DET ØKONOMISKE RÅD

SEKRETARIATET

Transport Regulation Analysed in a Danish Equilibrium Model

Jens Hauch[1], Ninette Pilegaard[2] and Thomas Bue Bjørner[3]

Working Paper 2006:1

1 Danish Transport Research Institute,
Danish Economic Council until June 2006, jeh@dtf.dk
2 Danish Transport Research Institute, np@dtf.dk
3 AKF – Danish Institute of Governmental Research,
Danish Economic Council until March 2006, tbb@akf.dk

The Secretariat publishes a series of Working Papers, which primarily contains detailed information of selected subjects of the reports by the Chairmanship. The Secretariat is responsible for the series of Working Papers.

Lars Haagen Pedersen
Head of Secretariat

ISSN 0907-2977 (Working Paper - Danish Economic Council)
List of previous Working Papers: See last page.

To order, contact:

Danish Economic Council
Secretariat
Amaliegade 44
DK-1256 København K
Denmark

Phone: +45 33 13 51 28
Fax: +45 33 32 90 29
E-mail: dors@dors.dk
Homepage: www.dors.dk

Symbols:
$ Not applicable/data not available
Due to rounding, the figures in tables may not add up to the totals.

Transport Regulation Analysed in a Danish Equilibrium Model

Jens Hauch, Ninette Pilegaard and Thomas Bue Bjørner
Working Paper 2006:1

Abstract:
We present a static comparative equilibrium model for road pricing in Denmark. The model analyses the joint problems of the taxation of the congestion externality and the effects on the labour supply. We combine two regulatory instruments, a toll ring and kilometre-based road pricing, with three ways of recycling the revenue (eased income taxes, increased subsidies for public transport and increased tax deductions for commuting). We find that the largest gain would arise from a combination of a toll ring and eased income taxes. Kilometre-based road pricing is less beneficial because the system costs are higher. The model is inspired by Parry and Bento (2001) and Van Dender (2003) and extended in several ways. Most important are the inclusion of several regions, more alternative modes of transportation, regionalised labour supply, modelling of a toll ring, peak/off-peak substitution and the inclusion of system costs.

Keywords: Transport, congestion, road pricing, labour market
JEL: C68, H23, J20 and R48

Content

1. Introduction

Due to high car taxes, transport congestion problems in Denmark seem to have been less severe than in a number of other European countries. However, traffic levels have been growing steadily over the past decade and there has been increased focus on congestion problems, especially in Copenhagen. For example, traffic volumes in Copenhagen have increased by 17 percent since 1990, while speed seems to have decreased at the same rate (The Danish Economic Council 2006). Congestion indicators also suggest a severe increase in congestion on the motorways around Copenhagen (The Danish Road Directorate 2005). Finally, a recent study by Nielsen (2005) shows that traffic congestion each day causes 120,000 hours of delay in and around Copenhagen.

From an economic point of view, congestion can be regarded as a classical externality: the individual traveller does not take into account in his trip decision the fact that his trip will reduce the speed of other travellers. The textbook solution is a Pigouvian road-pricing tax that internalizes the externality in the trip decision of individuals. In practice, toll rings have often been used instead. It is only recently that road pricing has become an option from a technological point of view, and it remains a more expensive alternative. London and Stockholm are recent examples of large cities that have introduced toll rings. It has, however, also been pointed out by some economists that expectations with respect to the benefits of road pricing or toll rings may be too high. In an early evaluation of the London scheme, Prud'homme and Bocarejo (2005) found that the benefits of the system were considerably lower than the cost (due especially to the high implementation and investment costs). In addition, optimal regulation reduces but does not necessarily eliminate congestion.[1] Thus, given that private car travel is already heavily taxed in Denmark, the 120,000 daily hours lost in congestion noted above could in principle reflect an optimal regulation level (or a level of congestion being too low!).

Congestion regulation is complex, and several things should be taken into account when deciding on the level of regulation. First, there are large investment and operational costs associated with road pricing and toll ring schemes.

[1] This is expressed in the following way by Arnott (2005): "*Traffic congestion is so high because of the spatial concentration of economic activities in cities. Everyone benefits from this spatial concentration through new and more varied products, lower prices for many consumer goods and higher economic growth, and city residents additionally through higher wages, ready access to experts, urban amenities and a richer set of social contacts. Traffic congestion is simply one of the costs we pay to enjoy these benefits. It is excessive congestion (due to under priced auto travel) that should be our principal concern.*"

Second, there are a number of other externalities associated with traffic (noise, air pollution, barrier effects etc) which should also be taken into account. Third, road pricing will have an effect on the income distribution between individuals and between regions. Fourth, a tax on transport may increase or reduce the impact of other distortions in the economy.

There are basically two arguments for taxing transport activities: correction for external effects (Pigovian tax) and the need to raise public revenue (Ramsey tax). According to the Ramsey argument, goods and services which have low demand elasticities should be taxed relatively highly, as this will create less distortion than taxing goods and services with high elasticities of demand. Taxation of commuter traffic may have a significant indirect effect on the labour market. About a third of all transportation is commuting or work related. A tax on commuting transportation will indirectly serve as an additional tax on the already highly taxed labour supply, and thus lead to lower labour supply. Leisure transport, on the other hand, is a complement to leisure time, which is untaxed. This suggests that commuting transport should be taxed less than leisure transport (Van Dender 2003 and Munk 2003). This is the efficiency rationale for the Danish commuting tax deduction.[2] An optimal level of road pricing also requires modifications of other transport related taxes and subsidies. In the past, one of the economic efficiency arguments for subsidizing urban public transport has been that it was not technically feasible to tax private urban traffic at a higher rate than rural traffic. Given this earlier technical restriction on the available policy instruments, subsidies to urban public transport may have been a good second best instrument (Glaister and Lewis 1978). However, in the ideal situation, where the externalities of private transport can be regulated directly, public transport should be taxed (instead of subsidized) according to its marginal external effects (congestion and environmental effects).[3]

A number of earlier papers on the complex regulation of the transport externalities have applied partial equilibrium models with a fairly detailed description of the transport system, but without an explicit inclusion of the derived effects on the labour market (see for example De Borger et al. (1996) and Proost and van Dender (2001)). Another more recent group of articles include

[2] However, in the long run a lower tax on commuting could lead to a non-optimal localisation pattern. Thus, there is a trade off between the short run flexibility of the labour market (low tax on commuting) and the desire for an optimal localisation pattern (high tax on commuting).

[3] There may of course be income distribution arguments for subsidising public transport, but it should also be noted that subsidies to public transport may not be a very finely tuned instrument for achieving a given distribution target.

the derived labour market effects (see Parry and Bento (2001), van Dender (2003) and Parry and Small (2005)). These studies suggest that the use of the road pricing revenue combined with the derived effects on the labour market have greater welfare implications than the benefits stemming from correction of the congestion externality. Parry and Bento find that the benefit of road pricing is doubled if the revenue is used to reduce the distortionary tax on labour. The models in the later studies are, however, very stylized, with only simple descriptions of the transport demand system.

The contribution of this present paper is to combine such types of labour supply models with a fairly detailed description of the transport demand system based on Danish data. In addition, we include three different regions in the model to allow for a calculation of the regional distribution impacts of different types of regulation. Partial models (without labour supply effects) have previously been used to compare the welfare effects of road pricing and toll rings. These studies have, however, not explicitly included the cost of the different systems. We explicitly include the costs of road pricing and toll rings in the model. As the system cost of a toll ring is lower than for road pricing, the net revenue from the toll rings tend to be larger than from the road pricing system. It is shown in Parry and Bento that the size of the net revenue cannot be ignored if the net revenue is used to reduce other distortions in the economy. On the one hand, a toll ring can be considered less efficient than road pricing, as the toll ring only indirectly targets the congestion externality. On the other hand, the lower cost of the toll ring may yield higher net revenue, which may be used to reduce other distortions.

The model used for this study – denoted ASTRA (Applied Static equilibrium model for Transport Regulation and lAbour market) – is a static equilibrium model with three regions (Copenhagen, Greater Copenhagen and the rest of Denmark). We only consider passenger transportation. Consumers are allowed to substitute between different modes of transport and between travelling at peak or at off-peak hours. Congestion is explicitly modelled using a speed-flow function, while geographically differentiated marginal costs of other externalities are included in the welfare calculation. Labour supply is determined in the model with substitution between consumption and leisure. Finally, the model distinguishes between transport for leisure and for commuting, where the latter is linked to labour supply. Thus labour supply is linked to commuting time via the speed-flow function.

The results of the analyses using the model suggest that there would be a small gain from a toll ring around Copenhagen, while road pricing appears to have a small negative impact on welfare due to the relatively high annualised cost. In the public debate on road pricing and toll rings, it is often argued that the revenue should be used to increase the subsidies to public transport. In contradiction to this point of view, the model shows that the welfare benefits of the toll ring would be substantially higher if the revenue was used to reduce income tax instead of subsidising public transport. Finally, without a toll ring – i.e. with a situation similar to the current regulation regime in Denmark – there would be a welfare gain from a further increase in the high taxes on car use, i.e. an increase in the tax on car use in both rural and urban areas.

The model is presented in the next section. Input data and model calibration are described in section 3, while results of analyses using the model are presented in section 4. Conclusions are offered in section 5.

2. The Model

We follow Parry and Bento (2001) and van Dender (2003) and model a static comparative equilibrium model with emphasis on the description of consumers' transport activities and their supply of labour. This model has three regions and it is calibrated to describe the Danish economy. There is a representative consumer in each region with a fixed residence location. The public sector collects different kinds of taxes, subsidises public transport, finances fixed government consumption and pays a lump sum transfer to all consumers. The public sector operates with a balanced budget. There is no explicit description of firms or international trade. Firms demand labour at a fixed wage and supply goods and commodities at fixed prices. With this formulation, the model can be interpreted as representing a fully open economy. In the modelling of the transport system, we include four modes of transportation (car, bus, train and cycling/walking), and there is a distinction between peak and off-peak travel, and between commuting and leisure transport. Congestion on roads is included by using an aggregated speed-flow function for each region. In addition to congestion, we include externalities such as noise, air pollution and accidents by modelling geographically differentiated marginal external costs. Labour supply is determined via substitution between leisure and consumption, subject to both financial and time budget constraints. Finally, we include the annualised costs of road pricing and toll rings. There is no description of freight transport.

In the following, the theoretical model will be described in more detail. Endogenous variables are in capital letters, while parameters and exogenous variables are in lower case letters.

The transport system

Consumers demand trips as a part of their demand for commodities. Transport demand is described by the number of trips purchased by the consumers, $Q_{i,p,od,m,t}$. The indices are defined in the following way:

Index i represents the geographical location (residence) of the consumer: $i \in \{$Copenhagen, Greater Copenhagen, Rest of Denmark$\}$.[4] Index p represents the purpose of the trip: $p \in \{$commuting (c), leisure (n)$\}$. Index m represents the transport mode: $m \in \{$car, bus, rail, light (bicycle/walking)$\}$. Index t represents time: $t \in \{$peak, off-peak$\}$. Index od represents the origin and destination of the trip.

Origin and destination represent the same three geographical zones as the residence index, and consequently there are potentially nine different od combinations, i.e. for each region a trip to a destination within the same region or to a destination in either of the other two regions. However, we treat trips to a given od destination symmetrically, independent of where the trips start, thus leaving only 6 od combinations. Furthermore, commuting trips are only considered relevant if the region of residence is part of the od; consumers from a given region can therefore choose three commuting od combinations.

The number of trips is transformed into traffic in each region in the following way: $cap_{i,p,od,m,t}$ is the number of passengers per conveyance and $dist_{i,ii,p,od,m,t}$ is the distance driven in region ii when a consumer living in region i purchases a trip with the origin-destination combination od. The set ii includes the same elements as the set i.

The amount (flow) of traffic in region ii, $F_{ii,m,t}$ is then given as a simple summation of the kilometres driven in the region ii:

$$F_{ii,m,t} = \sum_{i,od,p} (Q_{i,p,od,m,t} \cdot dist_{i,ii,p,od,m,t} / cap_{i,p,od,m,t})$$

We furthermore define the road traffic, $FR_{ii,t}$, as the traffic flow on roads in each region:

$$FR_{ii,t} = F_{ii,car,t} + 2 \cdot F_{ii,bus,t}$$

[4] Copenhagen (1) is the capital and is defined as the municipalities of Copenhagen and Frederiksberg. Greater Copenhagen (2) is defined as the counties of Copenhagen, Frederiksborg and Roskilde, and Rest of Denmark (3) is defined as the rest of Denmark.

i.e. road traffic consists of cars and buses, with buses being weighted twice as much as cars in our definition of road traffic.

The speed, $S_{ii,m,t}$ for cars and buses is assumed to depend (linearly) on the road traffic flow in the region:

$$S_{ii,car,t} = \alpha_{ii,car,t} - \beta_{ii,car,t} \cdot FR_{ii,t} \quad and \quad S_{ii,bus,t} = \alpha_{ii,bus,t} - \beta_{ii,bus,t} \cdot FR_{ii,t}$$

where α and β are non-negative exogenous parameters. It is, however, assumed that β equals 0 in "Rest of Denmark", i.e. it is assumed that there is no congestion here (the motivation for this is partly lack of data, see section 3). It is similarly assumed that congestion does not affect the speed of trains and light transport in any of the regions, and the speed is therefore exogenous for these modes of transport, i.e.

$$S_{ii,light,t} = \alpha_{ii,light,t} \quad and \quad S_{ii,train,t} = \alpha_{ii,train,t}$$

Transport has two types of cost, a monetary cost and a time cost.

The time use per trip, $T_{i,p,od,m,t}$ for consumers living in region *i*, is composed of the time use in each of the regions *ii* in which the trip takes place, and these time uses depends upon the distance and speed in the regions *ii*. The time use per trip is given by:

$$T_{i,p,od,m,t} = \sum_{ii} \frac{dist_{i,ii,p,od,m,t}}{S_{ii,m,t}}$$

The private monetary cost, $P_{i,p,od,m,t}$, per trip is given by:

$$P_{i,p,od,m,t} = \sum_{ii} ((c_{i,ii,p,od,m,t} + tax_{i,ii,p,od,m,t}) \cdot dist_{i,ii,p,od,m,t}) + toll_{i,p,od,m,t}$$

Here *c* is the factor cost per kilometre, while *tax* is the tax per kilometre (or if negative, the subsidy). The tax may depend on trip purpose e.g. if there is a tax deduction instrument for commuting trips (as is currently the case in Denmark). *toll* is the fee for passing toll rings.

Traffic creates other externalities besides congestion, e.g. accidents and pollution. We assume that these externalities depend linearly upon the kilometres driven, and we assume that the level of externalities per kilometre depends only upon mode of transport and region. We assume further that consumers can attach a monetary value to the externalities independent of other variables in the consumption system. The value to consumers in region *i* of externalities E_i is therefore given by:

$$E_i = \sum_{m,t} (e_{i,m} \cdot F_{i,m,t})$$

where $e_{i,m}$ is the value of externalities per kilometre by each mode of transport in each region.

The representative consumer

Besides transport, the representative consumer in each region consumes pure leisure and other consumption. [5]

The consumer chooses his labour supply and pure leisure consumption as well as the composition of his consumption as divided between other consumption and leisure trips. The consumer has different preferences for leisure trips to different regions and therefore substitutes imperfectly between leisure trips with different *od* combinations. In addition, he also chooses the transport mode and whether to leave at peak or off-peak hours for each trip. Similarly, the consumer has different preferences for working in each region, and substitutes imperfectly between labour supply to the three regions as well as choosing the mode of transport and whether to leave at peak or off-peak times for each commuting trip. The trips (leisure and commuting) are tied to utility units by a nested CES function, just as other consumption and leisure trips are linked together in a CES function (see the figure in Appendix A).

The utility function of the representative consumer in region *i* is given by:[6]

$$\Psi_i(Q^o, Q_{i,n,od,m,t}) + \Gamma_i(N) + \Omega_i(Q_{i,c,od,m,t}),$$

where Q^0 is a composite consumer good and *N* is pure leisure. Ψ represents the contribution to utility from consumption. The additive separable term, Γ, represents the contribution to utility from pure leisure. This follows the standard of the Danish DREAM model (see Knudsen et al. 1998). Following van Dender (2003) and Parry and Bento (2001), commuting is included as an individual additive separable term in the utility function Ω. The commuting

[5] Other consumption covers everything else than transport that the consumer can spend money on.

[6] We normalise the number of households in each region to 1.

sub-utility function Ω allows commuting modes of transport to be imperfect substitutes.[7]

Note that the model focuses on the economic consequences of transport and labour-market-related policies. Consequently, the description of transportation-mode-choice is relatively simple, and there is no route-choice in the model.

Labour supply from the consumer in region i is given as L_i. The length of a work-day is assumed to be exogenously given, while the number of days worked is endogenous. The consumer can choose to supply his labour in each of the three regions. To supply a day of labour the worker always needs transport. Therefore, the labour/leisure decision is closely connected to the consumption of commuting transport, and it is assumed that there is a strict complementarity between labour and commuting. However, commuting to the different regions costs different amounts in time and money (a longer commute is generally more expensive than a shorter commute).

Therefore, there is the following restriction on the labour supply for the consumer living in region i, where h_i is the labour supply connected to a commute (i.e. the length of the work-day) for a consumer in region i:

$$L_i = \sum_{od,m,t} h_i \cdot Q_{i,c,od,m,t}$$

The income of a consumer is given as after-tax labour income and lump-sum transfers (O_i). Net income is spent consuming transport and other consumption. tax^L is income tax, w is wage and P^0 and Q^0 are the quantity and price of a non-transport commodity.

$$(1 - tax_i^L)(w_i L_i + O_i) = P_i^0 Q_i^0 + \sum_{p,od,m,t} P_{i,p,od,m,t} \cdot Q_{i,p,od,m,t}$$

The consumer's time is restricted by an initial endowment, $\overline{T}_i$.

$$\overline{T} = N_i + L_i + \sum_{p,od,m,t} T_{i,p,od,m,t} \cdot Q_{i,p,od,m,t}$$

When the consumer spends time on transport (either leisure or commuting) this reduces his time of pure (utility-generating) leisure.

[7] Besides the top nest, we have modelled everything else in the utility tree with CES functions.

The consumer's problem is therefore to maximise his utility function subject to a financial and a time budget and subject to a strict complementarity between labour supply and commuting:

$$\underset{Q^0,Q_{i,p,od,m,t},N_i,L_i}{MAX} \quad u_i = \Psi_i(Q_i^0, Q_{i,n,od,m,t}) + \Gamma(N_i) + \Omega_i(Q_{i,c,od,m,t})$$

sub.

$$(1 - tax_i^L)(w_i L_i + O_i) = P_i^0 Q_i^0 + \sum_{p,od,m,t} P_{i,p,od,m,t} \cdot Q_{i,p,od,m,t} \qquad (\lambda)$$

$$L_i = \sum_{od,m,t} h_i \cdot Q_{i,c,od,m,t} \qquad (\mu)$$

$$\overline{L} = N_i + L_i + \sum_{p,od,m,t} T_{i,p,od,m,t} \cdot Q_{i,p,od,m,t} \qquad (\nu)$$

The solution of the consumer's problem gives the following conditions for leisure and commuting trips:

$$-\frac{\partial \Psi_i / \partial Q_{i,n,od,m,t}}{\partial \Psi_i / \partial Q^0{}_i} + \frac{P_{i,n,od,m,t}}{P_i^0} + \frac{\partial \Gamma_i / \partial N_i}{\partial \Psi_i / \partial Q^0{}_i} \cdot T_{i,n,od,m,t} = 0$$

$$-\frac{\partial \Omega_i / \partial Q_{i,c,od,m,t}}{\partial \Psi_i / \partial Q^0{}_i} + \frac{P_{i,c,od,m,t}}{P_i^0} + \frac{\partial \Gamma_i / \partial N_i}{\partial \Psi_i / \partial Q^0{}_i} \cdot \left(T_{i,c,od,m,t} + h_i\right) = \frac{1}{P_i^o}\left(1 - tax_i^L\right) w_i \cdot h_i$$

The conditions express the fact that the marginal utility of a given leisure trip must equal the cost of the trip in time and money, while the marginal utility of a commuting trip must equal the cost of the trip in time and money, including the time spent working, minus the private income from a working day.[8]

Consumption of transportation generates negative externalities. This includes both the separable externalities (such as noise, pollution and accidents) and the non-separable externality congestion. Congestion is directly included in the consumer's utility function, since congestion increases the time that is needed for a given trip; i.e. there is a feedback effect of congestion. The sepa-

[8] The conditions for commuting trips are parallel to the conditions given in Parry & Bento (2001). Parry and Bento do not include leisure trips.

rable externalities do not influence the behaviour of consumers but have a negative effect on their utility.

Firms and international trade

Firms demand labour at a given wage in each of the regions. They supply other consumption goods. The model is a small open economy, but there is no explicit description of international trade or foreign countries.

Since labour supply can be met in each region, consumers can choose to change the composition of their labour supply to the different regions. This also implies that the location of production and workplaces changes as a result of policy changes. Thus, while residential location is fixed, the workplace location is endogenous.

The model only offers a somewhat incoherent description of production, and firms' demand for freight and passenger transport is not included in the model. An explicit modelling of production would, however, require a major extension of the model, and transportation connected with production comprises only a small proportion of total transportation.

The public sector

The role of the public sector is to supply public transport, finance a fixed public consumption, *G,* and regulate the economy; more specifically, the public sector regulates traffic in the scenarios that we consider in the following. We keep this public consumption constant in all the scenarios and therefore we do not have to take into account how changes in public consumption influence consumers' utility. Wage income is taxed as well as transport and other consumption. The government pays a lump sum transfer to consumers. The government operates subject to a balanced budget restriction.

The government collects taxes to finance public consumption and to regulate traffic. It uses a wide range of taxes: tax on wages, consumption tax and different kinds of transport-related taxes. The transport-related taxes comprise kilometre-based taxes differentiated according to modes of transport. In the scenarios set out the government uses kilometre-based taxes which are differentiated according to time of day, and toll-ring taxes which are differentiated according to mode of transport.

Letting $P_i^0 = p_i^0(1 + vat_i)$ where vat_i is the value added tax, the government's budget restriction is given by:

$$
\sum_i tax_i^L \cdot (w_i \cdot L_i + O_i) + \sum_{i,p,od,m,t} Q_{i,p,od,m,t} \cdot \left(P_{i,p,od,m,t} - \sum_{ii} c_{i,ii,p,od,m,t} \cdot dist_{i,ii,p,od,m,t} \right)
$$
$$
+ \sum_i p^o \cdot vat_i \cdot Q_i^o
$$
$$
= \sum_i O_i + G
$$

The welfare measure
We evaluate the welfare effects of the alternative scenarios using a social welfare function (SWF). Social welfare is defined as the sum of the utilities of consumers (all have identical weights in the SWF). We measure the welfare effect of a proposed policy by equivalent variation for each representative consumer, and add the monetary value of the change in the negative effects of the separable externalities.

3. Calibration and data

Calibration overview
The model is calibrated to the year 2003. A perfect competition general equilibrium is assumed. The model is calibrated to replicate this equilibrium in the base scenario. The calibration is carried out in three steps.

First, wages, tax levels, employment, working hours, transfers, public consumption etc. are calculated using regional macro data. The consumption levels and consumer/factor prices of the specified commodities are also calculated in this step.

Second, the transport system is calibrated using information about consumers' purchase of transportation commodities (trips), capacity utilisation, travel time and speed-flow data. As described below, the transport data are obtained from different sources, but the α's in the speed-flow function are calibrated so that these speed levels are replicated at the 2003 traffic levels. Consumers' time use for transport is calculated by combining the data for speed and trips.

In the third step, the consumers' utility tree is calibrated simultaneously. Information about elasticties is obtained from different sources. Share parameters in the CES functions are calibrated taking the elasticities, the consumption levels and the prices as given.

In the base scenario the model replicates the 2003 economy. In the policy scenarios one or more parameter values are changed (e.g. tax levels) and the result is compared with the base scenario. Data for the model are obtained from a wide range of sources.

Macro data
A number of general economic variables such as labour supply, transfers, and income and commodity taxes were obtained at regional levels using the regionalized national account databases of AKF (Institute of local government studies – Denmark).[9] A table describing the values of core variables for the three regions in the model can be found in Appendix B.

Transportation data
Information on travel behaviour is based on the Danish TU data (Transportvane Undersøgelsen), which are interview-based trip diary data.[10] On the basis of the TU data, the average number of trips by residents, Q, and the average travel distances of these trips were calculated, according to the following factors as defined in section 2: residence (three geographical areas defined above), mode of transport (car, bus, train, cycling/walking), time (peak, off-peak), purpose of trip (commuting, leisure), origin-destination combination of trip (Copenhagen-Copenhagen, Copenhagen-Greater Copenhagen, etc.)

As there are a large number of combinations of these characteristics it was necessary to use TU data from several years (1998 to 2003) instead of only 2003.[11]

To calculate the impact of changes in travel behaviour on changes in traffic we used average capacity utilisation parameters (assumed to be fixed). The TU data were used to calculate the capacity parameters for car use (between 1.1 and 1.6 depending on residence, peak/off-peak and trip purpose). For bus and rail transport the information on average capacity utilisation was calculated on the basis of information from Statistics Denmark, HUR and DSB.

The speed-flow functions, which are necessary to calculate the impact of changes in traffic levels on travel time, and ultimately on congestion externality costs, are based on information from the Danish OTM traffic model cover-

[9] The regionalised data were kindly provided by Bjarne Madsen, AKF. These data are documented in Madsen et al. (2002 and 2005).

[10] More information about the Danish trip diary data (including overall descriptive statistics) can be found at www.dtf.dk.

[11] This was necessary even though the TU data are based on a fairly large sample of respondents (about 16,000 interviews are carried out each year).

ing the areas of Copenhagen and Greater Copenhagen.[12] A simple linear functional form is used, as this has a reasonably good fit between average speed and average traffic for relevant traffic levels.[13] The slope of the speed-flow functions for these two areas was, however, subsequently adjusted, as a recent study suggests that the congestion time loss given by the OTM model is lower than the time loss found for a large number of cars where GPS instruments were installed to measure actual speed (Nielsen 2005). After this adjustment the derived average speeds for Copenhagen were 32.4 kph at off-peak times and 27.2 kph at peak hours.[14] At peak traffic levels this corresponds to a congestion elasticity parameter (percentage change in speed for a percentage change in traffic) of about -0.3 in Copenhagen. In comparison, the congestion elasticity parameters in the stylized studies by Parry and Bento (2001) and van Dender (2003) are -0.9 and -1.0 respectively. These higher congestion elasticities apply to US and Belgian data, and it seems reasonable to presume that congestion in Denmark is at a lower level compared to these countries.

For the last region in the model (Rest of Denmark) there are no comparable speed-flow data, and it is assumed that increases in traffic do not affect speed in this area (i.e. there is no congestion externality). Although there are definitely some levels of congestion in some of the major cities in the "Rest of Denmark", it is also worth noting that only a few of the national motorways outside the Greater Copenhagen area are affected by congestion (The Danish Road Directorate 2005).

Besides congestion, the model includes the marginal external cost from air pollution, CO_2 emissions, noise, accidents and finally costs of wear and tear on infrastructure using cost estimates from the Danish Ministry of Transport (2004). For a close description of the applied values see Appendix B.

[12] This information was kindly provided by Otto Anker Nielsen, Jeppe Husted Rich and Stephen Hansen from the Institute of Traffic and Transport at the Technical University of Denmark.

[13] Note that this relationship applies to the aggregate average speed and traffic volumes. The speed-flow relationships for the different road sections in the underlying OTM traffic model have a different shape. Note also that the linear speed-flow relationship yields a marginal congestion cost that increases exponentially with traffic levels; see in general Newbery (1990) and Maddison et.al. (1996) or the Danish Economic Council (2006) for calculations of the marginal external congestion cost based on the speed-flow functions used for Copenhagen and Greater Copenhagen.

[14] The reduction in speed from off-peak to peak does perhaps appear fairly small. It should, however, be taken into account that the average speed is calculated for all traffic in the areas. Thus, speed for traffic going out of Copenhagen in the morning peak hours is also included. In any case, we consider the speed-flow data used to be the best that are available.

The annualised investment and operating costs of road pricing (GPS based) and toll rings have been calculated using information from a recent Danish study (Wrang et al. 2006).[15] The annual cost of a road pricing system is DKK 510 million, which is considerably greater than the cost of the simpler toll ring technology of DKK 210 million per year.

Consumer system

The prices of and taxes on car use have been calculated by including variable costs (fuel, oil, tyres and repairs), annual costs (insurance and car ownership taxes) and annualised car purchase costs. The car purchase cost is annualised by assuming that the lifetime of a car is 15 years and that a car drives 250,000 km during its lifetime. This yields an average price of DKK 2.59 per km including all taxes, while the price without taxes is DKK 1.22 per km. The fixed car costs are included in order to reflect the long-run cost of car use in a simplified way.[16] Due to the very high car purchase taxes in Denmark, the car purchase cost accounts for a large part of the overall cost per km (DKK 1.09, of which DKK 0.69 is the car purchase tax). As this has important fiscal implications it is important to include the revenue from the car purchase tax in the model. A table with the prices, taxes/subsidies and production costs for the different modes of transport can be found in Appendix B.

Due to the Danish commuting tax deductions, the cost of transportation depends on the purpose of travel, with a lower cost for commuting as compared with leisure travel. Based on a 10 percent sample of the population we have calculated average commuting deductions depending on location of residence.

We turn now to the most important behavioural parameters in the model. The labour supply elasticity used is 0.2. This is composed of a working-hour elasticity taken as 0.1 on the basis of the calculation by Frederiksen et al. (2001), and a participation elasticity of 0.1. It has been shown by Kleven and Kreiner (2005) that these two elasticities can be added together in modelling a linear tax. The substitution elasticities between transportation and consumption on the one hand, and between car use and non-car use on the other, were chosen

[15] Note however that the annualised investment costs have been recalculated using a discount rate of 3 per cent instead of the 6 per cent discount rate applied in Wrang et al. (2006). In addition, Wrang et al (2006) add the marginal cost to public funds when calculating the cost of the different systems. We do not add these costs, as the public fund restriction is explicitly included in the model and accounted for in the welfare measures.

[16] In principle the car ownership and use decision is more complex (see for example Bjørner 1997) and the model could be extended to allow for separate effects on car use and car ownership. However, this is beyond the scope of this paper.

so that the model reflects the price elasticities obtained in empirical studies by Fosgerau et al. (2004), Transportrådet (1999) and Bjørner (1994). The derived own price elasticity of car use is -0.95, the cross-price elasticities between car use and non-car use is 0.35, while the own price elasticity of non-car use (mainly train and bus) is -1.28. The own price elasticity of car use may appear high, but it should be recalled that it applies to a measure of all car costs and not just the variable cost.[17]

The substitution between peak and off-peak travel time was chosen to allow for some (though modest) substitution based on results from the OTM traffic model on the traffic implications of road pricing and toll rings (see Københavns Kommune 2005). The substitution elasticity between workplace locations was determined in a more ad hoc manner, as we have not been able to locate relevant empirical studies. The substitution elasticity was set so that a reduction in the wages (after transportation costs and income tax) in Copenhagen by one percent would reduce the commuting to Copenhagen from Greater Copenhagen by one half a percentage point.

As some of the elasticities are uncertain, a number of experiments have been carried out with different levels of substitution (presented in the following section). It appears that the qualitative conclusions from the study are not contradicted even in the case of substantial changes in the substitution parameters.

4. Model simulations

In this section we first discuss the regulatory instruments analysed, and then present the results. After this, the levels of importance of the uncertainties in the model are quantified in several sensitivity analyses. Finally, a few supplementary analyses are presented.

The regulatory instruments

We analyse two types of road pricing system, a kilometre-based system and a toll ring. The greatest congestion problems in Denmark are in the capital area. We therefore focus on road pricing in Copenhagen and a toll ring around this area.

We take the existing tax system as given, and impose the regulation on the top of this. This implies that inefficiencies in the existing system are also present

[17] The own price elasticity of non-car use is higher than the estimate of -0.7 found in Transportrådet (1999). However, due to the restriction of the nesting, it is not possible to match all the (empirically) observed elasticities.

in the scenarios analysed. The results therefore do not correspond to an ideal solution but are probably closer to a realistic situation.

We focus on two instruments:

- A kilometre-based road pricing system in Copenhagen with a charge of DKK 4 per kilometre in peak hours and DKK 2 per kilometre in off-peak hours.
- A toll ring around Copenhagen with a fee of DKK 40 per passage in peak hours and DKK 20 in off-peak hours.

The toll levels chosen for the toll ring are approximately equal to twice the Stockholm tax level. Our simulations indicate that high taxes are needed to achieve a welfare gain, because of the high fixed costs that are necessary for running the systems. The level of the kilometre-based tax is chosen so that the revenues from the two systems are of approximately the same size. The main differences between the two systems is that the fixed costs of the toll ring are smaller, and that the toll ring does not directly affect the cost of car trips which both start and end either inside or outside the ring. Thus the ring does not directly target the congestion externality, as only some of the relevant car trips are regulated.

We also look at three alternative ways to recycle the revenue. Recycling of the revenue is important, as it can contribute to increasing the labour supply and thereby production and total welfare. We assume that public consumption is unchanged, i.e. that all the net revenue is recycled to consumers. We analyse three types of recycling:

- Reductions of income taxes
- Subsidies to public transport in Copenhagen
- Commuting tax deductions for trips in Copenhagen

The income tax reductions are constructed so that the public balance towards the consumers in each region is unchanged, i.e. the regions where the consumers are most affected by the road pricing also experience the largest reductions in income tax.

Income tax reductions stimulate the labour supply. A welfare gain can be expected because the distortion on the labour market is reduced. Earmarking the revenue to subsidise public transport is widely debated and makes public transport cheaper and therefore more attractive, and can therefore potentially reduce congestion on the roads further. Commuting tax deductions reduce the effects of the road taxes on the total amount of transport but maintain an incentive to switch to non-car modes of transport.

Results

Table 1 summarises the results from using the two instruments with the different recycling schemes.

Tabel 1 Annual welfare gain of alternative road pricing systems in Copenhagen combined with different methods of recycling the revenue[18]

	Income tax reductions	**Subsidises to public transport**	**Commuting tax deduction**
	----------------------	DKK, millions	---------------------
Road pricing	-200	-338	-379
Toll ring	244	109	55

Source: Own calculations with ASTRA.

It can be seen from the table that there is a welfare reduction from using road pricing at the given level, though the loss is only small when revenue is used to reduce income tax. Thus, the gain from the road pricing regulation is smaller than the annualised fixed costs of the system.

There is an annual welfare gain from a toll ring equal to DKK 244 million if the revenue is used for reducing income taxes. The toll ring is to be preferred to a kilometre-based system because of the lower fixed costs.

The difference between the welfare gains from a kilometre-based system and from a toll ring is larger than the difference in system costs. This may seem surprising, as road pricing can be targeted more precisely. However, the greater recycled revenue from a toll ring stimulates the labour supply more via the larger reductions in income taxes. This increases the difference between the welfare effects of the two systems.

The toll ring with a reduction in labour tax decreases road traffic by 6 % in peak hours and 2 % in off-peak hours. The traffic passing the toll ring will be reduced by 9 %. The consumption of transport commodities and the level of externalities will be reduced. There are two opposite impacts on leisure. On the one hand, increased labour supply decreases leisure. On the other hand, the lower level of congestion increases the amount of leisure. In total leisure is increased.

Income tax reductions are the most effective means of recycling the revenue, because of the stimulation of labour supply. Increased labour supply increases c.p. the amount of transportation, and thus increases congestion and other ex-

[18] Note that the welfare results divert from the results in Danish Economic Council (2006). This is due to a correction of the weight of the externalities in the welfare measure. Only the welfare results are affected.

ternalities. These negative effects are, however, more than counter-balanced by the positive effects from increased income.

It is not efficient to use the revenue to subsidise public transport further. One reason is that labour supply is not stimulated as much as with reduced income taxes. Today public transport is heavily subsidised, due to distributional concerns. Increasing these subsidies further will increase the present tax distortion. Similarly, increased commuting tax deductions are not the most effective means of recycling revenue either. Congestion is reduced by less, as the commuting tax deduction makes commuting more attractive; that is to say, the positive effects from the toll ring are reduced. The level of redistribution between consumers with high transport consumption and consumers with low transport consumption is however less with increased commuting tax deduction or subsidies to public transport than it is with income tax reductions.

Table 2 shows the consequences of a toll ring around Copenhagen combined with reduced income taxes.

The largest welfare gain is achieved by consumers living in Copenhagen. They are the most affected by the toll ring, as they experience the largest reduction in congestion and receive the greatest reduction in income tax. However, they also pay the highest total road taxes per capita.

The labour supply increases both in Copenhagen and in Greater Copenhagen. The toll comprises a barrier to labour supply and reduces mobility. However, the effect of recycling the revenue to reduce income taxes increases labour supply, as does the increased speed of traffic. The total effect is an increased labour supply.

The total positive effect on labour supply is not uniform; there are regional differences. Interregional commuting is reduced, but intraregional commuting is increased.

Traffic is only reduced by six percent in peak hours and two percent in off-peak hours. This implies an increase in speed of two percent in peak hours, but there is almost no change in speed in off-peak hours. These changes are rather small.

Other types of transport are affected in several ways. There is a substitution away from cars towards the other modes of transport – the substitution effect. The increased cost of car transport decreases the demand for car transport, which reduces the demand for all transport commodities – the income effect. The increased labour supply increases total demand, including demand for transportation. The demand for bus transport is furthermore affected by the reduced congestion resulting from the smaller number of cars on the road. It is assumed that buses are not taxed at the toll ring, and there will be an increase in the demand for bus transport.

Table 2 Consequences of a toll ring around Copenhagen combined with reduced income taxes. Fee DKK 40 per car in peak hours and DKK 20 in off-peak hours

	Copenhagen	**Greater Copenhagen**	**Rest of Denmark**
	---------- Change, DKK millions ----------		
Welfare	139	93	11
Revenue from taxation	980	1,350	59
	------------- Change, percent -------------		
Consumption of transportation	-2.26	-0.49	-0.02
Other consumption	034	0.29	0.00
Leisure	0.03	0.01	0.00
Externalities	-3.30	-0.60	-0.01
	-------- Change, percentage points --------		
Income tax	-1.0	-0.7	0.0
	------------- Change, percent -------------		
Labour supply, from	0.22	0.16	0.00
Commuting:			
From Copenhagen, to	2.5	-6.1	- a)
From Greater Copenhagen area, to	-6.2	1.9	1.7
From Rest of Denmark, to	- a)	0.2	0.0
Speed (car in Copenhagen)			
Peak hours	1.60	0.17	0.00
Off-peak	0.13	0.02	0.00
Traffic (car in Copenhagen)			
Peak hours	-6.17	-0.63	0.00
Off-peak	-2.42	-0.38	-0.02

a) Excluded from the model due to numerical problems.
Source: Own calculations with ASTRA.

Sensitivity analyses and discussion

The empirical support for some of the elasticities in the demand system is relatively weak. In this section we discuss these weaknesses and quantify their importance.

A labour supply elasticity of 0.2 is assumed in the standard version of the model. This is composed of a working time elasticity of 0.1 and a participation elasticity of 0.1. It is, however, possible that the working time elasticity would not increase transportation correspondingly. This could be the case if the working time per day was increased or if the increased labour supply came from increased skills or increased effort. Changes in the consumer choice of place of residence could reduce transportation. Assuming a labour supply elasticity of 0.1 increases the welfare gain from a toll ring with reduced income taxes to DKK 290 million and does not change the ranking of the different types of regulation.

A wide range of other sensitivity analyses have also been carried out. Table 3 presents the calculated welfare gain with alternative parameter specifications.

Table 3 Welfare effects of a toll ring combined with reduced income taxes with alternative parameter specifications

	Parameter value halved	**Parameter value doubled**
	Welfare change, DKK millions	
Speed-flow function (dspeed/dflow)	29	564
Consumers' elasticity of substitution between:		
Transport – other consumption	210	322
Car use – non–car use	235	260
OD choice, commuting	140	561
OD choice, leisure	231	268
Peak hour travel – off peak travel	203	296

Source: Own calculations with ASTRA.

It is clear from the table that changes in the assumed elasticities of substitution in the consumer demand system affect the resulting welfare changes from a toll ring. However, none of the alternative specifications change the overall result that there is a positive net benefit from a toll ring. This result also holds for significant changes in the speed-flow relationship. As expected, greater flexibility in either demand or the speed-flow relationship would result in greater welfare gains from a toll ring.
The effects of regulation on the level of traffic depend on the chosen nesting structure in the demand system. The nesting structure in our model is similar to the structure used in the existing literature but is extended somewhat. This structure with very deep nests implies, however, that transportation types are generally complements. Other demand structures could result in greater substitution between types of transport. It is, however, a major task to change the structure of the demand system, as the connection between commodity consumption and time use means that the standard stepwise modelling of the CES functions cannot be used. Thus, this is an area for further work on the model.

The road tax levels are chosen on the basis of the Stockholm experiences. These, however, are not the levels that maximize welfare in the model. Varying the tax used in the model indicates that the toll that maximizes the welfare gain is larger than the DKK 20 and 40 used in table 1. There are, however, costs that are not included in the model. A toll ring would create a more separated labour market, with larger matching problems and less labour market competition. Commodity markets would also be more separated, possibly reducing competition. These negative effects would be expected to increase with increasing fees. Higher fees than used in table 1-3 are therefore not necessarily appropriate even though a higher level is indicated by the model.
Both road pricing and investments in infrastructure reduce congestion. Infrastructure investments reduce the marginal value of road pricing, and vice versa. This implies that the two instruments cannot be viewed separately but should be included simultaneously in a model analysis. This is theoretically possible in ASTRA, but it requires that the link between relevant potential infrastructure investments and the manner in which they affect the speed-flow relationship is known. This knowledge can be obtained with traffic models but requires several detailed analyses – analyses which have not yet been systematically carried out. The analyses made using ASTRA are for a fixed level of infrastructure. This means that the ASTRA results overestimate the potential gain from road pricing if the amount of infrastructure is less than the optimal, and underestimate the gain if the amount of infrastructure is greater than the optimal (De Borger and Wouters 1998 and Proost 1997).

Finally, a completely open economy is assumed. This may not be very realistic. A more detailed description of the effects on industries, trades and services and commodity markets would be an obvious next step. This description should also include the transport used by industries, trades and services. The exclusion of this type of transport probably reduces the welfare gain indicated by the model for both road pricing systems.

Supplementary analyses
In the long term, economic growth will increase the demand for transportation. Assume that economic growth has increased labour productivity by 20 percent (modelled as an increase in the pre-tax wage of 20 percent). This increases the demand for transportation and consequently the need for regulation. Assume also that the fee at the toll ring is increased by 20 percent. A toll ring combined with reduced income taxes will in this case give an annual welfare gain of DKK 372 million. Kilometre-based road pricing will now result in a welfare gain of DKK 50 million.

Technological development will probably reduce the costs of kilometre-based road pricing. The necessary GPS technology is already installed in several new cars and it is expected to become standard equipment in most cars in the future. The annual welfare gain from a kilometre-based system combined with income tax reductions would be DKK 361 million if it is assumed that the fixed costs of kilometre-based road pricing are halved. That is a gain very similar to the gain from a toll ring.

It is clear from the above that the fixed costs associated with road pricing reduce the net benefit substantially. Increased petrol taxes could be an alternative that has practically no fixed costs. This instrument cannot be targeted towards congestion problems in specific areas, but it can reduce externalities in general and may create less distortion than income taxes.[19] Analyses in Danish Economic Council (2006) indicate that the average taxation of cars is less than the marginal value of externalities in urban areas but greater in rural areas. Transport should be taxed both because of the externalities (a Pigou argument) and because of the public revenue (a Ramsey argument). Car transportation in urban areas is therefore under-taxed, but it is uncertain whether this is the case for rural areas.

Analyses with ASTRA indicate that an increase in the taxation of cars by DKK 0.50 per kilometre would result in a welfare loss of DKK 219 million per year if the revenue were used to reduce income taxes. Lower taxes would also produce a welfare loss, while a very small tax increase would result in a very small welfare gain. This indicates that the present tax level is close to optimal if a uniform kilometre tax is the only instrument.

Public transport is heavily subsidised. A reduction in these subsidies might therefore be beneficial, using the same arguments as for cars. Analyses with ASTRA show, however, that reducing subsidies to public transport by DKK 0.50 per kilometre only creates a welfare gain of DKK 7 million per year, i.e. almost no gain. The gain would, however, increase if the subsidises were reduced further.

We have also used the model to make cost effectiveness analyses of hypothetical infrastructure investments. It is possible to calculate the benefit from infrastructure investments that reduce average speed in a region by varying the α's in the speed-flow function. We do not know the costs of such infrastructure investments, and further work should be done before the model can be used for cost-benefit analyses of specific infrastructure investments. If an investment increases α by one percent, traffic will increase, and as a result the average speed will only increase by 0.9 per cent. In total this will lead to an

[19] Cross-border trade in petrol might, however, reduce the gain from increased petrol taxes. This effect is not included in the model.

annual increase in welfare by DKK 701 million. Assuming that investment has a life-time of 30 years and that the rate of discount is 3 percent, there would be a positive welfare gain if it were possible to increase α by 1 percent by investments with a net present value of DKK 14 billion (DKK 11 billion with a rate of discount equal to 5 percent). This result can be compared with results from traffic models that calculate the effects from specific investments in infrastructure.

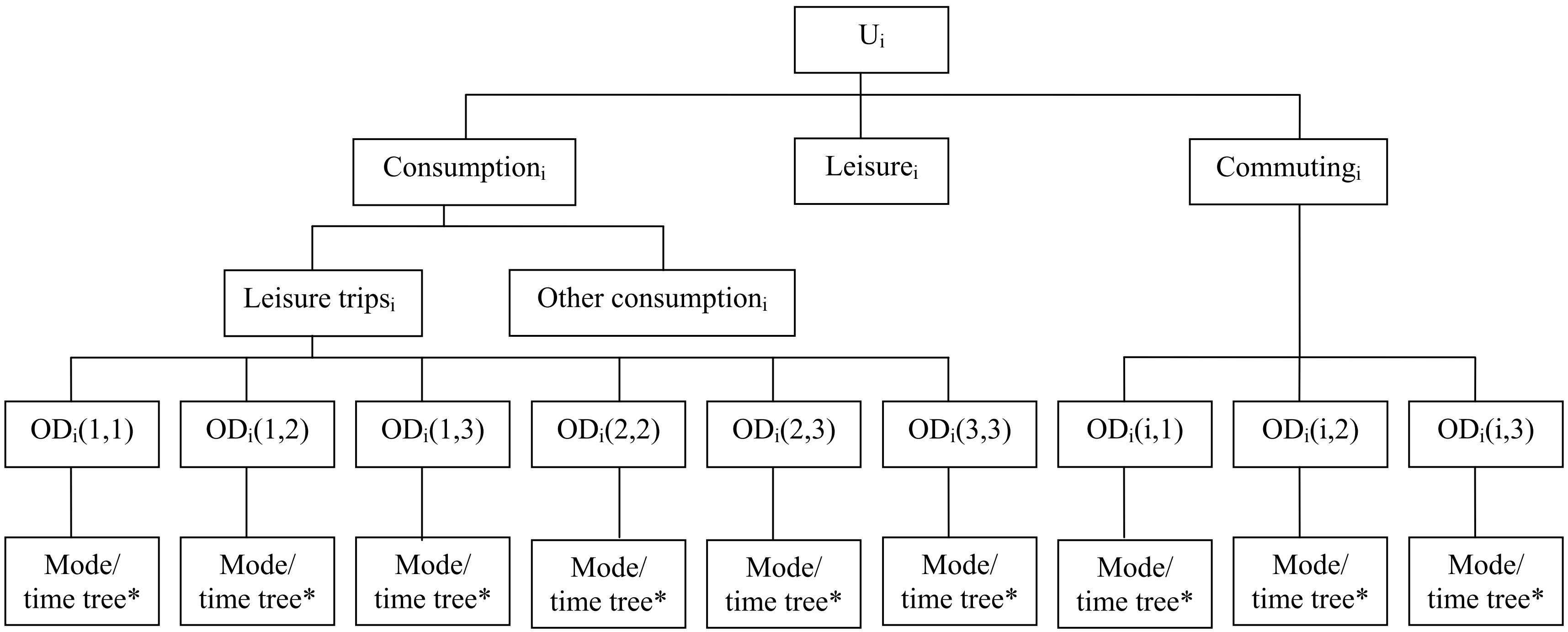
5. Conclusion

We have constructed a model for transport in Denmark with special focus on regulation of congestion and the derived labour market effects.

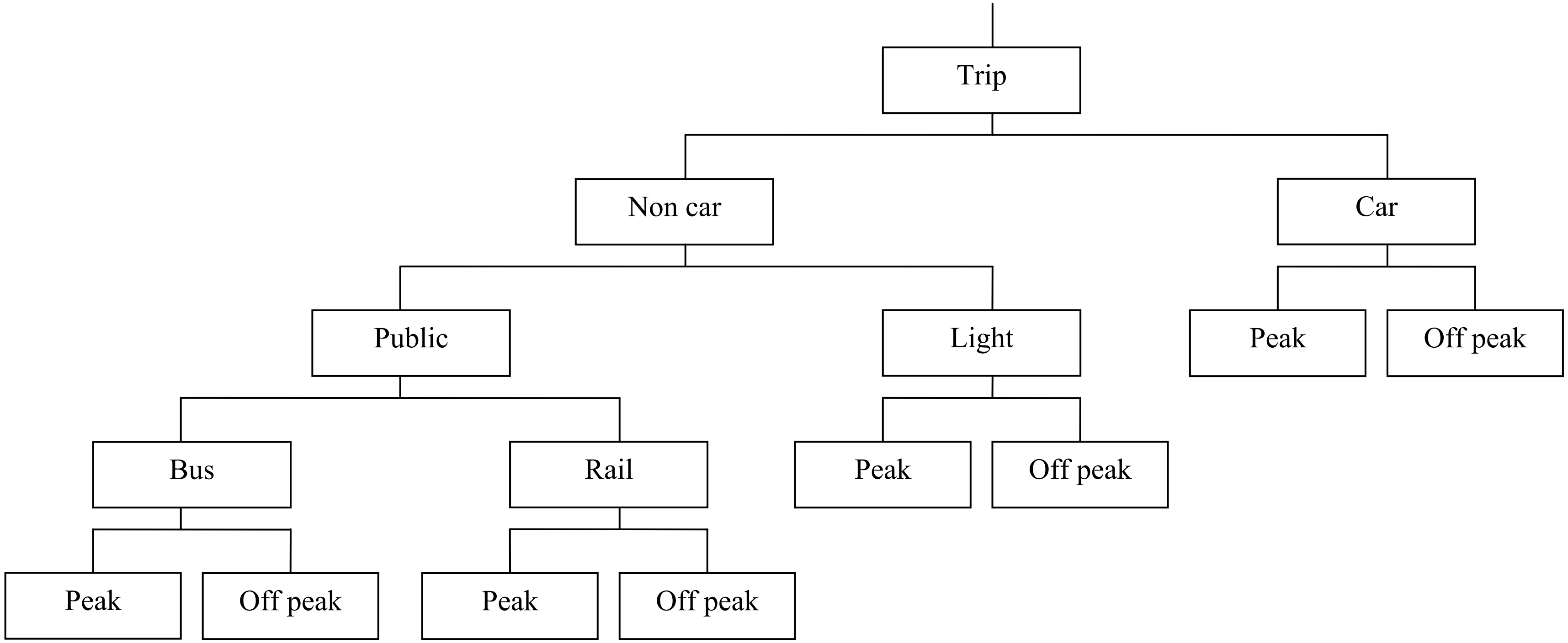
Our main finding is that there would most probably be a gain from a toll ring around Copenhagen, and that the greatest gain would be obtained if the revenue were used to ease income taxes. This is the case because of the increased labour supply resulting from the eased income taxes. Alternative uses of the revenue such as increased income tax deduction for commuting costs or increased subsidies to public transport would also result in positive welfare effects, but at a lower level. The gain thus increases with growth, and could therefore be expected to increase over time. The empirical basis for the estimation of parts of the demand system is somewhat uncertain, but a wide range of sensitivity analyses indicate that the above qualitative results are not contradicted if other levels of demand and congestion parameters are used.

A kilometre-based road pricing system produces a negative welfare effect in the standard specification of the model. Alternative specifications of the model generate a positive gain in some cases, but a toll ring gives the highest welfare gain. The primary reason for this is the high fixed costs associated with a kilometre-based road pricing system. The price of the necessary GPS technology that would be needed for the kilometre-based road pricing system is expected to fall over time. In this case, the road pricing instrument may of course become the overall best instrument.

Appendix A. Consumers' utility nesting structure



* For each trip the mode/time tree is as shown on the next page.



Note: This tree is included for each OD combination for each consumer and for each purpose.

Appendix B: Further description of the applied data

In table B.1 the values (by region) of a number of central input variables can be found. Not surprisingly it appears from the table that the share of non-car increase with increasing levels of urbanisation.

Table B.1 Value of central variable by region

	Copenhagen	**Greater Copenhagen**	**Rest of Denmark**
	-----------	Billion DKK (2003 level)	-----------
Primary Income	77.7	184.6	432.0
Income tax	38.8	90.1	194.1
Transfers	22.9	35.8	115.5
Commodity tax	18.6	30.7	82.8
	------------	Million persons (adults)	------------
Residents	0.49	0.94	2.73
		Billion hours per year	
Labour supply	0.54	1.15	3.18
	---	Billion person kms in region (per year)	---
Car	1.29	7.54	26.76
Bus	0.38	0.43	1.30
Train	0.49	1.60	1.84
Light	0.59	0.53	1.58

Source: TU data, AKF and own calculations.

The monetary values of the marginal external cost from air pollution, CO_2 emission, noise, accidents and finally tear and wear infrastructure cost are based on estimates from the Danish Ministry of Transport (2004). Here, a distinction is made between the marginal external cost in urban and rural areas, which, however, not directly conform to the three zones in the model. It is therefore assumed that the external cost of urban areas apply to Copenhagen and Greater Copenhagen, while the rural externality cost apply to the rest of Denmark. With respect to the external cost of noise it was, however, possible to obtain marginal cost estimates corresponding to the geographical areas of the model (see table 5.3 in the Danish Ministry of Transport, 2004). This is important, as noise is the most important contributor (apart from perhaps congestion) to geographical differences in the overall value of the marginal external cost of traffic.[20] The applied marginal external cost (not including congestion) can be seen in table B.2.

[20] With respect to noise it should, however, also been noted that the noise valuation method applied in the Danish Ministry of Transport (2004) have been criticized for severely exaggerating the cost of noise, see Bjørner og Lundhede (2003).

Table B.2 Marginal external cost (not including congestion), DKK per km. (2003 price level)

	Copenhagen	**Greater Copenhagen area**	**Rest of Denmark**
Car (gasoline)	1.09	0.49	0.17
Bus (diesel)	5.10	2.86	1.00
Train	17.46	18.63	11.50

Source: Danish Ministry of Transport (2004), Danish Ministry of Transport and Environment (2006) and own calculations.

The price and taxes/subsidies of the different modes are summarised in table B.3. The prices and taxes for car use have been calculated by including variable cost (fuel, oil, tires and repair), annual cost (insurance and car ownership taxes) and annualised car purchase cost. The car purchase cost is annualised by assuming that the lifetime of a car is 15 years and that cars drive 250.000 km during their lifetime. For bus and train the values are calculated using account information from HUR, DSB, DSB S-tog and information from Statistics Denmark. In the calculation of the average cost for train use, the infrastructure maintenance cost where not included, as these cost are not included for the other modes. The cost associated with walking/bicycling are assumed to be equal to half of the government mileage allowance for bikes and mopeds. It appears from table B.3 that the production cost of a bus passenger km is higher in densely populated areas. Initially, this may appear surprising, but bus trips in Copenhagen are also shorter and slower, and it is reasonable that it is cheaper to produce bus kilometres in rural areas, where speed is high and trips are longer.

Table B.3 Market price and production costs of modes, DKK per km. (2003 price level)

Mode		**Copenhagen**	**Greater Copenhagen**	**Rest of Denmark**
Car	Production cost	1.22	1.22	1.22
	Tax/subsidy	1.37	1.37	1.37
	Market price	2.59	2.59	2.59
Bus	Production cost	3.08	2.59	1.14
	Tax/subsidy	-1.44	-1.44	-0.50
	Market price	1.64	1.15	0.61
Rail	Production cost	1.68	1.52	1.20
	Tax/subsidy	-0.80	-0.72	-0.55
	Market price	0.88	0.80	0.65
Light	Production cost	0.20	0.20	0.20
	Tax/subsidy	0.05	0.05	0.05
	Market price	0.25	0.25	0.25

Source: HUR, DSB, DSB S-tog, Statistics Denmark, the Danish Road Directorate and own calculations.

The Danish kilometre based commuting tax deduction yields a wedge between the actual price of commuting and leisure transport. A matrix of average commuting deduction per km for the different regions can be found in table B.4. The after tax value of the commuting deduction rates is on average 33 per cent (average of the relevant tax rate) of the values in the table. As the commuting tax deduction is a piecewise linear function of the commuting distance the average commuting deduction can only be calculated using the distribution of commuting distances of commuters in different regions. This calculation has been carried out using a 10% sample of the population and the commuting deduction rates for 2003.

Table B.4 Average tax deduction rates, DKK per km (2003 level)

		Commuting to:		
		Copenhagen	**Greater Copenhagen**	**Rest of Denmark**
Commut- ing from:	Copenhagen	0.00	0.45	0.96
	Greater Copenhagen	0.69	0.53	0.96
	Rest of Denmark	1.00	1.00	0.62

Source: Own calculation based on a 10 percent sample of the Danish population.

Literature

Arnott, R. (2005): City Tolls – One Element of an Effective Policy Cocktail. *CESifo DICE Report 3/12*, pp. 5-11.

Bjørner, T.B. (1994): *Persontransport med bil*. AKF-memo. AKF Forlaget, København.

Bjørner, T.B. (1997): En økonomisk model for bilejerskab og bilkørsel. *Nationaløkonomisk Tidsskrift, 135 (3)*, pp. 233-250.

Bjørner, T.B. og T.L. Lundhede (2003): Prisen på stilhed 25 år senere. *Nationaløkonomisk Tidsskrift, 141*, pp. 279-299.

Danish Economic Council (2006). *Danish Economy, spring 2006*. Copenhagen.

Danish Ministry of Transport (2004): *External Costs of Transport. 2nd report – Marginal External Cost Matrices for Denmark*. Report conducted by COWI for the Danish Ministry of Transport, July 2004. Copenhagen.

Danish Ministry of Transport and Environment (2006): *Nøgletalskatalog – til brug for samfundsøkonomiske analyser på transportområdet, 2004*. Revideret udgave. København.

Danish Road Directorate (2005). *Statsvejnettet – Oversigt over tilstand og udvikling. Report no. 301*. Copenhagen.

De Borger, B., I. Mayeres, S. Proost and S. Wouters (1996): Optimal Pricing of Urban Passenger Transport. *Journal of Transport Economics and Policy, 30 (1)*, pp. 31-54.

De Borger, B. and S. Wouters (1998): Transport Externalities and Optimal Pricing and Supply Decisions in Urban Transportation: A Simulation Analysis for Belgium. *Regional Science and Urban Economics*, *28 (2)*, pp. 163-197.

Fosgerau, M., M. Holmblad og N. Pilegaard (2004): ART – En aggregeret prognosemodel for dansk vejtrafik. *Notat 5. Danmarks Transportforskning*. København.

Frederiksen, A., E.K. Gravesen and N. Smith (2001): Overtime Work, Dual Job Holding and Taxation. *IZA Discussion Paper no. 323.* The Institute for the Study of Labor, Bonn.

Glaister, S. and D. Lewis (1978). An Integrated Fares Policy for Transport in London. *Journal of Public Economics. 9(3)*, pp. 341-55.

Kleven, H.J. and C.T. Kreiner (2005): Labor Supply and the Design of Tax and Transfer Policy. *Nationaløkonomisk Tidsskrift 143(3)*, pp. 321-358.

Knudsen M. B. L. H. Pedersen, T.W. Petersen, P. Stephensen and P. Trier (1998): *Danish Rational Economic Agents Model – DREAM, version 1.2*. Copenhagen.

Københavns Kommune (2005): *Kørselsafgifter i København*. Copenhagen.

Maddison, D.; D. Pearce, O. Johansson, E. Calthrop, T. Litman and E. Verhoef (1996). *The True Costs of Road Transport*. Earthscan, Newcastle.

Madsen, B. and C. Jensen-Butler (2005): Spatial Accounting Methods and the Construction of Spatial Accounting Matrices. *Economic Systems Research, 17 (2),* pp. 187-210.

Madsen, B., C. Jensen-Butler and P.U. Dam (2002): *A Social Accounting Matrix for Danish Municipalities (SAM-K)*. AKF Forlaget, København.

Munk, K.J. (2003): Computable General Equilibrium Models and Their Use for Transport Policy Analysis, *Report 4. Danmarks Transportforskning*, Lyngby.

Newbery, D.M. (1990): Pricing and Congestion: Economic Principles Relevant to Pricing Roads. *Oxford Review of Economic Policy, 6 (2)*, pp. 22-38.

Nielsen, O.A. (2005): *Trængselsprojektet – Modellering af trængsel*. Center for Trafik og Transport, København.

Parry, I.W.H. and A. Bento (2001): Revenue Recycling and the Welfare Effects of Road Pricing. *Scandinavian Journal of Economics, 103 (4)*, pp. 645-671.

Parry, I.W.H. and K.A. Small (2005): Does Britain or the United States Have the Right Gasoline Tax? *American Economic Review, 95 (4)*, pp. 1276-1289.

Proost, S. and K. van Dender (2001). The Welfare Impacts of Alternative Policies to Address Atmospheric Pollution in Urban Road Transport. *Regional Science and Urban Economics, 31(4)*, pp. 383-411.

Prud'homme, R. and J. Bocarejo (2005): The London congestion charge: A tentative economic appraisal. *Transport Policy 12*, pp. 279-87.

Transportrådet (1999): *PETRA – Analysemodel for persontransport*. Notat nr. 6-99. Copenhagen.

van Dender, K. (2003): Transport Taxes with Multiple Trip Purposes. *Scandinavian Journal of Economics, 105 (2)*, pp. 295-310.

Wrang, K., U. Nielsen and M. Kohl (2006): *Kørselsafgifter i København – en samfundsøkonomisk analyse*. Report from the Environmental Assesment Instiutte (IMV), Copenhagen.

Working Papers from Danish Economic Council, Secretariat

2001:5 Jakob Roland Munch and Michael Svarer: *Rent Control and Tenure Duration.*

2001:6 Steen Jørgensen: *Analyser af indkomstfordeling.*

2001:7 Jan V. Hansen, Jens Hauch and Mikkel T. Kromann: *Will the Nordic Power Market Remain Competitive?*

2002:1 Anders Frederiksen og Jan V. Hansen: *Skattereformer: Dynamiske virkninger og fordelingseffekter.*

2002:2 Jakob Roland Munch: *Har kommunal skat og service betydning for flyttemønstrene?*

2002:3 Svend Jespersen: *Den erhvervspolitiske værdi af støtten til den danske vindmølleindustri.*

2002:4 Jacob Krog Søbygaard: *Cost-benefit-analyser af energipolitik samt energi- og transportafgifter.*

2003:1 Svend Jespersen: *Dokumentation for analyser af erhvervsstruktur og produktivitetsvækst*.

2003:2 Michael Svarer, Michael Rosholm and Jakob Roland Munch: *Rent Control and Unemployment Duration.*

2003:3 Jakob Roland Munch, Michael Rosholm and Michael Svarer: *Are Home Owners Really More Unemployed?*

2003:4 Jakob Roland Munch: *Are Skills Firm-Specific? Evidence From Danish Micro Data.*

2004:1 Svend Jespersen, Jakob Roland Munch and Lars Skipper: *Costs and Benefits of Danish Active Labor Market Programs.*

2004:2 Thomas Bue Bjørner, Jens Hauch og Svend Jespersen: *Biodiversitet, Sundhed og Usikkerhed – En værdisætningsanalyse ved contingent ranking metoden.*

2005:1 Christian Dahl, Henrik Hansen og John Smidt: *Makroøkonomiske forudsigelser baseret på diffusionsindeks.*

2006:1 Jens Hauch, Ninette Pilegaard and Thomas Bue Bjørner: *Transport Regulation Analysed in a Danish Equilibrium Model.*