrium flow pattern x^*, calculate the optimal link tolls $\tau^{(k)}$.
3. Starting with the current demand matrix $T^{(k)}$, run the elastic demand UE assignment process, with the current optimal link tolls $\tau^{(k)}$. This results in a new, or adjusted, demand matrix $T^{(k+1)}$.
4. Compare the new matrix with the previous one, to check for convergence. If not yet converged sufficiently, increase k by 1 and return to step 2. If converged, stop. The latest set of tolls $\tau^{(k)}$ is the first-best, or marginal social cost (MSC) set of link tolls.

This optimal set of tolls then provides the benchmark by which the effectiveness of other schemes can be compared or evaluated.

The resulting set of optimal tolls range, over the 344 links, from zero to € 7.25, with an average value of 46 cents per link. In terms of the toll *rate* (€ cents per km), they range from zero to 277, with a flow-weighted average of 38.2. The average toll rate for links in Region 1 is 68.5 cents/km; the average rate for links in Region 2 is 39.0, and for links in Region 3 it is 15.9. The average for motorway links is 16.2, and that for other roads is 39.9. All averages given here are flow-weighted.

Figure 9-4 shows a histogram of the toll rates of individual links. Not surprisingly, the links with the highest values of toll rate tend to be those with the highest flow.

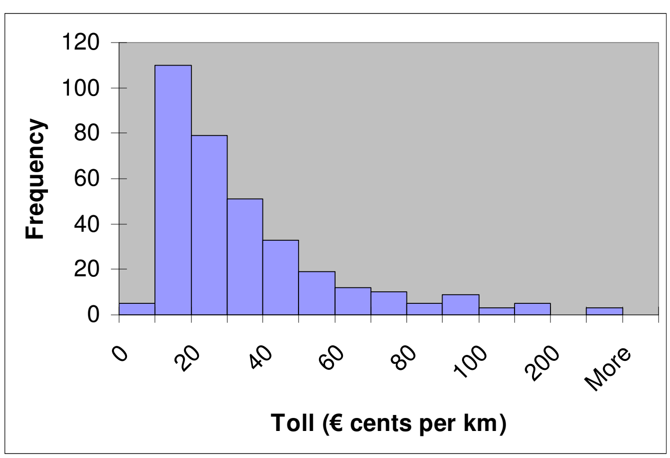


Figure 9-4 Histogram of Link Toll Rates in the First-Best Set of Tolls

The resulting level of demand and flow pattern when these tolls are applied, is described by the measures in Table 9-8, comparing directly the case of no tolls (the original base network UE equilibrium) and the optimal tolls case, with an assumed elasticity of *e* = 0.3.

Table 9-8 Comparison of Results from "No Charges" and "Optimal Tolls" with *e* = 0.3

Measure	No tolls	Optimal tolls	Change	
			Absolute	Relative
Total vehicle trips [‘000]	109.7	93.0	-16.7	-15%
Total person trips [‘000]	131.6	111.6	-20.0	-15%
Total vehs crossing inner cordon [‘000]	28.8	24.3	-4.5	-16%
Total vehs crossing outer cordon [‘000]	37.8	32.4	-5.4	-14%
Total veh*km [‘000]	1798.2	1530.5	-267.7	-15%
Percentage veh*km on motorways	58.9	64.3	+5.4	9%
Total veh*h [‘000]	56.4	39.2	-17.2	-31%
Percentage veh*h on motorways	41.7	91.2	+49.5	+119%
Total veh*km in Region 1 [‘000]	77.0	65.6	-11.4	-15%
Total veh*km in Region 2 [‘000]	511.2	430.8	-80.4	-16%
Total veh*km in Region 3 [‘000]	1210.0	1034.0	-176.0	-15%
Average trip length [km]	16.4	16.5	+0.1	+1%
Average trip duration [min]	30.8	25.3	-5.5	-18%
Total cost of delay [€ ‘000]	355.9	215.8	-140.1	-39%
Total cost of externalities [€ ‘000]	58.3	49.6	-8.7	-15%
Total cost of tolls charged [€ ‘000]	0.0	377.7	+377.7	-
Benefit (measured from no tolls case)	0.0	148.8	+148.8	-

What has also been done is to carry out runs with “fractional MSC” tolls: that is, where the toll on each link is a uniform fraction of the optimal toll. Results have been obtained with fractions of 0.1, 0.2 … 0.9, 1.0 and, as might be expected, the measures in the output table show a steady and smooth progression from the no tolls case (fraction = 0) to the optimal tolls case (fraction = 1). The use of the “fractional MSC” case will be seen in the next section, when a comparison of results from different charging schemes will be made.

It is interesting to consider the effect of applying these MSC tolls just on urban links rather than across the whole network. (Here, “urban links” means all those links that fall inside the outer cordon). The results from this scheme are displayed in Table 9-9. Of course, the total toll revenue is appreciably less than that from “full” MSC tolls (210.4 as compared with 377.7) but the total veh*km in Regions 1 and 2 are very similar to the values for the full set of MSC tolls, whilst the total veh*km in Region 3 are almost the same as that for the no tolls case. A further comparison is with the case with distance-based charging applied at a uniform rate per km in Regions 1 and 2. In this latter case, for purposes of comparability, the rate of charging is set at 48 cents per km, in order to achieve virtually the same total toll revenue as when MSC tolls are applied to these links. In this case, whilst the total veh*km in Region 3 are almost unaffected, the uniform rate leads to a higher number of veh*km in Region 1 and a lower number in Region 2 than when the MSC tolls are applied across urban links. It also leads to a greater reduction overall demand.

Table 9-9 Results from applying MSC and uniform tolls on urban links only with *e* = 0.3

Measure	No tolls	Urban links only		Optimal tolls
		MSC	Uniform	
Total vehicle trips [‘000]	109.7	97.5	95.4	93.0
Total person trips [‘000]	131.6	117.0	114.5	111.6
Total vehs crossing inner cordon [‘000]	28.8	24.0	25.3	24.3
Total vehs crossing outer cordon [‘000]	37.8	36.0	34.4	32.4
Total veh*km [‘000]	1798.2	1697.6	1642.4	1530.5
Percentage veh*km on motorways	58.9	61.8	62.3	64.3
Total veh*h [‘000]	56.4	47.5	49.5	39.2
Percentage veh*h on motorways	41.7	54.6	55.4	91.2
Total veh*km in Region 1 [‘000]	77.0	65.0	69.0	65.6
Total veh*km in Region 2 [‘000]	511.2	423.3	370.3	430.8
Total veh*km in Region 3 [‘000]	1210.0	1209.3	1203.1	1034.0
Average trip length [km]	16.4	17.4	17.2	16.5
Average trip duration [min]	30.8	29.2	31.1	25.3
Total cost of delay [€ ‘000]	355.9	283.1	311.5	215.8
Total cost of externalities [€ ‘000]	58.3	55.0	53.2	49.6
Total cost of tolls charged [€ ‘000]	0.0	210.4	210.8	377.7
Benefit (measured from no tolls case)	0.0	76.1	49.5	148.8

9.6.8 Motorway “Protection Toll” Scheme

One further charging scheme was modelled, specifically for the co-introduction work in chapter 10.

This is referred to here as a motorway “protection toll” scheme, the purpose of which is to discourage drivers from using motorway links for short trips, without imposing an excessive charge for longer trips. In this scheme, a charge is imposed on any vehicle accessing the motorway network within the overall network. (In the model of the network, with the exception of some short links in Region 1, all links of motorway or near-motorway standard are connected, and so form a distinct sub-network. Therefore, once a vehicle has accessed a motorway link, it may, if it wishes, travel to and on any other motorway link in this sub-network, without leaving the sub-network. Hence, the payment of one charge is sufficient to gain access to the whole of the motorway sub-network.

To model this charging scheme, the network was modified by the addition of dummy links at nodes where there a mix of motorway and non-motorway links. These dummy links acted effectively as on-ramps and off-ramps. A fixed toll was imposed on all on-ramps.

Further description of the modelling of this scheme and the results from it are given in Chapter 10.

9.6.9 Summary

Each of a number of different charging schemes has been modelled, and its effects quantified by means of a variety of output measures. These outputs obviously depend on the nature of the charging scheme and the level of charges applied within it. In each case, the results are broadly as would be expected, and the changing pattern of travel within the network (as measured, for example, by the veh*km in each of the three regions) can be seen to reflect the location or type of charges imposed. With any set of charges, under elastic demand, total demand reduces from the base, “no tolls”, case. Total veh*km travelled in the network, total delay, and total cost of externalities all reduce, and the total toll revenue increases.

Whilst these results for each type of charging scheme in turn all demonstrate the effectiveness of the modelling process, what it does not do is to provide an overall framework for *comparing* different charging schemes, ranking them by their effectiveness. This is the subject of the next section.

9.7 A FRAMEWORK FOR THE COMPARISON OF DIFFERENT CHARGING SCHEMES

9.7.1 Introduction

For any given type of scheme – for example, a simple outer cordon – the effects of any level of charge can be modelled using the variety of output measures listed in the tables in the previous section. It can be shown how each of these measures rises or falls from the base, "no tolls" case, as the level of charge increases. In most cases, this rise or fall is quite steady and in the same direction. (One of the few exceptions to this was the case of motorway tolls when there was a U shape to the plot of total delay: an initial fall, followed by a steady rise. This can be seen later in Figure 9-5).

The dominant reason for the reduction in measures such as total delay, cost of externalities and veh*km is of course the reduction in demand, through elastic assignment, and the reason for the reduction in demand is the imposition of charges. The total toll revenue collected under any scheme is therefore a primary factor in determining the impact of any scheme. In order to make any fair or meaningful comparison between, say, an outer cordon with a charge of € 5 and a distance-based scheme with a charge of 25 cents per km in Region 1, it is necessary to compare them on the basis of both their impacts and their total toll revenues. Ideally two such schemes would be compared with their charging levels set such that the total toll revenue raised in each was the same. Then, when looking at their impacts, or indeed any other measure, they can be compared on an equal footing, or a "level playing field".

Therefore the results for all the schemes are displayed in plots of the various measures versus total toll revenue. Modelling each scheme at a variety of charging levels results in sets of curves, starting at the origin (that is, the no tolls case). It is then possible to compare one type of scheme with another, to see whether one is more "effective" than the other according to any chosen measure (that is, gives a greater change in that measure for the same total toll revenue). It is also possible to see the plot for any scheme in comparison with that for the benchmark scheme of the optimal, marginal cost, or first best tolls. Now the optimal tolls provide just one point in such a plot. However, there are also runs for fractional MC tolls, in order to obtain a curve for the impact versus the total toll revenue, as explained in section 9.6.7.

9.7.2 The Results

The results will be displayed through a sequence of plots: one for each of a number of measures to show the effect of a scheme. For example, to produce the plots of total cost of delay versus total toll revenue in Figure 9-5, each type of charging scheme has been taken and the charging level increased in steps from the base case of zero. Each level of charge gives one point, and the whole set of points are then connected to give the plot. The following notation is used for the types of schemes are considered:

- Fractional MSC: this provides the benchmark by which the effectiveness of other schemes can be assessed. Tolls that are a uniform fraction of the optimal tolls are applied (see section 9.6.7)
- Outer cordon: a charge of € *y* is applied at the outer cordon (and none at the inner cordon). See section 9.6.2.
- Inner cordon: a charge of € *x* is applied at the inner cordon (and none at the outer cordon). See section 9.6.2.
- Two cordons (2*x*, *x*): charges of € 2*x* and *x* are made respectively at the inner and outer cordons. See section 9.6.2.
- Distance (*x*, 0): charging is applied in Region 1 only, at a rate of *x* cents per km. See section 9.6.3.
- Distance (2*x*, *x*): charging is applied at rate of cents 2*x* per km in Region 1, and at *x* cents per km in Region 2. See section 9.6.3.
- Motorway-only uniform rate: charging is applied at a uniform rate per km on all motorway links, and zero elsewhere. See section 9.6.5.

- Mixed (3*y*, *y*): a charge of € 3*y* is applied at the outer cordon, and at a rate of *y* cents per km on all motorway links outside the outer cordon. See section 9.6.6.
- Area (*x*, 0): area-based charging is applied in Region 1 only, with a charge of € *x*. See section 9.6.4.
- Area (5*x*, *x*): area-based charging is applied, with charges of € 5*x* in Region 1 and € *x* in Region 2. See section 9.6.4.
- Uniform: a uniform charge per km is applied on all roads in the network (this is a proxy for an increase in fuel price, and is used here as a reference point scheme).

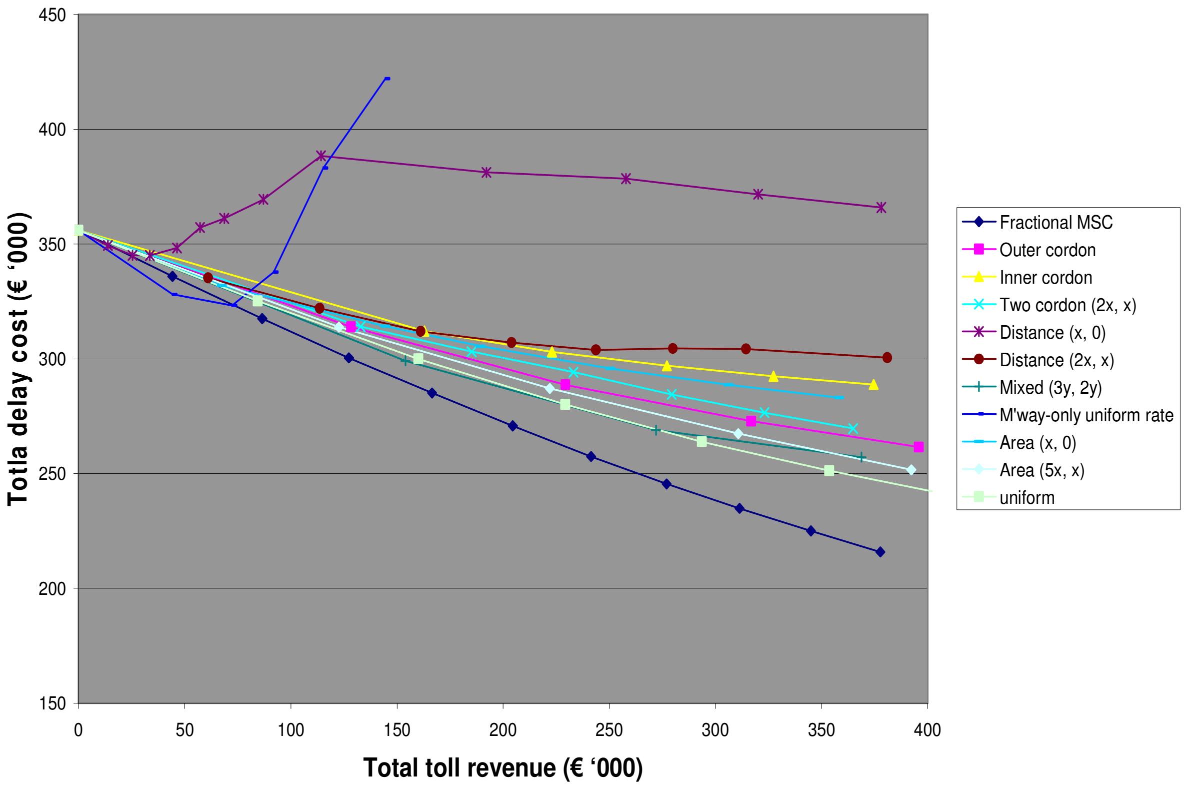


Figure 9-5 Plots of Total Delay Cost versus Total Toll Revenue for all Types of Charging Schemes

Of the eleven plots in Figure 9-5, nine behave in a reasonably regular pattern, with a steadily reducing value of total delay as the total toll revenue increases. However, the two others stand out as being quite different from the rest: those for "Distance (*x*, 0)" and "Motorway-only uniform rate". Both show an initial fall in total delay, like all the other plots, but then turn and start to rise. This effect has already been discussed, for the motorway scheme, in section 9.6.5, where it was explained that the higher rate of charge on the motorway links causes an increasing number of vehicles to reroute into the already congested Regions 1 and 2, leading to severe delays there. The decrease in congestion on the motorway links is more than offset by the increase on the rest of the network.

The form of the plot for the Distance (*x*, 0) scheme, though, is rather more complex and requires further explanation. In the first part of the plot, for charges of up to 60 cents per km, the contribution to total from Region 1 falls by 50% from the no tolls case, whilst in Region 2 it rises by 7% and in Region 3 by only 1%. The net effect is a reduction in total delay of about 3%. The demand between zones that both lie within Region 1 falls by 12%, with much smaller reductions in demand between a zone in Region 1 and other Regions. In the second part of the plot, for charges between 60 cents per km and 5 euros per km, the total delay rises. By this time, the demand between zones that are both within Region 1 has fallen to just over a half of the original "no tolls" demand level, and the contribution to total delay from Region 1 is less than a quarter of the base case, whilst the delay in Region 2 is 35% higher than the base case. In the third part, where the total delay falls gently within increasing charge level, the contributions to delay from each Region have flattened out and the demand levels also are reducing more slowly. In summary, inspection of the separate contributions to total delay from each Region shows that the plots for Regions 2 and 3 are steadily increasing, whilst that for Region 1 is steadily reducing, and each is steadily flattening out as the charge level rises. However, although these separate plots are monotonic, the plot of the sum is not but firstly falls, then rises, and then falls again.

A comparison with the effects of the Area charge (*x*, 0) is instructive, as the two schemes appear quite similar at first sight. At roughly equivalent levels of charges in the two schemes, the impact on the demand between zones that are both within Region 1 is very similar. The differences arise in the response of drivers travelling from zones outside Region 1 to zones inside Region 1, and vice versa. In the area charging scheme the response to the charge is almost entirely in terms of a reduced demand; in the distance charging scheme the response is in terms of a reduced demand and also rerouting, as the drivers seek routes to their destination in Region 1 that reduce the distance travelled within Region 1, and hence the charge incurred. This rerouting leads to an increase in congestion in Region 2. A comparison of the Area (*x*, 0) and Distance (*x*, 0) schemes shows that the principal reason for the difference shapes in the plots of total delay is due to the appreciably higher contributions to total delay from Region 2 from the distance charging scheme than the area charging scheme.

The remaining nine plots are generally similar in shape to each other: all showing a steady change, with total delay decreasing whilst total toll revenue rises as the charge level is increased. As would be expected, the “Fractional MSC” tolls plot is the lowest, providing the benchmark by which the effectiveness of the other schemes can be assessed.

The “Uniform” scheme, in which a uniform rate per km is charged on all links in the whole network (and is intended here to serve as a proxy for an increase in fuel duty) does surprisingly well in comparison with other schemes, given that it is so untargeted.

Generally, the eight other schemes can be placed in the following order for effectiveness:

1. Uniform
2. Mixed (3y, 2y)
3. Area (5x, x)
4. Outer cordon
5. Two cordons (2x, x)
6. Area (x, 0)
7. Distance (2x, x)
8. Inner cordon,

although the plots for the last two do cross, so that the Inner Cordon is actually more effective than Distance (2*x*, *x*) at higher levels of toll revenue.

Figure 9-6 shows the plots of total veh*km in the whole network versus total toll revenue for each of the charging schemes. The pattern, and order of schemes, is quite different from that for total delay in Figure 9-5.

The “Motorway-only uniform rate” gives the greatest reduction in veh*km for any level of toll revenue (but, as there is already seen, at the expense of a substantial increase in veh*km and congestion on non-motorway links, many of which are already congested). After that, the greatest reductions in veh*km are provided by the “Mixed (3*y*, 2*y*)” scheme, followed by the “Fractional MC” and “Outer cordon” schemes, and then in order the “Distance (2*x*, *x*)”, “Two cordon (2*x*, *x*)”, “Area (5*x*, *x*)”, “Area (*x*, 0)” and “Inner cordon”. The plot for “Distance (*x*, 0)” is again quite different from the rest, being initially quite flat, but then giving a slight increase in veh*km for higher levels of charge before starting to fall gradually for charges above € 5 per km.

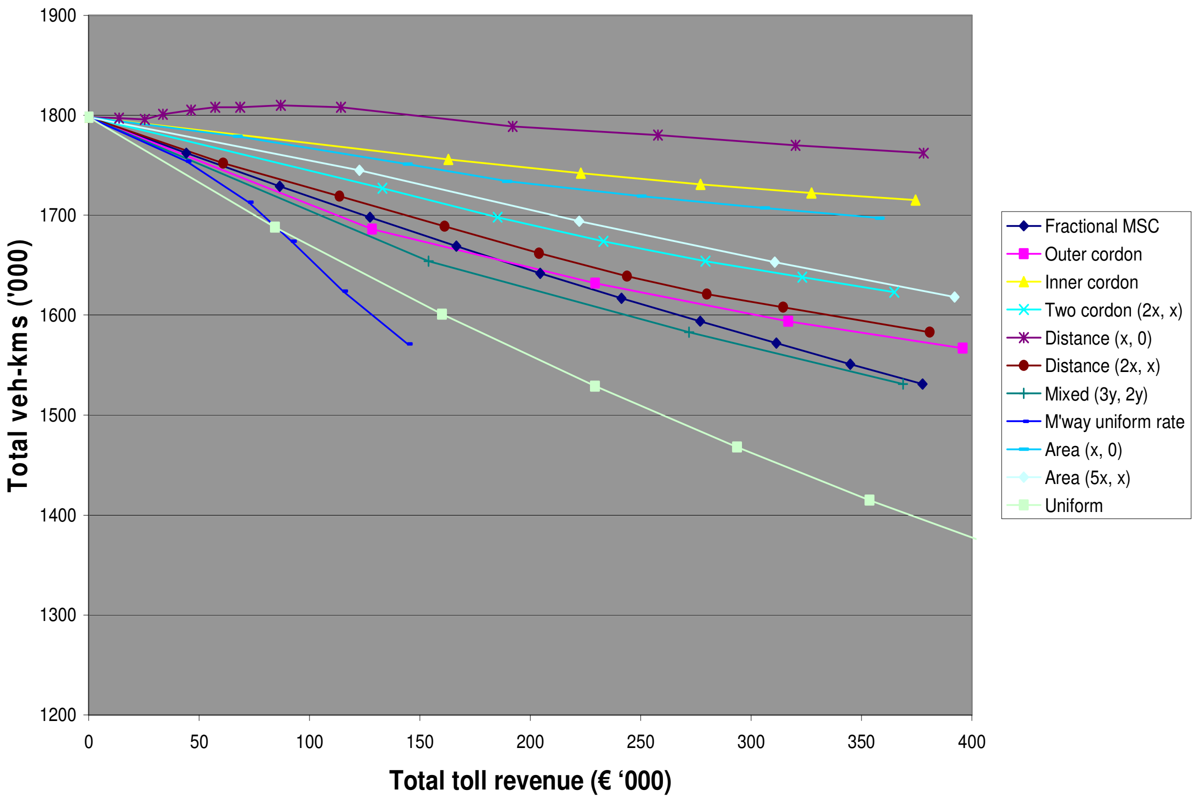


Figure 9-6 Plots of Total Veh*km versus Total Toll Revenue for all Types of Charging Schemes

Of course, the total veh*km comes from across the whole network. When this is broken down into the contributions from different regions, a different picture emerges. For example, Figure 9-7 shows the total veh*km travelled inside Regions 1 and 2. Here it can be seen that by far the greatest reduction comes from the Distance (2*x*, *x*) scheme, whilst the Inner Cordon scheme is the least effective.

Figure 9-8 shows the plots of total demand against the total toll revenue for the eleven schemes. The schemes that give rise to the greatest reductions in demand are the Distance (2*x*, *x*) and Area (5*x*, *x*) schemes, whilst those that produce the smallest reductions are the Outer Cordon, the Inner Cordon, and the Mixed (3*y*, 2*y*) schemes. The very different "Fractional MSC tolls" and "Uniform" schemes produce rather similar medium-scale reductions in demand.

It can be seen that the plot of veh*km show the "Uniform" scheme in a very different relationship to the other schemes than was apparent from the plots of impact and total delay. The "Uniform" scheme, being so untargeted, leads to by far the greatest reduction in veh*km across the whole network, whereas in contrast other more targeted schemes (such as cordon-based ones) result in smaller reductions in veh*km.

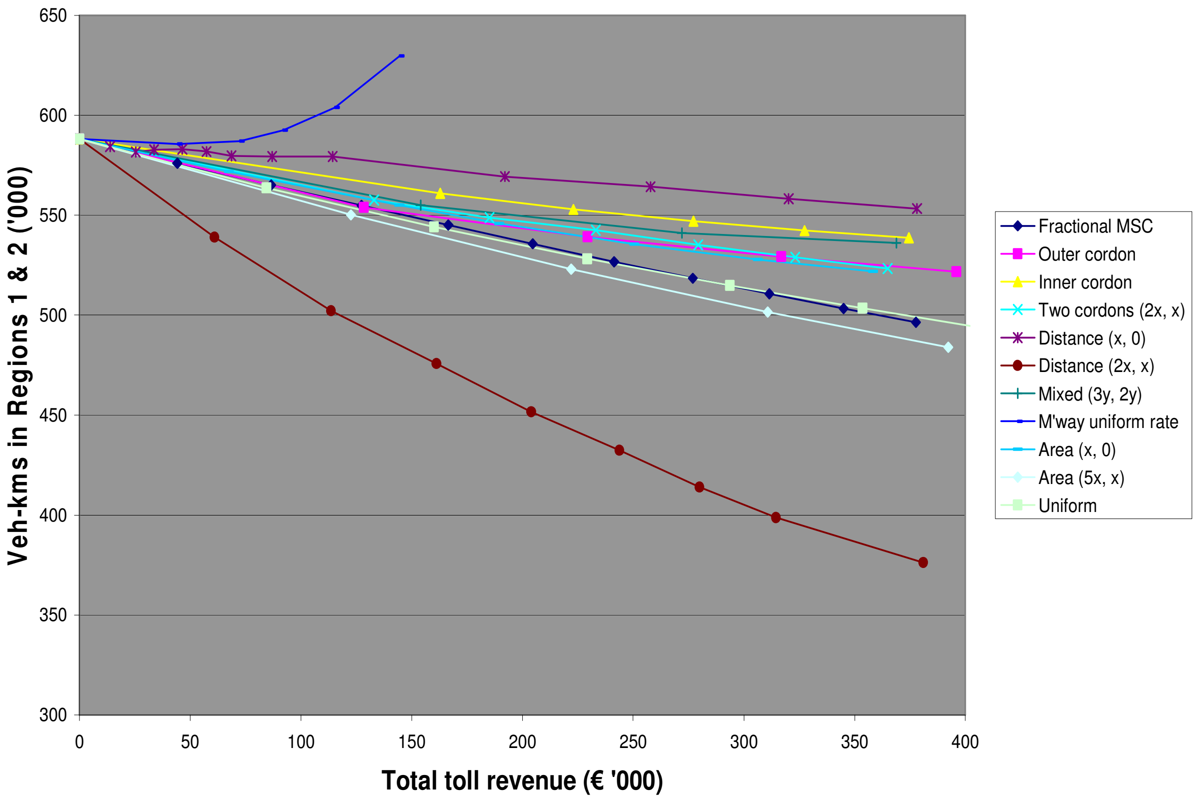


Figure 9-7 Plots of Total Veh*km in Regions 1 and 2 versus Total Toll Revenue

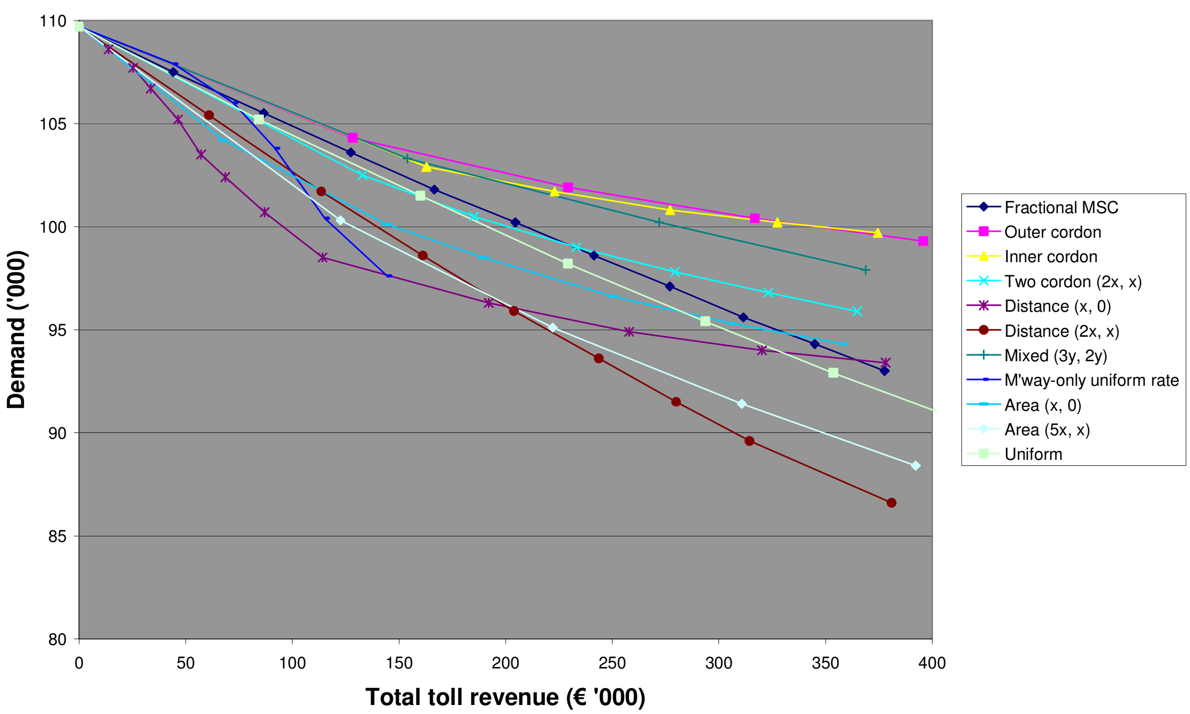


Figure 9-8 Plots of Demand versus Total Toll Revenue for all Types of Charging Schemes

If from the data in the graphs above for demand, total veh*km and total delay, interpolation is used to calculate the value of each at the value for total toll revenue for the MSC tolls (377.7) (that is, effectively drawing a vertical line at a value of the total toll revenue of 377.7 in each of the figures above, so as to read off the value on the vertical axis where it intersects each scheme's plot) the results are shown in Table 9-10. Then the percentage change in each measure (from the base case of no tolls) is obtained, the results are as shown in Table 9-11.

What is clear from this is that there is no one charging scheme of the ten considered that has most impact (in terms of the change from the no tolls case) according to all measures. By looking at either Table 9-10 or Table 9-11, the following can be noted (the minimum and maximum cells in each row are highlighted in Table 9-11 for ease of reference):

- The greatest reduction in total cost of delay is given by the MSC tolls, and the smallest by Distance (*x*, 0).
- The greatest reduction in demand is given by Distance (2*x*, *x*), and the smallest by the inner Cordon.
- The greatest reduction in veh*km (and in the cost of externalities) is given by the Uniform scheme, and the smallest by Distance (x, 0).
- The greatest reduction in veh*hrs is given by the MSC tolls, and the smallest by the Inner Cordon and Distance (*x*, 0).
- The greatest reduction in the number of vehicle crossing the inner cordon is given by the Inner Cordon, and the smallest by the Uniform scheme.
- The greatest reduction in veh*km in Region 1 is given by the Distance (*x*, 0) scheme, and the smallest by the Uniform scheme.

There is also some considerable similarity or overlap between different measures; indeed some are effectively identical. For example, the number of person trips is a constant multiple of the demand (number of vehicle trips); and the cost of externalities is almost directly proportional to the number of veh*km. Others are directly linked (for example, the sum of the veh*km in the three Regions is obviously the total veh*km). There is therefore scope for some data reduction in order to try to effect some simplification and help characterise the effects of each scheme and how they compare with each other. This will be carried out in the next section.

Table 9-10 Measures for Ten Schemes, at Common Value of Total Toll Revenue

Measure	Base	MSC tolls	Outer cordon	Inner Cordon	Two cordons (2x, x)	Distance (x, 0)	Distance (2x, x)	Mixed (3y, 2y)	Area (x, 0)	Area (5x, x)	Uniform
Total vehicle trips [‘000]	109.7	93.0	99.6	99.7	95.6	93.4	86.7	97.7	93.9	88.9	92.0
Total person trips [‘000]	131.6	111.6	119.4	119.6	114.8	112	104.1	117.2	112.6	106.7	110.4
Total vehs crossing inner cordon [‘000]	28.8	24.3	27.1	12.5	14.4	15.8	20.5	27.3	14.4	15.9	27.6
Total vehs crossing outer cordon [‘000]	37.8	32.4	20.1	36	22.8	38.0	32.8	20.6	36.7	33.3	29.2
Total veh*km [‘000]	1798.2	1530.5	1572.9	1714.7	1618.4	1762	1584.1	1526.2	1693.5	1624.3	1395.6
Percentage veh*km on principal roads	58.9	64.1	59.1	59.9	58.9	58.7	63.8	39.6	60.4	61.2	57.5
Total veh*h [‘000]	56.4	39.2	44.8	48.5	45.5	56.6	47.3	44.7	47.3	43.9	41.4
Percentage veh*h on principal roads	41.7	91.2	81.8	78.1	79.9	45.5	66.0	72.4	45.4	46.3	94.7
Total veh*km in Region 1 [‘000]	77.0	65.6	74.8	51.8	53.2	15.1	47.4	75.7	44.1	46.3	76.7
Total veh*km in Region 2 [‘000]	511.2	430.8	448.6	486.6	468.4	538.2	329.9	460	475.6	440.8	422.3
Total veh*km in Region 3 [‘000]	1210	1034	1049.4	1176.3	1096.7	1208.6	1206.8	990.6	1174	1137.2	896.6
Average trip length [km]	16.4	16.5	15.8	17.2	16.9	18.9	18.3	15.6	18.0	18.3	15.2
Average trip duration [min]	30.8	25.3	27.0	29.2	28.6	36.4	32.8	27.5	30.3	29.6	27.0
Total cost of delay [€ ‘000]	355.9	215.8	264.1	288.6	267.5	365.9	300.6	256.0	280.9	254.4	246.8
Total cost of externalities [€ ‘000]	58.3	49.6	51.0	55.6	52.4	57.1	51.3	49.7	54.9	52.7	45.3
Total cost of tolls charged [€ ‘000]	0	377.7	377.7	377.7	377.7	377.7	377.7	377.7	377.7	377.7	377.7
Benefit (measured from no tolls case)	0	148.8	99.1	70	94.3	-8.9	62.3	108.2	78.4	107.2	122.1

Table 9-11 Percentage Changes from Base Case for Nine Schemes, at Common Value of Total Toll Revenue

Measure	MSC tolls	Outer cordon	Inner Cordon	Two cordons (2x, x)	Distance (x, 0)	Distance (2x, x)	Mixed (3y, 2y)	Area (x, 0)	Area (5x, x)	Uniform
Total vehicle trips [‘000]	-15.2	-9.2	-9.1	-12.8	-14.9	-20.9	-10.9	-14.4	-18.9	-16.2
Total person trips [‘000]	-15.2	-9.3	-9.1	-12.8	-14.9	-20.9	-10.9	-14.4	-18.9	-16.1
Total vehs crossing inner cordon [‘000]	-15.6	-6.0	-56.7	-49.8	-45.1	-28.6	-5.3	-49.9	-44.9	-4.3
Total vehs crossing outer cordon [‘000]	-14.3	-46.8	-4.8	-39.7	0.5	-13.1	-45.4	-2.9	-12.0	-22.8
Total veh*km [‘000]	-14.9	-12.5	-4.6	-10.0	-2.0	-11.9	-15.1	-5.8	-9.7	-22.4
Percentage veh*km on principal roads	-7.4	-12.2	-3.0	-10.0	-2.3	-4.6	-42.9	-3.4	-6.1	-24.3
Total veh*h [‘000]	-30.5	-20.5	-14.1	-19.3	0.4	-16.1	-20.8	-16.1	-22.2	-26.7
Percentage veh*h on principal roads	52.0	56.0	60.9	54.6	9.5	32.9	37.6	-8.6	-13.7	66.6
Total veh*km in Region 1 [‘000]	-14.8	-2.8	-32.7	-30.9	-80.4	-38.5	-1.7	-42.8	-39.9	-0.4
Total veh*km in Region 2 [‘000]	-15.7	-12.2	-4.8	-8.4	5.3	-35.5	-10.0	-7.0	-13.8	-17.4
Total veh*km in Region 3 [‘000]	-14.5	-13.3	-2.8	-9.4	-0.1	-0.3	-18.1	-3.0	-6.0	-25.9
Average trip length [km]	0.6	-3.5	4.9	3.0	15.2	11.5	-5.0	10.0	11.4	-7.6
Average trip duration [min]	-17.9	-12.2	-5.2	-7.1	18.2	6.4	-10.7	-1.7	-4.0	-12.4
Total cost of delay [€ ‘000]	-39.4	-25.8	-18.9	-24.8	2.8	-15.5	-28.1	-21.1	-28.5	-30.7
Total cost of externalities [€ ‘000]	-14.9	-12.5	-4.7	-10.0	-2.1	-11.9	-14.8	-5.9	-9.6	-22.4

9.8 PRINCIPAL COMPONENTS ANALYSIS

Principal components analysis (PCA) is a well-established statistical technique to reduce the dimensionality of data in order to help establish the patterns of similarity and dissimilarity between variables, and hence simplify analysis and interpretation of the data.

It works on the correlations or covariances between a set of variables, and finds the principal components or directions of variability within the data. Here there are fifteen variables, or measures, shown in Table 9-10 ranging from the number of trips through to the total costs of externalities. There are ten schemes, ranging from MSC tolls to the Uniform charging scheme, each of which gives rise to different values for these variables. What PCA does is to determine a set of "components", or linear combinations of these variables that are orthogonal to each other, and provide the greatest explanation of the variation between the schemes.

The first two components explain 80% of the variance, with coefficients as shown in Table 9-10. In the first component (which in itself accounts for almost 60% of the variance between schemes), a scheme gets a positive score from larger than average percentage reductions in vehicles crossing the outer cordon, total veh*km, percentage veh*km on motorways and total delay, and smaller than average percentage reductions in vehicles crossing the inner cordon, percentage veh*hrs on motorways and veh*km in Region 1. In the second component, a scheme gets a positive score largely from smaller than average reductions in demand and veh*km in Region 2.

Table 9-10 Coefficients for First Two Components from PCA

Measure	Coefficients	
	Component 1	**Component 2**
Total vehicle trips ['000]	0.08	0.54
Total person trips ['000]	0.08	0.54
Total vehs crossing inner cordon ['000]	0.28	-0.07
Total vehs crossing outer cordon ['000]	-0.24	-0.17
Total veh*km ['000]	-0.31	0.20
Percentage veh*km on principal roads	-0.24	-0.10
Total veh*h ['000]	-0.28	0.18
Percentage veh*h on principal roads	0.22	0.17
Total veh*km in Region 1 ['000]	0.33	0.04
Total veh*km in Region 2 ['000]	-0.12	0.43
Total veh*km in Region 3 ['000]	-0.31	-0.02
Average trip length [km]	-0.32	-0.16
Average trip duration [min]	-0.29	-0.06
Total cost of delay [€ '000]	-0.27	0.10
Total cost of externalities [€ '000]	-0.30	0.20

Figure 9-9 is a diagram of the ten schemes plotted by their first two principal components. It therefore provides a visual representation of how the ten schemes are similar or different from each other. In the upper left hand quadrant are three schemes targeted specifically at Region 1: the Inner Cordon, Distance (x, 0) and Area (x, 0) schemes. In the lower left quadrant are two schemes that focus on jointly on Regions 1 and 2: Distance (2x, x) and Area (5x, x). In the upper right quadrant are schemes that involve the use of an outer cordon: the pure outer Cordon, the Mixed (3*y*, 2*y*) scheme and the Two Cordon (2x, *x*) scheme which, it can be noted lies roughly halfway between the Inner Cordon and Outer Cordon schemes. Finally, in the lower right quadrant are the MSC tolls schemes and the Uniform scheme, both of which apply charges across the whole network, although in one the charge is link specific whilst in the other the charge is simply proportional to length. The similarity of the two schemes is noteworthy.

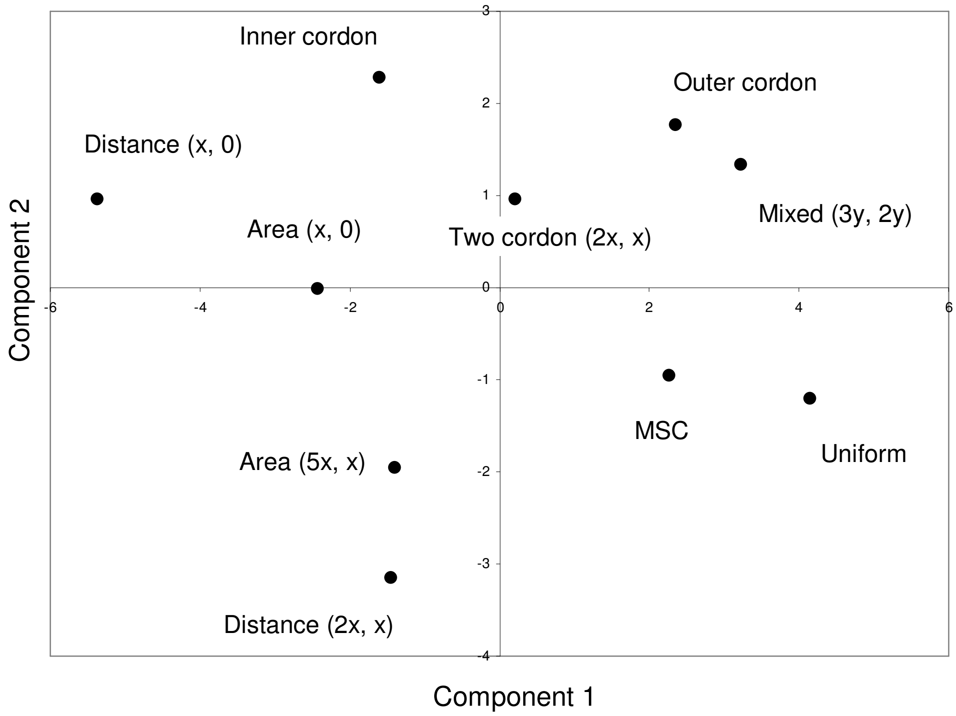


Figure 9-9 PCA Diagram Showing Ten Schemes by First Two Components

9.9 SENSITIVITY OF RESULTS TO VALUE OF ELASTICITY

A value for elasticity of $e = 0.3$ has been assumed in the demand model. Therefore the values of total delay, (or total veh*km, or any other output measure) for each of the charging schemes considered at any level of charge is dependent on the value assumed for *e*. Further sets of runs of the model were carried out for selected schemes for other values of the elasticity: namely for $e = 0.2$ and $e = 0.4$.

Consider what can be expected to happen for any given charging scheme, at any fixed level of charge, as the assumed value of *e* is increased in the model: because of the bigger response of users to the imposed charges, the demand decreases, as does the total veh*km, the total cost of delay and the total cost of other externalities. The total toll revenue falls, since the demand decreases. Hence, the cost of total delay decreases, along with the total toll revenue.

Rather than repeat, for each alternative value of *e*, all the many sets of runs that had been carried out already for $e = 0.3$, three representative types of scheme were considered: (i) the outer cordon, (ii) distance (2*x*, *x*), (iii) area (5*x*, *x*), plus the fractional MSC tolls that act as a benchmark. In each case, results from the elastic demand assignment model were obtained at various levels of charge, at each of the three values of elasticity. Also, one representative measure was selected for these additional runs: that of total delay cost.

Figure 9-10 shows the plots of total delay cost versus total toll revenue for the outer cordon scheme for the three different values of *e*. As may be seen, the overall form of the plot is the same for the three values of elasticity and, at any level of total toll revenue, the relative values of the impacts of a scheme at different values of *e* are virtually identical. Similar plots were produced (but are not shown here) for the three other schemes.

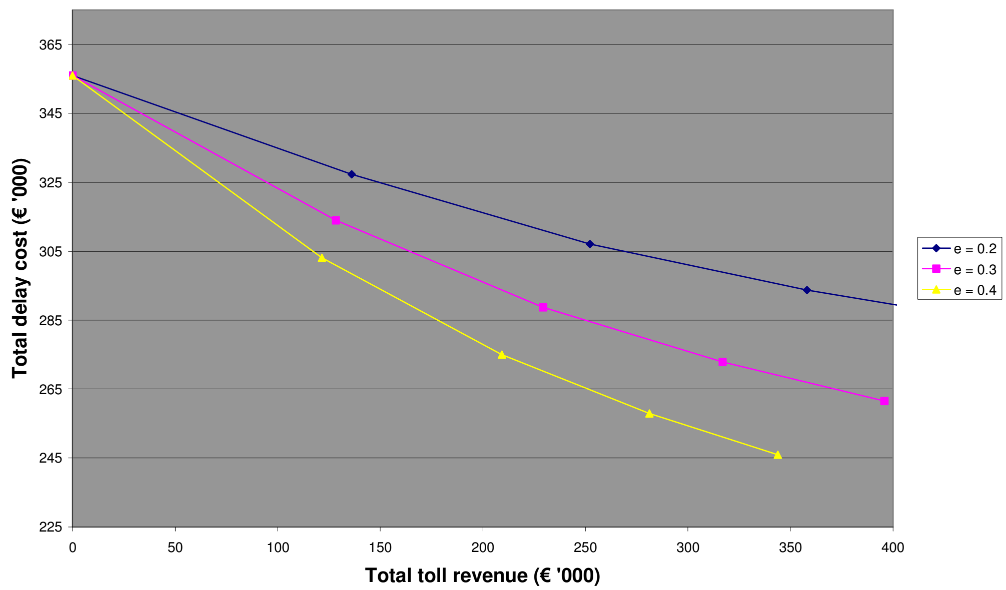


Figure 9-10 Total Delay Cost versus Total Toll Revenue for Outer Cordon, for *e* = 0.2, 0.3 and 0.4

The main interest, however, is in how different schemes compare with each other, and with the benchmark, with different assumed values of elasticity. Figure 9-11 shows the plots of total delay cost versus total toll revenue for *e* = 0.2; Figure 9-12 the same for *e* = 0.3 (with data extracted from Figure 9-5), and Figure 9-13 the same plots again for *e* = 0.4.

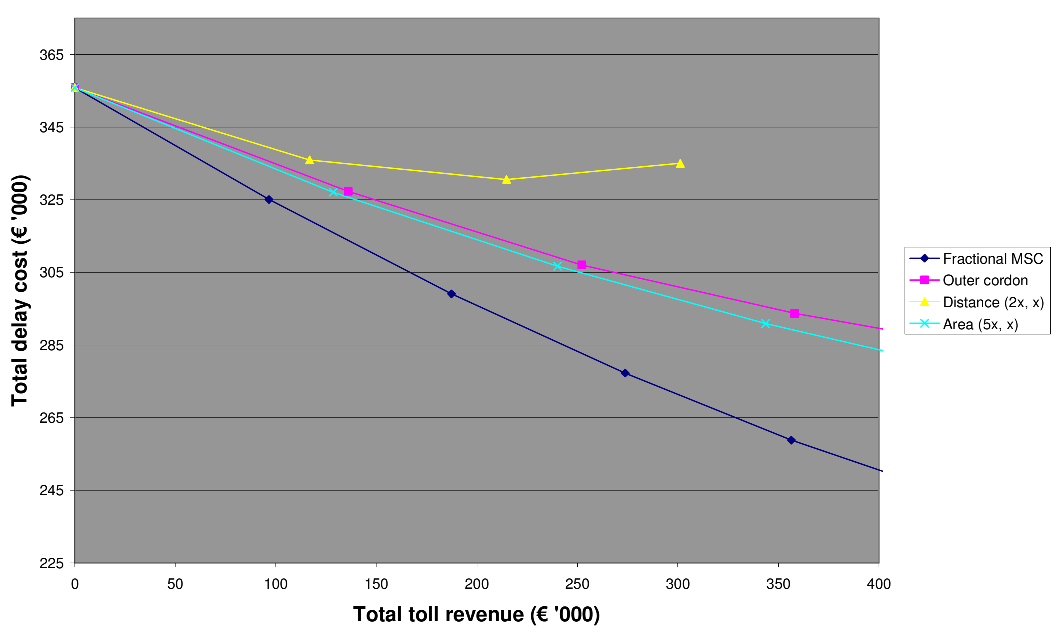


Figure 9-11 Total Delay Cost versus Total Revenue for Four Schemes at *e* = 0.2

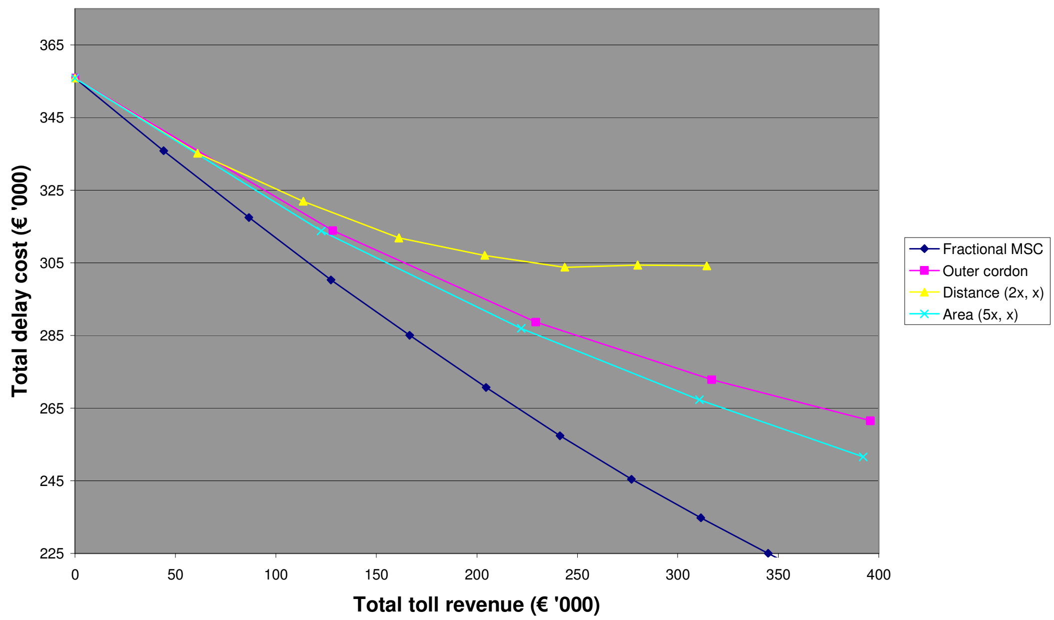


Figure 9-12 Total Delay Cost versus Total Revenue for Four Schemes at *e* = 0.3

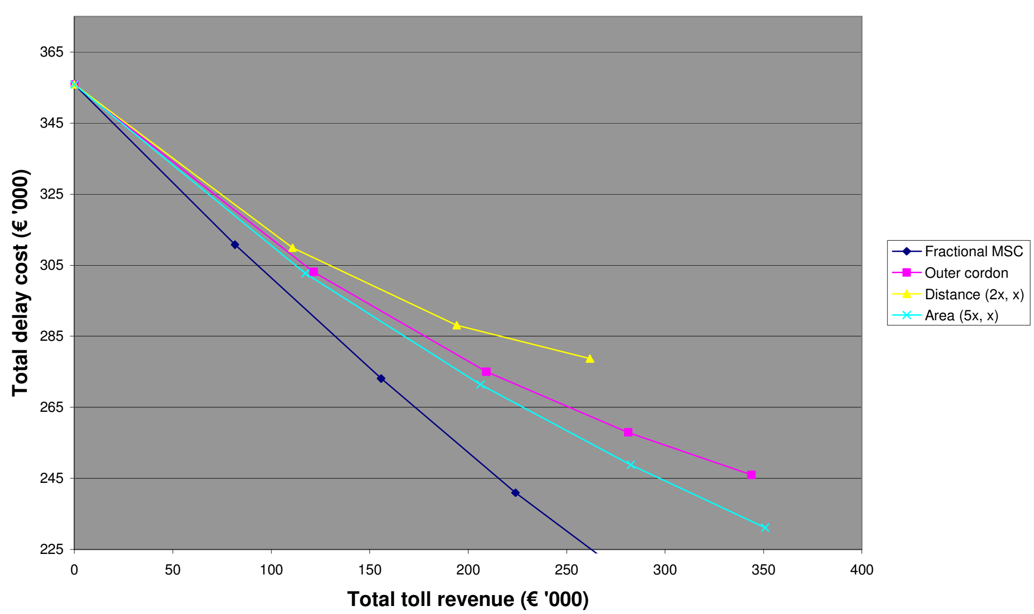


Figure 9-13 Total Delay Cost versus Total Revenue for Four Schemes at *e* = 0.4

The following observations can be made form a study of these sets of plots:

- The broad pattern of the plots is the same in each case, and there is a smooth transition from one value of *e* to the next.
- The Outer Cordon and Area (5*x*, *x*) schemes are very similar in performance at all levels of total toll revenue and at all values of *e*.
- The rank order of the four schemes, in terms of their total delay cost at the same level of toll revenue, is the same at all values of elasticity.

- The total delay cost of the Distance (2*x*, *x*) scheme is higher than the other three, and becomes increasingly inferior at higher levels of toll revenue, and at lower values of elasticity. Indeed, it is apparent that as charge levels are increased, there comes a point at which the total delay of this scheme is minimised and after which it steadily rises. The value of toll revenue at which this turning point occurs increases as the value of *e* is raised.
- The relative performance of the three schemes, compared with the benchmark of the fractional MSC tolls, is about the same at all values of *e*.

It can therefore be concluded that whilst the numerical results for any scheme are very much dependent upon the value of elasticity assumed in the modelling, their relativities are not so strongly dependent and that the relative performances of the various charging schemes, with each other and with the benchmark MSC tolls scheme, remains quite stable and consistent.

9.10 SUMMARY AND CONCLUSIONS

A network, based on that of the city of Edinburgh, has been used to model the effects of a variety of different road charging schemes, using an elastic demand assignment model, with an elasticity of $e = 0.3$ in the main body of tests. Two of the schemes modelled were primarily for benchmarking purposes: a system of MSC tolls applied across the whole network, and a Uniform scheme (at a common rate per km across the whole network) intended to act as a proxy for a fuel duty increase. Other schemes modelled were cordon-based, distance-based, area-based, plus some motorway-based schemes that were largely for use in the co-introduction study in chapter 10. The positions of the two cordons were regarded as fixed, and corresponded with those proposed for actual implementation.

This gave a set of eleven schemes in the main body of tests, each of which was modelled at a number of different charging levels. The effects of each scheme were summarised through a series of measures, some of which were aggregate values across the whole network (such as demand, total veh*km, total delay cost), and some of which were with reference to different parts of the network (such as veh-km in each of Regions 1, 2 and 3 or the flow across each of the two cordons). Clearly the value of these measures depended on the charge level, and in almost all cases the value varied smoothly, continuously and monotonically as the charge level was increased.

To enable meaningful and fair comparisons between different schemes, it was found necessary to place them within a framework and look at the outputs through a number of plots of the summary measures against total toll revenue. From these it was then possible to compare the schemes with their charge levels set at values that ensured that the total toll revenue was the same as that produced from the MSC tolls scheme. In this way, it was possible to compare like with like. (However, it should be noted that, in order to achieve this value for total toll revenue, in some schemes the charge had to be set at a very high level that would be considered impracticable. For example, in the Distance (x, 0) scheme, the required level was 25 € per km). The main conclusions that can then be drawn are:

- The system of MSC tolls gives the greatest reduction in total network delay, and the greatest “benefit” (as measured by the sum of the reductions in the cost of total delay and externalities, from the base, “no tolls”, case).
- No one scheme could be said to be best under all aggregate measures.
- The principal components analysis showed that the schemes were clustered primarily on the way in which they targeted different parts of the network (Regions 1, 2 and 3).
- The simple Uniform scheme (a distance-based scheme with a common rate per km on all links across the whole network) was perhaps surprisingly similar to the first-best MSC tolls scheme. This shows that it is the spatial nature of the charging scheme that is more dominant than the precise link-by-link level of charge (once the total toll revenue is kept fixed). The histogram of MSC toll rates per km showed that these are very widely spread, and range from zero to 277 cents per km, with a mean of 38 cents per km. The uniform charge per km needed to give the same total toll revenue was 27 cents per km.
- The next most effective schemes are those involving charging within Regions 1 and 2: the Area (5*x*, *x*), Distance (2*x*, *x*) and Two Cordon (2*x*, *x*) schemes.

- Direct comparisons of area-based and distance-based schemes (such as Area (5x, x) versus Distance (2x, x), and Area (x, 0) versus Distance (x, 0)) indicate that, whilst they give similar reductions in demand, the area-based scheme gives a much greater reduction in total delay, whilst the distance-based scheme gives a much greater reduction in veh*km in the relevant Regions. In each case, the pure cordon schemes (Two Cordon (2*x*, *x*) and Inner Cordon respectively) give a rough compromise between the distance-based and area-based equivalent, but with a somewhat smaller reduction in demand. An important distinction between the area-based and distance-based schemes is that, in the latter, drivers will seek to reroute to minimise the charge they incur. This was evident in the Area (*x*, 0) and Distance (*x*, 0) cases, where the latter scheme induced a considerable increase in veh*km in Region 2, and at some levels of charge, to an overall increase in veh*km in the whole network.

Of course, all modelling has been carried out using the one network. Therefore all findings must be regarded to some extent as specific to this network. The network modelled here is highly congested and this congestion is not limited to the central areas of the network, but is spread quite widely. However, the results show that the size of the area covered by the scheme, and therefore the overall number of drivers who would have to pay the charge, is more important in terms of overall effect of the scheme than the type of scheme used or the degree of differentiation within it, and it seems safe to say that this is not specific to the network modelled here, but would be found in other networks as well.

Whilst the results described here were obtained assuming a value for elasticity of $e = 0.3$, a further (more limited) series of tests were conducted assuming different values for e. In these, a representative set of charging schemes were modelled. The sample results from these further tests confirm that, whilst the numerical value of measures such as total delay obviously depend on the value of e, the broad nature of the results, and crucially the relative ranking of schemes, is not significantly affected by this. Therefore, it seems safe to conclude that the findings obtained from the main series of tests are not particularly sensitive to the assumed elasticity value. Furthermore, it appears safe to say that this would not only apply to the network modelled here, but that more generally the precise estimate of elasticities is much less crucial for the comparison between different schemes than for the estimate of their effects in absolute terms.

10 CO-INTRODUCTION OF CHARGES ON URBAN ROADS AND MOTORWAYS

10.1 INTRODUCTION

10.1.1 Purpose of this Case Study

Motorways and urban roads have different functions and generally serve different types of traffic. However, when motorways pass through, or near, metropolitan areas these distinctions may become blurred and it becomes impossible to optimise the performance of one type of road without considering its interaction with the other.

This investigation seeks to examine the relationship, within metropolitan areas, between charges on motorways and on other types of road, to explore the case for a coordinated approach to setting tolls on motorways and other roads and to consider the constraints which might make this difficult to achieve.

The investigation considers evidence on how charges on motorways might affect urban roads, how charges on urban roads charges might affect urban motorways and, more positively, how charges on the two types of road could work together.

A key issue is, of course, whether and in what circumstances it is appropriate or necessary for charges to be differentiated by type of road.

10.1.2 Approach Adopted

The investigation involves the specification and assessment of alternative scenarios for the co-introduction of charges on motorways and other roads in metropolitan areas. The scenarios will, between them, exhibit different degrees of differentiation and coordination. The assessment will be based on theory and on results from case studies and will address the respective merits of the alternative designs according to generally accepted assessment criteria.

10.1.3 Criteria for Assessment of Scenarios

The nature and degree of differentiation and coordination envisaged in a given scheme will have implications for its practical and political feasibility and is likely to affect its performance. The assessment of any given design should address all these issues.

Practical Issues

Different scheme designs can have very different implications for the feasibility and cost of implementation. The nature and degree of differentiation envisaged for the scheme may require particular technical or administrative challenges which impact on its technical and financial viability. The required nature and degree of coordination between different authorities (e.g. the body responsible for the motorway network and the body responsible for local roads) may similarly bring administrative difficulties.

A scheme characterised by highly differentiated charges and/or a non-intuitive relationship between the charges on urban roads and motorways might not be easily understood by road users. Such lack of comprehendability could be a significant problem, if it prevented people from understanding the intended price signal (because their behaviour would not reflect the signal) or if it led them to put pressure on the political authorities to abandon the scheme.

Some scheme designs may be inherently more politically acceptable than others. For example, public objection to pricing is generally less marked in respect of motorways than in respect of local roads, and schemes whose charge structure is thought to penalise a particular group of road users may (depending on which group is seen to be targeted!) be widely regarded as unfair and therefore unacceptable.

Impacts

The impact on **congestion** is clearly a major consideration for any urban charging scheme and is also potentially significant for motorway charging schemes. The impact on congestion is usually measured by estimating the total amount of delay in the system with and without the charges. This approach requires an agreed definition of delay and there is, unfortunately, no consensus on what that definition should be. Most authorities try to measure the total amount of time spent travelling (in vehicle hours or, preferably, in person hours) and subtract the total amount of time which would have been incurred if the traffic had been free-flowing. The problem with this approach is that it does not allow for the fact that some of the “delay” would simply be attributable to people adhering to speed limits, so a variant approach takes the “uncongested” time as that which would be incurred if people drove at the speed limit (but a problem with this definition is then that “congestion” can be reduced simply by reducing speed limits!). These methods, although open to some criticism, can provide a basis for quantifying, and via appropriate values of time for different types of vehicle, putting a monetary value on the amount of congestion. Alternative, more emotive, approaches to the measurement of congestion include estimating the proportion of travel time, or vehicle distance, spent at speeds below specified thresholds (e.g. such as 20 km/h or 10 km/h), or the proportion of time spent in queues.

The extent of **diversion of trips to other routes, modes or times of day** and of **trip suppression or generation** are important to any understanding of the full impact of a road charging scheme. Although it might be said that the consequences of such changes are already taken account of by measuring changes in congestion, the implications of a given reduction in congestion are clearly very different if achieved by, say, trip suppression rather than diversion to other routes. In general terms a city authority is unlikely to welcome a reduction in congestion brought about purely by trip suppression. An economic appraisal of a charging scheme will need to know the extent of the various forms of diversion and of trip suppression, because they have very different implications for the overall benefit (for example; diversion of trips to public transport may have implications for subsidies and producer surplus, while trip suppression will affect consumer surplus and the performance of the local economy).

A road charging scheme may affect **road safety**, if traffic levels or speeds are significantly affected. The extent of any impact on the number or severity of accidents is generally assumed to reflect changes in traffic volumes and speeds (but note that this general rule would not apply if the design of the charging scheme was such that it affected driving styles)[9].

The **environmental impacts** of a road charging scheme are likely to be a matter of considerable interest (particularly in schemes where the objective is to charge traffic according to the externalities produced). The key elements are green-house gasses, local air pollution and noise, each of which can be estimated indirectly from estimates of traffic volume, composition and speed. The consumption of fuel may also be of interest and it too can be estimated from traffic statistics.

The **net revenue generated** by a road charging scheme will clearly be a particular concern for scheme sponsors. They will be interested not only in the total value of charges paid, but also in the costs involved in implementing and running the scheme.

The impact that a road charging scheme might have on the **local or regional economy** will be of considerable interest to government and planning authorities. Impacts on employment, retail activity, property rents, economic output or efficiency might be expected, but are likely to be very difficult to predict. An appraisal of likely impacts would therefore be likely to start from first principles by looking at the effect that the scheme is likely to have on the costs of doing business in the city or region. This implies an interest in any change in the transport costs (after allowing for any expected congestion relief) experienced by commuters, shoppers, and suppliers, and any predicted suppression or generation of trips. The effect that the introduction of a scheme might have on local environmental

9 For example, there is evidence (from Bonsall and Palmer, 1997) to suggest that a congestion charging regime which charged drivers at a higher rate when they were driving below a specified speed would encourage unsafe driving).

conditions, or on business sentiment, might also be considered, albeit that the effect is likely to be difficult to quantify.

The potential **social impacts** of a road charging scheme will be of interest to governments. Equity issues are likely to be a matter of particular concern and will require thought to be given to the incidence of costs and benefits among the affected population. Such an analysis will, of course, need to consider the incidence of benefits from investment of revenues.

10.2 Scenarios For Co-Introduction of Charges on Motorways and Urban Roads

This section outlines some alternative scenarios for the co-introduction of user charges on motorways and other roads in urban areas. The scenarios range from those in which there is no distinction between motorways and other roads to those in which the charges have different structures to reflect the different objectives of the authorities responsible for the different types of road, the different roles served by motorways and other roads, and the different constraints which might apply in different cases. They do not purport to cover all possible combinations of charge regimes, but include examples of all the most interesting variants.

A. **Universal distance charge disaggregated by vehicle type and size but with no distinction between different types of road**. This regime makes no distinction between motorways and other roads and might be implemented, if the agreed objective of the highway authorities was to minimise green-house gasses or fuel consumption (these being broadly proportional to distance travelled).

B. **Distance charge with a peak period surcharge, disaggregated by vehicle type and size, but with no distinction between different types of road.** This regime again makes no distinction between motorways and other roads. It differs from the preceding one only in having a peak period surcharge. It might be implemented if the agreed objective of the highway authorities was to minimise green-house gasses or fuel consumption, while making some effort to reduce peak period congestion and/or maximise revenue (the peak period surcharge would dissuade some people from driving during the peak but, since peak traffic is generally less elastic with respect to price, revenue would be increased).

C. **Charges at cordons or screen lines, with disaggregation by vehicle class and a peak surcharge, but no explicit distinction between different types of road.** Although the cordons or screen lines would necessarily affect different parts of the network to different extents, this regime makes no explicit distinction between motorways and other roads (see J below for a variant which avoids putting cordons or screen lines on motorways). It might be implemented if the agreed objective of the highway authorities was to manage the network as a single entity with one overall objective such as minimisation of overall congestion.

D. **Charges for the use of any roads, including motorways, within a specified zone, with disaggregation by vehicle class and a peak surcharge.** It is assumed here that the defined zone includes at least one stretch of motorway (see J below for a variant in which the zone is defined to exclude motorways). As above, this regime might be implemented, if the agreed objective of the highway authorities was to manage the network as a single entity with one overall objective such as minimisation of overall congestion.

E. **Link-specific charges varying by vehicle class, reflecting the externalities attributable to the marginal vehicle of the specified class using that link.** A regime of this kind might be adopted, if the highway authorities responsible for both categories of road were seeking to maximise social welfare via marginal cost pricing and, although the different characteristics of motorways and other roads would result in different levels of externalities and hence different charges, this would be inherent in the regime rather than an explicit objective.

F. **Urban road charges combined with distance-based tolls on motorways.** It is assumed that motorway users are subject to a distance charge, while users of other roads pay to use roads in a specified zone or to cross specified cordons or screen-lines charge. Although both sets of charges might be disaggregated by vehicle class and incorporate a peak surcharge, this scenario assumes that different objectives are being pursued for the different categories of road. The motorway authorities may be seeking to maximise revenue (in which context the peak surcharge might reflect the lower elasticity of peak traffic), while the authorities responsible for the other roads might be prioritising reduction in congestion.

G. **Dynamic tolls on motorways combined with an urban area charge.** It is assumed that users of some, or all, motorway lanes are charged at a level which reflects the current level of congestion. As with the dynamically-priced US HOT lanes, the charge level is continually revised such that it is at the lowest level required to maintain free flow on the charged links (excess traffic being priced-off onto other lanes or parallel links). It is assumed that the non-motorway roads are also subject to charges (an area or cordon charge perhaps incorporating disaggregation by time of day and type of vehicle) and that the overall regime might reflect a general desire to minimise congestion in the conurbation with overriding priority given to maintaining free-flow on some or all of the motorway links.

H. **An urban area charge combined with dynamic charges on selected links.** This regime is a variant of that described above, except that dynamic charging might be applied not only on motorways but also at some bottlenecks in the non-motorway network (existing examples of dynamic charging occur only on motorways, but there is no reason in principle why the concept cannot be applied on any link to which access can be restricted). This regime might reflect a general desire to minimise congestion in the conurbation with overriding priority given to maintaining free-flow on strategic links – some of which are not motorways.

I. **Urban road charges combined with motorway access or egress charges.** This regime envisages an urban area charge, perhaps disaggregated by time of day and vehicle type, with an additional charge levied on drivers accessing or egressing the motorway within the urban area. This regime would reflect a general desire to minimise congestion in the conurbation, but with an attempt to protect the motorways from becoming clogged up with traffic seeking to avoid the urban road charges.

J. **Urban road charges with no charges applied on the motorways.** This regime is a variant on Scenarios C and D. It envisages charges on urban roads (an area charge or cordon charges, perhaps disaggregated by time of day and vehicle type) without any charges on the motorways. It might reflect a desire to minimise congestion on the general purpose roads in the conurbation and a belief either that the motorways have sufficient capacity to absorb any diverted traffic, or that congestion on the motorways was an acceptable consequence of the desire to free up the general purpose roads.

K. **Dynamic tolls on selected links.** This regime is a variant on Scenario H. It assumes that there are no charges other than those applied on selected strategic links. It might reflect the simple objective of maintaining free-flow on strategic links, of whatever type, in the conurbation area.

L. **Distance charge on motorways.** This variant of Scenario B assumes that the distance charges, which may be disaggregated by vehicle class and may include a peak surcharge, are applied only on the motorways – all other roads being free at the point of use. It is the type of regime which might be applied, if the motorway authorities are seeking to maximise their revenue (capitalising on different elasticities) without regard to the consequences for other roads in the conurbation and if the local highway authorities have been unable to implement charges for technical or political reasons.

M. **Motorway user charge.** This variant on Scenario L assumes that charges are applied on motorways only but that, rather than being distance-based, they are set to a given value (which might vary by time of day or type of vehicle) irrespective of the distance driven. This kind of charge might be implemented as a motorway access or egress charge (see I above) and would perhaps be appropriate, if the authority's prime concern is to protect strategic traffic on the motorways from congestion caused by short distance traffic which "ought" to be using the local network.

10.3 EVIDENCE

10.3.1 From Implemented Schemes

Local Experience on Integration of Interurban and Urban Charging: The Trondheim Case

Trondheim has a tolled motorway on the E6 between the city and the airport and, for fourteen years, had a toll ring around the city[10]. The coordination between the two provides an interesting case study.

The first stage of a new toll road on the E6 national trunk road route from Trondheim to the airport was opened in 1988. Its purpose was to divert through-traffic from the old route for environmental and traffic safety reasons and to provide a faster connection between the city and the airport. This toll has since been in operation 24 hours a day and drivers passing through the toll plaza at Ranheim, located at the periphery of the city, have to pay in both directions. The construction of the motorway continued in stages until it reached the airport in the late nineties, and a second toll plaza (Hommelvik) was

[10] More fully described in chapter 2 of this report

added closer to the airport. A vehicle travelling the whole distance on the motorway between Trondheim and the airport is charged at both stations.

Figure 10-1 The Ranheim Toll Plaza

The charges for heavy vehicles (gross weight more than 3.5 tons) are shown in Table 10-1. Light vehicles are charged exactly half these amounts. Reduced charges applied for local[11] traffic heading inbound, provided that the vehicle has a tag[12].

The inbound route through the Ranheim toll plaza was the fastest route in the direction of the city centre, as well as the preferred route from an environmental perspective, since it passed through a tunnel and avoided built-up areas. For the same environmental reason, it was important that the route through Ranheim was chosen for traffic heading east out of the city, rather than parallel routes through built-up areas. Therefore, a by-pass lane that was free of charge for local traffic was built close to the Ranheim toll plaza.

Table 10-1 Prices per Passage (2002 – 2005) for Heavy Vehicles for Using the Toll Road

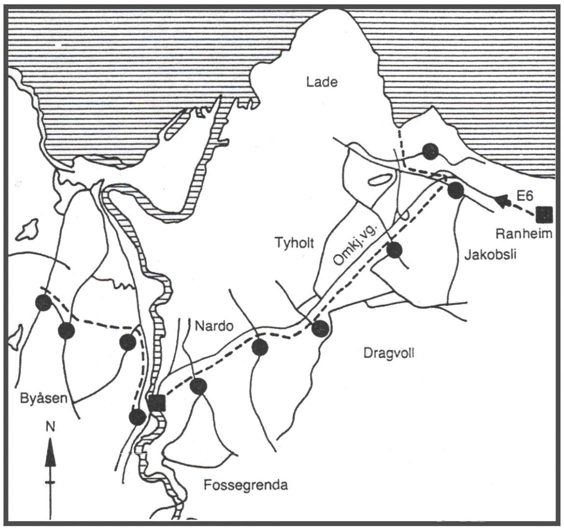
Charges (NOK) depending on payment options	Ranheim		Hommelvik
	Long-distance traffic	Local traffic	
Manual payment (basic charge)	50	50	20
Prepayment of NOK 500	35	17.5	14
Prepayment of NOK 2500	30	15	12
Prepayment of NOK 5000	25	12.5	10
Postpayment by bank giro:			
Up to 5 passages/week	45	22.5	18
Up to 10 passages/week	40	20	16
More than 10 passages/week	35	17.5	14

Note: 1 NOK amounts to about 0.125 Euros

11 "Local traffic" being that which was detected as having entered the toll station by a special ramp that collected local traffic and traffic from the old and un-tolled E6 route from the east via a roundabout.

12 Right from the start, all vehicles were offered windscreen-mounted electronic tags which would allow them to pass through the toll plaza at normal speed without any delay. This was one of the earliest full scale implementations of electronic fee collection in the world, based on an on-board unit and communication (DSRC) with roadside equipment. The electronic tags are activated by roadside transmitters, which send a signal to the tag that responds with its identity. This response is read by the receiver at the roadside, enabling a charge to be added to or deducted from a centrally held credit or debit account

The main characteristics of the Trondheim toll ring system, which was implemented in 1991, are given in Figure 10-2. This system went through two major revisions before it was terminated in December 2005 (when the projects that the charging system was introduced to part finance were completed).



- Fully electronic from the start
- All stations had non-stop lanes
- 80% of transactions in morning peak by electronic tags at opening in October 1991
- Only inbound crossings were charged
- Three charge periods:
  - Monday-Friday, 0600-1000 (full charge)
  - Monday-Friday, 1000-1700 (reduced)
  - Evenings, Weekends (free)
- For subscribers, a maximum of one crossing per hour and 75 crossings per month were charged for

Figure 10-2 The 1991 Trondheim Toll Ring

In Norway, the introduction of charges on interurban highway facilities, as well as urban charges like toll rings, are based on local initiatives, and they need approval by local and regional political bodies, and sanctioning by the National Parliament. The purpose of the charging is to raise private sector money to finance (wholly or jointly with public authorities) infrastructure investments. Loans are usually taken up before charging begins and some new infrastructure is typically in place when charging is introduced. The management of the finance operations and the collection of tolls are subcontracted to locally based private companies with limited responsibility. Municipal and county authorities are majority shareholders in these toll companies.

In the Trondheim case, a toll company (Trøndelag Bomveiselskap AS) was established in 1983 with the purpose of financing the new motorway between Trondheim and the airport, in cooperation with the Public Roads Administration. Its responsibility was later expanded to cover financing and toll collection for the Trondheim toll ring. The tolled motorway and the Trondheim toll ring were strictly defined as two separate projects, although they shared the same administrative services. Income from the Ranheim toll plaza went to the motorway project, whilst that from all the other charging stations in the toll ring went to the Trondheim Investment Package. Shared operating costs were allocated between the two projects pro-rata to their income.

From a motorist’s perspective, an agreement about electronic charging and pre- or post-payment with the toll company was valid for both projects. Coordination of the motorway charging system with the urban charging system ensured that traffic which had been charged at Ranheim was not subsequently charged for using the Trondheim toll ring or for passing through the city. Similarly, charges levied at any of the toll ring charging points were cancelled for any long-distance traffic which, within an hour, entered the E6 motorway through Ranheim (in the direction of the airport). The general rule was that for all toll ring stations and including Ranheim, if you had more than one passing within an hour, you only paid for the most expensive passing.

The AutoPASS System: Interoperability within Norway and with Neighbouring Countries

The original electronic tolling systems in Trondheim and at other locations in Norway were subsequently upgraded to the national AutoPASS system. Since February 2004 a coordinated payment system has been in operation in Norway, now involving more than 25 project sites, including 6 urban toll ring systems (Oslo, Tønsberg, Kristiansand, Stavanger, Bergen and Namsos). Around one million vehicles are equipped with the AutoPASS On-Board-Unit (OBU). EasyGo is a service where drivers can use their BroBizz or AutoPASS tag as a payment means at facilities in Norway, Sweden and Denmark (Figure 10-3).

For AutoPASS holders, EasyGo takes effect automatically without additional cost; cars are only charged for the passages they make. Regardless of where the passage is made, the passage will be registered and charged to the account at the toll operator where the driver has a contract.

(red dots: toll plazas, blue dots: ferry terminals)

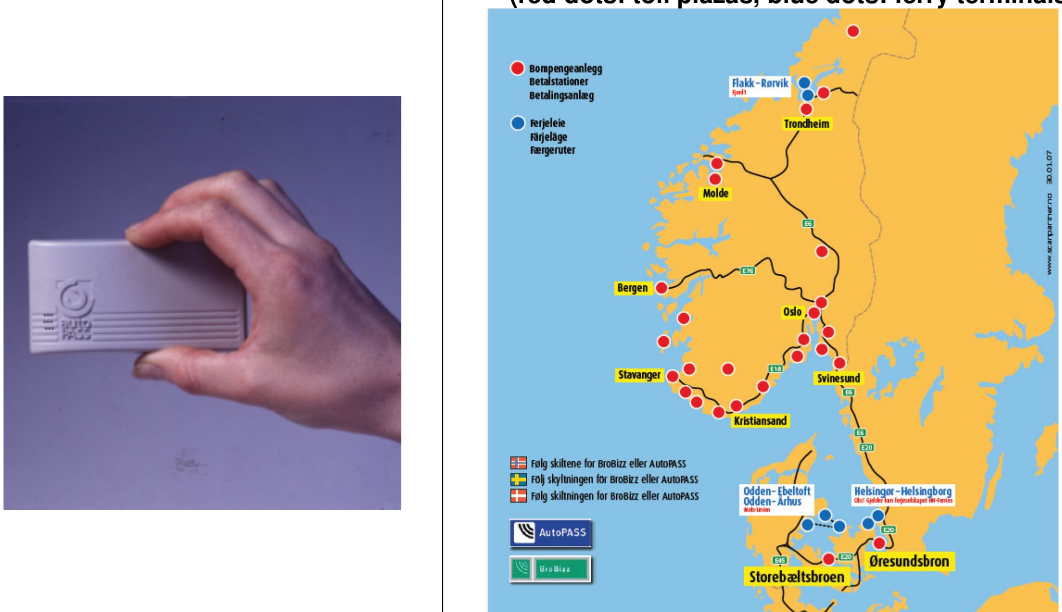


Figure 10-3 The AutoPASS OBU and Map Showing Where the Tag Can Be Utilized

Singapore

Singapore's experience with road pricing is described in chapter 6 of this report, but has some important lessons in the context of the coordination of charges on motorways and other types of road. The original Area Licence Scheme (ALS) was aimed at traffic in the central city but, when the ALS was replaced by electronic road pricing (ERP), charges were extended to include the expressways. This then caused some diversion onto arterial roads and so charges were introduced on these roads too (though at lower levels). The current system uses a common technology (stored-value smart cards from which charges are deducted at charge points) combined with a charge regime in which charges vary by location, type of vehicle, time of day and level of congestion. The differentiation by location allows charges to be set to reflect the different roles of different roads. The system appears to give the authorities the ability to manage demand throughout the urban network (including the expressways) in pursuance of clearly stated objectives (optimising the use and performance of the overall network).

Toll Modulation on Peri-Urban Motorways in France

A recent study by the ASFA Association (ASFA 2007) identified five situations in which toll modulation might help to better manage the infrastructure capacity and reduce emissions:

- Nationwide use of peak/off peak differentials;
- "Weekend-return" premium tolls;
- Urban and peri-urban coordination;
- Off-peak discounts for HGVs; and
- "Ecological pricing" for HGVs.

Of these, the proposal for coordination in urban and peri-urban areas is particularly relevant here. Its aim would be to prevent the overlapping of peak demand by local traffic and longer distance traffic and the detailed design would need to reflect local conditions. These proposals were made in the light of experience with weekend-return premium tolls and of peak period pricing in the Marseilles area[13] and of US evidence that, if targeted at commuter traffic, such differentiation may reduce congestion considerably (evidence from Florida suggests that a 50% differentiation in bridge toll levels can divert 20% of the traffic from peak to off-peak periods (US FHA 2006).

Toll levels on several French motorways are differentiated in order to spread returning holiday traffic more evenly over the day. Surcharging for congestion costs has been introduced on motorways in the Paris region (A1 Paris-Lille, A14 SAPN, A86 Duplex tunnel) at weekends and experiments have been developed on the major links with the South (A10-A11, A5-A6) during periods of peak flow during the summer holidays.

Weekend return tariff modulation on A1-Sanef. A pilot project was established in 1992 to target traffic returning time to Paris on Sunday evenings. The scheme has been regarded as successful and still continues. Under this scheme, tariffs are increased by 25% in the peak ("red") periods and directions (traffic heading for Paris on every Sunday and some holiday Mondays and Tuesdays 16:30 to 20:30), while some tariffs were reduced by 25% in the in off-peak ("green" periods from 14:30 to 16:30 and from 20:30 to 23:30)[14]. The stated purpose was to spread the passenger cars returning to Paris from the north from holidays more evenly over the day. The impact of the scheme was mainly on the timing of trips. Comparisons of traffic counts showed that southbound traffic at the mainline toll barrier near Paris declined by approximately 4% during the red period and rose approximately 7 % during the green period, relative to a six-year trend for comparable Sundays. The most pronounced shift was from the last hour of the red period to the later green period. A survey in November 1992 confirmed that many people – about one-fifth of those travelling during the green period – sought to lower their toll by shifting the timing of their trips, sometimes by stopping for meals at service areas along the highway (Centre d'Etude 1993).

Tariff modulation on A5-A6 (1995-7 pilot project – Delache 2003). The A6 motorway, which links Paris to Lyon and the Alps, has traditionally suffered from periodic congestion during winter holiday departures and returns. Since December 1994, the A5 motorway has provided an alternative route to the A6, but is 71 kilometres longer than the A6 motorway between Paris and Beaune and is more expensive and not well known. The main objectives of the pilot project was to shift up to 20% of the A6 traffic to the A5, to reduce congestion on A6, and make the A5 motorway well known to users. During winter holidays and the Easter weekends in 1995-1997, differential toll tariffs were implemented for light vehicles in favour of the A5 motorway (the A6 toll was increased and the A5 toll was decreased). This pricing regime did have an impact on route choice; about 7000 vehicles transferred to the A5 per weekend and per direction. 15-20% of the potentially reroutable traffic was now on the A5.

Tariff modulation on A10-A11 (1996 experiment – Delache 2003). From March to November 1996, a toll modulation experiment was implemented for light and heavy vehicles returning to Paris. Figure 10-4 summarises the toll periods and differentials which were applied. The result was a 12% decrease of peak-flow traffic, a 6-9% reduction in peak hour traffic and a 60% reduction in delay due to congestion. The tolls caused a negligible amount of diversion to parallel roads (0.5% per weekend).

13 In September 1993, a disused railway tunnel running under the centre of Marseilles was converted into a road tunnel by a commercial company. Users of this tunnel are required to pay a toll - the first example of a street toll in France. The tunnel connects the Prado station to the Careening basin. Tariffs vary by time of day/night (the "green" period is from 20:00 to 7:00). http://www.tunnelprado.com/

14 The reduction is applied to the Lille/Paris gear direction, at exit 10, 9, 8 and at the of Chamant (Senlis) toll barrier and applies only vehicle classes 1 and 2 (cars, monospace, and 4x4). A slightly higher discount is available for very short trips.

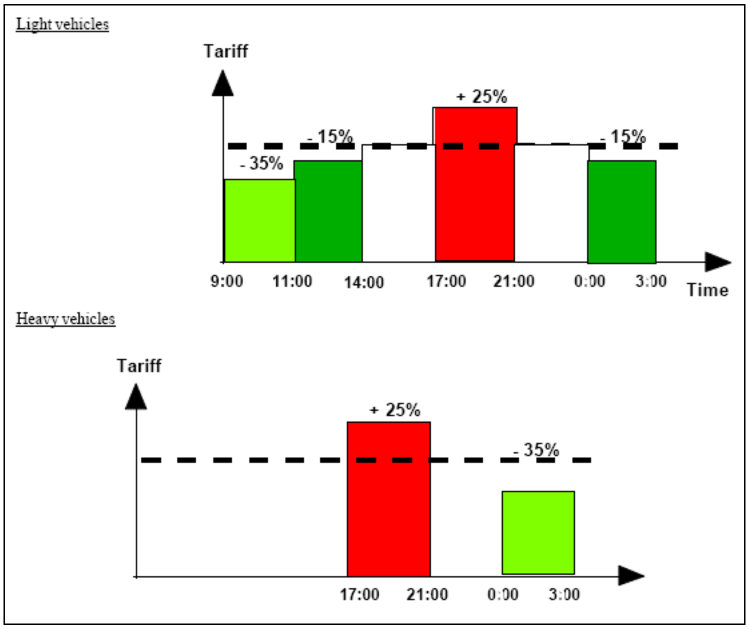


Figure 10-4 Tariff Modulation According to Time on A10/A11 in 1996

"Liber-t A14 Week-End"** - **off peak weekend tariff reduction on the A14-SAPN around Paris. A 50% reduction is available to light vehicles (toll class 1) making round trips made on the A14 motorway (the outward trip has to be made between 12:00 on Friday and 20:00 on Saturday and the return trip has to be made between 12:00 on Sunday and 20:00 on Monday). In contrast to the A1-Sanef scheme, this tariff structure does not seek to avoid weekend peaks – rather it seems designed to encourage use of the motorway. The fact that the Liber-t charge periods do not match those used on the A1-Sanef is clearly a potential source of confusion among drivers.

Tariff modulation on A86. As of December 2007 (when this case study was prepared), Cofiroute were proposing that, from Spring 2008, the tariff for use of the Duplex tunnel, which links the A86 with western Paris, would be varied according to the time of day. Discounts of up to 35% are likely to be offered to holders of telematic passes. Further reductions will be available for regular commuters, under the *Activ-t A86* subscription scheme.

This evidence of the effect of toll modulation in France gives a mixed message. On the one hand there are several examples of toll modulation, which have helped to address strategic routing problems (e.g. the continuing A1-Sanef scheme and the now discontinued schemes on the A5-A6 and the A10-A11). On the other hand there are two apparently successful projects that have been discontinued, and the current generation of proposals (*Liber-t* and *Activ-t)* are more concerned with the maximisation of income for the toll operating companies and seem likely to increase the total amount of traffic on general purpose roads as well as on the motorways. The wider community benefit might not be best served by toll differentiation of this kind. Also, the toll structures which emerge from a profit maximisation objective look quite complex (they are aimed at niche markets) and, if several such packages are offered by competing operators, the emerging toll structure may be difficult for users to understand and may lessen the effectiveness of any attempt to use tolls or charges to manage demand on the urban network.

10.3.2 From Previous Modelling Work

A number of studies in the UK have used models to examine scenarios for the introduction of charges on motorways and other roads in urban/metropolitan areas. These paragraphs seek to summarise the relevant results of these studies. Bibliographic details are provided so that readers can follow up specific points in more detail.

Motorway Charging in West Yorkshire

The authors of this study (Mauchan and Bonsall, 1995) used a fixed matrix SATURN assignment model to assess the effect of different forms of motorway toll on traffic diversion to the non-motorway network. Two types of differentiation were tested (i) a simple per-km charge was compared with a flat rate charge irrespective of distance travelled which effectively penalised traffic using the motorways to travel short distances, and (ii) tolls imposed on all motorways were compared with those imposed only on "strategic" motorways which thereby favoured local traffic. Tolls were assumed to be imposed on all traffic throughout the day and night with no distinction between different types of vehicle or between peak and off-peak times. The effect of these charges at high and low levels was investigated (per km charges were tested in the range of cents 3 to 12 per km, flat rate charges were tested in the range of cents 15 to 30 per trip).

The key findings of the study were:

- That the introduction of charges on the motorways caused traffic flows to increase significantly on the main non-motorway roads, especially in the off-peak period;
- That, with charges in place, peak period congestion increased on the minor non-motorway roads (via a knock-on effect whereby motorway traffic moved onto the major non-motorway roads and in turn displaced traffic from these roads onto the more minor ones);
- That the distance-based charge diverted more traffic than did flat rate charges yielding the same overall revenue (the per distance charges typically caused increases of up to 25% in the flow on major non-motorway roads - five to ten times as much as was caused by the flat charges);
- That tolls introduced on only the "strategic" motorways caused 25% less diversion to non-motorway roads than tolls levied for all motorways – even though the tolls were set to produce a similar overall revenue;
- That traffic was diverted away from 'feeder' motorways even when they themselves were not tolled; and
- That diversion of traffic away from motorways caused increases in overall travel time and overall mileage in the network.

The authors concluded that the introduction of tolls on motorway in or near urban areas could have significant deleterious effect on the urban network, if tolls were not simultaneously introduced on those urban roads. The broader conclusion is that differentiation by type of traffic (long-distance *v.* short distance) and by type of motorway (strategic *v.* general purpose) can be used to control the impacts on the surrounding network.

South and West Yorkshire Multi-Modal Study (SWYMMS)

This was one of three multi-modal studies commissioned by the Department for Transport which sought to examine sustainable strategies for reducing congestion on the strategic road network. Among the road user charging schemes examined in this study were:

- An urban centre congestion charging scheme (CC2) comprising a £ 1 charge to enter or leave town centres (raised to £ 3 to enter or leave Sheffield or Bradford city centres and to £ 5 to enter/leave Leeds city centre) at any time of day;
- Urban fringe charging (UFC2) comprising a £ 2 charge to enter/leave various town/cities and a £ 3 charge to enter/leave Leeds at any time of day;
- Urban area charging (UCC1) a 30 p/km charge for travelling in any of 11 urban areas at any time of day;
- Motorway charging (MC1) a 2 p/km charge for use of motorways or the A1 (a major strategic route) at any time of day;
- Two variants on urban area charging combined with motorway charging: (i) (UUC2+MC101) a 20 p/km charge in 11 urban areas and 2 p/km on motorways and the A1 to apply all day, (ii) (UCC2+MM102) the same as UUC2+MC101, but only in peak periods.

The performance of these schemes, as predicted by a strategic scale multi-modal model, is outlined in Table 10-2 for the year 2020 and the following conclusions can be drawn:

- The urban centre (CC2) congestion charging scheme generates a modest revenue, but increases journey times and leads to net disbenefits to car drivers and good vehicle traffic;
- Urban fringe charging (UFC2) produces significant revenues, as well as time savings and significant benefits for all classes of road user;
- Urban area charging (UCC1) produces very significant revenues as well as very significant time savings for car drivers and goods vehicles and significant total user benefits;
- The introduction of charges only on motorways and the A1 (MC1) generates reasonable revenues, but results in small increases in car journey times (presumably because some traffic diverts from motorways onto more congested routes) and produces only modest overall benefits;
- The combination of urban area charging and motorway charging leads to very significant revenues, very significant reductions in journey times and significant overall benefits to road users; a comparison of UCC2+MC101 with UCC2+MC102 shows that the majority of the benefit and revenue is associated with off-peak traffic.

Table 10-2 SWYMMS: Transport User Benefits

	£m per annum, 2020 relative to do nothing					
	CC2	**UFC2**	**UCC1**	**MC1**	**UUC2+MC101**	**UCC2+MC102**
Time savings:						
• car users	(-76)	332	540	(-23)	562	269
• goods vehicles	(-88)	136	290	(-44)	315	111
• public transport users	16	21	(-56)	(-8)	30	60
• all modes	(-148)	489	774	(-75)	907	440
Reduced out-of-pocket costs (all modes)	15	236	585	193	533	111
Total user benefits:						
• time + money	(-133)	772	1359	118	1440	551
Revenues	267	1465	2350	720	2323	908

Source: Coombe (2004), MVA (2004)

More detailed results (not shown in the table) suggest that the simultaneous introduction of charges in urban areas and on the motorways is particularly effective in reducing traffic and increasing speeds on the motorways.

The results from the SWYMMS study indicate that, in areas where motorways pass close to urban areas and serve local as well as strategic traffic, the combination of urban congestion charges (at a high rate per km) with motorway charges (at a lower rate per km) appears to perform better than charges introduced only on the motorways or only on the urban roads (the introduction of charges only on city centre roads, or only on motorways, seems likely to be particularly difficult to justify).

The SWYMMS study was one of several multimodal studies commissioned by the UK Department for Transport (DfT, 2002). Between them, these studies examined a range of very interesting charging strategies, including several options for motorway charges, and some important conclusions were drawn. Those of relevance to the co-introduction of charges on motorways and other roads in urban areas are:

- That charges imposed solely on motorways had deleterious impacts on other traffic on non-motorway roads;
- That motorway charges could help "lock-in " the benefits of capacity increases; and
- That the performance of motorway charges could be enhanced, if accompanied by the introduction of tolls on non-motorway roads or appropriate traffic control measures.

Greater Bristol Strategic Study

This study looked at strategic transport options for the greater Bristol area from the present day up to 2031. Some of those options involve road charging. The introduction of charges solely on the motorway network, or on access links to it, was considered, but was rejected by the consultants because of previous evidence that the main effect of such charges would be to divert traffic onto non-motorway roads – with consequential increases in congestion, accidents and environmental nuisance. The consultants were of the opinion that, while the introduction of charges solely on motorways might yield useful revenue, it was unlikely to yield economic benefit.

Having thus rejected the introduction of charges solely on motorways, four charging scenarios were examined: (i) an intermediate cordon charge of £ 5; (ii) a distance charge in the urban area; (iii) a distance based charge levied at a constant rate on all roads in the study area (separate tests being run for charges ranging from 10 p per mile to £ 1.25 per mile); and (iv) a link-specific charge related to the level of congestion on individual links. The results, summarised in Table 10-3, show that the most effective type of charging in terms of reducing vehicle delay and increasing average vehicle speed was the area-wide link-specific charge (with charges dependent on congestion on that link).

Table 10-3 SWYMMS: Greater Bristol Strategic Study - Road User Charging Tests

Measure	Bristol Intermediate Cordon (£ 5)	Urban Area Charge (25p/mile)	Area-wide Charge (25p/mile)	Area-wide Charge (50p/mile)	Area-wide link-specific Charge
Change compared with Background Transport Strategy					
Car trips	-2.4%	-2.1%	-5.4%	-10.0%	-4.6%
Total vehicle km	-1.0%	-1.9%	-10.3%	-18.1%	-5.0%
Average journey length	+0.7%	-0.5%	-6.9%	-12.2%	-1.9%
Total vehicle delay	-2.5%	-3.7%	-13.4%	-22.3%	-21.2%
Average vehicle speed	+0.9%	+1.0%	+1.1%	+1.4%	+9.4%
Estimate Annual Gross Revenue (2003 prices)	£ 170 million	£ 250 million	£ 1050 million	£ 2080 million	£ 580 million

Source: Atkins (2006)

Simple Models of Networks in Which Some Classes of Link are Left Un-tolled

It is a well-known principle that efficient prices should reflect marginal costs, but it is also known that maximum efficiency is not achievable in a transport network, if some links cannot be tolled (for example, if there are technical, political or administrative reasons why tolls cannot be imposed on a particular class of roads). In such situations, marginal social cost pricing of those links which can be tolled is not welfare maximising and a better result is achieved by ‘quasi first-best pricing’ on the tolled roads – setting tolls which take account of the spill-overs upon unpriced capacity (Lévy-Lambert, 1968; Marchand, 1968). It is known that the welfare gains from second-best tolls with unpriced substitutes are generally rather low (e.g. Liu and McDonald, 1998), but become higher, if allowance is made for heterogeneity of travellers (Verhoef and Small, 2004) or for the dynamics of departure time adjustments (Braid, 1996; De Palma and Lindsey, 2000).

A number of studies have explored the performance of networks in which certain classes of link are left un-tolled or in which different objectives are being used to set the tolls on different classes of link (for example, if different authorities or toll-concessionaires have control over different parts of a network). Most of this work has been based on simple networks – with only a very small number of links, which are exclusively parallel or, less commonly, exclusively serial[15], or as in the case of Verhoef (2002) and Proost and Sen (2006) respectively, on generalised representations of networks or without any modelling of an explicit network.

15 A recent exception to this generalisation is provided by the work of Verhoef and Small (2004) and Verhoef and Rouwendal (2004) who use a three-link network with serial and parallel links.

Verhoef et al (1996) considered two private ownership regimes; one where one of the routes is private and the other has free access, and a second situation where a private monopoly controls both routes. They found that revenue maximising tolling on two routes may actually sometimes lead to a more efficient usage of road space than does second-best optimal one-route tolling. Hence, it may be more efficient to have a monopolist controlling the entire network, rather than just a part of it.

De Palma and Lindsey (2000) were among the first to consider strategic competition in this line of research. They focused on the efficiency of private toll roads versus free access, but also versus public toll road pricing, employing a dynamic model of bottleneck congestion. Their results show that two competing private roads can yield most of the potential efficiency gains from first-best pricing, at least if neither road has a dominant fraction of total capacity.

Ubbels and Verhoef (2008) study policy interactions between an urban and a regional government, each controlling one link of a two-link serial road network, where regional drivers may use both roads and urban drivers use the urban road only. Both governments set capacity and toll on one link, in a two-stage game where tolls are set after capacities have been committed to, and try to maximise social surplus for their own population. Using a simulation model to investigate the welfare consequences of the various possible game-theoretical set-ups, the authors find that governmental competition may be rather harmful to aggregate social surplus, compared to first-best policies. The main determinant of social welfare is not which exact type of game is played between the two governments, but much more whether there is cooperation (leading to first-best) or competition between them. The question of which (if either) actor is leading in the price stage appears to be of only secondary importance. Sensitivity analysis suggests that the relative performance for most game situations improves when demand becomes more elastic, but remains insensitive with respect to the unit cost of capacity expansions.

It is difficult to summarize the findings from such a broad literature in a few, generally supported conclusions. Tautologically, when public regulators are involved, policy coordination is, in terms of overall efficiency impacts, preferable to competition between governments. Because ‘foreign’ users on a jurisdiction’s road(s) only matter for local welfare in that they may bring in toll revenues and hinder local travellers (on the own road or elsewhere in the network), a government’s behaviour may resemble that of a profit-maximizer with respect to its tolling of foreign travellers. For private operators, Small and Verhoef (2007) show how the main insights from Economides and Salop (1992) carry over to congested networks: an increasing number of parallel private competitors (suppliers of substitutes) seems to bring tolls closer to the efficient level, while an increasing number of serial competitors (suppliers of complements) has the opposite effect. Insofar as perverse incentives for public operators are fed by the desire to raise toll revenues from foreign users, one would expect a similar regularity for governments.

More broadly, it is clear that the welfare implications of road pricing in networks where more than one operator is involved will depend on the details of the network structure, the elasticities of demand and the distribution of demand over the network, on the nature of congestion and its distribution over the network, on the distribution of toll-free roads and operators over the network (e.g. which operators control which roads?), on the type of operators involved, and on the type of instruments they have available.

10.3.3 From New Modelling Work

The modelling work described here was conducted within the DIFFERENT project expressly to investigate the effects of the introduction of urban and motorway charges to a metropolitan network. The model is described in detail in chapter 9 of this report but, for convenience, can be summarised here as an elastic user equilibrium assignment model applied to a 52 zone network which represents a medium-sized metropolitan area in which there are 347 km of urban road and 143 km of motorway.

The effect of introducing charges, separately or in combination, to the urban roads and motorways in this network was measured using a variety of statistics, which attempt to describe not only the *total* amount of travel (in veh*h) but the way in which this is spread over the network: either as the percentage on motorway links, or in three separate regions, with Region 1 being the central part of the city, Region 2 being outside this but inside the outer ring road, and Region 3 being outside the outer ring road.

Eight scenarios for the co-introduction of tolls were specified:

1. ***"First best"***; optimal tolls applied on each link in the network without specific regard to whether it is an urban road or a motorway link (optimal tolls being those which reflect the contribution to delay and externalities by the marginal vehicle on each link). Under this scenario the average toll charged on urban roads is 39.9 cents per km while that on motorways is 16.2 cents per km.
2. "***Best urban";*** the "optimal" tolls defined in scenario 1 are applied to urban roads only (leaving motorways un-tolled). Note that the tolls on each urban link are the same as in Scenario 1; they were not re-calculated to be optimal for a situation in which motorways are not tolled.
3. ***"Constant urban";*** a constant (39.9 cents) per km toll was charged on every urban link (leaving motorways un-tolled). The 39.9 cents value being the average rate charged on urban roads under scenarios 1 and 2.
4. "***Best motorway***"; the optimal tolls defined in scenario 1 are applied to motorway links only (leaving urban roads un-tolled). Note that the tolls on each motorway link are the same as in Scenario 1; they were not re-calculated to be optimal for a situation in which urban roads are not tolled.
5. "***Constant motorway***"; a constant (16.2 cents) per km toll was charged on every motorway link (leaving urban roads un-tolled). The 16.2 cents value being the average rate charged on motorways under scenarios 1 and 4.
6. ***"Cordon only";*** a € 15 charge to cross an inbound cordon (the cordon, referred to as the "outer cordon" in chapter 9, surrounds the main built-up area just inside a circumferential motorway, but intersects some motorway spurs; traffic on these spurs has to pay the cordon charge). The charge was chosen, after inspection of the performance of a number of different values, as one likely to achieve significant reduction in delay per trip without suppressing total trip numbers by more than 10%.
7. ***"Cordon & motorway"***; the cordon defined in scenario 6 plus a 10 cents per km charge for using motorways outside the cordon. The 10 cents charge was chosen, after inspection of the performance of a number of different values, as one likely to yield a revenue approaching that of the "first best scenario".
8. ***"Access charge"***; a € 3 charge was levied on all trips accessing the motorway network. The same charge applied irrespective of the distance travelled (unless the driver left the motorway and then rejoined it – in which case he would pay a second access charge). The justification for such a structure was that it would dissuade local traffic from using the motorways and preserve it for strategic traffic – for whom the one-off charge would be quite modest. The charge level was selected after testing a range of values – the € 3 charge being the one which minimised congestion (and incidentally, maximised benefit relative to the base).

The results for these scenarios are summarised in Table 10-4.

It appears that the greatest reduction in vehicle trips (and person trips) occurs under the "first best" scenario, that applying charges only to urban links has slightly less impact than the first best scenario, and that applying them only to motorways has relatively little impact. Constant charges have virtually the same impact on trip numbers as link-specific charges.

Table 10-4 Results of Scenarios

Measure	Base	Scenario							
		1	2	3	4	5	6	7	8
	No tolls	First best	Best urban	Constant urban	Best motorway	Constant motorway	Cordon	Cordon & motorway	Access charge
Total person trips ('000 per day)	132	112	116	115	126	125	121	117	124
Total vehicle trips ('000 per day)	110	93	97	96	105	104	100	98	104
Vehs crossing inner cordon* ('000 per day)	29	24	26	26	28	29	27	27	30
Vehs crossing outer cordon* ('000 per day)	38	32	35	35	34	33	21	21	32
Total veh*km ('000 per day)	1798	1531	1657	1608	1677	1674	1594	1531	1720
Percentage veh*km on motorways	59	64	69	72	47	34	59	40	50
Veh*km ('000 per day) on motorways	1059	895	1143	1153	780	567	940	612	852
Veh*km ('000 per day) on urban roads	738	636	514	457	897	1107	654	919	868
Percentage veh*km in Regions 1 +2	33	32	30	30	36	35	33	35	34
Veh*km ('000 per day) in Regions 1 + 2	588	497	494	475	601	592	529	536	581
Veh*km ('000 per day) in Region 3	1210	1034	1163	1133	1076	1082	1065	995	1139
Total veh*h ('000 per day)	56	39	49	53	50	55	46	45	54
Percentage veh*h on motorways	42	91	57	55	58	42	74	72	34
Average trip length (km)	16	17	17	17	16	16	16	16	17
Average trip duration (min)	31	25	31	33	29	32	28	28	31
Total cost of delay (k€ per day)	356	216	310	355	293	338	273	257	331
Total other externality cost (k€ per day)	58	50	54	52	55	55	52	50	56
Total revenue from tolls (k€ per day)	0	378	210	182	141	92	317	369	96
Naive benefit relative to Base (k€ per day)*	0	526	260	189	207	113	406	476	123

** Defined as [scenario revenue] + [base externalities (incl. delay) – scenario externalities (incl. delay)]; this naive indicator does not take account of costs of operation, loss of consumer surplus, loss of tax revenues, etc, etc, but is nevertheless instructive.*

The picture for veh*km is similar, with the first best scenario again seeing the greatest reduction and the effect of urban-only charges being again greater than that of motorway-only charges. The cordon charge, with or without the accompanying motorway charge, has a greater effect on veh*km than do any of the other second best charges – even though they had less impact on overall trip numbers (this is presumably because many trips are unaffected by the cordon but those that are, are severely affected).

The constant urban charge has more impact than the per-link urban charge (presumably because, with a constant charge, long journeys are penalised even though they are not congested).

Unsurprisingly, introduction of tolls solely on motorways causes a diversion of trips to the urban roads and vice versa. The constant motorway charge diverts more traffic to urban roads than did the best motorway charges (again this is presumably because, with a constant charge, long journeys are penalised even though they are not congested). Interestingly, the cordon has no impact on the balance between urban and motorway traffic volumes. The motorway access charge leaves a significant proportion of veh*km on the motorway – its main impact being to divert short distance trips from the motorway onto the urban network.

Turning now to the impact on delay, it appears that the greatest reduction is achieved under the “first best” scenario, followed in turn by the cordon & motorway charge, the cordon-only charge, the best motorway charge and the best urban charge. The constant charges on motorways and on urban roads do not perform at all well in terms of their impact on delay - with the constant urban charge performing worst of all (presumably because the charges are not related to congestion and cause very inefficient routing by people attempting to minimise the distance they travel). The motorway access charge does not manage to reduce congestion very much (any reduction in congestion on the motorways is counterbalanced by increased congestion on the urban roads).

Concerning the impact on externalities other than delay, the greatest reduction is achieved under the “first best” scenario and the least under the scenarios which have charges only on motorways. The cordon scheme, particularly if combined with a motorway charge, performs almost as well as the first best scenario.

Concerning the naïve definition of delay, it is clear that first best tolls are the most beneficial and that the cordon scheme, particularly if combined with a motorway charge, performs quite well, but that charges on motorways only, or on urban roads only, do not perform at all well - particularly when constant charges per km are applied.

The conclusions which can be drawn from these results are that, in respect of the co-introduction of differentiated tolls on motorways and urban roads in metropolitan areas:

- The best results are achieved, almost however defined, by applying charges to each link which reflect the contribution to externalities make by the marginal user of that link - irrespective of whether it is a motorway link or an urban link;
- The effect of a cordon charge can be enhanced by adding a per-km charge for use of motorways outside the cordon;
- Fixed per-km charges on motorways or on urban roads are much less effective than charges which are differentiated to reflect conditions (most notably congestion) on individual links (fixed per km charges on urban roads (only) are particularly ineffective because they cause people to use congested – albeit short – routes);
- The introduction of charges on motorways, but not on urban roads, produces little benefit and causes unwanted diversion to urban roads;
- The introduction of a charge designed to protect strategic motorway traffic succeeds in achieving that goal, but yields little revenue and, because it diverts traffic onto the urban network, its overall impact on delay and other externalities is quite modest.

10.4 DISCUSSION

Careful consideration of the scenarios outlined in Section 10.2, in the light of evidence presented in Section 10.3, indicates that the un-coordinated introduction of charges on motorways and other types of road in metropolitan areas could seriously compromise the efficiency of the overall network and the effectiveness of such charges that are introduced. The most serious problems are likely to be:

- Charges on general purpose roads might cause diversion of traffic to motorways, with the consequential **congestion on the motorways** making it impossible for them to fulfil their strategic role. This is an obvious risk in Scenario J, which assumes no charges at all on the motorways, but could occur in any scenario where charges on general purpose roads exceed those on parallel motorways during peak periods.
- Charges on motorways are very likely to cause diversion of traffic on to general purpose roads exacerbating **local congestion** and **increasing externalities** (e.g. increased local pollution affecting other road users and riparian activity, increased accidents due to the interaction with other road users). This is an obvious risk in Scenarios L and M, which assumes no charges at all on the urban roads, but could occur in any scenario where charges for use of motorways exceeds that of using parallel urban roads at any time of day.
- Although distance-based charges (as envisaged in Scenarios A, B, F and L) might be an attractive option for motorway owners wishing to maximise revenue or overall network managers seeking to minimise emission of greenhouse gasses, previous work has suggested that, to the extent that they influence drivers' route choice, **distance-based charges can exacerbate congestion in urban areas** (because they encourage use of direct routes rather than by-passes) and perhaps **harm the local economy** (because the increased costs and congestion are likely to lead to trip suppression).
- The **overall costs of implementation** would be higher, if the equipment and procedures required for the two schemes were different (e.g. if the motorway charges relied on GPS/GPNS to estimate distance travelled while the urban charges required smartcards to be read at cordons or screen-lines). Such costs would fall not only on the scheme sponsors, but also, conceivably, on end-users.
- The complexity of an un-coordinated scheme (potentially comprising different charging formulae, different start and finish times for charging periods, and different rules for exemptions) would almost certainly cause confusion and resentment among the population. This might make it difficult for people to understand how best to respond to the pricing signals (causing **loss of efficiency and utility**) and might also lead to **political problems.**
- The failure to coordinate details such as start and finish times, vehicle classifications and exemptions might create **perverse incentives** and so generate unwanted responses (e.g. if, in order to maximise revenue, the motorway authority started the morning peak surcharge period earlier than that on urban roads, early morning traffic might switch to the urban roads - exacerbating the build up of the urban peak; or if, given the objective of reducing production of greenhouse gasses, motorway charges were based on engine emissions, the most polluting vehicles would be the most likely to switch to the urban roads - with unwanted implications for urban air quality).
- The sheer complexity of an un-coordinated system might make it difficult to avoid creating **adverse effects on the regional economy** (e.g. it would become difficult to protect strategic traffic while maintaining general accessibility within the urban area).
- The sheer complexity of an un-coordinated system might make it difficult to ensure appropriate protection of disadvantaged groups and hence lead to **equity problems** (simply granting discounts or exemptions to such groups is no solution, because it would itself create equity concerns at the boundary of any group definition).

Consideration of the scenarios outlined in Section 2 does, however, indicate considerable scope for increased benefits by appropriate coordination of charges on motorways and other types of road. Although institutional barriers may exist (e.g. if different authorities, with different powers and objectives, are responsible for the different types of road), the scale of potential benefits may be sufficient spur to seek to overcome them. Examples of the potential benefits to be gained by treating the whole network as a single entity include the following:

- Adoption of a common basis for charging (as in Scenarios A, B, C, D and K) would make it **easier for end-users to understand** the pricing regime and to respond appropriately.
- A coordinated approach, which treats the overall network as a single entity, will obviously have a **greater chance of achieving an agreed common objective** (e.g. minimisation of greenhouse emissions in Scenario A, minimisation of congestion in Scenarios C or D, maximisation of social welfare in Scenario E, or maintenance of free-flow on strategic links in Scenario K).
- Similarly, a coordinated approach which treats the overall network as a single entity will have **greater chance of achieving agreed prioritisation of objectives** (e.g. Scenario B's minimisation of greenhouse emissions *and* of congestion, Scenario H's minimisation of general congestion while giving overall priority to the maintenance of free-flow on strategic links).
- Only by adopting a coordinated approach is it likely to be possible to **achieve complicated, multi-faceted, objectives** such as regional development or social equity.

The adoption of a coordinated approach does not mean that no distinction should be drawn between motorways and other types of road. For example:

- If the motorways in a given metropolitan area **serve a very different function** from that of other roads, it might be wholly appropriate for this to be recognised by imposition of a different charge structure on such roads (e.g. Scenarios G, and I might be ideal in a metropolitan area where sufficient capacity exists in the non-motorway network to warrant protection of strategic traffic on the motorways from encroachment by local traffic during peak hours; in some circumstances it might even be appropriate to apply charges on only one type of road – as in Scenarios J and L).
- If the motorway access and egress points in a given metropolitan area are infrequent or local traffic would have to make a considerable diversion in order to use the motorway, and if the capacity within the urban network is wholly adequate, the two networks may **serve different markets** and it might therefore not matter, if different charge structures were imposed on the two networks or if one network were left un-charged.

Even if, as in Scenarios F, G, H and I, the two types of road are treated differently, a coordinated approach to the planning, implementation, publicity and administration is likely to bring benefits. For example:

- Cooperation on scheme specification might make it possible to **agree common technology and procedures**, and thereby **reduce costs for scheme sponsors and end-users.** Although there will sometimes be practical reasons for adopting different methods (for example, although potentially useful in an urban area, motorway charges could not rely on enforcement by peripatetic wardens or require vehicles to be travelling at low speed whilst their identity was confirmed or an electronic transaction was completed), it must make sense to explore the possibilities for adoption of common technology and procedures.
- Cooperation on scheme specification might make it possible to avoid unnecessary differences in the definition of time periods, vehicle classes, exemptions etc, and thereby reduce unnecessary complexity and potentially perverse incentives. Where different definitions would be appropriate for the different networks, some compromise may be necessary to maximise overall benefit.
- Cooperation on matters such as launch dates and publicity should help to **maximise users' understanding, and acceptance, of the schemes.**

Evidence from Trondheim and Singapore indicates that, given appropriate administrative arrangements, cooperation on technical and design issues can produce an effective coordination of urban and motorway charges.

Evidence from the Paris Region suggests that, without some central coordination or control, profit-oriented concessionaires may produce schemes which, in addition to causing some confusion among motorists (given the adoption of different time periods and toll groups) may not best serve overall societal goals (the offer of return tickets and regular user discounts may increase overall demand not only on the concessionaire's motorway, but also on the roads leading to and from that motorway).

Previous modelling work, reinforced by the new work described in Section 10.3.3, has shown that charges imposed on part of the network can have profound consequences for traffic patterns elsewhere in the network, but that differentiation of charges by type of traffic (e.g. long distance v short distance), by time of day (e.g. peak v off peak), or by type of road (e.g. motorway v. motorway access link v. urban road) can be used to influence driver behaviour and thereby minimise delay and other externalities. It has also shown that the performance of motorway-only and urban-road-only charging schemes is generally inferior to that of schemes which include charges on both types of road. The highest benefits were seen to be associated with schemes in which the charges are based simply on link and traffic characteristics without any attempt to distinguish, ab initio, between motorways and other roads (the ideal charge on a motorway link may be different from that on a non-motorway link, but this will reflect its characteristics and role in the network, and the traffic which uses it, rather than being a consequence of it being a motorway link per se).

Theoretical modelling has indicated that, while social welfare may be maximised by having charges set by one government agency responsible for the entire network, competition between government agencies attempting to maximise the welfare of their separate constituencies is likely to yield less welfare than that might come from a monopolistic profit optimiser or from effective competition between profit optimisers.

10.5 CONCLUSIONS

It is quite common for the administration of motorways in a conurbation to be separated from that of other roads in the area. In such cases it is likely that the owners, managers and/or franchisees of the different networks will have different objectives. Typically, the motorway manager will want to maximise revenue (initially to cover the costs of the infrastructure and subsequently to generate profit) or maintain strategic connections, while the urban roads manager will want to manage congestion and/or promote the local economy. These different objectives would lead them to favour different charging regimes and, left to their own devices, they might introduce different, potentially conflicting, regimes.

The arguments and evidence presented above lead to the following conclusions:

- The degree of interaction between urban roads and adjacent motorways depends on the location and frequency of motorway access and egress points, the density of the urban network and the degree of spare capacity on parallel links in each network. Obviously, the greater the degree of interaction the more important it is to consider the potential cross-impacts.
- Considerable problems are likely to occur, if charges on urban roads are designed without regard to their potential impact on any adjacent motorways or if charges on motorways passing through metropolitan areas are designed without regard to their potential impact on the roads in those areas or on the local economy.
- Some diversion of traffic from one network to the other is an inevitable consequence of introducing charges. Although some diversion may be desirable in order to achieve a better match of demand to capacity or to prioritise particular types of traffic, excessive diversion can cause serious problems. Diversion of traffic from motorways to other roads can be particularly serious, because it leads to increased accident risk and environmental externalities.
- Cooperation on technical and procedural issues, and over detailed definitional points such as start and finish times, vehicle classifications and exemptions, is desirable even if the two road authorities have different objectives. In the absence of such cooperation the resulting complexity will increase costs for system operators and end users and cause particular resentment among the latter.
- Although it has not been proven by detailed modelling, it appears unlikely that a scheme designed to maintain free-flow on the motorways or maximise revenue for the motorway manager would simultaneously minimise congestion and other externalities within the urban area. It follows that, in order to maximise overall benefits, a degree of prioritisation or compromise is required.

- Although benefits are likely to be obtained by introducing a charge regime which draws no distinction between motorways and other roads, the different roles of the different types of road may make it wholly appropriate to introduce different charges on the different road types.
- It seems likely that overall benefits (defined as minimisation of delay, accidents and other externalities while maximising the benefits to society and the economy) might be maximised by combining a charge on the urban roads with charges designed to give a degree of protection to traffic using motorways and other strategic links. The urban charge might be levied on traffic crossing specified cordons or using roads within a specified are, while the strategic-link-protection charge might involve specific charges for using motorway access or egress links or dynamic charges just sufficient to preserve free flow conditions.
- Where motorways and other roads come under different political or administrative jurisdictions, it is particularly important to ensure effective coordination and cooperation. Competition between government authorities seeking to best serve their own constituents may produce charge regimes which perform no better, and perhaps much worse, than that likely to result from competition between profit-oriented concessionaires.
- Although it is likely to be easier to gain political support for introducing charges on motorways than on other types of road, the benefits from so doing are generally lower than can be obtained by introducing charges on urban roads.

11 MAIN FINDINGS FROM THE UK NATIONAL ROAD PRICING STUDY

11.1 INTRODUCTION

In 2003, the UK Department for Transport commissioned a feasibility study into road pricing. The purpose of the study was to advise on "practical options for the design and implementation of a new system for charging for road use in the UK". The advice was to cover:

- The options for the structure of the charging regime;
- The estimated impact of each charging regime, based on a range of scenarios, with the impacts to include those on congestion and accidents and on the environment;
- The relationship with charging schemes already in place;
- Legal issues, and in particular, safeguards for confidentiality;
- Options for the technology to be used, and the potential costs for the introduction and the operation; and
- Options for the transition to a full scheme and a potential timetable.

The sole focus here is on the second of these: the estimated impact of each of a number of possible scenarios of a charging scheme. These impacts were to be obtained by use of the National Transport Model (NTM).

11.2 THE NATIONAL TRANSPORT MODEL: STRUCTURE AND ASSUMPTIONS

The NTM is a strategic, multi-modal transport model, comprised of a series of sub-models, the main three of which are:

- The Demand Model: this deals with mode choice and distance travelled, and outputs the trips by each model.
- The Road Capacity and Costs Model: this outputs traffic, congestion, emissions and road costs.
- The National Rail Model: this outputs rail costs, emissions and passenger km.
- Of particular interest here is the Road Capacity and Costs Model. It is important to recognise that this is *not* a network model. Instead, it tabulates a sample of links in the road network, by 20 sub-regions, 10 area types, and up to 7 road types, and by 19 times of day and by direction of flow. From this sample, the outputs are factored up to represent the whole road network and vehicle traffic.
- The model assumes that the total number of trips, by all modes (including walking and cycling) remains constant and is therefore not affected by any pricing scheme. Users respond to policies or charges by changing their destination or mode, or by changing the length of their trip, but not by rerouting (because the model is not a network model). Car passenger is regarded as a separate mode (and this is more significant in the responses to the pricing scenarios than change of mode).
- In the context of the impact of road pricing, the model assumes that users' responses to price changes are in line with their response to fuel price changes. Evidence from recent years in the UK has shown that an elasticity of 0.3 was appropriate in 2000. However, at the time of the study, it was assumed that future fuel costs would steadily fall as a proportion of overall travel costs. As a result, it was assumed that by 2010, the relevant year for all outputs from the model, elasticity would be reduced to 0.17.
- The assumed values of time savings are: £ 5 per hour for car drivers outside the course of their work; £ 18 per hour in the course of work; and £ 8 per hour for van and other commercial vehicle drivers. The study assumed that fuel duty would be 3.5 p/km in 2010.

It should be noted that the assumption of fuel prices falling as a proportion of overall travel costs may be critical for the whole modelling exercise from today's point of view, since it is now not only clear that this assumption was incorrect, but that instead even the opposite has happened; and it is difficult to assess how the modelling results might have been affected by an assumption of rising fuel prices.

11.3 THE SCENARIOS MODELLED

The basis of the charging schemes is marginal social cost (MSC) pricing. From the tabular way in which the road network is divided down, by:

- location (conurbation, other urban, rural),
- type of road (motorway, A road, other),
- direction of travel and
- time of day,

there are 75 separate combinations identified and, for each combination, an average cost of the marginal externalities (comprising the costs of congestion, infrastructure, accidents, local air quality, noise, greenhouse gases and indirect taxation) is calculated as a rate per km. The full MSC pricing scenario is therefore carried out with these 75 charges which range from zero to approximately 80 p/km. As may be expected, the distribution of charges is very skewed: just over half of road users would be paying less than it would in fuel duty, and the proportion paying above 15 p/km would be less than 5%, and such levels of charge would only account for part of a journey. Many of these 75 charge levels are very similar in value and so some simplification can be effected by grouping adjacent values.

Therefore, six further simpler scenarios (numbered 2, and 5 – 9 in Table B3 in Annex B of the report) are then created by grouping these 75 charges into 10 (or in some cases, 9, or 8) separate levels, and by capping the maximum level of charge (e.g. to 80 p/km or 60 p/km or 40 p/km).

A further scenario (number 3) is a revenue-neutral version of the "10-charges capped at 80 p/km" scenario, in which it is assumed that fuel duty is reduced by an amount such that the loss in fuel duty is offset by the revenue raised from the road pricing.

A further scenario (number 4) consists of *no* road pricing, but instead there is an increase in fuel duty by such an amount as to raise the same amount of revenue as the "10 charges capped at 80 p/km" scenario. This approximates to a uniform charge per km across all links in the network.

Two further scenarios (numbered 10 and 11) are (i) to charge only in London and other conurbations, and (ii) to charge only in all urban areas (towns with a population of 10,000 and over).

Three final scenarios (numbered 12 – 14) are very crude schemes of charging (i) purely by road type (three types: motorway, A roads, and other roads), (ii) purely by area type (three types of area: conurbations, other urban and rural), and (iii) purely by time of day (no breakdown seems to be given in the report).

Table 11-1 shows the average marginal external costs (and therefore the pricing levels) for the nine different combinations of area and road type (all in p/km):

Table 11-1 Average Costs of Externalities

	Conurbations	Other urban	Rural
Motorway	3.2	n/a	0.6
A road	54.0	22.9	0.3
Other	26.2	5.5	3.8

Source: Webtag Unit 3.9.5 Annex A Table A1

These are taken from Webtag and apparently are the basis of charges imposed in three the simple pricing schemes. However, no information is provided there on the average costs at different times of day. Neither is it possible to find an (appropriately weighted) average either across the rows in Table 11-1 or across the columns to find the values of the average cost of externalities by area or by road type that are used as prices in scenarios 12 – 14 in Annex B Table B3.

11.4 RESULTS

The results obtained from running the NTM under the different charging schemes are presented as percentage changes from the base "no tolls" case in terms of the impact on both traffic and congestion on all roads, in the year 2010 – but in terms of 1998 prices. Each of these is broken down into percentage changes on urban roads and inter-urban roads.

The full 75 charge MSC scheme (scenario 1) is estimated to give a 48% reduction in congestion (52% on urban roads and 34% on inter-urban roads), but only a 3% reduction in traffic (9% on urban roads, and no change on inter-urban roads).

The results from the other scenarios will be presented in stages, so as to make the assimilation of the results more manageable and to highlight the principal findings. The first stage consists of comparing the impacts of the full, 75 charge, MSC scheme with those from the various simplified schemes (scenarios 2 and 5 – 9), produced by (i) grouping the separate charges, and (ii) reducing the maximum charge rate. The scenario numbering system used here is that given in the original report.

Table 11-2 Comparison of Impact of Charging Scenarios: Stage 1

Scenario	Charges	Change in Traffic			Change in Congestion		
		All Roads	Urban Roads	Inter-Urban Roads	All Roads	Urban Roads	Inter-Urban Roads
1	MSC: 75 charges	-3%	-9%	0%	-48%	-52%	-34%
2	10 charges, capped at 80p/km	-4%	-9%	-2%	-46%	-52%	-34%
5	10 charges, capped at 60p/km	-4%	-9%	-2%	-44%	-49%	-34%
6	9 charges, capped at 50p/km	-4%	-9%	-2%	-42%	-46%	-34%
7	9 charges, capped at 40p/km	-3%	-8%	-1%	-39%	-42%	-33%
8	9 charges, capped at 30p/km	-3%	-7%	-1%	-35%	-36%	-31%
9	8 charges, capped at 20p/km	-2%	-6%	0%	-28%	-29%	-29%

In scenario 2, the original 75 charges are grouped into the following ten levels: 1.5, 2.5, 3.5, 4.5, 5.5, 8.5, 14.5, 23.5, 53.5 and 83.5 p/km (including fuel duty). The maximum charge (*excluding* fuel duty) is therefore 80 p/km – hence the scenario is referred to as "10 charges, capped at 80 p/km". This simplification of the full MSC charging can be seen, from Table 11-2, to have virtually no effect on the percentage reduction in congestion (-46% instead of -48%) and very little effect on percentage traffic reduction.

As the capping level is steadily reduced, from 80 to 60, 50, 40, 30 and finally 20 p/km and the number of charge levels reduced accordingly, where necessary, from 10 to 9 and finally 8, the percentage reductions in congestion fall steadily, from the initial -48% on all roads to -28%. This change is seen predominantly on the urban roads, as would be expected, as that is where the highest charges are made. The change in congestion on inter-urban roads is quite slight, falling only from an initial -34% to -29%. The impact on the changes in traffic are far smaller, with the initial -9% change in traffic on urban roads under full MSC charges falling to -8% only when the cap is reduced to 40 p/km, and then to -6% with a cap of 20 p/km. The steps in percentage reductions in congestion between successive scenarios get steadily greater, as the cap is reduced.

These results demonstrate that a very large proportion of the benefits of a full MSC charging scheme can be obtained from a relatively simple charging structure: for example, with just nine charging levels, and a cap of 40 p/km, over 80% of the reduction in congestion from MSC charging can be obtained. Hence, simplified MSC schemes can produce a very high proportion of the potential benefits.

In stage 2 of the presentation of the results, scenario 2 (10 charges, capped at 80 p/km) is taken as the base, and two alternative schemes are compared with it. The first (scenario 3) is a revenue-neutral version of scenario 2: that is, it is assumed that fuel duty is reduced to compensate motorists for the revenue raised from the p/km road charges. The second (scenario 4) is one where there are no road charges, but fuel duty is *increased* so as to raise the same revenue as in scenario 2. The results are displayed in Table 11-3.

Table 11-3 Comparison of Impact of Charging Scenarios: Stage 2

Scenario	Charges	Change in Traffic			Change in Congestion		
		All Roads	Urban Roads	Inter-Urban Roads	All Roads	Urban Roads	Inter-Urban Roads
2	10 charges, capped at 80p/km	-4%	-9%	-2%	-46%	-52%	-34%
3	Revenue neutral version of (2)	+2%	-4%	+6%	-41%	-48%	-17%
4	Increase in fuel duty	-5%	-5%	-7%	-7%	-7%	-15%

The results show it is not the total amount of revenue that is raised that is important, but the way that it is spread over links and time. A comparison of scenarios 2 and 3, which have the same *variation* in the pattern of charging, but with quite different amounts of revenue raised, shows the impacts are quite similar in terms of changes in congestion. Most of the potential reduction in congestion is obtained from the revenue neutral scheme (a 41% reduction in congestion compared with the 46% from scenario 2). The comparison of scenarios 2 and 4, which raise the same total revenue, show very different results: the increase in fuel duty only reduces congestion by 7%. This confirms the conclusion that it is the structure of charges that is more important than the overall level.

Looking in finer detail at the breakdown of the results in Table 11-3, it can be seen that under the revenue neutral scheme it is forecast that there will be an increase in traffic, especially on inter-urban roads. This is because some drivers will be paying less than they would otherwise have done; also, as there is a significant reduction in congestion, the travel time costs are decreased by more than the road charges and the overall costs are reduced, leading to an overall increase in demand.

It is already very clear that the greater impact from charging is in urban areas, so in stage 3 of the comparisons of the model results, two further scenarios are set alongside scenario 1, fully complex MSC pricing. Both of these apply charges only in urban areas. In the first of these (scenario 10) full MSC charging is applied only in London and other major conurbations, and in the second this is extended to all urban areas with populations in excess of 10,000. The results are shown in Table 11-4.

Table 11-4 Comparison of Impact of Charging Scenarios: Stage 3

Scenario	Charges	Change in Traffic			Change in Congestion		
		All Roads	Urban Roads	Inter-Urban Roads	All Roads	Urban Roads	Inter-Urban Roads
1	Full MSC, with 75 charges	-3%	-9%	0%	-48%	-52%	-34%
10	Charging in London and conurbations only	-3%	-8%	-2%	-27%	-44%	-10%
11	Charging in all urban areas	-6%	-10%	-5%	-43%	-53%	-18%

The results are broadly as would be expected, in that the reductions in congestion from charging in all urban areas (scenario 11) are almost the same as those from full MSC pricing, and those from scenario 10 (charging only in London and the major conurbations) are not quite as effective, although the reduction in congestion in urban areas is -44% compared with the -52% from scenario 2. The impact on inter-urban roads is obviously much more limited. Note that charging in all urban areas is forecast to lead to a greater reduction in traffic on all roads than with full MSC pricing, and particularly on inter-urban roads.

The 75 levels of charge were allowed to vary by location (urban, rural etc), road type (motorway, A road etc), time of day, and level of congestion on that link at that time of day. In stage 4 of the comparison of the effects of different scenarios, some very simple charging schemes were tried out. In scenario 12, charging was applied purely by road type (that is, no differentiation by time of day, or area type). In scenario 13, charging was applied purely by area type (that is, no differentiation by road type or time of day); and in scenario 14 charging was applied purely by time of day (that is, no differentiation by road type, or area type). In each case, there was a maximum of four charges. These are obviously quite crude schemes, and the levels of charge applied were simple average charges based on the average cost of externalities shown in Table 11-1. No exploration of the best prices (from an economic perspective) was carried out, so the results should be treated with caution and regarded merely as a first guess at the appropriate charging levels. The results, showing the comparisons of the impacts of these simple schemes with full MSC pricing, are shown in Table 11-5.

Table 11-5 Comparison of Impact of Charging Scenarios: Stage 4

Scenario	Charges	Change in Traffic			Change in Congestion		
		All Roads	Urban Roads	Inter-Urban Roads	All Roads	Urban Roads	Inter-Urban Roads
1	Full MSC, with 75 charges	-3%	-9%	0%	-48%	-52%	-34%
12	Simple charging by road type	-5%	-5%	-4%	-3%	-3%	-14%
13	Simple charging by area type	-5%	-12%	-3%	-10%	-13%	-9%
14	Simple charging by time of day	-6%	-5%	-9%	-5%	-4%	-20%

It can be seen that these schemes deliver far smaller reductions in congestion than the fully targeted MSC scheme: even the best of these schemes (simple charging by area) produces less than a quarter of the reductions in congestion than full MSC. Given how much variation there is in congestion within each road type (or area type, or time period), this is hardly surprising. For example, the amount of congestion on a busy urban motorway is very different from that on a largely rural motorway, and yet the simple scheme in scenario 12 would charge the same rate on both roads. Similarly, there are great variations in congestion on urban roads at different times of day and in different directions of flow. By applying an average price for each group, many users will be overpaying and many will be underpaying relative to the external costs they impose. Hence, the inefficiency of such simple schemes is only to be expected. It can also be noticed that the overall reductions in traffic from these simple schemes is larger (roughly double) than from full MSC pricing.

The main findings from these results can be summarised as follows:

- Simplified versions of MSC schemes, such as those in scenarios 2, and 5 – 9, can be very effective in producing a large proportion of the percentage reductions obtained from full MSC pricing.
- It is the pattern of variation in charging that is important, and not the overall level, as is demonstrated by the results from the revenue-neutral scheme (scenario 3) and the increase in fuel duty scheme (scenario 4).
- Charging only in urban areas can deliver a very large proportion of the potential reductions in congestion (as shown by the results from scenario 11).
- Simple charging (by area type, road type or time period) is very ineffective in reducing congestion, emphasising again that it is the targeting of charges that is important.

11.5 Other Impacts of the Charging Schemes

The discussion of the results from the NTM has so far been limited to the impacts on road traffic: that is, measured by the percentage changes in traffic and in congestion. A brief summary will now be given of the other impacts of the schemes, with the main attention being focussed on the full and simplified versions of MSC pricing (scenarios 1, 2 and 5 – 9) which have been shown in the previous section to be the most effective.

Firstly, the impact on other modes will be considered. All these schemes have a relatively modest impact on other modes: public transport (bus and rail) is estimated to increase its share by around 5%, and there are smaller increases (1 – 2%) in cycling. The main shift is estimated to be through an increase in car sharing.

Secondly, there are reductions of around 4 - 5% in CO_2 emissions overall, but with larger reductions (6 – 7%) in local pollutants in London and large urban areas, with these reductions generally reflecting the reductions in traffic in urban areas.

The impacts in economic welfare have also been estimated. These estimates include the time savings to road users, the changes in vehicle operating costs, the environmental and safety impacts, and changes in road maintenance costs. They also include the welfare costs to road users of paying the charge (these are a cost to those to those paying the charge, but a benefit to society, and different road users will have different values of their time savings), and also the revenue raised from the charges, plus changes in indirect taxation (such as fuel duty and VAT on fuel).

However, the model makes no assumption about how the revenues raised might be used (for example, for improvements to public transport). Neither have any estimates been made of the costs of operating any of the charging schemes. Therefore, the estimates of economic welfare shown in Table 11-6 are lacking these significant aspects.

Table 11-6 Estimated Welfare Benefits (in £ billion per year in 2010, at 1998 prices) from Selected Charging Schemes

	Scenario				
	1	2	6	3	4
Road users' benefits from time savings	+11.8	+11.3	+10.2	+10.1	+2.1
Road users' change in costs	-10.2	-10.4	-10.5	-0.1	-10.2
Revenue	+8.2	+8.6	+8.8	-2.2	+10.5
Environment and safety benefits	+0.5	+0.5	+0.5	+0.1	+0.5
Public transport	-0.2	-0.2	-0.1	-0.2	-0.1
Total benefits	+10.2	+9.9	+9.0	+7.8	+2.8

The table shows the estimated benefits for schemes in the following order:

- Scenario 1: full MSC pricing, with 75 levels;
- Scenario 2: 10 charges, capped at 80 p/km;
- Scenario 6: 9 charges, capped at 50 p/km;
- Scenario 3: revenue neutral version of 10 charges scheme;
- Scenario 4: increase in fuel duty, to raise same amount of revenue as scenario 2.

It can be seen that the estimates broadly follow the changes in congestion. Full MSC pricing, with 75 charges, gives the greatest benefits, but simplifying the scheme to have only 10 charges does not reduce the benefits significantly. Reducing the maximum charge from 80 to 50 p/km reduces benefits by around £ 1 billion. For scenarios 1 and 2, the benefits to road users from time savings outweigh the costs of paying the charges, but once the maximum charge is lowered to 50 p/km, this is no longer the case.

The revenue neutral scheme produces total benefits that are only a little less than those from scenarios 1, 2 and 6, but the pattern is very different: whilst there are still substantial time savings, road users would also gain through the substantial reduction in fuel duty. However, the revenue would be much reduced.

Scheme 4, the increase in fuel duty without road charges, produces far smaller benefits: only slightly more than one-quarter of those from MSC pricing. This is very largely because of the much lower time savings.

The very simple pricing schemes in scenarios 12 – 14 (by road type, by area type, and by time period) deliver very much smaller benefits of, respectively, £ 0.0, +0.5 and +1.2 billion per year.

Finally, the benefits from scenarios 10 and 11 (charging only in London and the conurbations; and in all urban areas) give benefits of £ +5.4 and +6.4 billion per year. Again, this is largely due to the smaller time savings produced by these schemes.

11.6 DISTRIBUTIONAL EFFECTS OF MSC PRICING

11.6.1 Introduction

It has been shown that the total benefits produced by MSC pricing are approximately £ 10 billion per year, whether the full, 75 charge, form of scenario 1, or the simplified, 10 charge, form of scenario 2. This is the total benefit, aggregated over all users and over all modes, all journey purposes and all areas. In this section, this total is broken down in a variety of ways to investigate how this total benefit is distributed. This analysis is carried out specifically for scenario 2 for which the estimated total welfare benefit is £ 9,860 million per year. Again it needs to be remembered that no assumptions have been made about how the revenue is to be used, so the benefits given here are "first round" estimates.

11.6.2 Benefits by Source and Journey Purpose

As was seen in Table 11-6, the welfare benefits to road users are £ 955 million, and those to public transport users are £ -230 million. The £ 955 million to road users is distributed between car users (£ 700 million) and freight (£ 255 million). The £ 700 million to car users is made up of £ 1370 million to car users on employer's business, whilst those on personal travel suffer a loss of £ 670 million. This £ 670 million can be broken down further by journey purpose: commuters (because of travelling at peak times and paying higher prices) suffer a loss of £ 994 million, whilst those on recreational trips or holidays have a benefit of £ 313 million (with other minor categories of education, personal business and "other" making up the residual of £ 16 million)

11.6.3 Benefits by Area Type

In this section, the distribution of the total net welfare benefits to car users of £ 700 million per year across different area types is considered. The net welfare benefit to any group of car users is made up of the time savings and money savings. The travel time of those on employer's business is valued much more highly than those on personal travel: hence the positive benefits for those on employer's business in all areas, and the negative benefits for those on personal travel in all urban areas. Only in rural areas is there a positive benefit to those on personal travel. The full breakdown is shown in Table 11-7.

Table 11-7 Distribution of Net Benefits (Time Savings + Money Savings) to Car Users by Area

Area type	Net benefits (£ million per year)		
	Employer's business	Personal travel	Total
London	278 (758 – 480)	-599 (2145 – 2744)	-321 (2904 – 3224)
Metropolitan	202 (425 – 223)	-646 (1363 – 2009)	-444 (1788 – 2232)
Large urban areas	204 (336 – 132)	-133 (920 – 1053)	71 (1256 – 1185)
Small urban areas	242 (474 – 232)	- 305 (1134 – 1439)	-63 (1608 – 1671)
Rural	445 (506 – 61)	1017 (1367 – 350)	1462 (1873 – 411)

11.7 LOCAL MODELLING

Although the vast majority of the modelling work in the UK road pricing feasibility study was devoted to the application of the national transport model, a small section is describes some findings from multi-modal studies with four local models: South and West Yorkshire, London Orbital, Cambridge to Huntingdon, and Belfast. The results from this local modelling are only preliminary and are given only in broad terms in the report.

In the local models, both cordon-based and distance-based charging schemes were modelled. The cordon schemes consisted of an inner cordon around the central business district, and an outer cordon at the outer edge of the urban area, and with no charging outside the outer cordon. No information on the levels of charge is given in the report and it is concluded that detailed work would need to be done, for each separate network, to establish appropriate charging levels.

In the distance-based charging schemes, the initial levels of charge were broadly in line with the MSC charges in the NTM, and hence varying by link, area type, road type and level of congestion, although other simplified schemes were tried, with a smaller range of charges.

Of course, because of their network structure, the local models could model any rerouting of traffic in response to charges, in a way that was not possible in the NTM. It was noted that, with highly variable charges link by link, drivers would respond by taking more circuitous routes (thereby increasing the average trip length), but that nevertheless congestion would be reduced. However, it was found to be possible to compress the range of charges, so as to reduce this variability in charges, and prevent drivers taking circuitous routes, thereby keeping any increase in average trip length to a minimum. In fact, it was found that a flat-rate distance charge produced higher economic benefits. Whilst this is contrary to the findings from the NTM, it is in line with the findings in Section 9.

11.8 OVERALL CONCLUSIONS

The main findings from the UK road pricing feasibility study can be summarised as follows:

- Road users impose external costs on other road users and the environment. Congestion accounts for roughly three-quarters of marginal social costs. To capture fully the benefits from road pricing, the system of charges needs to be set according to the level of congestion.
- MSC-based pricing schemes should deliver substantial benefits – largely due to time saving reductions – of the order of £ 10 billion per year.
- Simplified MSC schemes (for example, with just 10 separate levels of charge per km, rather than the full 75) can produce a very large proportion of the potential congestion reduction.
- The modelling suggests that pricing would lead to only a modest amount of modal shift, and that the main response would be through car sharing. However, it is important to appreciate that the national modelling covered the whole of the country with a sample of links rather than a network representation, and therefore could not model rerouting.
- A simple revenue neutral version of MSC pricing would deliver benefits that are not significantly less than a full MSC scheme. This demonstrates clearly that it is the *structure* of charges that is important and not the overall level. On the other hand, an increase in fuel duty to raise the same revenue as an MSC pricing scheme would reduce congestion by only one-fifth of that given by MSC pricing.
- If charging were imposed only in urban areas (for example, in all cities with population in excess of 10,000), this would produce benefits that were not far short of those from a full MSC scheme.
- The local modelling carried out was quite limited in scope, but indicated that cordon-based schemes could produce overall benefits, but that these are likely to be smaller than distance-based schemes. It also suggested that, with highly differentiated charges, distance-based charging could lead to a significant amount of rerouting, with drivers seeking circuitous routes to avoid or minimise the charge.

- The local modelling also found that a simple, flat-rate charge imposed in urban areas could produce significant benefits. This was somewhat at odds with the findings from the national modelling in the main part of the report, although it needs to be noted that, in contrast to the national modelling, the local models could model rerouting. The findings about the flat-rate distance charge are quite consistent with the findings in Chapter 9, in regard to the Uniform scheme (see, for example, Figure 9-9 and the discussion around it).

12 SPITSMIJDEN

12.1 INTRODUCTION

A well-known fundamental insight in economics states that under otherwise first-best circumstances, efficient prices should reflect marginal costs. In the context of road pricing this translates into the well-known Pigouvian tax rule, which states that the toll on a road be equated to the marginal external cost. Such a pricing scheme is often referred to as *first-best* because it maximizes efficiency, given that efficiency is also maximized in all other relevant markets in the system considered.

Although the guiding principle of external cost pricing is straightforward, it is obvious from common practise that such a welfare optimisation is seldom implemented, be it in road transport or elsewhere. There are many issues complicating the implementation of a road taxation scheme, including inherent dynamics of policy making as well as the epidemic unpopularity of taxation as a policy instrument.

The literature on road pricing has been extended in various directions, including many cases where such first-best pricing is either not feasible, because the tax instrument itself is not optimal, or it is not efficient, because there are other market failures to be considered besides the external costs on the road under consideration. In such cases, *second-best* pricing becomes relevant. A recent review of the rapidly growing literature on second-best road pricing is provided by Small and Verhoef (2007).

In order to overcome the unpopularity of a tax, many have suggested the possibility of a *Pigouvian subsidy* on substitutes of the underpriced good. Kolstad (2000) discusses the setting of a subsidy versus a tax, and concludes that a subsidy cannot be welfare optimal under general assumptions. The rationale is that subsidies increase overall demand to a level that is inefficient. These conclusions do however assume a symmetric price elasticity that is identical for taxes and subsidies.

The literature on travel time valuation (Gunn, 2001) suggests that travel time savings are valued differently to losses. More generally, the psychological literature (Kahneman and Tversky, 1979) describes how choice alternatives are compared to a point of reference, with relative savings and losses being valued asymmetrically (see Kristensen and Garling, 1997). Extending these findings to the field of taxes and subsidies, it seems reasonable to expect a significantly different valuation of both by road users.

This case study focuses on a time differentiated reward that targets the congestion externality. The observations collected in the *Spitsmijden*[16] experiment, which involved rewarding of commuters for avoiding travelling by car during the peak hours using automated vehicle identification, are the basis for a discrete choice model that includes departure time as well as modal choice.

Other externalities (accidents, environmental damage (emissions and noise) and road maintenance) are not addressed here and probably require differentiation across other dimensions. The conclusions drawn are however independent of the externality considered and can be extended to any generic reward (Pigouvian) scheme. An overview of external transport costs for urban areas is provided by Bickel, Schmid, Krewitt, and Friedrich (1997); Maibach et al. (2007); Mayeres, Ochelen, and Proost (1996). A common observation in the assessment of the external cost levels is that congestion and accident costs have a larger degree of magnitude than environmental damage and also road maintenance in the case of passenger cars.

This section introduces the reward experiment that was carried out. A more detailed discussion can be found in the *Spitsmijden* project report (Knockaert et al., 2007).

16 *Spitsmijden* can be roughly translated as 'avoiding rush hour'.

12.2 EXPERIMENTAL DESIGN

12.2.1 Overview

The trial was launched on October 2, 2006. The test area was the Dutch A12 motorway corridor from Zoetermeer towards The Hague. On weekday mornings, this stretch of motorway is heavily congested with vehicles heading towards The Hague. There are few alternative routes or on- and off-ramps on this stretch of motorway, which made the trial relatively easy to control.

The morning rush-hour was defined as lasting from 7:30 to 9:30, since this period has the highest reported traffic densities. The participants in the trial could earn a reward for not travelling by car from Zoetermeer to The Hague during the morning rush hour.

The objective was to recruit 500 participants. To this end, three recruitment waves were organised. The first two waves were based on license plate observations, where frequent rush hour travellers on the A12 motorway stretch (minimum three trips per week) were approached. These two rounds delivered 283 participants to the experiment. To further increase this number, a last recruitment wave was organised, using a *member get member* approach and a renewed invitation to vehicle owners that had not reacted in the first two waves. This delivered a final sample of 341 participants who completed the full experiment.

Before the start of the experiment the participants had an electronic device installed in their cars, allowing for the registration of their car travel behaviour on the corridor under consideration. The registration system was further completed with licence plate recognition cameras in order to extend the coverage of the study area.

The trial lasted for ten weeks. Observation in the two weeks preceding the trial as well as the week after the trial covered reference behaviour under unrewarded conditions. The participants had to complete a daily logbook providing additional morning commuting information during the full period of the experiment.

12.2.2 Reward

Upon registration the participants were asked which type of reward they would prefer. There were two options. The first type of reward was an amount of money for each morning rush hour that the participant avoided. At the moment of registration the premium was indicated to amount to about € 5.

The second type of reward was saving for a Yeti smartphone. The participants received a Yeti smartphone at the beginning of the trial. The Yeti provided them with traffic information during the trial. If the number of credits earned over the duration of the experiment exceeded a stated number, the participant would be allowed to keep the Yeti at the end of the trial. If the participant failed to meet the threshold, he/she would have to return the smartphone at the end of the trial. Thus, it was an all-or-nothing scenario.

The majority of the participants chose a monetary reward. As the trial was set up to test both reward types, the remainder of the participants (including those who had said that they did not have a preference for one reward type over the other) were assigned to the Yeti variant. However, to prevent participants ending up with an unwanted and hence lowly valued reward type, they were allowed to switch to the other type until the start of the trial.

During the ten week trial period, different levels of the reward were tested. The monetary reward amounted to € 3 or € 7 to avoid the entire morning peak interval (7:30 to 9:30) and a more refined scheme made the participant receive € 7 to avoid the entire morning peak, which was reduced to € 3, if travelling in the shoulder periods (7:30 to 8:00 and 9:00 to 9:30).

For the Yeti reward, two schemes were tested, one scheme where the participant could save credits to obtain the smartphone, while in another period no credits could be earned, but traffic information was still provided via the smartphone.[17]

All users faced each of the different schemes corresponding to their preferred reward option for the same amount of time, but in a randomised order to minimise possible biases.

Although only reasonably frequent rush hour car travellers were recruited, the observations from the unrewarded pre-trial weeks revealed differences in trip frequencies. To bring overall reward levels in line with reference behaviour, the reward conditions were customised for each participant. For the monetary reward, this meant a weekly maximum number of rewards ranging from one to five, whereas for the Yeti reward the threshold level was set between fifteen (frequent travellers) and 25 (infrequent travellers) credits over the five week reward period.[18]

The unit of behaviour rewarded was the use of the participant's car (by the participant or someone else) in combination with the place and time of driving. In the *logbook* (an online travel diary), the participant could indicate, if the registered car were exceptionally used by someone else, or the converse situation where the participant used a different car. This information was not included in the reward algorithm, in order to remove any stimulus for the participant to provide incorrect information in the logbook.[19]

To calculate reward levels the observation data were checked for peak hour travel (by the respondent's own car), applying a five minute tolerance. For days on which no observation was available in the 6h to 11h period, the logbook information was used for verification in order to correct for any possible failures in the observation technology. In case of ambiguities, the available data together with any comments by the participants were processed manually.

12.2.3 Other Circumstances

Given that the experiment was carried out in a real world setting, circumstances other than the reward levels could of course not be excluded from influencing the participant's behaviour.

A major factor was the somewhat chaotic supply of public transit during the experiment. The corridor studied is historically served by a mainline railroad, a local heavy rail loop and some express buses to fill in a couple of missing links. The experiment was originally scheduled to start after a planned summer downtime of the local rail loop, during which it was to be converted into a light rail operation.

However, the conversion works were not completed within the originally projected timeframe, meaning that the experiment had to start with substandard public transit supply (and overcrowded mainline services).

As our experiment progressed, efforts were made to start up the local rail operation, but this consistently ground to a halt, when after a few days a train derailed. The parallel shutdown of the substandard bus replacement service was carried out as foreseen, resulting in very chaotic and more or less unscheduled public transport supply over extended periods of time.

A minor factor influencing travel behaviour is a change in weather conditions. The distance under consideration (10–15 km), together with available infrastructure, makes biking a valid alternative weather permitting. At the beginning of the experiment (end of September), summer weather

17 While this unrewarded period seems pointless in the light of the DIFFERENT analysis, it was included to allow testing for the impact of traffic information only, which will be reported in a subsequent paper.

18 Travel behaviour on all days Monday through Friday was considered to determine the overall reward. For the reference behaviour, days reported as *holiday* in the logbook were excluded.

19 Upon recruitment the participants were also asked for the licence plate of any other household's cars. The camera recognition technology allowed tracking these cars as well. Together with the logbook information it was periodically checked during the trial whether any participants were too eager to receive rewards and, therefore, used another car rather than avoiding car travel during the rush hour, in order to exclude them from further participation.

conditions prevailed, whereas further down the experiment weather conditions became more severe. Weather observations for Rotterdam (the closest weather recording station) were registered for the analysis to correct for this.

12.2.4 Data Collection

The data used in the analysis was collected using different technological means.

The first and probably most important source of behavioural observations are the *vehicle passages* registered by automated roadside equipment. Two networked observation systems were installed. A first system used license plate recognition cameras. A second system used EVI[20] beacons that connected with an OBU[21] installed in the participant's car. Both the EVI beacons and recognition cameras were installed at the exit of Zoetermeer on all roads belonging to the corridor studied.

Although the dual setup introduces redundancy, both systems have specific advantages. The EVI/OBU system proved to have an extraordinary reliability of 99.99%, but of course being limited to equipped vehicles. The reliability of the camera system is in the 94–98% range, but the camera system is more tamper-proof (no OBU in the participant's car) and allowed to follow up the use of other cars available to the participant (as far as registered in the database).

In the analysis, from the merged table of both observation systems the observation (if any) that is closest to 8:30 was taken as indication of the participant's behaviour in morning rush hour.

A second source of behavioural information is the *logbook* (a travel diary). The participants completed for every day (Monday–Friday) a webform presented on a personal webpage. The form collected information on trip motive (commute or other), transport mode used (or telework) and possibly the use of the participant's car by a different driver or the participant using a different car. The data was automatically coded and saved in a database.

A last source of information referred to here are a range of *surveys*. All participants completed three questionnaires and a stated choice experiment. All surveys were implemented using a web based approach.

One more source that is not considered in this section, but should be mentioned for completeness are GPS positions registered by the Yeti smart phones.

All information collected has been entered in a single database and, apart from the last source (GPS), all information can be linked individually for all participants.

12.3 EX-ANTE SURVEYS

The participants to the experiment had to complete a number of compulsory surveys. Most surveys were conducted before the experiment. This section provides a summary overview of selected results; for an in-depth discussion see the project report (Knockaert et al., 2007). Upon recruitment, the participant completed a first survey about their daily commute, followed by another survey on socio-demographic characteristics and the organisation of work and household.

Of the participants, 64.7% were male. About half of all participants were aged between 35 and 49. About 25% were younger than 35, while 25% were older than 49. The majority of the participants held a higher professional education certificate or a university degree. Most of the participants were married or cohabiting; most had children.

20 Electronic Vehicle Identification

21 on-board unit

Of the participants, 98% lived in Zoetermeer; the rest lived in the surrounding municipalities (e.g. Benthuizen, Berkel en Rodenrijs, Bleiswijk). Most of the participants worked in The Hague, although some worked in Delft, Leidschendam, Rijswijk or Voorburg.

Asked for the motivations for participation, the most frequently raised reason was the reward itself, although the overall majority of the participants also had another motivation. Both the contribution to more insight into congestion and experimentation with alternative travel options were relevant motivations.

Of the participants, 62% commuted at least five times per week towards The Hague, using the A12 motorway; 26% commuted four times per week.

In a subsequent survey, a stated preference experiment was conducted. The respondents were presented with a choice between different means of transport, and the option to work at home. The car alternative had three to five variants per choice set. The different attributes in the choice experiment included travel time, reward, departure time and estimated transit time at the measurement point. A multinomial logit choice model was estimated.

The discussion of the model is limited here to a presentation of the travel time and schedule delay valuations (Table 12-1) based on the estimated coefficients.[22] For a full presentation of the stated preference survey and its results see the project report (Knockaert et al., 2007).

Table 12-1 Value of Time and Value of Schedule Delay Based on Stated Preference Data

	VOT	VOSDE	VOSDL
Cost-based	15.85	10.59	9.87
Reward-based	5.3	3.54	3.3

Source: (Knockaert et al., 2007)

It is important to note that the modelling specification used here departs from what will be applied in the estimation in a further section. This results mainly from a different definition of the attribute variables, which limits the possibilities to directly compare estimated coefficient values.

12.4 BEHAVIOURAL ANALYSIS

12.4.1 Discrete Choice Theory

Discrete choice theory provides a broad range of modelling frameworks. An in-depth discussion on discrete choice theory can be found in Anderson, Palma, and Thisse (1992); Ben-Akiva and Lerman (1985); K. Train (1986/1990); K. E. Train (2003).

Discrete choice theory models the probability that a consumer n chooses a given alternative j in choice situation[23] m as a function of the *random utility* U_{jmn} of the alternatives, expressed as:

$$U_{jmn} = V_{jmn} + \varepsilon_{jmn}$$

where:

22 The values presented here have been derived from the model coefficients and depart from the values presented in the project report (Knockaert et al., 2007). It appeared that the values presented in the project report are incorrect.

23 The index for choice situation m is introduced here to account for the repeated choice character of survey data.

V_{jmn}: the *deterministic part* of the utility for alternative j as obtained by consumer n in choice situation m — this section assumes that V_{jmn} is linear in parameters: $V_{jmn} = \beta' x_{jmn}$ with β a vector of coefficients and x_{jmn} a vector of decision variables relating to consumer n and alternative j in choice situation m;

ε_{jmn}: the stochastic part.

The consumer then chooses the alternative with the highest utility (utility maximisation).

The *multinomial logit* model (MNL) assumes a Gumbel distribution with variance $\sigma^2\pi^2/6$ for the stochastic utility ε_{jmn}. As the expression above shows, any linear transformation does not affect the choice probabilities as it does not affect the relative order of the alternatives' utility. This makes it impossible to identify the scale parameter s of the stochastic part separately from the coefficients β of the deterministic part. In the estimation the utility U_{jmn} is scaled by a factor $1/\sigma$ which normalises the variance of the stochastic part to $\pi^2/6$. The estimated coefficients β^ include the scale parameter σ of the stochastic utility:

$$\beta\hat{} = \beta / \sigma$$

The *nested multinomial logit* model (NL) extends the multinomial logit specification by allowing for correlation in unobserved preferences (stochastic utility) for a subset of alternatives. A partition structure defined by the researcher groups the alternatives in subdivisions or nests $S_1 \ldots S_K$. The utility U_{jmn} of alternative j in nest k can be expressed as:

$$U_{jmn} = V_{jmn} + \underbrace{\eta_{kmn} + \varepsilon_{jmn}}_{\text{stochastric utility}}$$

with:

V_{jmn} the deterministic (observed) utility of alternative j;

ε_{jmn} independent for all alternatives j, choice situations m and respondents n;

η_{kmn} independent for all nests k, choice situations m and respondents n;

ε_{jmn} i.i.d. Gumbel distributed with scale parameter λ_k;[24]

η_{kmn} distributed so that $\max_{j \in S_k}\left(U_{jmn}\right)$ is Gumbel distributed with scale parameter σ normalised to unity.

For each nest k the parameter λ_k ($0 \le \lambda_k \le 1$) is a measure for the correlation between the alternatives in nest k, with values closer to unity indicating less correlation.

The choice probability P_{jmn} of alternative j (in nest k) in choice situation m by respondent n can in a nested logit specification be expressed as:

$$P_{jmn} = \frac{e^{\lambda_k I_{kmn}}}{\sum_{i=1}^{K} e^{\lambda_i I_{imn}}} \frac{e^{\beta\hat{}' x_{jmn}/\lambda_k}}{e^{I_{kmn}}}$$

with I_{kmn} the inclusive value of nest k, defined as:

$$I_{kmn} = \ln \sum_{j \in S_k} e^{V_{jmn}/\lambda_k}$$

24 In fact λk is defined as $\sigma k/\sigma$ with σ the scale parameter of $\max_{j \in S_k}\left(U_{jmn}\right)$ (here normalised to unity) and σk the scale parameter of εjmn.

12.4.2 Genesis of a Queue

A second line of modelling relevant for this case study concerns the modelling of traffic congestion, queuing in particular.

To represent the dynamics of a traffic queue, a commonly used model is that of a stretch of road with a bottleneck at its end. When demand for trips, expressed as a flow or rate of attempted entries into the bottleneck, exceeds the capacity of the bottleneck, a queue grows. For demand to exceed capacity, it has to be that for a certain period of time, more travellers want to arrive at the destination than the bottleneck can handle. These are the basic assumptions behind the *bottleneck model* widely used to represent traffic congestion. Although the empirical analysis here does not treat queue lengths explicitly and/or endogenously, this bottleneck model is briefly introduced here, because the demand side modelling has important parallels with the work that will be presented.

In order for an equilibrium over different travellers to arise, the concept of schedule delay cost is introduced. Upon equilibrium, the trade-off between schedule delay cost and change in queuing time cost are equal. In its simplest form, the assumption is that all travellers want to arrive at the same preferred arrival time and have linear schedule delay costs. Different rates per unit of time are connected to arriving early as opposed to arriving late.

The classical application of the bottleneck model is that of a congestion charge. Upon introducing the charge, a new equilibrium will arise. The corresponding change in queuing time together with the change in schedule delay cost makes an overall social welfare change. So it is key to design the charge such that welfare improves as much as possible. Arnott, Palma, and Lindsey (1993) provide an illuminating introduction on the topic and discuss optimal charging schemes both under first and second best conditions.

The application of a reward has received far less attention in traditional bottleneck modelling. Whereas the queuing dynamics are not different, the optimal charging scheme is. In the framework of the *Spitsmijden* experiment, the application of the bottleneck model was studied by Rouwendal, Verhoef, and Knockaert (2007).

12.4.3 Setting the Scope

An ample number of observations are available from the reward trial. The logbook information was collected over 13 weeks of five days, and 341 participants completed the experiment, resulting in 22,165 observations. There is, however, some variation as to which choice is underlying each observation. Different trip motives, different people using the same car and even different cars being used by the same respondent make the dataset cover rather heterogeneous choice situations.

In order to limit the analysis here to choice behaviour which is as homogenous as possible, the focus is limited to commuting trips. Using the logbook information, all days on which the participant indicated not to have worked are eliminated. Furthermore, it has to be ensured that the participant's car was available for the morning commute. For this reason all days were eliminated for which the participant indicated not to have his car available (e.g. because of maintenance), having travelled with a different car, or days on which someone else travelled with the participant's car during morning rush hour. Finally, also days were excluded for which the participant indicated to have travelled during the morning rush hour but not for commuting.

It is important to note here that the reward was granted independently from trip motive, but only taking in account the use of the participant's car during the morning rush hour. As such, there was therefore no stimulus to provide biased information in the logbook, and it is safe to assume that information to select a subset of observations.

As discussed in a next section, travel time is a key variable, for which there is no observation for all choice alternatives in the dataset. Hence choice situations with lacking travel time observations are excluded.

Similar to travel time, a definition for schedule delay costs for each choice alternative is introduced in a next section. To allow the definition of schedule delay, a measure of reference behaviour is needed in order to define a "most desired passage time" (passage of the roadside equipment). This reference behaviour was defined as the behaviour during the two weeks preceding and the one week following the reward trial.[25] Therefore, observations by participants for which insufficient or no reference behaviour observations were available (e.g. because they were on holidays in the period considered) were eliminated.

The final dataset covered 14,585 individual choice observations, made by 322 participants.

12.4.4 Choice Alternatives

The behaviour to be analysed concerns the choice for a departure (or arrival) time, as well as the choice for a different transport mode or working at home. As shown in a next section, in the analysis the time of passage at the roadside equipment is used as a proxy for departure time.

The choice for a passage time is in reality a choice from a continuum of possible passage times. To make the setting fit in the discrete choice theoretic framework it was decided to work with fifteen-minute intervals. The choice for a passage time is then represented by a choice between twelve possible time periods between 7:00 and 10:00.[26]

Given that the resolution of passage time periods is finer than the logbook travel information, those trips that were reported in the logbook as rush hour private car trips, but for which no matching observation was registered, were excluded.[27]

For the other modes passage time choice was not included. The choice set in the analysis hence consists of eighteen alternatives:

- Twelve rush-hour private car alternatives, each representing a fifteen minutes passage time interval;
- One off-peak private car travel alternative (before 7:00 or after 10:00);
- Public transport;
- Cycling;
- Car-pooling (as a passenger);
- Other mode;
- Work at home.

12.4.5 Choice Variables

In the choice model, the different choice alternatives are defined by a set of attributes. The rush hour private car choice alternatives will be represented in much more detail, consistent with the choice between these alternatives being the focus of the analysis.

A first attribute of rush hour car travel is *schedule delay*. This attribute is normally defined as the difference between the preferred arrival time and the actual arrival time. In the dataset, however, there is no variable describing preferred arrival time unambiguously. Considering that neither there is a precise observation of the actual arrival time itself, it was decided to define schedule delay as the difference between the passage time in the unrewarded reference behaviour and the actual passage time, both measured at the observation point. The actual passage time is defined as the middle of the

25 The alternative approach of using survey data was considered, but it was decided to stick to revealed behaviour as a reference setting for our analysis

26 Limiting rush hour passage time choice to the 7:00 – 10:00 interval is based on the observation that queuing on the corridor studied generally occurs between 7:30 and 9:30.

27 The earlier quoted figure of 14,585 individual choice observations already accounts for this.

fifteen minute time interval considered. The reference is defined as the middle of the fifteen minute interval that corresponds to the average passage time in unrewarded behaviour.[28] Although the exact timestamp for all observed passage times is available, it was decided to stick to the middle-of-the-interval approach in order to ensure consistency with the representation of the unchosen time-period alternatives in the choice set.

A second attribute is travel delay or *queuing time*. As described earlier, the Yeti smartphone provided the corresponding participants with traffic information, including instantaneous travel time on the corridor studied. This travel time information is based on real time speed-flow observations on the motorway, at different points about one kilometre apart. These travel times were used in the model in the form of the middle of each fifteen minutes time interval.[29]

A third attribute relates directly to the purpose of the trial and is the *reward* corresponding to each choice alternative. In the experiment the stimulus to avoid rush hour car travel was consistently positioned as a reward in all communication with the participants. However, in the analysis here the stimulus was defined as a marginal cost, corresponding to the reward the participant would loose by travelling during rush hour time periods. For the monetary reward this marginal cost may actually be zero, when accumulated rush hour travel by a participant already implies that no further reward could be earned. For the Yeti reward, the marginal cost becomes zero, when the participant avoided rush hour car travel sufficiently to keep the smartphone at the end of the experiment, or when the remaining time is insufficient to reach the threshold level.

For the choice alternatives other than rush hour private car travelling, a *mode specific constant* is included in the model. Its estimated coefficient will capture all mode specific preferences, insofar as these are constant over participants and over time. To account for the evolution in weather, the maximum temperature as observed was included, interacting with the constant for cycling.

An overview of the model attributes is presented in Table 12-2.

Table 12-2 Definition of Choice Variables Use in the Model Estimates

Attribute	Unit	Definition
t_{jm}	hour	car travel time corresponding to time interval j on day m
m_{jmn}	euro	marginal loss of monetary reward for participant n of rush hour car travel in time interval j on day m
y_{jmn}	credit	marginal loss of Yeti credit for participant n of rush hour car travel in time interval j on day m
w_m	°C	maximum temperature observed on day m
C_{mode}		mode specific constant
D_{jmn}		(dis)utility related to schedule delay for choice alternative j on day m by participant n (different functional forms will be tested for)

12.4.6 Multinomial logit

In a first model estimation, the multinomial logit specification was used. The reward coefficients are estimated generically, with separate values for monetary and yeti rewards. Also the travel time coefficient is estimated generically. The systematic utility V_{jmn} (see section 12.4.1) for alternatives j faced on day m by participant n is defined in Table 12-3. All estimations are done with the Biogeme software version 1.5 (Bierlaire, 2003).

Table 12-3 Deterministic Utility V_{jmn} of Alternative j Faced on Day m by Participant n

28 To calculate the average reference behaviour the observations in the 7:00 – 10:00 time interval were selected, where the participant indicated in the logbook to have commuted.

29 As random observations are missing, linear interpolation was used between the closest available observations in order to obtain the wanted value. This interpolation was carried out only if the interval between the closest available observations was fifteen minutes or less. No extrapolation was applied. Furthermore values that are unrealistic (corresponding to average speeds well beyond 140 km/h) were excluded.

Alternative j	Monetary reward	Yeti reward
private car 7–10	$\beta_{traveltime}\, t_{jm} + D_{jmn} + \beta_{euro}\, m_{jmn}$	$\beta_{traveltime}\, t_{jm} + D_{jmn} + \beta_{yeti}\, y_{jmn}$
bike	$\beta_{weather}\, w_m + C_{bike}$	$\beta_{weather}\, w_m + C_{bike}$
other	C_{mode}	C_{mode}

For the (dis)utility related to schedule delay early and late D_{jmn} no functional form (of disutility by time of day) was imposed a priori. There is some evidence that a linear function may be inappropriate (Tseng and Verhoef, 2007). Given that the passage time choice resolution in the model is fifteen minutes, the schedule delay early or late is an integer multiple of fifteen minutes. Therefore a constant for each possible multiple was defined.

The estimation results are presented in Table 12-4. The log-likelihood is –34,151, the adjusted rho-square 0.189.

Table 12-4 Multinomial Logit Model with Constants for Schedule Delay

Description	Coeff. Estimate	Robust Asympt. std. error	*t*-stat	*p*-value
Constant for bike	–5.00	0.261	–19.11	0.00
Constant for other	–3.49	0.0759	–46.01	0.00
Constant for telework	–2.74	0.0574	–47.76	0.00
Constant for car (not 7h–10h)	–1.03	0.0385	–26.75	0.00
Constant for carpool	–3.32	0.0706	–47.03	0.00
Constant for public transport	–1.78	0.0425	–41.99	0.00
Constant for 1 quarter before ref	–0.333	0.0305	–10.91	0.00
Constant for 2 quarters before ref	–0.988	0.0372	–26.55	0.00
Constant for 3 quarters before ref	–1.33	0.0441	–30.25	0.00
Constant for 4 quarters before ref	–1.64	0.0518	–31.68	0.00
Constant for 5 quarters before ref	–2.30	0.0738	–31.20	0.00
Constant for 6 quarters before ref	–3.18	0.129	–24.75	0.00
Constant for 7 quarters before ref	–4.18	0.260	–16.05	0.00
Constant for 8 quarters before ref	–4.35	0.318	–13.70	0.00
Constant for 9 quarters before ref	–4.56	0.410	–11.11	0.00
Constant for 10 quarters before ref	–2.94	0.292	–10.08	0.00
Constant for 11 quarters before ref	–3.70	0.970	–3.81	0.00
Constant for 1 quarter after ref	–0.735	0.0365	–20.13	0.00
Constant for 2 quarters after ref	–1.50	0.0495	–30.34	0.00
Constant for 3 quarters after ref	–1.90	0.0594	–32.01	0.00
Constant for 4 quarters after ref	–2.19	0.0652	–33.63	0.00
Constant for 5 quarters after ref	–2.60	0.0751	–34.57	0.00
Constant for 6 quarters after ref	–2.84	0.0860	–33.04	0.00
Constant for 7 quarters after ref	–3.13	0.104	–29.93	0.00
Constant for 8 quarters after ref	–4.11	0.179	–23.02	0.00
Constant for 9 quarters after ref	–4.17	0.225	–18.51	0.00
Constant for 10 quarters after ref	–4.65	0.448	–10.39	0.00
Constant for 11 quarters after ref	–4.72	0.970	–4.87	0.00
β_{euro} [euro] (reward)	–0.291	0.00648	–44.92	0.00
$\beta_{traveltime}$ [hour] (rush hour car)	–2.33	0.222	–10.48	0.00
$\beta_{weather}$ [max temp in °C] (bike)	0.125	0.01538	20	0.00
β_{yeti} (reward)	–1.92	0.0611	–31.41	0.00

The generic coefficients for marginal loss of reward and travel time have the expected negative sign. The weather coefficient also has the expected sign.

As for the constants representing schedule delay, there is a close-to-linear evolution, with schedule delay late being valued larger than schedule delay early for the same amount of time. This finding is in line with literature (see Arnott et al., 1993). For large amounts of schedule delay early, it is not very clear what happens. Probably the small number of observations plays a role here: only for participants with a reference travel behaviour beyond 9:30 the constant for 10 quarters before reference time enters the utility of one or two early choice alternatives.

While all constants differ significantly from zero, attention should be drawn to the fact that the *t*-statistics as calculated assume that the choices are independent, a highly unlikely fact given the repeated choice character of the experiment. Although correlation across choice observations does not bias the coefficient estimates, it does overestimate the corresponding *t*-statistics (see Bunch, Bradley, Golob, Kitamura, and Occhiuzzo, 1993).

The high values of the rush hour schedule delay constants may seem odd compared to the lower constant for off-peak travel: do commuters really prefer travelling off-peak rather over delaying a rush-hour trip by half an hour? While this can be a correct observation for a specific fifteen minute interval compared to all off-peak passage times, it does not hold, if comparing all rush hour alternatives to off-peak private car travel. Peak hour travel being represented by twelve fifteen minute intervals results in each interval being chosen by a relatively small probability, whereas off-peak travel is presented by a single choice alternative.

Based on the findings of this model, it was decided to opt for a second degree polynomial form for schedule delay early and late, and estimated the model again (Table 12-5). This model has a log-likelihood of –34,244, and an adjusted rho-square of 0.187.

Table 12-5 Multinomial Logit with Linear and Square Schedule Delay Terms

Description	Coeff. Estimate	Robust Asympt. std. error	*t*-stat	*p*-value
Constant for bike	–5.01	0.262	–19.13	0.00
Constant for other	–3.50	0.0754	–46.41	0.00
Constant for telework	–2.74	0.0568	–48.32	0.00
Constant for car (not 7h–10h)	–1.04	0.0377	–27.47	0.00
Constant for carpool	–3.33	0.0701	–47.46	0.00
Constant for public transport	–1.79	0.0416	–43.03	0.00
β_{euro} [euro]	–0.293	0.00650	–45.05	0.00
β_{sde} [hour]	–1.64	0.0824	–19.87	0.00
β_{sdl} [hour]	–2.86	0.0699	–40.91	0.00
$\beta_{sde\wedge 2}$ [euro^2]	–0.177	0.0646	–2.74	0.01
$\beta_{sdl\wedge 2}$ [euro^2]	0.528	0.0383	13.79	0.00
$\beta_{traveltime}$ [hour]	–2.40	0.224	–10.68	0.00
$\beta_{weather}$ [max temp in °C]	0.126	0.0153	8.21	0.00
β_{yeti}	–1.92	0.0612	–31.36	0.00

12.4.7 Nested Logit

The issue of correlation in preferences over different choice occasions was mentioned already. There is, however, also the possibility of correlation in unobserved preferences for different choice alternatives in the same choice set. To accommodate for such a correlation, the nested logit model can be used.

The most obvious correlation structure is one where the different rush hour car travel choices are tied in a nest. These choice alternatives only differ in travel time and schedule delay cost, and have the other (unobserved) attributes in common.
Table 12-6 presents the estimation results of the specified nested logit model. The estimated model has a log-likelihood of –33,988 and an adjusted rho-square of 0.193. While this is an improvement over the corresponding MNL specification, it is a fairly small one.

Table 12-6 Nested Logit with Square Schedule Delay

Description	Coeff. Estimate	Robust Asympt. std. error	*t*-stat	*p*-value
Constant for bike	–4.87	0.230	–21.20	0.00
Constant for other	–3.77	0.0703	–53.61	0.00
Constant for telework	–3.02	0.0495	–60.98	0.00
Constant for car (not 7h–10h)	–1.31	0.0246	–53.32	0.00
Constant for carpool	–3.60	0.0649	–55.48	0.00
Constant for public transport	–2.06	0.0330	–62.52	0.00
β_{euro} [euro]	–0.101	0.0101	–9.99	0.00
β_{sde} [hour]	–0.596	0.0623	–9.56	0.00
β_{sdl} [hour]	–0.868	0.0924	–9.40	0.00
$\beta_{sde{\wedge}2}$ [euro^2]	0.00160	0.0204	0.08	0.94
$\beta_{sdl{\wedge}2}$ [euro^2]	0.157	0.0211	7.44	0.00
$\beta_{traveltime}$ [hour]	–0.599	0.0967	–6.19	0.00
$\beta_{weather}$ [max temp in °C]	0.0992	0.0135	7.36	0.00
β_{yeti}	–0.612	0.0678	–9.01	0.00
Inclusive value 1/λ for car 7–10h	3.51	0.358	7.03	0.00

Concerning the coefficient values, it can be observed that the mode specific constants are generally slightly larger in absolute value compared to the corresponding MNL specification (Table 12-5), reflecting that a larger part of the choice behaviour is now captured by the systematic utility V_{jmn} (see section 12.4.1).

As for the schedule delay variables, the schedule delay early is linear whereas schedule delay is slightly concave. The inclusive value coefficient λ has a value of 0.28 indicating a rather strong correlation in preferences for private car rush hour alternatives.

The coefficients of schedule delay early and travel time do not differ significantly, both are however significantly different from schedule delay late.

Based on the coefficient estimates the value of time and schedule delay can now be calculated. The resulting values are presented in Table 12-7, which also includes some earlier values, which are drawn from the TRACE project results (Jong and Tegge, 1998). The values presented here relate to commuting as a car user and have been converted to year 2007 values for comparability with the results of the experiment here.

Table 12-7 Value of Time and Schedule Delay (in 2007 Prices per Hour)

			Jong and Tegge (1998)	
Variable	**unit**	**Spitsmijden**	**NL**	**EU**
value of travel time	€/h	5.93	8.0	4.9–8.0
value of schedule delay early	€/h	5.90		
value of schedule delay late	€/h	8.59		

The relative size of the different time valuations is in line with common findings in literature (see Small, 1982), where the value of schedule delay early is smaller than the value of travel time, which in turn is smaller than schedule delay late. The estimate of value of travel time is somewhat smaller than values found in the literature.

In a similar way the value of a Yeti credit could be calculated. Such a credit is valued at about € 6.1.

12.5 CONCLUSIONS

It is often suggested that a reward may be a far more popular policy instrument compared to the traditional taxation approach towards containing externalities. Given the implied policy potential, an extended reward experiment was conducted in real world conditions on a congested motorway corridor.

The data collected in the experiment was used to estimate a number of discrete choice models that describe commuter's behaviour with respect to departure time choice as well as transport mode choice. The estimated behavioural parameters were all significant, with the expected signs. The estimates give a clear indication that a reward can be used as an effective policy instrument.

The analysis of the participant's behaviour revealed that the shadow prices of schedule delay in the experiment are close to constant, a finding in line with the classic assumptions in literature, but departing from other recent findings. The correlation in preferences for different departure times for car trips within the rush hour matches expectations. This indicates that shifting departure time is likely to be a more important behavioural response to policies for congestion relief, compared to a modal shift or teleworking. But there is a caveat here, given the limited quality of the other modes in the specific setting of our experiment.

If the relative size of the different valuations of schedule delay early, schedule delay late and travel time are compared, it shows that they are similar to past findings in literature. Also for the absolute size of travel time valuation under a reward stimulus, the value obtained does not depart from literature.

Further research will focus on the efficiency of a reward as a congestion policy instrument, which is of course not the same as its effectiveness. With respect to analysing choice behaviour, mixed logit choice model specifications will be explored, in order to accommodate for the repeated choice character of the dataset. Joint stated and revealed preference estimations will be possible, because the participants also completed stated choice questionnaires; this may allow extending the scope of the analysis considerably. Finally, the behavioural impact of the traffic information provided by the Yeti smartphones will be further investigated.

13 GENERAL CONCLUSIONS

The types of 'case studies' presented in this report cover a range of not only different charging schemes, but moreover schemes that focus on different issues, and it is therefore obvious that different case studies have different messages. However, even where different case studies do investigate the same issues, their messages are also often not the same and in cases even contradictory.

General Effects of Charging Schemes

Relevant evidence for the general impact of road user charging on traffic comes from Trondheim, London, Milan, Stockholm, Singapore and Rome.

Total Traffic Reduction

The first criterion for the assessment of effects is of course the overall traffic reduction through charging. In Trondheim, the initial cordon charge led to a reduction of 10% in traffic crossing the cordon during the charging hours, but this was offset by increases of 8 to 9% in the evening and on weekends, so that, overall there was no notable traffic reduction. In general, there was zero growth in annual traffic during the initial years due to an economic recession period in Norway at that time. However, it should be noted that the level of charge was very modest and the scheme was designed to raise money and not to reduce traffic. The removal of charges at the end of 2005 led to a traffic increase at representative toll stations of 3.8% overall and 11.5% during (previous) charging hours. The overall growth was again in line with the general traffic growth in the area.

In contrast, in London, there was a dramatic effect at the original introduction in 2003 with 14% of all traffic and 33% of cars, and although the effect of the price increase from £ 5 to £ 8 was comparatively small, it was still noticeable with 3% reduction of all vehicles and 3% of cars.

In Stockholm, the effect was equally strong: the introduction of the trial scheme led to traffic reductions of up to 35% on some arterials and in average over the whole charging period and the entire cordon by 19%. This is even more remarkable, since the level of charge, with a maximum of € 2.00 per crossing and an average of € 2.80 per driver per day is only a fraction of the charge in London (£ 5.00 equated at the time to between € 7.00 and € 8.00).

In Milan, the Ecopass reduced traffic reduction during charging hours by 26% in the charging zone and 12.5% outside during the first month of operation, and even though these figures dropped then in the next two months to 14% and 8% respectively, these are still substantial reductions.

In Singapore there was a 15% traffic reduction for the whole day after the introduction of the initial ERP, but this is compared to a previous area licensing scheme, which, together with cultural differences, makes it impossible to compare it to traffic reductions in any of the European schemes.

In Rome, there were very different results from the modelling of different charging schemes. For the day-time scheme it was found that none of scenarios has a substantial impact on modal split but, instead the main impact comes from the reduction of through-trips. In contrast, for the summer night scheme there is a reduction in car use by one third for work trips at a charge of € 6 per trip and by three quarters for shopping trips, while – somewhat surprisingly – the effect on recreational trips is very low; the highest impact by far comes also here from the reduction in crossing trips. Aggregate figures for the winter night scheme also show an overall reduction in car use by two thirds for the most expensive scheme; crossing trips by car are reduced by 85% already at a charge of € 3 per trip, and nearly disappear altogether at the € 6 charge.

Overall, although some of the difference from the figures above are not directly comparable, since some relate to charging hours only and others to the average 24-hour day, it is clear that the different schemes achieved different traffic reductions, which were not merely related to the level of charge or the type of charge. Any further exploration into the possible reasons behind this did not lead to any conclusive findings that would be transferable to other sites. It appears that there is such a strong influence of specific local factors, incl. but by no means ending with

- the way the charge was introduced and advertised, and therefore accepted by the public as fair and equitable,
- the size of the charged network,
- the provision, both in terms of quantity and quality, of public transport alternatives,
- the potential to use slow modes instead of cars, and related to that:
- the average length of the trips affected,
- the potential to reroute in the given road network,

that is impossible to predict the overall impact of any charging scheme without taking account of these local circumstances.

Change in Travel Timing

With regard to the timing of trips, there was one clear common finding for Trondheim and London since there was a small shift in departures times towards a very small increase in traffic in the early morning before charging starts, but a clear peak in the evening after the end of charging, deriving from drivers who delay their departure, presumably mainly from work, until after the end of the charging period.

In contrast, while there were also some very small traffic peaks just before and just after the charging period in Stockholm, overall, here there was no shift to non-charging hours of any substance, and, according to some of the data, traffic volumes even went down outside the charging hours.

Congestion

In London, the traffic reduction initially also led to a substantial reduction in congestion in the range of 30% in 2003 and 2004. After that congestion increased again to near old levels, but this is attributed by Transport for London to traffic management that reduces road space in favour of cyclists and pedestrians and to increased level of roadwork.

For Stockholm there are no overall figures for congestion reduction, but only for certain groups of roads. For the through-routes through the inner city during the morning peak, there was an average reduction in travel time of around 20% and a reduction in congestion of 33%, while traffic levels only dropped by 2%, which is astonishing, but there is no specific reason to doubt this data. On the other inner city streets, the congestion reduction was slightly lower.

During the afternoon congestion in 2005 was significantly larger than in the morning on the southbound through-roads and on the other city streets, and the congestion tax could reduce congestion on both by about one third. Northbound traffic on the through-route experienced about 10% less congestion than in the morning, but congestion tax could reduce congestion here by three quarters, so that traffic was flowing here now very smoothly.

Severe congestion can also be found on the approach roads into the inner city around the charging cordon, most of all during the morning for traffic travelling into the city. The tax managed to reduce traffic levels by 14%, congestion by 30% to 40% and the respective travel times by around 20%.

Overall, it is clear that the relationship between traffic reduction and congestion reduction cannot be predicted in general terms, but again depends very much on local circumstances, in particular on the level of congestion that was there in the first place and on the traffic management measures that may be introduced together with the road user charge.

Public Transport

For Trondheim, London, Milan and Stockholm there is data available that shows the increase in public transport usage after the introduction of the charge.

In Trondheim there are no absolute figures, but the mode share of public transport increased for trips that would have been affected by the initial charge from 23% to 27%; for the trips that were only affected by the later introduction of the zonal system these figures were 11% and 12% respectively.

In London, the number of bus passenger increased from 77,000 to 106,000 from 2002 to 2003, but it is not possible to possible to distinguish how much of this was the direct effect of the charge and how much was due to the improved provision in public transport. As for traffic reduction, the 2005 price increase had no detectable impact on public transport use.

In Milan, public transport benefited from the Ecopass with an increase of 9% in underground passengers and an 11% increase in surface commercial speed during the first month of its operation although that went down to 4% in the next month.

In Stockholm, data provided by the public transport operator, allows to account for the effect of the improved public transport provision alone, since a comparison without and with all improvements in place, but before charging started, showed that passenger numbers had increased by 2%. Overall, as a combined effect of PT improvement and the tax, for the whole county the operator reports a 6% increase in PT use with 140,000 more boarding passengers. On the inner city trunk bus routes the increase is also 6%, but on the inner city local bus routes even 14%.

Impact on the Local Economy

Results with regard to the impact of urban road user charging on the local economy are available from Trondheim, London and Stockholm.

In Trondheim there was a very small short-term loss in city centre trading, but in the longer term there was still overall growth, even if the city lost some market share to out of town trading. However, since this was a general trend in many European cities, it is not clear whether all of this was due to the road pricing scheme. Furthermore, following the cessation of the charge there was, at least in the short-term no up-turn in city centre trade.

The effects in London are disputed. Transport for London claims that the congestion charge had a positive impact on jobs, business turnover and profits, while Chamber of Commerce claims a negative impact on retailers.

During the Stockholm trial, no visible effect on trading or other business activity could be found and it remains to be seen whether there will be any long-term effect from the permanent scheme.

But overall it appears that urban road user charging has little or no impact on the local economy.

Charging on Urban Roads or Motorways

Finally, it should be mentioned that the co-introduction study concluded that, although it is generally easier to gain political support for introducing charges on motorways than on other types of road, the benefits from so doing are generally lower than can be obtained by introducing charges on urban roads.

Specific Effects of Differentiated Charging

Evidence about real or potential effects of purely urban differentiated charges is available for Trondheim, London, Stockholm and Milan as well as from the conceptual model. Furthermore, there are a number of conclusions that can be drawn with regard to the possible combined introduction of urban and interurban charges. Unfortunately, for Singapore, the most highly differentiated scheme of all, there is no data that shows the effect of this differentiation.

Differentiation by Vehicle Class

In the case of London, the effect on different types of vehicles stems from the exemptions given to licensed taxis, buses and coaches, and all two-wheelers. Their number with the congestion charging zone increased between 2002 and 2006 by 16%, while the number of chargeable vehicles, i.e. cars, vans and lorries decreased by 30%.

In Milan, the vehicles with the lowest emission classes were also exempt, but furthermore there were different levels of charges fro the different levels of classes with higher emissions. What was very noticeable as a result of this charge was the strong shift from higher to lower emitting cars. The share of passenger cars with for emission class 3 among all cars went down from 15% to 9%, for class 4 from 22% to 11% and for the highest emission class 5, where the charge is € 10 per day, from 0.4% to 0. For Light Duty Vehicles numbers the share of class 4 went down from 49% to 39% and for class 5 from 22% to 15%. At the same time, the share of low emitting cars increased accordingly.

Differentiation by Time of Day

The initial charging scheme in Trondheim led to a 4 percentage point reduction for home to work and home to shopping trips during the highest charge in the morning peak. The main traffic reduction happened during the low charge period from 10:00 to 17:00 with a decrease of 13 percentage points in work to home and of 15 percentage points in home to shopping trips.

This pattern of the highest reduction occurring during the lower charged periods was also found in Stockholm. Although the charging scheme here is highly differentiated by time, there is no direct correlation between charging level and traffic reduction: both in the morning and in the afternoon, the traffic reduction is larger in the pre-peak shoulder with the € 1.50 charge than in the main peak with the € 2.00 charge and, furthermore, the biggest reductions overall occur during the first charging period in the morning and the last in the afternoon, when the charge is only € 1.00.

The general explanation for this lack of correlation between level of charge and level of traffic reduction is the difference in elasticities of different types of road users, with shopping trips being much more elastic than trips to work. However, in Stockholm this was not sufficient to explain, in particular, the large reductions during the first charging hours in the morning, and further research is needed to establish the underlying patterns of user reaction.

In the Edinburgh modelling exercise, no effects were found from charging by time of day nor by number of cordons, other than the simple fact that more cordons catch more people and that this has more impact on traffic levels than charging fewer drivers more money.

Differentiation by Location and Time of Day

In Trondheim, it was found that the introduction of the more differentiated zonal scheme only had minimal impact on modal split for trips that were uncharged before and charged after, while the initial scheme had increased the car share for trips across the cordon by around 6 percentage points.

The main effect of the zonal system was again a time shift for trips made by car drivers. While, for trips not charged in the original but only in the revised scheme, the average total increase in mode share of cars between 1992 and 2001 was 10 percentage points, it was only 1 percentage point in the highest charged morning peak, 6 percentage points during the lower charged mid-day and afternoon, 13 percentage points during the evening and night, and 21 percentage points during the weekend.

Different Degrees of Differentiation

From the work carried out with the conceptual model it was found that the system of MSC tolls gives the greatest reduction in total network delay, and the greatest “benefit” as measured by the sum of the reductions in the cost of total delay and externalities, from the base, “no tolls”, case, but that no one scheme could be said to be best under all aggregate measures.

The simple Uniform scheme was perhaps surprisingly similar to the first-best MSC tolls scheme. This shows that it is the spatial nature of the charging scheme that is more dominant than the precise link-by-link level of charge once the total toll revenue is kept fixed. The next most effective schemes are those involving charging both within the inner city and within the city by-pass.

Direct comparisons of area-based and distance-based schemes indicate that, whilst they give similar reductions in demand, the area-based scheme gives a much greater reduction in total delay, whilst the distance-based scheme gives a much greater reduction in veh*km in the relevant regions. In each case, the pure cordon scheme gives a rough compromise between the distance-based and area-based equivalent, but with a somewhat smaller reduction in demand. An important distinction between the area-based and distance-based schemes is that, in the latter, drivers will seek to reroute to minimise the charge they incur, which can induce a considerable increase in veh*km.

The results for the specific network modelled show that the size of the area covered by the scheme, and therefore the overall number of drivers who would have to pay the charge is more important in terms of overall effect of the scheme than the type of scheme used or the degree of differentiation within it; and it seems safe to say that this is not specific to the network modelled here, but would be found in other networks as well.

Overall Findings for the Effects of Differentiation for Car Drivers in Urban Areas

In this which, from the overall point of view of the project, is a key area of the work carried out in Task 9.2, unexpected conclusions have emerged. In the most important ones of the real-life case studies, namely Trondheim and Stockholm, it is not only that surprisingly little recognisable effects of differentiation by time-of-day could be shown, but moreover in the case of Stockholm some truly astonishing effects were be observed that are very counterintuitive.

Furthermore, the modelling exercises with the conceptual model also show less impact of a charge differentiation that reflects Marginal Social Costs than could have been reasonably expected.

The analysis of the effect of differentiation by type of vehicle class shows, however, very different results: both in Milan and in London, clear effects could be observed and, moreover, these point into the direction that would have been expected and predicted in the first place.

Very clearly, more research is needed in this area to explain these results and to allow accurate forecasts of the likely effect of the introduction of a new differentiated charging scheme elsewhere, most notably if the differentiation is done by time of day. What could be most revealing would be further research into the breakdown of the actual travel behaviour in Stockholm by different groups of travellers.

Co-Introduction of Urban and Interurban Charges

A UK study with a view to the potential introduction of a UK wide road user charging scheme found that a highly differentiated MSC-based pricing scheme with 75 different levels of charges should deliver substantial benefits, largely due to time saving reductions, but that somewhat simplified MSC schemes (for example, with just 10 separate levels of charge per km) can produce a very large proportion of the potential congestion reduction. Furthermore, also a simple revenue neutral version of MSC pricing would deliver benefits that are not significantly less than a full MSC scheme, while an increase in fuel duty to raise the same revenue as an MSC pricing scheme would reduce congestion by only one-fifth of that given by MSC pricing, which indicates that it is the *structure* of charges that is important and not the overall level.

If charging were imposed only in urban areas (for example, in all cities with population in excess of 10,000), this would produce benefits that were not far short of those from a full MSC scheme. Simple charging systems by road type, area type or time of day reduce overall traffic volumes more than the full MSC scheme, and for the charge based on area type even in urban areas, but they all have only a fraction of the MSC scheme's impact on congestion. However, it should be noted that the report contains a series of caveats, so the results should be taken with a degree of caution.

A separate modelling exercise, focusing only on congested urban areas, indicated that cordon-based schemes were likely to produce smaller benefits than distance-based schemes, although the latter could lead to a significant amount of rerouting, and also found that a simple, flat-rate charge imposed in urban areas could produce significant benefits. This was somewhat at odds with the findings from the national modelling in the main part of the report, but is probably more reliable given that the national model covered the whole of the country, but only with a sample of links rather than a network representation, and therefore could not model any rerouting.

This current report also explored different scenarios for the combined introduction of urban and motorway charges. The investigation concluded that considerable problems are likely to occur if charges on urban roads are designed without regard to their potential impact on any adjacent motorways or if charges on motorways passing through metropolitan areas are designed without regard to their potential impact on the roads in those areas or on the local economy. Some diversion of traffic from one network to the other is an inevitable consequence of introducing charges. Diversion of traffic from motorways to other roads can be particularly serious because it leads to increased accident risk and environmental externalities.

Cooperation on technical and procedural issues, and over detailed definitional points such as start and finish times, vehicle classifications and exemptions, is desirable even if the two road authorities have different objectives. In the absence of such cooperation the resulting complexity will increase costs for system operators and end users and cause particular resentment among the latter. In order to maximise overall benefits, a degree of prioritisation or compromise is required, which also involves the introduction of different charges on the different road types. It seems likely that overall benefits will be maximised by combining a charge on the urban roads with charges designed to give a degree of protection to traffic using motorways and other strategic links. The urban charge might be levied on traffic crossing specified cordons or using roads within a specified area, while the strategic-link-protection charge might involve specific charges for using motorway access or egress links or dynamic charges just sufficient to preserve free flow conditions.

Elasticities

Elasticity estimates are available from Trondheim, London, Singapore and, most extensively from Rome, but they vary widely:

- For Trondheim, with an increase of 22% in generalised costs, the estimate of the arc elasticity is -0.32.
- For Singapore, the change in generalised cost is not known, but estimates for the CBD range from 0 to -0.42 and for the expressways from -0.16 to -0.44, which means that the medium values are in a similar range to Trondheim.

Furthermore, these values lie in a range that is generally assumed to be fairly typical. However,

- For London, where the generalised costs with the introduction of the £ 5.00 charge increased by 23.5 %, i.e. similar to Trondheim, the estimated elasticity is -1.3 according to independent research. Transport for London put the figure even higher at -1.6, but both values are unusually high.
- On the other hand, the response to the increase in the level of charge from £ 5.00 to £ 8.00 was extremely inelastic: a price rise of 60% only led to a reduction in chargeable vehicles by 5%. Part of this can be explained by the fact that, at the same time, the fleet scheme became more attractive, and many drivers avoided the top charge by joining a fleet scheme. However, this can only be one contributor to the apparently inelastic user reaction.

Overall for London, there was undoubtedly a very large difference in the effects of the initial scheme introduction and the increase in price.

In Rome, there were also substantial differences between elasticities, here between daytime and night time schemes and between different user groups. The aggregate elasticity for car drivers at a charge of € 6 per trip covers a wide range:

- -0.02 for occasional users in the daytime;
- -0.07 for regular users in the daytime;
- -0.18 for recreational trips in the summer nights;
- -0.46 for work trip in the summer nights;
- -1.4 for all trip purposes in the winter nights;
- -2.0 for shopping in the summer nights;
- -2.0 for crossing in the winter nights; and
- -7.0 for crossing trips in the summer nights.

This is not only a remarkable range, but also contains some surprising details, in particular the low elasticity for recreational trips, which is a mere third of that for work trips at the same time.

The differences between all of the above figures for the four cities mean that extensive further research is needed to obtain a clearer picture about user reaction to road pricing per se and, even more so, to differentiated charges.

However, the work carried out in DIFFERENT with the conceptual model indicates that, while the assumptions on elasticities are crucial for the estimate of the absolute benefits of any scheme, they are much less crucial for the comparison of alternative schemes.

Outlook

The work carried out in Task 9.2 and 9.3 brought a substantial corpus of evidence concerning actual and, based on modelling, estimated effects of different urban road user charging schemes together and this report could highlight a significant number of interesting, and often surprising, findings. However, the research also opened a number of new questions, which are still waiting for an answer and require further research.

Notwithstanding any such gaps in current knowledge, DIFFERENT deliverable D9.3 will build on this current report as well as on work carried out in Task 9.1 and reported in Deliverable D8.3/9.2 to draw, as far as possible, overall and general conclusions concerning the impact of urban as well as motorway charging schemes and come up with recommendations for future differentiated charges for car drivers.

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APPENDIX 1

ELASTICITY VALUES FOR ROME

DAYTIME SCHEME

LTZ Systematic Users

		Modal Split				Aggregate elasticities			
		Car	Moped	PT	Change of destination	Car	Moped	PT	Change of destination
Price level (€)	1	50.8%	17.4%	23.7%	8.1%	-0.01	0.00	0.02	0.01
	2	50.2%	17.4%	24.1%	8.2%	-0.02	0.01	0.03	0.03
	3	49.6%	17.5%	24.5%	8.4%	-0.04	0.01	0.05	0.04
	4	49.0%	17.6%	25.0%	8.5%	-0.05	0.01	0.07	0.05
	5	48,4%	17.6%	25.4%	8.6%	-0.06	0.01	0.08	0.07
	6	47.8%	17.7%	25.8%	8.7%	-0.07	0.01	0.10	0.08

DAYTIME SCHEME

LTZ Non-Systematic Users

		Modal Split				Aggregate elasticities			
		Car	Moped	PT	Change of destination	Car	Moped	PT	Change of destination
Price level (€)	1	65.8%	13.9%	16.4%	3.8%	0.00	0.00	0.01	0.01
	2	65.6%	13.9%	16.5%	3.9%	-0.01	0.00	0.02	0.02
	3	65.4%	14.0%	16.7%	3.9%	-0.01	0.00	0.03	0.04
	4	65.2%	14.0%	16.9%	4.0%	-0.01	0.00	0.04	0.05
	5	64.9%	14.0%	17.1%	4.0%	-0.02	0.00	0.06	0.07
	6	64.7%	14.0%	17.3%	4.1%	-0.03	0.00	0.07	0.09

SUMMER NIGHT SCHEME

Work Trips

		Modal Split				Aggregate elasticities			
		Car	PT	Moped	Change of destination	Car	PT	Moped	Change of destination
Price level (€)	1	13.81%	52.22%	30.57%	3.41%	-0.07	0.01	0.01	0.02
	2	12.83%	52.83%	30.87%	3.46%	-0.15	0.02	0.02	0.03
	3	11.92%	53.41%	31.16%	3.52%	-0.22	0.03	0.03	0.05
	4	11.06%	53.95%	31.43%	3.57%	-0.30	0.04	0.03	0.06
	5	10.25%	54.46%	31.68%	3.62%	-0.38	0.05	0.04	0.07
	6	9.48%	54.93%	31.92%	3.67%	-0.47	0.05	0.04	0.08

SUMMER NIGHT SCHEME

Shopping Trips

		Modal Split				Aggregate elasticities			
		Car	PT	Moped	Change of destination	Car	PT	Moped	Change of destination
Price level (€)	1	19.03%	47.25%	30.50%	3.22%	-0.22	0.05	0.05	0.11
	2	15.03%	49.42%	31.98%	3.57%	-0.49	0.08	0.09	0.20
	3	11.61%	51.24%	33.23%	3.92%	-0.81	0.10	0.10	0.25
	4	8.76%	52.74%	34.26%	4.23%	-1.17	0.10	0.11	0.28
	5	6.48%	53.94%	35.08%	4.51%	-1.56	0.10	0.10	0.28
	6	4.69%	54.86%	35.71%	4.73%	-1.99	0.09	0.09	0.26

SUMMER NIGHT SCHEME

Recreational Trips

Price level (€)	Modal Split: Car	Modal Split: PT	Modal Split: Moped	Modal Split: Change of destination	Modal Split: Delay in departure	Aggregate elasticities: Car	Aggregate elasticities: PT	Aggregate elasticities: Moped	Aggregate elasticities: Change of destination	Aggregate elasticities: Delay in departure
1	22.90%	27.57%	43.45%	5.20%	0.88%	-0.03	0.01	0.01	0.01	0.01
2	22.23%	27.84%	43.78%	5.26%	0.89%	-0.06	0.02	0.01	0.03	0.02
3	21.57%	28.11%	44.09%	5.33%	0.90%	-0.09	0.03	0.02	0.04	0.04
4	20.92%	28.37%	44.40%	5.40%	0.91%	-0.12	0.04	0.03	0.05	0.05
5	20.28%	28.63%	44.70%	5.46%	0.92%	-0.16	0.05	0.03	0.06	0.06
6	19.65%	28.89%	45.00%	5.53%	0.93%	-0.19	0.05	0.04	0.07	0.07

SUMMER NIGHT SCHEME

Crossing trips

Price level (€)	Modal Split: Car	Modal Split: Change of destination	Modal Split: Delay in departure	Modal Split: Change of route	Aggregate elasticities: Car	Aggregate elasticities: Change of destination	Aggregate elasticities: Delay in departure	Aggregate elasticities: Change of route
1	61.38%	3.64%	5.71%	29.27%	-0.44	0.72	0.68	0.70
2	33.70%	6.38%	9.57%	50.34%	-1.51	0.81	0.73	0.77
3	13.96%	8.40%	12.22%	65.42%	-2.95	0.51	0.44	0.48
4	4.91%	9.35%	13.40%	72.34%	-4.36	0.24	0.21	0.23
5	1.61%	9.70%	13.83%	74.86%	-5.64	0.10	0.09	0.09
6	0.52%	9.81%	13.97%	75.70%	-6.85	0.04	0.03	0.04

WINTER NIGHT SCHEME

Winter Model

		Modal Split					Aggregate elasticities				
		Car	PT	Moped	Change of destination	Delay in departure	Car	PT	Moped	Change of destination	Delay in departure
Price level (€)	1	28.50%	42.87%	22.93%	4.16%	1.55%	-0.17	0.07	0.07	0.09	0.08
	2	23.84%	45.61%	24.36%	4.52%	1.67%	-0.37	0.11	0.11	0.16	0.14
	3	19.64%	48.04%	25.65%	4.88%	1.78%	-0.60	0.14	0.14	0.22	0.19
	4	15.96%	50.14%	26.77%	5.24%	1.90%	-0.86	0.15	0.15	0.27	0.23
	5	12.80%	51.89%	27.71%	5.60%	2.00%	-1.13	0.15	0.16	0.31	0.26
	6	10.14%	53.33%	28.50%	5.94%	2.10%	-1.43	0.15	0.15	0.33	0.27

WINTER NIGHT SCHEME

Crossing trips

		Modal Split				Aggregate elasticities			
		Car	Change of destination	Delay in departure	Change of route	Car	Change of destination	Delay in departure	Change of route
Price level (€)	1	48.42%	4.03%	1.59%	45.95%	-0.16	0.14	0.14	0.05
	2	26.63%	5.58%	2.22%	65.57%	-0.46	0.15	0.16	0.11
	3	12.20%	6.54%	2.62%	78.64%	-0.84	0.10	0.11	0.12
	4	5.00%	7.01%	2.81%	85.18%	-1.23	0.06	0.06	0.08
	5	1.94%	7.21%	2.89%	87.96%	-1.59	0.03	0.03	0.05
	6	0.74%	7.28%	2.93%	89.05%	-1.93	0.01	0.01	0.03