1. INTRODUCTION

The paper presents a socio-economic analysis of road pricing in the Copenhagen area. The analysis considers four different road pricing schemes, all of which are analysed according to their impact on traffic and environment. The main purpose is to present a socio-economic assessment of all benefits and costs involved. The work is based on a trial involving long-term monitoring of road-pricing behaviour by means of GPS. In combining these results with a transport model for Copenhagen, the various systems are analysed in a framework which allows congestion effects and changes in the infrastructure layout to affect demand.

Several findings are put forward. It is concluded that the introduction of road pricing with current traffic levels can not be expected to be socially expedient in Copenhagen. However, if the opening year is postponed to 2015 the projected social net benefits of the two most favourable road pricing schemes analysed will be positive and neutral respectively. This is due to a steady increase in annual congestion. Furthermore, if long-term demand effects are accounted for, both schemes can potentially bring considerable long term socio-economic benefits. Finally, it is found that the degree to which benefits outweigh costs depends considerably on the use of revenue from road pricing. Although it may contribute to decreasing congestion, recycling all of the revenue back to the transport sector turns out to be very inefficient and costly.

The various road-pricing schemes have significant, although quite different impacts on the daily transport pattern. In all four schemes analysed, demand effects are found to be lower than what has been observed in London and Stockholm. However, this conforms well to the fact that the demand model employed is short-term driven. Secondly, among external effects, accidents and noise are the far most important. Air pollution and Climate effects are found to be negligible. Thirdly, the importance of a careful system design
phase is exposed. In all of the four schemes, design problems are identified, which tend to produce severe detouring and queuing problems.

1.1 Outline of the four road pricing schemes

The four schemes analysed in the present paper has been selected on the basis of a pre-study (The Municipality of Copenhagen, 2005a) in which twelve different systems were considered. According to a wide range of criteria's, a panel of experts, planners, and politicians selected four prototypes for further investigation (The Municipality of Copenhagen, 2005b). These four prototypes are identical to the four systems in the present paper, except that we have allowed for further price discrimination between time periods, type of vehicle, and direction to internalise externalities in the best way. A detailed description of the reasoning behind the system design can be found in two recent project reports, Rich and Nielsen (2006) and Wrang et. al. (2006).

The four road pricing schemes includes a pure kilometre based GPS system, a detailed cordon based system, and two toll ring systems. Table 1 below summarises the details.

**Table 1: Outline of the four road pricing systems.**

<table>
<thead>
<tr>
<th>Name</th>
<th>Type of charging system</th>
<th>Geographical area</th>
<th>Technical solution</th>
<th>Payment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Km-charge</td>
<td>The charge depends on the location in space and time.</td>
<td>The system is restricted to four regions, with the city centre as the inner zone and the outer suburbs as the outer zone.</td>
<td>GPS device in the car.</td>
<td>Kr. pr. km. Peak Off peak</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Outer suburbs 1.00 0.50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Inner suburbs 2.00 1.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bridge area 3.50 1.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>City centre 5.00 2.50</td>
</tr>
<tr>
<td>Cordon tax</td>
<td>Charge when passing two zones. There are 13 zones in all. The tax depends on the location in space and time.</td>
<td>The charge area is similar to the Km-charge area. However, charge-region is subdivided into additional zones, 13 in all.</td>
<td>GPS device in the car.</td>
<td>Kr. pr. km. Peak Off peak</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Outer suburbs 2 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Inner suburbs 4 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Areas adjacent to city centre 8 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>City centre 12 6</td>
</tr>
<tr>
<td>Small toll ring</td>
<td>Charge for passing the toll ring. The charge depends on time of day and direction.</td>
<td>Toll ring around the city centre (follows the lakes).</td>
<td>Tags in the car.</td>
<td>Kr. pr. passage Peak Off peak</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>To the centre 30 15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>From the centre 30 15</td>
</tr>
<tr>
<td>Large toll ring</td>
<td>Charge for passing the toll ring. The tax depends on time of day and direction.</td>
<td>Toll ring between areas adjacent to city centre and inner suburbs (follows the freight-rail corridor).</td>
<td>Tags in the car.</td>
<td>Kr. pr. passage Peak Off peak</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>To the centre 30 15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>From the centre 30 15</td>
</tr>
</tbody>
</table>

**Km charge**

In the km charge model, the size of the charge depends on the amount of driven kilometers, the location of driving, and the time where the driving takes
place. The charge is differentiated so that drivers pay double charge in peak hours. The charge is also differentiated by location, so that the charge in the most congested areas is the highest. Technically, the solution is based on GPS technology.

**Cordon charge**
The cordon based system covers the same area as the km charge model. However, the 4 charge regions are subdivided into 13 zones separated by cordon. Car drivers pay for each crossing and the tax for each crossing are differentiated in order to make crossings nearby the city centre most expensive. As for the km charge model, the system is based on GPS technology. However, as opposed to the km charge model, cars can drive for free as long as they do not cross cordon.

**Small toll ring**
The toll ring systems are less complex than the two GPS systems. In the small toll ring system a crossing triggers the same payment irrespectively of the crossing point. However, the charge depends on the time of the crossing. Technically, the solution is based on tags in the car and side-road equipment. This system is presently running at the Storebælt bridge.

**Large toll ring**
The large toll ring system covers a significantly larger area than the small ring. However, all of the principles are the same.

### 2. METHOD

The modelling framework consists of a number of building blocks. A simplistic illustration of the model structure is shown in figure 1.

**Figure 1: Model structure for transport demand effects.**

The five building blocks, which make up the model structure is outlined below.

2. Road pricing elasticity table for 2004. Include direct demand effects and cross price demand effects as a result of road pricing. The table is

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measured at OD level and includes direct effects and substitution effects between modes, time periods, and destinations. The table is differentiated by trip purpose (these are assumed to be independent). Effects do not include congestion.

3. A module, which adjust demand according to changed congestion as a result of road pricing.

4. A demand module, which on the basis of new public level of service variables determines changes in demand (direct and cross substitution effects).

5. Route choice models for public transport and car traffic, which assigns traffic to the network.

The base matrices have been produced by a large scale traffic model for Copenhagen (The OTM model, Jovicice and Hansen 2003). Also, the model has been used to find mode choice substitution patterns and to assess the effects of improved public transport.

The elasticity table is based on a large real world road pricing experiment in Copenhagen, the AKTA project (Nielsen 2004, Nielsen and Jovicice 2003). The project analysed more than 500 cars, which in a two years period were exposed to synthetic road-pricing schemes. Cars were equipped with GPS devices and they were taxed according to their driving behavior in certain synthetic taxation areas. In order to make the experiment realistic, the cars drivers were observed in a control period and pre-paid an initial amount equal to the amount of taxation had they been driving in a tax period. Then subsequently, the drivers were exposed to road pricing in a period of similar duration to the control period. After the experiment they were allowed to keep the potentially saved money from their changed behavior.

Clearly, the AKTA project did not consider congestion effects, e.g. when road pricing reduces the number of cars congestion decreases and travel time decreases. This was taken into account in a separate module which was based on the OTM model. In Figure 1 this is the “Feed-back adjustment of demand”.

In the feed-back adjustment, the model compares level of service before and after road pricing is introduced. The adjustment is relatively small and only one iteration is therefore used.
2.1 Recycling of revenue to the transport sector

If the revenue from the road pricing experiment is to be used in the transport sector, we need to adjust the demand further according to the improved level of service.

This is done by adding two additional steps to the structure in figure 1.

1. Run the structure in figure 1 with unchanged infrastructure and improved infrastructure.
2. From 1) we obtain an equilibrium supply for each situation. The difference between the two situations is then used to determine a demand change by combining the difference with an elasticity matrix for level of service (e.g. travel time and waiting time).
3. From the new OD matrix a new assignment is processed without feedback.

The model has been processed for 2004 and 2015 and corresponds to base matrices from OTM, e.g. all of the changes are relative to the base case matrices.

2.2 Modelling externalities

Externalities are modeled in two steps. Firstly, all of the external effects are dealt with by applying special effect models for the various environmental impacts. Secondly, the environmental impact, which are measured in Decibel, Kilos, and Accidents are transferred to monetary units by the use of norm-values identified by the Danish Ministry of Transport (2004).

The five types of externalities considered (beyond congestion) are;

- Operation and maintenance cost
- CO₂ emissions
- Air pollution
- Accidents
- Noise

Generally, the models conform to the most recent guidelines from the Danish Road Directorate and the Ministry of Finance (in the use of norm values). The
Noise model is a detailed GIS model with buffers in the range of 55-75 decibel. By adding a population layer and a layer for the building mass an estimate of the number of exposed houses/apartments can be found. The model for accidents uses traffic at the link-level and detailed information related to the road-types to project accidents in intersections and stretches and their type (severe/non severe).

2.3 Long-term versus short-term effects

The elasticities used in the present model are adopted from two sources. The AKTA project and the OTM model. In the AKTA project, elasticities are estimated on the basis of linear generalised models. This is possible because the same driver has been observed in different pricing regimes (charge and no charge) over periods of 2 to 3 month time. Even so, nothing is known about the potential substitution to other modes. As a result, a second source is needed, the OTM model. In the OTM model, mode-choice substitution elasticities and demand effects due to changes in the level of service has been used.

However, each of these two sources are short term based. It means that we do not assume agents to optimise behaviour in the longer run, e.g. by changing job, moving to another house, and/or selling their car. As a consequence, demand effects are underestimated. According to Goodwin and Degay (2004) the degree of underestimation could be as much as 2-3 times the short-term effect.

3. TRAVEL DEMAND IMPACTS

Table 2 below outlines the overall impacts for the four systems.

Table 2: Overall traffic related effects – relative change from the base case 2004 and the annual revenue.

<table>
<thead>
<tr>
<th>Effect</th>
<th>Km tax</th>
<th>Cordon tax</th>
<th>Large toll ring</th>
<th>Small toll ring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of trips</td>
<td>-6.3%</td>
<td>-7.5%</td>
<td>-2.6%</td>
<td>-1.6%</td>
</tr>
<tr>
<td>Car kilometers</td>
<td>-7.0%</td>
<td>-6.5%</td>
<td>-2.9%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Non-congestion travel time</td>
<td>-5.8%</td>
<td>-6.7%</td>
<td>-3.1%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Congestion travel time</td>
<td>-13.1%</td>
<td>-14.1%</td>
<td>-8.1%</td>
<td>2.0%</td>
</tr>
<tr>
<td>Annual gross revenue (billion dkr.)</td>
<td>4.5</td>
<td>2.4</td>
<td>2.5</td>
<td>1.3</td>
</tr>
</tbody>
</table>

The km tax system return the largest gross revenue at 4.5 billion kr., whereas the small toll ring generates 1.3 billion kr. The number of car kilometers driven is reduced the most in the km charge system, whereas the number of trips is reduced the most in the cordon system. Measured in terms of overall demand effects, the cordon based system tends to be the most efficient scenario in the
sense that we expect most demand changes compared to the amount of charges paid by drivers.

It is also worth noting that there are significant differences between the cordon based system and the toll ring systems. Clearly the revenue is different; however, it is worth noting that the small toll ring actually generates more traffic than before the experiment. This is an unfortunate property of this scheme, which is due to incentives for detouring around the city centre.

The schemes have different effects on travel time. Clearly, the potential reduction in travel time as a result of reduced congestion is the core argument for introducing road pricing. We can observe that the km charge and the cordon charge system perform quite well in this respect. On the contrary, the small toll ring system tends to increase travel time. The reduction in congestion time is between 2-3 times higher than the reduction in free travel time. This is due to the fact that the speed-flow curve is non-linear and that the present situation in Copenhagen is located on the non-linear part (to the right) of the curve.

Although congestion is reduced significantly, the overall congestion level compared to international standards is low. In London, before the toll ring, average travel speeds of 2.5 min/km were observed compared to 1.8 min/km at night. Outside the ring the congestion was worse or at the same level. In other words, London has had congestion percentages in large parts of the city in the range of 35-40%. For Copenhagen as a whole, this number is 13%.
For the small toll ring system, it can be seen that congestion increases compared to the base case. This is due to massive detouring in the areas adjacent to the city centre along Jagtvejen and Fasanvejen. In fact, this congestion effect tends to spread out from the city centre and can be observed as far away as on the Ring 3 motorway. It can also be seen that the large toll ring is relatively efficient in its ability to reduce congestion. The total number of car kilometers is reduced only by 2,8%, whereas congestion is reduced by more than 8%.

The largest reductions take place in the municipality of Copenhagen as seen in table 3 below. The km charge reduces the number of car kilometers by more than 16% in this area. The charge is designed to decrease by the distance from the city centre, which is evident from the results. The increase in car kilometres in the outer regions, Frederiksborg Amt and to some extent Roskilde Amt, in all systems but the Cordon charge scheme, is due to substitution to other destinations and detouring.

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### Table 3: Relative % reduction in the number of car kilometers at regional levels 2004.

<table>
<thead>
<tr>
<th>Name</th>
<th>Km charge</th>
<th>Cordon charge</th>
<th>Large toll ring</th>
<th>Small toll ring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Municipality of Frederiksberg</td>
<td>-17,3</td>
<td>-5,4</td>
<td>-3,7</td>
<td>10,1</td>
</tr>
<tr>
<td>County of Frederiksborg</td>
<td>4,3</td>
<td>-2,4</td>
<td>0,6</td>
<td>1,7</td>
</tr>
<tr>
<td>Municipality of Copenhagen</td>
<td>-16,2</td>
<td>-12,4</td>
<td>-9,4</td>
<td>-5,7</td>
</tr>
<tr>
<td>County of Copenhagen</td>
<td>-6,7</td>
<td>-4,7</td>
<td>-0,4</td>
<td>2,9</td>
</tr>
<tr>
<td>County of Roskilde</td>
<td>-0,1</td>
<td>-4,1</td>
<td>0,5</td>
<td>1,4</td>
</tr>
<tr>
<td>Total</td>
<td>-7,0</td>
<td>-6,5</td>
<td>-2,9</td>
<td>0,2</td>
</tr>
</tbody>
</table>

As noted before, the small toll ring gives rise to additional detouring to avoid crossing the ring. Especially the municipality of Frederiksberg will be affected by additional traffic.

### 3.1 Mode choice effects

Table 4 below summarises the overall mode substitution pattern. Generally, there are sizable substitution effects for all scenarios and almost all of the reduction in car kilometers is taken over by other modes. All of the scenarios have a positive substitution to other modes than car.

### Table 4: Relative % change in the number of trips by mode 2004.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Km charge</th>
<th>Cordon charge</th>
<th>Large toll ring</th>
<th>Small toll ring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cars</td>
<td>-6,3</td>
<td>-7,5</td>
<td>-2,6</td>
<td>-1,6</td>
</tr>
<tr>
<td>Public transport</td>
<td>7,9</td>
<td>4,5</td>
<td>3,6</td>
<td>3,4</td>
</tr>
<tr>
<td>Bicycle</td>
<td>7,1</td>
<td>4,3</td>
<td>3,0</td>
<td>3,0</td>
</tr>
<tr>
<td>Walk</td>
<td>4,1</td>
<td>2,5</td>
<td>1,6</td>
<td>1,7</td>
</tr>
</tbody>
</table>

In the km charge system public transport, bike and walk increases by 8%, 7% and 4% respectively. The relative change in public transport follows the general traffic reduction. The same pattern has been observed in London, whereas the substitution has been lower in Stockholm.

The distribution of the mode choice substitution pattern by purpose and time-of-day indicate that the largest relative substitution towards public transport is for work trips in the peak hour. Generally, fewer leisure and shopping trips changes mode.

### 3.2 External Effects

The summary of the external effects are illustrated below.

### Table 5: Annual reductions in external effects measured in 2005 million dkr.*

<table>
<thead>
<tr>
<th>External effect</th>
<th>Km tax</th>
<th>Cordon tax</th>
<th>Large toll ring</th>
<th>Small toll ring</th>
</tr>
</thead>
</table>

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Reduced climate and air pollution effects | 60 | 60 | 20 | -10
Reduced accidents | 270 | 250 | 130 | 90
Reduced noise | 160 | 160 | 80 | 10
Reduced wear damage | 10 | 10 | 5 | 0
Total (million dkr.) | 500 | 480 | 235 | 90

*Economic values are derived using the external cost estimates found in Danish Ministry of Transport (2004) except external costs from air pollution, which have been adjusted upwards to reflect a higher than average urban population density in Copenhagen.

The highest contribution is due to reduced accidents. The number of damaged persons is outlined below in table 6.

Table 6: Reduction in road casualties, severely damaged, non-severely damaged and material damage.

<table>
<thead>
<tr>
<th>Type of damage</th>
<th>Km charge</th>
<th>Cordon charge</th>
<th>Large toll ring</th>
<th>Small toll ring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction in road casualties</td>
<td>2,41</td>
<td>2,23</td>
<td>1,18</td>
<td>0,81</td>
</tr>
<tr>
<td>Reduction in severely damaged</td>
<td>62,70</td>
<td>58,19</td>
<td>30,67</td>
<td>21,20</td>
</tr>
<tr>
<td>Reduction in non severely damaged</td>
<td>60,37</td>
<td>56,03</td>
<td>29,54</td>
<td>20,41</td>
</tr>
<tr>
<td>Material damage (mill. dkr.)</td>
<td>219</td>
<td>197</td>
<td>101</td>
<td>64</td>
</tr>
</tbody>
</table>

3.3 Design issues

Designing road-pricing systems generally requires several attempts before all unsuitable elements are eliminated. Even though this paper is the outcome of a two-stage process, there are still significant unresolved problems in most of the schemes analysed here. This is particularly true for the cordon based systems. The issue has been discussed in details in Rich and Nielsen (2005), however, we shall pass on some of the experience.

For instance, the design of the small toll ring system fails as the “Avedøre-Amager” corridor becomes a “free entry” to Copenhagen city centre. Consequently, too many detours are expected to be taken around the city, in particular along Sjællandsbroen. The detailed cordon based scheme appears to have a range of unresolved crossing problems where two cordons were passed, but only one was paid for. This is to some extent a connector problem on the network. However, more attention should be paid to this issue. Overall, the “large toll ring” scheme was less problematic than the other two schemes. However, a significant number of detours were still being taken on the Ring 3 motorway. Finally, results from the km tax system seem to indicate that the

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taxation area should be expanded to avoid detouring. This could be done by adding a small kilometre tax in a fifth outer zone.

Generally, Copenhagen is quite different from cities like Stockholm and London, which causes results to be different. Contrary to Stockholm, there are only few natural boarders or obstacles (lakes and rivers) on the way to Copenhagen. Hence, setting up toll rings is likely to produce more transverse travel. For London, there are differences in the structuring of the public transport. Copenhagen has only few transverse public transport corridors, whereas there are numerous radial lines. This causes relatively low expected substitution from cars to public transport for transverse travel in Copenhagen.

4. COST-BENEFIT ASSESSMENT

The cost benefit assessment is based on a socio-economic calculus in which all of the relevant elements are accounted for. This includes changes in the consumer surplus for travellers due to changed travel times and cost, the value of external effects, potential tax distortion effects and system financing costs.

The fact that demand is only estimated for a benchmark year means that we cannot determine a flow of effects for each year in the project period. As a result, we cannot perform a traditional Social Cost Benefit analysis, where benefits and costs are discounted back to a net present value. As an alternative, a representative year is considered. If all of the initial construction costs (and other initial costs) are annualised to each year in the lifetime of the system, a proper share can be assigned to the opening year. The result is a cost benefit assessment for the opening year based on the assumptions in this year. By testing different opening years it is possible to verify how the time aspect affects the socio-economic potential of the project. The disadvantage of this approach is that neither long term changes in demand, nor changes in traffic patterns are factored into the cost-benefit calculation. The results should therefore be interpreted with caution.

A producer surplus in public transport is expected, given an assumed excess capacity in existing public transport. It is assumed that 50 percent of trips changed from cars to public transport take place at times when excess capacity exist in public transport.

It is assumed that the revenue from road pricing is used to reduce distorting taxes in the economy. Following the guidelines from the Danish Ministry of
Finance (1999) this translates to a potential benefit from road pricing, assumed to be 20 percent of the revenue. At the same time, however, road pricing may itself introduce distortion in other markets, e.g. the labour market. Thus, a ‘net tax distortion effect’ is calculated, reflecting the difference between the potential for reduced and increased tax distortion.

A central parameter in the calculation is the loss of consumer surplus for motorists from cancelling or changing car trips (e.g. change in destination, departure time, or mode of transport). This can be used as an estimated of loss of utility, since the demand for car trips already takes into account other alternative transport modes (Sugden & Williams, 1978).

The actual revenue resulting from road charges do not enter the social cost benefit calculation, since this is merely a transfer of funds from motorists to Government.

The results are summarised in Table 7. As can be seen, none of the four analysed schemes can be expected to generate net benefits in the short run. The km charge scheme is estimated to lead to a net social loss of approximately 80 million dkr compared to a base situation in 2005 without road pricing. The large toll ring is estimated to lead to a net social loss of approximately 200 million dkr. The result for the cordon charge system and the small toll ring is estimated to be a considerable net social loss (700-750 million dkr annually for the two schemes.

<table>
<thead>
<tr>
<th>Table 7 Social costs and benefits for the four schemes, mill. dkr. per. year, 2005¹,²</th>
<th>Km charge</th>
<th>Cordon charge</th>
<th>Large toll ring</th>
<th>Small toll ring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced climate and air pollution effects</td>
<td>60</td>
<td>60</td>
<td>20</td>
<td>-10</td>
</tr>
<tr>
<td>Reduced accidents</td>
<td>270</td>
<td>250</td>
<td>130</td>
<td>90</td>
</tr>
<tr>
<td>Reduced noise</td>
<td>160</td>
<td>160</td>
<td>80</td>
<td>10</td>
</tr>
<tr>
<td>Reduced wear damage</td>
<td>10</td>
<td>10</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Improved passability</td>
<td>185</td>
<td>-350</td>
<td>0</td>
<td>-630</td>
</tr>
<tr>
<td>Producer surplus, public transport</td>
<td>150</td>
<td>100</td>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td>Potential for reduced tax distortion</td>
<td>20</td>
<td>-80</td>
<td>40</td>
<td>35</td>
</tr>
</tbody>
</table>

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| Lost utility from changed trips | -300 | -220 | -260 | -100 |
| System costs$^3$ | -620 | -620 | -250 | -215 |
| Payments from motorists | -4,500 | -2,400 | -2,500 | -1,300 |
| Public income (charges) | 4,500 | 2,400 | 2,500 | 1,300 |
| **Total** | **-80** | **-700** | **-200** | **-750** |

$^1$ The four schemes are compared to a base situation without road pricing in 2005.
$^2$ Numbers are rounded and may therefore not add up to the total amount.
$^3$ System costs have been annualized using a discount rate of 6%.

The results are to a considerable extent sensitive to assumptions made about tax distortion. If road charges are assumed not to have distorting effects, both the km charge scheme and the large toll ring scheme turns from leading to net social costs to net social benefits.

It may be expected that changes in travel patterns away from cars towards increased cycling and walking will lead to social benefits from improved health. These effects have also been estimated in a supplementary analysis. The size of these benefits is, however, not earthshaking (approximately 45 million dkr. annually for the km charge scheme and 20 million dkr. for the large toll ring).

### 4.1 Results for year 2015

By considering the opening year 2015 rather than the present situation (2005), the social benefits of the projects will change. This is primarily because the amount of congestion will increase, which will cause congestion charging to be more beneficial. A second reason is that more transport infrastructure will be in place in year 2015. Among the most important improvements are the Ring 3 motorway and the ring metro.

In 2015 the km charging scheme is estimated to lead to a net social benefits of approx. 330 million dkr. annually, whereas the large toll ring almost breaks even at an expected net social cost of approx. 50 million dkr. annually.

In order to analyse the impact of possible long-term effects, a simulation of 2005 where demand effects (elasticities) are set to the double, is carried out. As expected, this yields considerably better results from the point of view of the charging schemes. The value of improved accessibility and reduced external effects clearly outweigh costs. In turn, the socio-economic benefit for the km charge system with opening year 2005 becomes positive, whereas it becomes neutral for the large toll ring.

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In addition, if the impact of long-term effects is combined with a postponement of the schemes to 2015, both projects can be expected to lead to significant socio-economic net benefits.

As a final exercise a socio-economic calculation of a 2015 situation, in which all the revenue is used to finance investments in public transport and road development, has also been performed. Although this will lead to a considerable decrease in congestion (following a 6% reduction in traffic) the high costs of infrastructure investments and the potential effects on tax distortion from no longer being able to use the revenue as a means to reduce distorting taxes leads to an expected major net social loss of approximately 1900 million dkr. annually for the km charge scheme and 1700 million dkr. for the large toll ring.

5. SUMMARY

5.1 The overall socio-economic assessment
Introducing road pricing with the traffic level of tomorrow in Copenhagen (2005) will yield a negative internal rent in all of the four analysed systems. The two best projects are the advanced km charging scheme and the large toll ring scheme. These systems yield an annual net social benefit of -80 and -200 mio. dkr.

However, if the introduction of road-pricing are postponed to 2015, the net social benefit estimates for the km charge system turns positive and neutral for the toll ring system.

The obvious reason for this is that the level of congestion in Copenhagen today is modest, but steady growing. Because we are on the non-linear part of the speed-flow curve, a linear growth in car kilometres will produce a far more than linear growth in congestion.

The demand effects in the model are based on short term surveys and models. However, it is well known that long-term effects are significantly larger (Goodwin and Degay, 2004) because households and firms in the long run include strategic decisions in their optimisation process. If demand effects are assumed to be doubled, the km charge system turns positive already in 2005, whereas the large toll ring turns neutral.
It can therefore be concluded, that the overall economic assessment is critically dependent on the time-schedule for the project implementation and to whether the underlying models are capable of projecting long-term demand effects.

If all of the revenue is recycled back to the transport sector consumers will experience higher accessibility and better level of service. However, the additional costs of implementing new infrastructure clearly outweigh the improved consumer surplus. In other words, recycling of revenue should be decided on a project-to-project basis and not be a target in it self.

5.2 Traffic related impacts

The four systems led to overall reductions in car mileage: 7 % for the km tax system in 2005, 6.5 % for the detailed cordon based system, 3 % for the “large ring” and -0.2 % for the “small ring”. Traffic growth in the latter is due to excessive detours being taken. Generally, the closer to Copenhagen city centre, the greater the reductions. The reductions in the municipalities of Copenhagen and Frederiksberg were approximately twice that of the system as a whole.

The reduction in congestion time was approximately twice that of the reduction in car mileage. E.g. for the two most expensive systems – the GPS and the detailed cordon based system 2004 – a 14 % reduction in congestion time was observed. This is due to the fact that the system is already in a “state of congestion”, with congestion increasing exponentially as a result of traffic.

Among the external effects, accidents and noise tend to be the most significant. Maintenance costs and emissions less so. The reduced number of accidents where damage to individuals occurred totalled 110 for the GPS system (figures for 2004), 102 for the detailed cordon based system, 54 for the “large ring” and 37 for the “small ring”. Significant effects were also observed with regards to traffic noise. One reason why noise appears to play a more prominent role than often observed, is that all of the systems have a tendency to re-distribute more traffic to the surrounding motorways, which are all well equipped with noise protection screens.

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