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Transport and location effects of a ring road with or without road pricing

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Abstract

Congestion is a serious problem in many cities. Road investment and road pricing are two possible policy options to relieve the problem. Cities are very complex systems and the impacts of different policies are difficult to predict. Road investment and road pricing will not only affect the demand for transport in various respects but may also, in the long run, change the location of activities. To be able to evaluate transport policies appropriately, tools are needed that could clarify transport as well as land use effects of different policies. In a previous article Eliasson and Mattsson (2001) developed a stylised model of a "generic" symmetric city for the simulation of such policies. The model was used to evaluate transport and land use effects of congestion pricing and of an inner and outer toll ring in the road network. In the present study we extend the model and the analysis to the effects of a ring road connecting the innermost suburbs. Different scenarios are constructed in which the ring road is combined or not with congestion pricing or an inner or outer toll ring. The ring road makes the inner suburbs much more attractive for location, and congestion pricing has a strong relieving effect on congestion similar to the one found in the previous study.

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1. Introduction

Sustainability is one of the key issues in urban policy-making of today. This does not mean that there is a general agreement on its meaning or definition. In relation to urban transport policies, however, sustainability is very much about how to achieve a reasonable balance between actions that will increase mobility of people and goods and actions that will reduce transport demand and, in particular, the use of motorised vehicles.

Many cities grow more or less rapidly. For this and other reasons they often face increasing congestion problems on the roads. Both citizens and trade and industry often express their claims for investments in the road network. However, in a situation when demand has been suppressed because of congestion, it is not clear to what extent congestion actually would be relieved by simply increasing the supply of road facilities. Many transport analysts argue that such a policy should be accompanied with a congestion pricing scheme to reduce the use of the enhanced road network to an efficient level.

Cities are very complex systems. To be able to evaluate transport policies in an appropriate way, decision support systems are necessary. By now many city and traffic planners have access to sophisticated network-based travel demand modelling tools by which they can analyse the effects of different policies on, e.g., trip generation, distribution, mode and route choice. However, road network investments, or the introduction of congestion pricing, will not only affect the demand for transport in a direct and immediate way. Such policies will also, in the long run, change the attractiveness of different places for location of activities and hence the land use structure of the city. To be able to evaluate such policies appropriately, city and traffic planners need tools that could help them clarify transport as well as land use effects of different actions. For the strategic planning they need be able to analyse the interaction between the transport and land use markets. As an example, will the effects of a policy instrument in the transport market be counteracted or amplified by the relocation of households and workplaces in the land market?

There is a considerable interest in developing combined transport and land use models (Wegener 1994; Wilson 1998) and there are also some commercial systems available. One of the authors has been involved in developing a residential and employment location model that combined with a transport demand model has been applied in the Stockholm regional planning and to some extent also in other places in the Nordic countries (Anderstig and Mattsson 1991; 1998). Presently, a lot of interesting modelling and policy studies are carried out in many EU projects such as the PROSPECTS[1] and other projects within the LUTR cluster[2]. However, there is no doubt that the actual application of combined land use/transport modelling tools in urban policy analysis still is fairly limited compared with stand-alone transport demand models. One natural reason is the fact that the calibration and implementation of a land-use/transport interaction model is quite a demanding task.

This kind of experience motivates our present interest in simplified urban simulation models based on spatial symmetry assumptions. Such a symmetry assumption excludes the possibility to represent many

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[1] Procedures for Recommending Optimal Sustainable Planning of European City Transport Systems: http://www-ivv.tuwien.ac.at/projects/prospects.html

[2] The Land Use and Transport Research Cluster: http://www.ess.co.at/LUTR/

details of a particular transport and land-use system as opposed to what is possible by a full-fledged operational land use/transport interaction model. It allows, however, a much more realistic representation than would be possible with a typical analytical urban economics model. It has also the advantage that the "typical" effects of a policy may be simulated in some detail without letting the results be distorted by the peculiarities of a specific city.

In a previous article, Eliasson and Mattsson (2001) developed such a stylised model of a "generic" symmetric city. The functioning of the model relies heavily on the assumed symmetry of the city. The city is star-shaped with a radial transport system including a viable public transport alternative, connecting discrete and homogenous zones. There are four groups of actors: households, employers, shops and service establishments. The households commute to the workplaces and make shopping and service trips by car, public transport and a slow mode. The trips may take place during the morning peak, office hours or the afternoon peak. In addition to the personal travel, there are also road-based deliveries from the workplaces to the shops and service establishments. There is congestion on the roads depending on the level of car traffic, while the public transport system is assumed to be subject to increasing returns to scale, i.e., the travel time between any two zones by public transport is assumed to go down as the demand goes up. The different actors locate in the city in response to accessibility factors and land prices in a way that is specific to each group of actors.

Eliasson and Mattsson (2001) used this model to simulate transport and land use effects of a congestion pricing scheme as well as simplified pricing policies in form of toll rings. In this companion paper, we first extend the modelling framework by allowing for a ring road connecting the innermost suburbs. With this modified model we can extend the previous analysis to the impact of a ring road in itself as well as to how it would function in combination with optimal (i.e., marginal cost-based) congestion pricing or a toll ring. The analysis includes the effects on travel time and travel distance by mode of transport and the effects on the location of households, workplaces, shops and service establishments.

The rest of the paper is organised as follows. First the policy context with reference to the Stockholm region will be discussed a bit further in Section 2. Then the model is described briefly in Section 3 and the scenarios to be analysed are defined in Section 4. The results from the simulation of the scenarios are presented and discussed in Section 5 followed by a summarising section.

2. Ring road and road pricing: What are the likely effects?

Many cities suffer from severe congestion problems (see Schneider et al. 2002, for an overview and discussion of possible actions). Stockholm is no exception. After a period of reduced traffic volumes in connection with the economic recession during the mid 90s, traffic volumes and congestion have again increased to even higher levels than before. There has been considerable political turbulence about how to handle these problems. Over the years different strategic plans for the improvement of the transport system in Stockholm have been put forward but not, or only to a limited extent, implemented. The most notable example was the Dennis Package with its extensive proposal for investments in the road network and in the public transport system (Johansson and Mattsson 1995). This package also included a road pricing scheme in form of a toll ring. The pricing scheme was meant to fulfil the dual purpose of reducing traffic and hence congestion in the inner city and of raising necessary funds for the road investments. The political agreement behind the package eventually broke down related to disagreement about certain controversial road links and the road pricing scheme.

Presently a governmental committee with representatives from all parties in the national parliament is commissioned to propose actions to improve the functioning and capacity of both the public transport system and the road network in the extended Stockholm region. The improved transport system should be environmentally, socially and economically sustainable. Among the road investments that are considered is the completion of a ring road around the inner city. Congestion pricing is one of the economic policy measures that is to be investigated.

A lot of the previous controversy around the transport policy in the Stockholm region has been related to the effectiveness of road investment and road pricing to reduce congestion. Many large cities of the size of Stockholm have introduced some kind of ring road to improve accessibility and to alleviate congestion in the city centre. Stockholm is one of the few exceptions, so is the argument from one side. The environmental-oriented side, on the other hand, claims that new roads simply induce new traffic leaving the congestion at the same level as before. Economic incentives such as congestion pricing would be a more effective and cheaper policy to mitigate congestion, so is the argument. Both sides have very firm views and they disagree on what the effects of these two specific policies would be.

Although the directions of the effects of a ring road or a road pricing scheme on transport demand are fairly clear, according to the research literature, the magnitude of the effects, and to what extent they counterbalance each other, are not evident. And when it comes to the long-term location effects, not even the direction of the effects is always obvious as is reviewed in Eliasson and Mattsson (2001).

This policy context may motivate our present study of transport and location effects of a ring road with or without some kind of road pricing. Congestion pricing is a policy that would be complicated to implement. A toll ring would be a much simpler policy from that perspective. A special question in this context is therefore how well congestion pricing can be approximated with a toll ring.

3. An urban simulation model

3.1 The original version of the model without a ring road

We will briefly present the model that will be used. The original version of the model was developed by Eliasson and Mattsson (2001), to which we refer for a full description of the mathematical structure and the choice of parameter values. The model has been calibrated with the intention to replicate location and transport patterns of a “generic” symmetric city. In the end, however, one has to make a choice of what a generic city is. In this paper behavioural parameters and size variables have, as far as possible, been chosen so that the model will resemble the situation in Stockholm.

The city consists of discrete, homogenous zones connected to each other by a symmetric radial network, with four zones on each of eight rays, as illustrated in Figure 1. The links connecting the zones are all 5 kilometres in length, and there is one link in each direction.

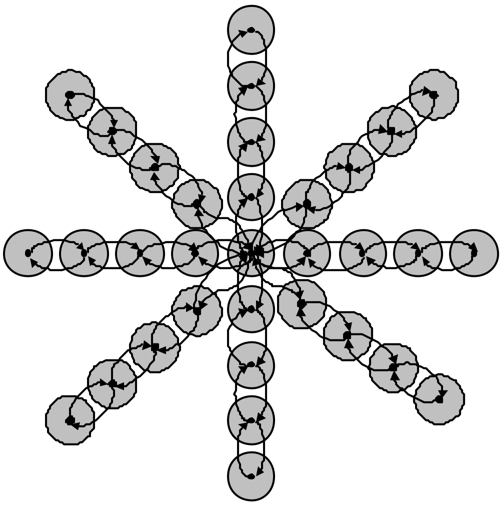

Figure 1. The star-shaped network of the original model

Since the city is completely symmetric in all respects, it is sufficient to regard only one of the rays when analysing the results of the simulations. The notation to be used is illustrated in Figure 2. The zones are denoted 1 to 5, from the city centre to the outermost suburbs, and the links are denoted A to D, from the innermost links to the outermost ones.

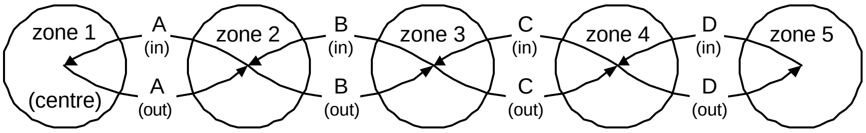

Figure 2. Notation along one representative ray of the symmetric original model

There are four groups of activities in the city:

- *households* represented by one individual (interactions within a household are not modelled),
- *workplaces* of only one kind,
- *shops* that can be thought of as grocery stores and where different shops are perceived as rather similar when the households make their shopping destination choices, and
- *service establishments* that can be thought of as banks, hospitals, travel agencies etc., and where different service establishments are perceived as fairly heterogeneous when the households make their service destination choices.

There are three travel modes available in the city:

- *car* for which the link travel times increase with increasing travel flows,

- *public transport* which is subject to economies of scale – the more people that choose to travel by public transport, the higher the frequency of service, and the denser the network within the zones, leading to shorter waiting and access times, and
- *slow mode* which is an aggregate of bicycle or walking and for which the speed is the same independent of congestion, and hence all link travel times will be equal.

The car and public transport modes are also subject to monetary costs that depend on the distance travelled, while the slow mode is free. For the car mode parking fees may be charged and some kind of road pricing may be levied on the users.

In this original version of the model there is no need to model the route choice explicitly, since there is a unique route between each pair of zones. When going from one zone to another, the travel distance as well as the travel time is the sum of the distances or travel times of the links that are used for the trip. The travel distance for intrazonal trips is assumed to be 2.5 km, and the travel time is assumed to be half the average travel time of the links connected to the zone. This means that also the intrazonal travel times will be sensitive to congestion.

The different groups of activities interact with each other through four kinds of trips: *work trips*, *shopping trips*, *service trips* and *deliveries*. The trips can take place during three different time periods of different length: *morning peak* (2.5 hours), *office hours* (6 hours) and *afternoon peak* (4 hours). Each household makes a work trip when it travels to work during morning peak and when it returns home during afternoon peak. Shopping and service trips take place during office hours and afternoon peak. If they are made by car, a parking fee is charged (parking is most expensive in the city centre and free in the outermost suburbs). The demand for shopping and service trips is elastic both with respect to the frequency and the choice of time period (office hours or afternoon peak). Deliveries are only made during office hours and always by car. Each shop and service establishment requires a fixed amount of deliveries each day.

The household travel demand and the deliveries are modelled by nested logit models (see Ben-Akiva and Lerman 1985, for a thorough introduction to this modelling tradition and Eliasson and Mattsson 2001, for a detailed account of how it has been done in the present model). Transport demand is modelled conditional on the location of activities. For work trips we consider mode and destination choices, whereas for shopping and service trips we also model, as mentioned above, the choice of frequency and time period. The destination choices for work trips are modelled so that the total number of individuals that works in a zone agrees with the number of workplaces in that zone. Deliveries are only modelled with respect to destination choice, since they, by assumption, go by car. All these demand models depend on travel times and travel costs with respect to the involved modes of transport. The different trip types then have different sensitivities to time and cost in a way that is consistent with empirical data. As a consequence shopping trips, for example, have a stronger preference for car than service trips have. It should be remembered that the car travel time on a link is an increasing function, and the public transport travel time a decreasing function, of the number of people choosing that specific mode. In this way it is possible to model how congestion affects the transport pattern in the city. It is also possible to model how different road pricing schemes would affect the transport pattern by changing the monetary car travel costs accordingly.

Finally, it remains to explain how the activities are located into the zones in the city. The city is “closed”, i.e. the total number of members of each group in the city is constant. There is a fixed amount of land reserved in each zone for households, shops and service establishments, respectively. These different groups hence act on different land markets. For workplaces it is assumed that there is no scarcity of land in any zone. One interpretation of this is that workplaces are located at the edge of the zones where there always is enough land available.

The location of activities is also modelled by nested logit models, where:

- *households* value lot size (inversely proportional to the number of households in the zone), accessibility to shops and service establishments and to potential workplaces,
- *workplaces* value accessibility to households (as workforce), and
- *shops and service establishments* value accessibility to households (expressed in terms of the number of customers attracted to the zone) accessibility to workplaces (from which they get a certain amount of deliveries each day) and lot size (shops to a greater extent than service establishments do).

The location of activities is linked to the transport system through accessibility measures. These measures are operationalised as logsums from the travel demand model that is relevant for each activity (for a detailed account of how this has been done, see Eliasson and Mattsson 2001). Through these accessibility measures, travel times and travel costs by different modes will affect the location pattern, and hence also the origin of the demand for the different trip types and for the deliveries.

In sum: The travel demand for different trip types depends on where different activities are located and what the travel times and travel costs are on the different links in the transport network. The travel times (and in case of congestion pricing also the travel costs) depend on the number of people choosing the different modes for the different links, i.e., on the travel demand. The location of activities, finally, depends on the accessibility in the different zones, which in turn depends on the location of other activities and the travel times and travel costs between the zones. All these relationships result in a number of equations that are solved for equilibrium.

3.2 The present version with a ring road added

In the present version of the model, it has been extended to allow for a ring road connecting the innermost suburbs, i.e., the zones denoted by 2 as is illustrated in Figure 3. This ring road is only open for car use.

With this ring road added to the network, there may be alternative routes for car trips between a pair of zones. We assume that the route choices follow Wardrop’s principle of user equilibrium, i.e., all used routes between a pair of zones have the same generalised cost and no unused route has a lower generalised cost. This generalised cost is computed as the monetary cost for the route plus the travel time multiplied by an average time value.

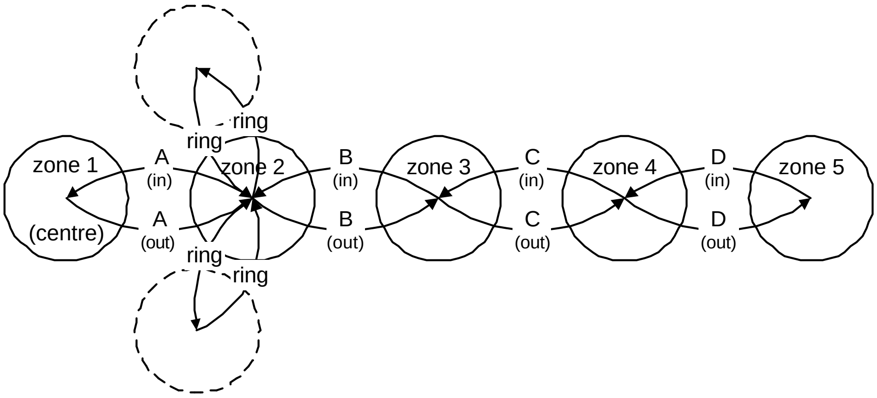

Figure 3. A representative ray of the star-shaped model, with the ring road added

Due to the convenient symmetry of the city it is possible to design a simple algorithm for the calculation of equilibrium routes without applying the more heavy machinery of solving an equivalent non-linear optimisation problem that is the typical approach in large-scale operational models (see Boyce and Daskin 1997, for an introduction to the latter approach).

This simple algorithm follows from a couple of observations. If a trip is between any two zones on the same ray (the city centre may be one of these zones), the unique user equilibrium route is to follow the straight-line route joining the two zones. Hence, it is only when a trip is between a suburb on one ray and a suburb on another ray, thus excluding the city centre, that there may exist multiple equilibrium routes. In that case, it is only for the part of the route that goes between the innermost suburbs of the two rays that there are alternatives. For this part there are at the most two options in equilibrium, either to use the ring road or to go via the city centre. We now subdivide the trips between different rays according to "how many rays away" they are. It then follows from simple geometrical considerations that there may exist multiple routes in equilibrium for one of these categories at the most. Trips between rays that are closer together, will all use the ring road, whereas trips between rays that are farther apart, will all go via the city centre. Thus the idea of the algorithm is to find this category of mixed route choice if it exists, and if so how the trips then are divided between the two route options. Sjölin (2001) provides a detailed account of the algorithm.

4. Scenarios

To study transport and location impacts of a ring road, and to what extent the impacts are modified by different kinds of road pricing, 8 scenarios in total have been constructed. These scenarios have been obtained by combining the original *base scenario* as well as the *ring road scenario* obtained by connecting the innermost suburbs, as is illustrated in Figure 3, with 4 different road pricing schemes: *no road pricing, (optimal) congestion pricing*, an *inner toll ring*, and an *outer toll ring*.

Optimal (first-best) congestion pricing, or congestion pricing for short, is achieved, which is well-known, by imposing a toll fee on each link that is equal to its social marginal cost. If all car users would have the same value of time, *t*, the optimal toll for a specific link as a function of the flow *f* on the link would be

$$toll(f) = t\,\frac{dt(f)}{df}\,f\ ,$$

where $t\,(f)$ is the travel time that is assumed to be an increasing function of the car flow on the link. This toll level has an intuitive interpretation. To achieve optimal congestion pricing, each car user on a link should be imposed a toll fee that is equivalent to the additional cost his presence on the link imposes on all other users of the same link, which is the additional travel time cause by him, $dt\,(f)\,/\,d\,f$, times the car users affected, f, times their value of time, t. Since this toll level depends on the actual car flow, it will be different for different links and different time periods. One additional difficulty should be noticed. The value of time varies, in fact, between different trip types, and hence the average time value on a link depends on the mixture of trip types. For computational reasons we neglect this difficulty and apply consistently a common average value of time of t = 42.60 SEK/h.

The road pricing scheme of an inner toll ring is implemented by levying a fixed toll of 10 SEK for all time periods on all car trips on inbound links between the innermost suburbs and the city centre (i.e. on all inbound A-links). Similarly, an outer toll ring is implemented by levying a fixed fee of 10 SEK on car trips on all inbound links immediately outside the innermost suburbs (i.e. on all inbound B-links).

5. Results and analysis

In applying the urban simulation model to the scenarios of the previous section, all parameter values have been kept at the same level as in the previous study by Eliasson and Mattsson (2001). As for the size of the city, there are 1,000,000 households, 1,000,000 workplaces, 10,000 shops and 10,000 service establishments. Due to the symmetry of the city it is only necessary to present the results for one ray. Links in different directions between two zones do not generally have the same flows and travel times, although they are fairly similar. We will suppress these differences and only display the average value for the two directions.

The application of the model to all 8 scenarios generates a considerable amount of results. It is here only possible to present a selection of the results to illustrate some interesting tendencies. For a full account of the results, see Sjölin (2001).

5.1 Impacts of a ring road with no road pricing

One immediate effect of introducing a ring road connecting the innermost suburbs (zone 2) is a drastic increase of the accessibility for the activities that may locate in these suburbs. Figure 4 shows the implications on the location pattern for the city as predicted by the model in form of the relative change compared with the base scenario. The increase of the accessibility has evidently a strong centralising effect on location, particularly for the innermost suburbs, where the increase is 20 % or more for all activities. In the city centre (zone 1) the number of households increases by 7 % and the number of workplaces by 9 %. The number of shops and service establishments decreases in the centre. The decrease is particularly pronounced for shops that decrease by 8 %. The number of service establishments decreases by 1%.

The way shops are modelled makes them more sensitive to generalised car costs than service establishments are, since shopping customers have a stronger preference for car use. Apart from depending on distance, the generalised car cost depends on parking fees and travel times. Introducing the ring road makes travel between the inner suburbs less expensive and hence they increase in attractiveness (especially for shops). Moreover, shops and service establishments value the expected number of customers attracted to the zone they consider for location. If a zone has a large number of shops or/and service establishments, and consequently a large number of customers, more shops and service establishments will find it attractive to locate there. When they do, the zone attracts even more customers, making it even more attractive for location. The increase in the number of shops and service establishments in the innermost suburbs shows how the model is capable of capturing this kind of *clustering* phenomenon.

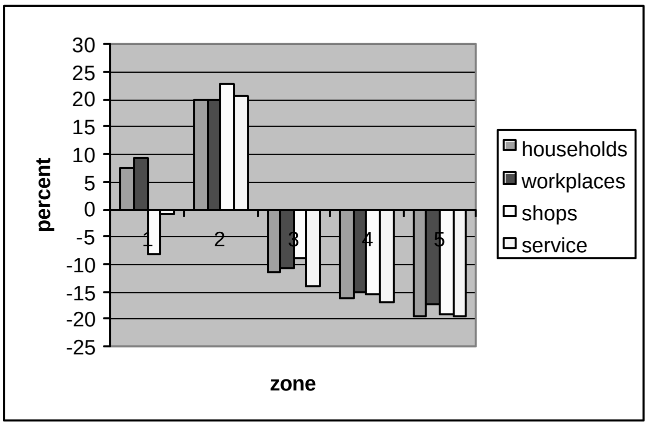

Figure 4. Relative change in the location of activities (%) by zone. The ring road scenario with no road pricing compared with the base scenario with no road pricing

The ring road causes the car traffic to and through the city centre to decrease substantially. In the base scenario car travel times on the innermost links (A-links) are about 30 minutes during morning and afternoon peak, and 22 minutes during office hours. With the ring road, morning travel time is 22 minutes, afternoon travel time is 23 minutes, and for office hours it is 13 minutes. Although the A-links still are quite congested (travel time at free flow is 6 minutes), the situation has obviously improved. Figure 5 shows the relative change in car travel flow (vehicles/hour), and Figure 6 in car travel time, on each link by time period for the ring road scenario compared with the base scenario. Evidently the ring road fulfils its purpose to relieve the congestion in the city centre.

The most surprising impact of the ring road on car travel is perhaps that congestion, and consequently car travel times, increase quite severely on the links just outside of the ring road (the B-links). The largest relative increase of the car traffic on these links occurs during office hours, when the increase of the car flow is 26 % and the resulting increase of the travel time is 55 % (from 11 to 17 minutes).

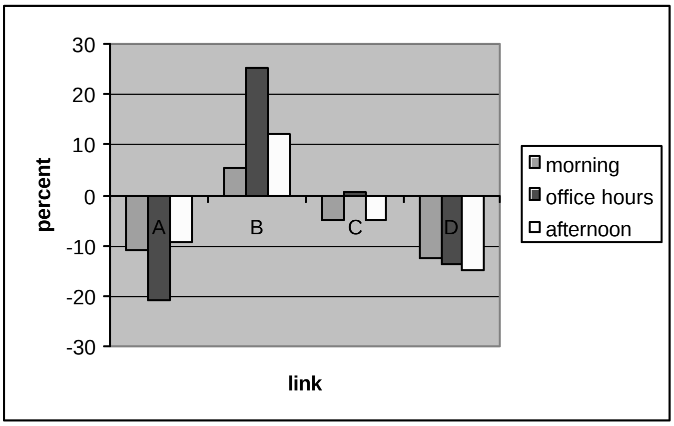

Figure 5. Relative change in car travel flow (%) by link and time period. The ring road scenario with no road pricing compared with the base scenario with no road pricing

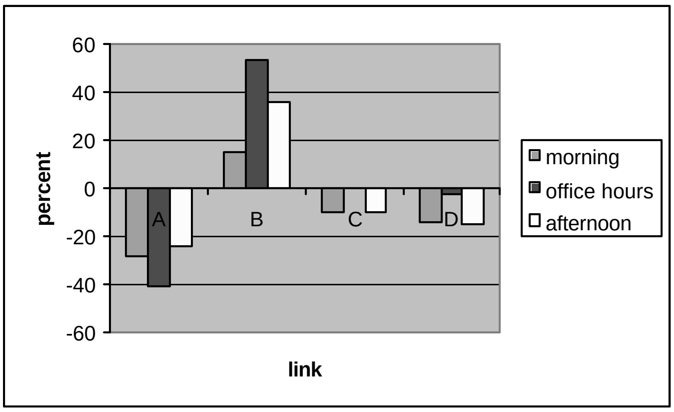

Figure 6. Relative change in car travel time (%) by link and time period. The ring road scenario with no road pricing compared with the base scenario with no road pricing

The introduction of a ring road increases the advantages of car use. This is not only because car travel times decrease on many of the links as a consequence of less congestion. It is also an effect of the fact that the ring road is only open for cars. People going by the slow mode or by public transport from one inner suburb to another have to travel via city centre. This increases the competitiveness of the car mode, since for instance during office hours travelling by public transport from one inner suburb to another on a neighbouring ray takes 39 minutes, while it takes only 13 minutes by car (using the ring road). In the base scenario the corresponding travel times are 39 minutes by public transport and 44 minutes by car.

Because of these improved conditions for car use in ring road scenario, the share of the car mode increases, and the share of public transport decreases, on all links and during all time periods compared with the base scenario. The largest changes are seen on the B-links, where the car share during office hours increases by 14 percentage units. In total, the car share increases by 9 percentage units on the B-links. The total increase on the C-links is 5 percentage units and on the D-links 3 percentage units. The largest increases of the car shares occur during office hours on all links, which is a consequence of the low service level of public transport during that time period. The smallest changes in the mode shares occur on the A-links. These changes are all in the range of 1 percentage unit up or down. The A-links are also the only ones where the share of the slow mode increases slightly, which occurs for morning and afternoon peaks.

Looking at the mode shares by residential zone, Eliasson and Mattsson (2001) concluded for the base scenario that the highest public transport shares and the lowest car shares occur in zone 2 rather than in the city centre (that might be expected). Their explanation for this is that the households living in the centre and using car need only pass one of the highly congested A-links to get access to the activities in all inner suburbs, whilst households located in one of the inner suburbs have to pass two such links to reach another inner suburb. Hence in the base scenario households living in the innermost suburbs are the ones that are least inclined to travel by car.

With the introduction of the ring road, residents in all zones and for all trip types increase their car use, and decrease their public transport use, compared with the base scenario (see Figures 7 and 8). The ring road enhances the road accessibility in particular for the inner suburbs, since people living there no longer have to pass the centre to go to other inner suburbs. It is then no longer residents in zone 2 (and neither those in the city centre) that exhibit the highest share of public transport use and the lowest share of car use, but residents in zone 3. To get to the activities on another ray or zone 1 or 2 on their own ray, the households in zone 3 have to pass at least one now heavily congested B-link, and therefore they have a higher tendency than other households to use other modes than car. The introduction of the ring road also affects the use of the slow mode (see Figure 9). The largest decreases of the slow mode shares occur for zone 2, especially for shopping trips.

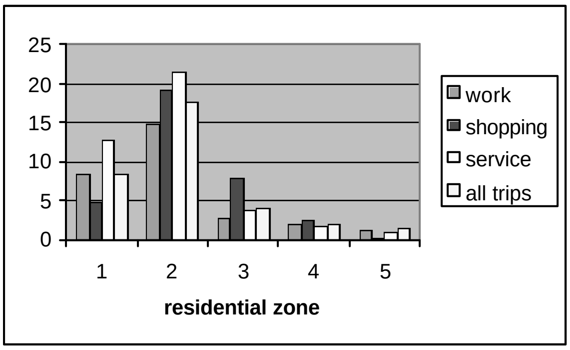

Figure 7. Change in car share (percentage units) by trip type and residential zone. The ring road scenario with no road pricing compared with the base scenario with no road pricing

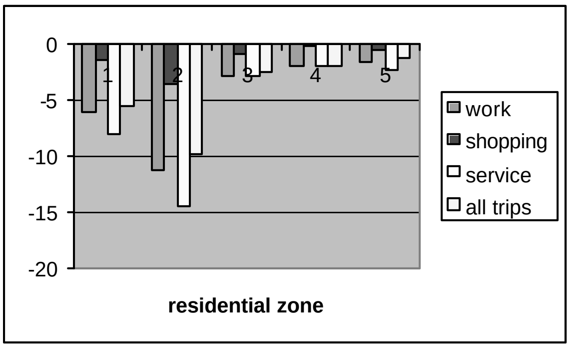

Figure 8. Change in public transport share (percentage units) by trip type and residential zone. The ring road scenario with no road pricing compared with the base scenario with no road pricing

Because of the lesser use of public transport in combination with its assumed economics of scale, the public transport travel times increase on all links. For the A-links they increase by slightly more than 1 minute during morning and afternoon peaks, or fom 14 to 15 minutes and from 12 to 14 minutes, respectively. The increases are quite small on the two outermost links, where the travel times in both scenarios are about 19 to 20 minutes.

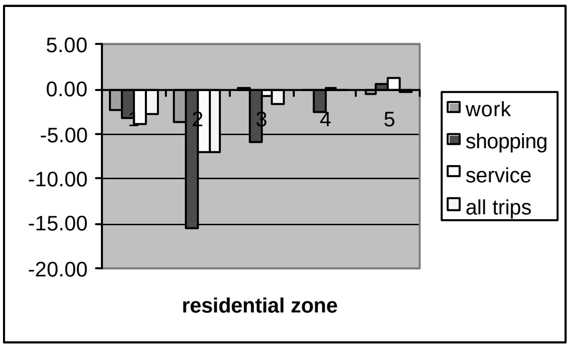

Figure 9. Change in slow mode share (percentage units) by trip type and residential zone. The ring road scenario with no road pricing compared with the base scenario with no road pricing

All in all, the total time and distance travelled by public transport decrease by 17 % and 21 %, respectively, compared with the base scenario. For the slow mode, both total time and distance travelled decrease by 18 % (they are equal because of the assumed constant speed). The total time and distance travelled by car increase by 25 % and 9 %, respectively. These increases are caused by the increased congestion on the B-links and the extensive use of the ring road. The ring road is used by almost everyone going by car between suburbs, which are up to two ring road links apart, during all time periods.

5.2 Impacts of a ring road combined with congestion pricing

How will the transport and location impacts change, if the ring road is combined with congestion pricing? Let us first see how the optimal toll level varies by time period and link. The toll levels reflect the congestion situation, and as Table 1 indicates, the A-, B- and ring road links are the most congested ones, particularly during the morning and afternoon peaks. Hence they will be subject to the highest tolls.

Combining the ring road with congestion pricing does not affect the location pattern very much except for the shops in the city centre. For most of the other zones and activities the changes caused by this pricing scheme are within 1 %. This is consistent with the conclusions for the base scenario according to Eliasson and Mattsson (2001).

Time period	A	B	C	D	Ring
Morning peak	16	18	9	4	17
Office hours	6	9	2	0	7
Afternoon peak	11	11	6	3	13

Table 1. Optimal congestion tolls by time period and link (SEK)

There is, however, a slight damping effect on the strong tendency to locate in the innermost suburbs that was observed for the ring road without road pricing. This is particularly evident for the shops. The previously observed out-moving of the shops from the city centre to the innermost suburbs is almost neutralised by the congestion pricing scheme. Congestion pricing means that car travel becomes more expensive, and it is therefore quite natural that the location effects of the ring road will become a bit damped. Since the shops are particularly sensitive to car costs, this tendency is more pronounced for this activity than for others.

The most obvious effects of congestion pricing are those on the transport pattern. The morning car travel times on the A-links, for example, are reduced from 22 to 13 minutes. More generally, morning and afternoon peak travel times by car are reduced by 42 to 62 % for the A- B- and the ring road links with the largest decrease for the afternoon peak on the ring road. This strong effect of congestion pricing is also consistent with the results in Eliasson and Mattsson (2001). As noticed in the previous section, the ring road without road pricing reduces car flows and travel times on all links but the B-links. When the ring road is combined with congestion pricing, also the car flows and travel times on the B-links are smaller than in the base scenario (the flows are further reduced on all other links too). As expected the ring road has less impact on travel times when combined with congestion pricing. The morning car travel times on the A-links, for example, go down from 31 to 22 minutes when the ring road is added to the base scenario with no road pricing, whereas the reduction is only from 15 to 13 minutes when comparing the same scenarios combined with congestion pricing.

When the ring road is combined with congestion pricing, the link car shares are 7 to 11 percentage units lower compared with the ring road scenario without road pricing, and 3 to 7 percentage units lower compared with the base scenario without road pricing. Compared with the base scenario with congestion pricing, however, the shares are 3 to 5 percentage units higher for all links but the A-links, for which they are about the same.

Table 2 provides an overall comparison of the scenarios with respect to total time and distance travelled by car and public transport. All in all, the ring road scenario combined with congestion pricing leads not only to less total distance travelled by car than for the ring road scenario with no road pricing (25 % reduction), which is expected, but also to less travel than for the base scenario with no road pricing (18 % reduction). However, adding congestion pricing to the base scenario, leads to an even larger reduction of total distance travelled by car (24 % reduction). It should also be noticed that the travel time reductions are still larger, since congestion pricing will reduce the car flows and hence increase the link speeds. When we look at the ring road scenario, congestion pricing leads to a reduction of the total travel time by 59 % compared with no road pricing. Compared with the base scenario with no road pricing the reduction is 48 % for the ring road combined with congestion pricing.

For public transport both total distance and time travelled are lower for the ring road scenario without as well as with congestion pricing compared with the base scenario with no road pricing. If we instead look at the specific effect of congestion pricing for the ring road scenario, there is an increase of total distance by 17 % and of total time by 11 %. Also total distance and time by the slow mode increase, in that case by 25 %.

Scenario	Car		Public transport	
	Distance	Time	Distance	Time
Base scenario and congestion pricing	-24	-57	15	9
Ring road	9	25	-21	-17
Ring road and congestion pricing	-18	-48	-7	-7

Table 2. Total distance and time travelled by mode. Relative change (%) compared with the base scenario with no road pricing

5.3 Impacts of a ring road combined with a toll ring

To implement optimal congestion pricing would be a complicated procedure – not the least technically. As an alternative to congestion pricing a toll ring is often considered and also sometimes implemented as is the case for the three largest Norwegian cities (see Small and Gomez-Ibañez 1997). Here we study two alternative locations for a toll ring, either an inner toll ring on the A-links or an outer toll ring on the B-links. In both cases a fixed toll fee of 10 SEK is charged on all car trips in inbound direction on the tolled links.

Eliasson and Mattsson (2001) concluded for the base scenario that an inner toll ring has a decentralising, and an outer toll ring a centralising effect on location. This is still true in the presence of the ring road. Compared with the ring road scenario with no road pricing, an inner toll ring relocates 1 to 3 % of the activities in the city centre and about 1 % of the activities in the innermost suburbs to the suburbs farther out. An outer toll ring, on the other hand, relocates 0 to 4 % of the activities in zone 3 to the city centre and the innermost suburbs (zone 2), while the outer zones are not very much affected. Compared with the ring road scenario combined with congestion pricing, an inner toll ring leads to less activities in the city centre whereas an outer toll ring leads to more activities in the city centre and the innermost suburbs, even if the picture is not uniform for all kind of activities.

When it comes to the transport effects of a toll ring the first conclusion is that they are essentially local and limited to the car mode. Adding an inner toll ring to the ring road scenario leads to a decrease of the car travel times on the A-links by 3 to 7 minutes depending on time period, whereas for an outer toll ring we obtain the same decreases but for the B-links. The effects for all other links are usually well below one minute. The effects on the public transport travel times are negligible.

Also the effects on the car shares are primarily local. The car shares are 3 percentage units lower on the A-links for an inner toll ring, and 3 percentage units lower on the B-links for an outer toll ring. The public transport and slow mode shares are 1 to 3 percentage units higher for corresponding links, whereas the changes for the rest of the links are small for all modes. Compared with the base scenario with no road pricing, the car shares are still higher on all links for both an inner and an outer toll ring except for the A-links.

Table 3 shows the changes in total distance and time travelled by car and public transport for the different toll ring scenarios compared with the base scenario with no road pricing. These changes should also be compared with Table 2. Both the inner toll ring and the outer toll ring lead to a reduction of the total car distance travelled by car by 4 to 5 %. This holds irrespective of if a ring road has been added to the network or not (cf. Table 2). The effects on the total time travelled by car are ever larger. In the latter case the damping effect of an inner toll ring is greater for the base scenario than for the ring road scenario, 16 and 9 % reduction, respectively, whereas for an outer toll ring the reduction is 11 and 12 %, respectively. The effects of a toll ring on public transport are negligible both with respect to total distance and total time travelled. The total travel by the slow mode increases in the ring road scenario by 6 % for an outer toll ring and by 4 % for an inner toll ring.

5.4 Comparison of the road pricing schemes

It is evident from the previous analysis that congestion pricing reduces car traffic more effectively than a toll ring. One obvious reason is that the costs that are imposed on the car users under congestion pricing are much higher than in either of the two toll ring alternatives. The total daily toll revenues for the ring road combined with congestion pricing are 18.3 million SEK, whereas they are 2.7 million SEK for an inner toll ring (when the A-links are tolled) and 3.1 million SEK for an outer toll ring (when the B-links are tolled). Would it be possible to attain the same level of car traffic reduction also for a toll ring by simply increasing the fee level? Figure 10 to 12 show, for the ring road scenario, how total toll revenues, total time travelled and total distance travelled by car per day vary with the fee level for an inner and outer toll ring.

Scenario	Car		Public transport	
	Distance	Time	Distance	Time
Base scenario and an inner toll ring	-4	-16	0	0
Base scenario and an outer toll ring	-5	-11	1	0
Ring road and an inner toll ring	5	16	-20	-17

Ring road and an outer toll ring	4	11	-21	-17

Table 3. Total distance and time travelled by mode. Relative change (%) compared with the base scenario with no road pricing

Figure 10 indicates that the maximum total toll revenues that are possible to attain for a toll ring are much lower than for congestion pricing. For an inner toll ring total revenues reach a peak of slightly more than 5 million SEK per day at a fee of about 35 SEK. For higher fees the traffic on the A-links decreases to such a degree that the total revenues decrease. The same thing happens for an outer toll ring, but then the total revenues reach a peak of 8.5 million SEK per day for a fee of about 65 SEK.

The relationship between total revenues and fee level for an inner toll ring may look somewhat peculiar, compared with the smooth curve for an outer toll ring. This is because a toll placed on the A-links affects the division of traffic between the A-links and the ring road in an entirely different manner than a toll placed on the B-links does.

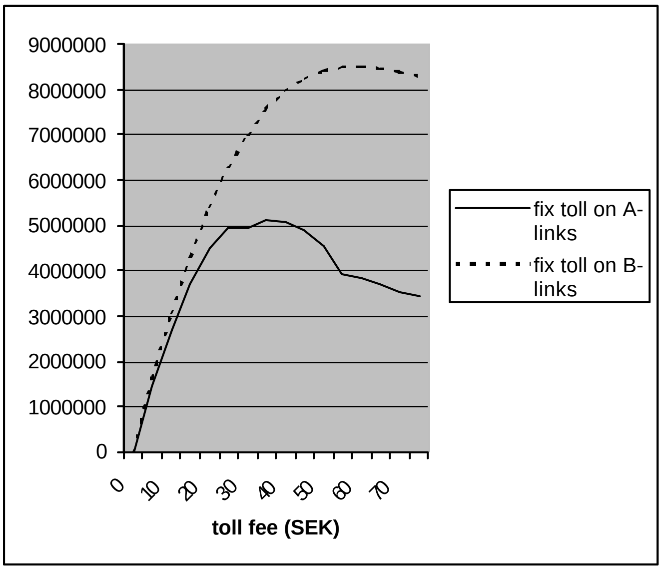

Figure 10. Total toll revenues per day (SEK) by level of toll fee for the ring road scenario

Figure 11 shows the total car travel time per day as a function of the toll fee for the two alternative toll rings. At a toll fee of 10 SEK the total travel time is around 740,000 hours for an inner toll ring, and 710,000 hours for an outer toll ring. The corresponding value for congestion pricing is as low as 330,000 hours. The total time decreases faster for an outer than for an inner toll ring. In the latter case, the total time seems to converge to a value of about 650,000 hours. The total time for an outer toll ring seems to converge to a value of about 450,000 hours. Therefore, it seems unlikely that it should be possible to reach the value of congestion pricing by means of a toll ring, irrespective of the chosen fee level.

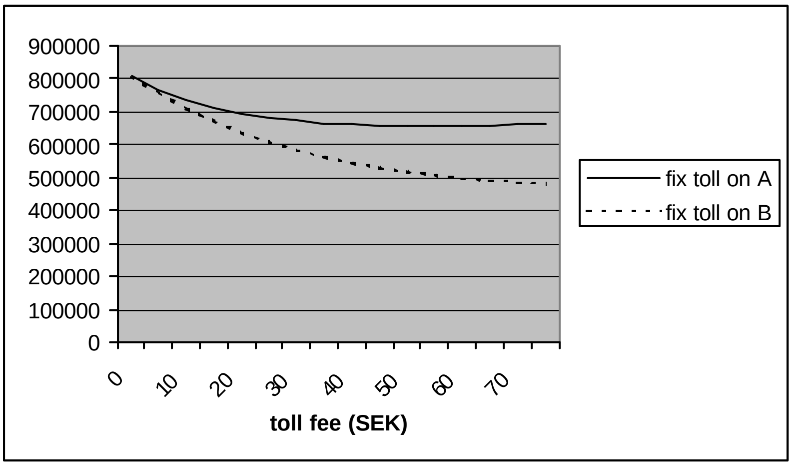

Figure 11. Total time travelled by car per day (h) by level of toll fee for the ring road scenario

The total distance travelled by car, on the other hand, can possibly reach the same value as that achieved by congestion pricing. Figure 12 shows how the total distance varies for increasing toll fees. At a fee level of about 60 SEK for an outer toll ring, the total distance travelled reaches 9,000,000 kilometres, which was achieved for congestion pricing. It seems unlikely that the total distance can ever be reduced to that level if the toll is placed on the A-links. At a fee of 75 SEK for an inner toll ring, the total distance travelled is about 9,500,000 kilometres. However, for these very high toll fees the congestion would be severe on many of the other links. For an inner toll ring, the congestion would be worst on the ring road, because of all traffic that would be redirected from the tolled A-links, but it would also be severe on the B-links. For an outer toll ring, the congestion would be severe on all other links than the tolled B-links.

A conclusion from these experiments is that we cannot attain the same order of reduction of time and distance travelled by car by means of an inner toll ring as is possible by congestion pricing. It is possible to achieve larger reductions by means of an outer toll ring. The fee levels that would be necessary, would probably be unrealistically high, however. If such tolls would be imposed anyhow, they would not only change the travel pattern but also the location pattern.

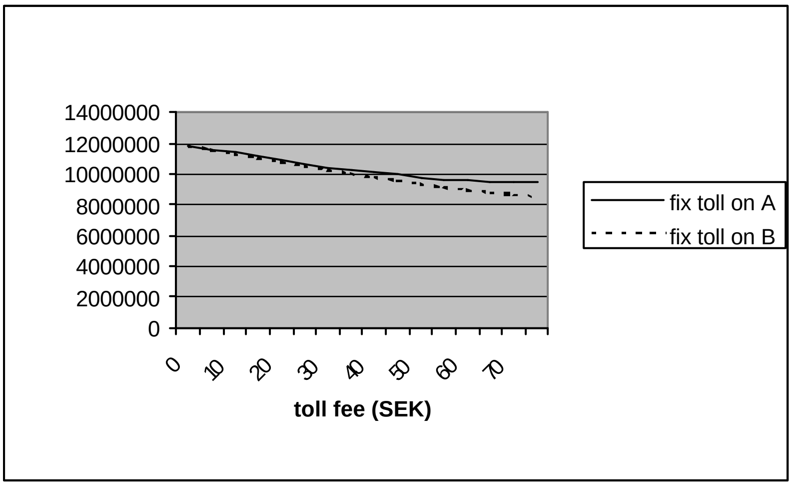

Figure 12. Total distance travelled by car (km) per day by level of toll fee for the ring road scenario

6. Summary

The effects of *a ring road* through the innermost suburbs with *no road pricing*, compared with *the base scenario* with *no road pricing*, can be summarised as:

- All four kinds of activities increase in the innermost suburbs (zone 2), by 20 % or more.
- The number of households and workplaces increase in the city centre (zone 1), by 7 % and 9 %, respectively.
- The number of shops and service establishments decrease in the city centre, by 8 % and 1 %, respectively.
- Car travel flows on the centre links (A-links) decrease by 9 to 21 % depending on time period. This is followed by a decrease in car travel time by 23 to 41 %. These effects are to a large extent a consequence of the new route choices that the ring road enables.
- Also car travel flows on the outer links (especially the D-links) decrease considerably. This is to a large extent a consequence of an altered activity pattern with fewer activities located in the outer suburbs (zone 3 to 5).
- Car traffic increases markedly on the B-links just outside of the ring road, travel flow by 6 to 26 % and travel times by 16 to 55 %.

- Car shares increase on all links. The largest increase (9 percentage units) is on the B-links just outside of the ring road, and the smallest (1 percentage unit) is on the centre A-links.
- Total travel by car increases by 25 % in time, and by 9 % in distance.
- Public transport travel decreases by 17 % in time, and by 21 % in distance, and slow travel decreases by 18 % in both time and distance (because of the assumed constant speed).

The effects of *the ring road combined with congestion pricing*, compared with *the ring road scenario with no road pricing*, can be summarised as:

- Congestion pricing per se has little effect on location. However, it dampens the location effects of the ring road somewhat. In particular, it dampens the moving-out of shops from the city centre. A bit surprisingly, it amplifies the moving-out of service establishments from the city centre.
- Car travel flows and times are reduced considerably on all links. The decreases are largest for the A- and B-links and for the ring road, for which the travel times go down by 42 to 62 %. On the B-links (that exhibit the largest increase in car traffic with the introduction of the ring road) car travel flows are even lower than in the base scenario without a ring road.
- Car shares are lower on all links, compared both with the ring road scenario without road pricing and with the base scenario. They are, however, not as low as when congestion pricing is applied to the base scenario.
- The total amount of car travel is reduced considerably, by 25 % in distance and 59 % in time. It is also reduced compared with the base scenario, by 18 % in distance and 48 % in time.
- Total travel by public transport is 17 % larger in distance, and 11 % larger in time. Also total travel by the slow mode is larger (25 %).

The effects of *a ring road combined with a toll ring* with a fixed fee of 10 SEK on inbound traffic, compared with *the ring road scenario with no road pricing* can be summarised as:

- An inner toll ring placed on the A-links has a decentralising effect, whereas an outer toll ring placed on the B-links has a centralising effect on location.

- The effects of a toll ring on car travel flows and times are mainly local, with traffic volumes being reduced on the tolled links.
- Car shares are reduced by about 3 percentage units on the tolled links, both for an inner and an outer toll ring.
- An outer toll ring placed on the B-links has, compared with an inner toll ring placed on the A-links, a slightly larger decreasing effect on total car travel time (12 % compared with 9 %), but the same decreasing effect on distance (4 %).
- The effects of a toll ring on public transport are negligible both with respect to total distance and total time travelled.
- An outer toll ring leads to an increase in travel by the slow mode by 6 % compared with 4 % for an inner toll ring.

Comparison of the total effects of the different road pricing schemes for the ring road scenario can be summarised as:

- The total revenues obtained by a toll ring can never reach the same level as those obtained by congestion pricing.
- For an inner toll ring, total revenues reach a peak for a fee level of about 35 SEK, whereas for an outer toll ring this happens for a fee level of about 65 SEK. The total revenues are then for an outer toll ring about one half as big as those obtained by congestion pricing and for an inner toll ring about one third as big.
- The total time travelled by car cannot, for any level of toll fee, get as low as that obtained by congestion pricing.
- The total distance travelled by car obtained by congestion pricing can possibly be reached for an outer toll ring but at a very high toll fee (60 SEK).

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