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Transport Regulation Analysed in a Danish Equilibrium Model

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Abstract:
We present a static comparative equilibrium model for road pricing in Denmark. The model analyses the joint problem of 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 commuting tax deduction). We find that the largest gain will arise from a combination of a toll ring and eased income taxes. Kilometre based road pricing is less beneficial as 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 inclusion of several regions, more modal possibilities, regionalised labour supply, modelling of a toll ring, peak/off peak substitution and inclusion of system costs

Keywords: Transport, congestion, road pricing, labour market

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[2] The views posed in this paper are not necessarily shared by the chairmanship of the Danish Economic Council.

1. Introduction

Due to high car taxes transport congestion problems in Denmark seem to have been less severe as compared to a number of other European countries. However, traffic levels have been growing steadily over the past decade and there have been increased focus on the congestion problems especially in Copenhagen. For example, traffic volumes in Copenhagen have increased by 17 percent since 1990 while speed seem to have decreased at the same rate, see the Danish Economic Council (2006). Congestion indicators also suggest a severe increase in congestion on the motorways around Copenhagen, see the Danish Road Directorate (2005). Finally, a resent study by Nielsen (2005) showed 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 traveler does not in his trip decision take into account, that his trip will reduce the speed of other travelers. 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 as only recently road pricing have become an option from a technological point of view and it is still more expensive. London and Stockholm are recent examples of large cities using such instruments. It has, however, also been pointed out by some economist that the expectations with respect to the benefits of road pricing or toll rings may be exaggerated. In an early evaluation of the London scheme Prud'homme and Bocarejo (2005) found that the benefits of the system was considerably lower than the cost (especially due to high implementation and investment cost). In addition, optimal regulation reduces, but does not necessarily eliminate congestion.[3] Thus, given that private car travel is already heavily taxed in Denmark, the above noted 120.000 daily hours lost in congestion could in principle reflect an optimal regulation level (or be too small!).

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 operation cost associated with road pricing and toll rings schemes. Second, there are a number of other externalities associated with traffic (noise, air pollution, barrier effects etc), which also should be taken into account. Third, road pricing will have effect on the income distribution

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[3] 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.*"

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 with inelastic demand elasticities should be taxed relatively high as this will create less distortion. As an example related to the Ramsey argument, indirect effect on the labour market may be important. About a third of the transport is commuting or work related. A tax on commuting transport will indirectly serve as an additional tax on the already highly taxed labour supply and lead to lower labour supply. Leisure transport, on the other hand, is a complement to the untaxed leisure time. This suggests that commuting transport should be taxed less than leisure transport, see Van Dender (2003) and Munk (2003). This is the efficiency rationale for the Danish commuting tax deduction.[4] An optimal level of road pricing will also depend on the will to modify other transport related taxes and subsidies. One of the economic efficiency arguments for subsidizing urban public transport has been that it earlier was not technically feasible to tax private urban traffic higher than rural traffic. Giving this technical restriction in the available policy instruments, subsidies to urban public transport may have been a good second best instrument, see Glaister og Lewis (1978). However, in the first best 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).[5]

A number of earlier contributions 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 e.g. De Borger et al. (1996) and Proost and van Dender (2001). Another more recent line of contributions include 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 larger welfare implication than the benefits steaming 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

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[4] However, in the long run a lower tax on commuting could lead to a not optimal localization pattern. Thus, there is a trade off between the short run flexibility of the labour market (low tax on commuting) and the consideration for a optimal localization pattern (high tax on commuting).

[5] There may of course be income distributive arguments for subsidizing public transport, but it should also be noted that subsidies to public transport may not be a very fine tuned instrument for achieving a certain distributive target.

distortionary tax on labour. The models in the later studies are, however, very stylized with only a simple description of the transport demand system.

The contribution of this paper is to combine such type of model labour supply model 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 distributive 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 ring in the model. As the system cost of a toll ring is lower than for road pricing the net revenue of the toll rings tend to be larger than for the road pricing system. It appears from Parry and Bento that the size of the net revenue can not 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 target 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 – 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 transport. Consumers are allowed to substitute between different modes and between traveling in the peak or at non peak. Congestion is explicitly modeled using a speed flow function, while geographically differentiated marginal cost of other externalities are also 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 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 model suggests that there will 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 relative high annualized 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. Contrary to this point of view, the model shows that the welfare benefits of the toll ring will be substantially higher, if the revenue is used to reduce the income tax instead of subsidizing public transport. Finally, in the absence of a toll ring – a situation similar to the current regulation regime in Denmark – there is a welfare gain by a further increase in the high car use taxes, i.e. an increase in the tax on car use both in rural and urban areas.

In the following section the model is presented. Input data and model calibration is described in section 3, while results of 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 collect different kinds of taxes, subsidise public transport, finances fixed government consumption and pays a lump sum transfer to all consumers. The public sector operates under budget balance. There is no explicit description of the firms or international trade. Firms demand labour to a fixed wage and supplies goods and commodities to a fixed price. With this formulation the model can be interpreted as a fully open economy. In the modelling of the transport system, we include 4 transport modes (car, bus, train and cycling/walking) and there is a distinction between peak and non peak travel, and between commuting and leisure transport. Congestion on roads is included using an aggregated speed-flow function for each region. In addition to congestion, we include geographically differentiated marginal external cost of externalities like noise, air pollution and accidents. Labour supply is determined via substitution between leisure and consumption subject to both money and time budget constraints. Finally, we include the annualized cost of road pricing and toll rings. There is no description of freight transport.

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

The transport system

The consumers demands 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 represent the geographical location (residence) of the consumer: $i \in \{$Copenhagen, Greater Copenhagen, Rest of Denmark$\}$[6]. Index p represent the purpose of the trip, $p \in \{$commuting (c), leisure (n)$\}$, index m rep-

[6] 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.

resent the transport mode, $m \in$ {car, bus, rail, light (bicycle/walking)}, index t represent time, t$\in$ {peak, off-peak} and index od represent the origin and the destination of the trip.

Origin and destination represent the same three geographical zones as the residence index and therefore, there are potentially 9 different *od* combinations. However, we treat trips on a given *od* destination symmetric independent of where the trips start leaving only 6 *od* combinations. Furthermore, commuting trips are only relevant if the region of residence is part of the *od* and 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 at the od-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 a simple summarization 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 as:

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

i.e. road traffic consists of cars and busses and busses weights twice as much as cars in our definition of the road traffic.

The speed, $S_{ii,m,t}$ for car and bus 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 (motivation for this is partly lack of data, see section 3). It is similarly assumed that congestion does not affect the speed of train and light transport in any of the regions and the speed is therefore exogenous for these modes, i.e.

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

Transport implies two types of costs, a monetary cost and a time cost.

Define the time use per trip, $T_{i,p,od,m,t}$ for consumers living in region *i*. This time is composed of 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 region *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 due to a tax deduction instrument for commuting trips (as is currently applied in Denmark). *toll* is the fee for passing toll rings.

Traffic implies 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 and region. We assume further that the consumers can attach a monetary value to the externalities independently on other variables in the consumption system. The value to consumers in region *i* of externalities, E_i is therefore give 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 in each region.

The representative consumer

Besides transport, the representative consumer in each region consumes pure leisure and other consumption. [7]

The consumer chooses his labour supply and pure leisure consumption as well as his composition of consumption between other consumption and leisure trips. The consumer has different preferences for leisure trips to dif-

[7] Other consumption covers every thing else than transport that the consumer can spend money on.

ferent 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 non peak 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 he chooses the transport mode and whether to leave at peak or non peak for each commuting trip. The trips (leisure and commuting) are tied together to utility units by a nested CES-function as well as other consumption and leisure trips are tied together in a CES function (see the figure in Appendix A).

The utility function of the representative consumer is given by[8]:

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

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 subutility function Ω allows commuting transport modes to be imperfect substitutes.[9]

Note that the model focuses on the economic consequences of transport and labour market related policies. Therefore, the description of 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 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 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 the consumer in region i:

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

[9] Besides the top nest we have modelled every thing else in the utility tree with CES functions.

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

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 is the quantity and price of a non transport commodity.

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

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.

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

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

$$sub.$$

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

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

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

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

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

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

The conditions express 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 of a working day.[10]

Consumption of transport 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 feed-back effect of congestion. The separable externalities do not influence the behaviour of the consumers but have a negative effect on their utility.

The firms and international trade

The firms demand labour to 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 the consumers can choose to change their composition of 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 the firms demand for freight and passenger transport is not included in the model. An explicit modelling of the production implies, however, a major extension of the model and this transport comprises only a minor part of the total transport.

The public sector

The role of the public sector is to supply the public transport, finance a fixed public consumption, *G,* and regulate the economy; more specific 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 the consumers' utility. Wage income is taxed as well as transport and other consumption. Furthermore, the government pays a lump sum transfer to the consumers. The government operates subject to a balanced budget restriction.

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[10] The condition for commuting trips are parallel to the condition found in Parry & Bento (2001). Parry and Bento does not include leisure trips.

The government collects taxes to finance the public consumption and to regulate traffic. It uses a vide range of taxes; wage-tax, consumption tax and different kinds of transport-related taxes. The transport related taxes covers km-based taxes differed according to modes. In the scenarios the government further introduces km-based taxes differed according to time of the day and toll-ring taxes differentiated according to mode.

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. Social welfare is defined as the sum of the utilities of the consumers (all have identical weight in the SWF). We measure the welfare effect of the proposed policy with the equivalent variation and add the monetary value of the change in the negative effect from 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 takes place in three steps:

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

Secondly the transport system is calibrated using information about the 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 with 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' demand/utility tree is calibrated simultaneously. Information about elasticties are obtained from different sources. Share parameters in the CES functions are calibrated taking the elasticities, the consumption levels and 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. The model distinguishes between 3 geographical areas; *Copenhagen* (defined as the municipalities of Copenhagen and Frederiksberg), *Greater Copenhagen* (counties of Copenhagen, Frederiksborg and Roskilde) and *Rest of Denmark.*

Macro data
A number of general economic variables like 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).[11] A table describing the value of core variables by the three regions in the model can also be found in appendix B.

Transport data
Information on travel behaviour is based on the Danish TU data (Transportvane Undersøgelsen), which are interview based trip diary data.[12] Based on the TU-data the average number of trips of residents, Q, (and average travel distance of these trips) was calculated subject to the following characteristics defined in section 2: Residence (3 geographical areas defined above), mode (car, bus, train, cycling/walking), time (peak, non-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.[13]

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[11] The regionalized data were kindly provided by Bjarne Madsen, AKF. These data are documented in Madsen et al. (2002 and 2005)
[12] More information about the Danish trip diary data (including overall descriptive statistics) can be found on www.dtf.dk.

[13] 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).

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

The speed-flow functions, which are necessary to calculate the impact of changes in traffic levels on the travel time and ultimate the congestion externality costs, are based on information from the Danish OTM traffic model covering Copenhagen and Greater Copenhagen.[14] A simple linear functional form is used as this has a reasonably good fit between average speed and average traffic for relevant traffic levels.[15] The slope of the (area) speed flow functions were, however, subsequently adjusted as a resent study suggest that the congestion time loss of the OTM model is lower than the time loss found for a large number of cars, where GPS were installed to measure actual speed, see Nielsen (2005). After this adjustment the derived average speeds for Copenhagen were 32.4 kph in non-peak and 27.2 kph in peak.[16] At peak traffic levels this corresponds to a congestion elasticity parameter (percentage change in speed for a percentage change in traffic) at about -0.3 in Copenhagen. In comparison the congestion elasticity parameter of the stylized studies by Parry and Bento (2001) and van Dender (2003) are respectively -0.9 and -1.0. 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. no congestion externality). Although there are definitely some level of congestion in some of the major cities in the "rest of

[14] 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.

[15] 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 marginal congestion cost that increase exponentially with traffic levels, see in general Newbery (1990) and Maddison et.al. (1996) or the Danish Economic Council (2006) for calculation of the marginal external congestion cost based on the applied speed flow functions for Copenhagen and Greater Copenhagen.

[16] The reduction in speed from non-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 is also included. In any case, we consider the applied speed flow data as the best that are available.

Denmark" it is also worth noting, that only few of the national motorways outside the Greater Copenhagen area are affected by congestion, see the Danish Road Directorate (2005).

Besides congestion the model include the marginal external cost from air pollution, CO_2 emission, noise, accidents and finally tear and wear infrastructure cost using cost estimates from the Danish Ministry of Transport (2004). The values are described in appendix B.

The annualised investment and operation cost of road pricing (GPS based) and toll rings have been calculated using information from a resent Danish study, see Wrang et al. (2006).[17] The annual cost of a road pricing system is 510 million DKK, which is considerably larger than the cost of the simpler toll ring technology, which is 210 million DKK a year.

Consumer system

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 car drive 250.000 km during their lifetime. This yields an average price at 2.59 DKK per km including all taxes, while the price without taxes is 1.22 DKK per km. The fixed car costs are included in order to reflect long run cost of car use in a simplified way.[18] Due to the very high car purchase taxes in Denmark the car purchase cost account for a high share of overall user cost per km (1.09 DKK of which 0.69 is the car purchase tax). As this has important fiscal implications it is important to include the revenue of the car purchase tax in the model. A table with the price, taxes/subsidies and production cost of the different modes can be found in appendix B.

Due to the Danish commuting tax deductions the transport cost depends on the purpose of travel, which 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 (also described in appendix B).

With respect to the most important behavioural parameters in the model the applied labour supply elasticity is 0.2. This represents a composition of a

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

[18] In principle the car ownership and use decision is more complex (see e.g. 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.

working hour elasticity of 0.1 based on 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, when a linear tax is modelled. The substitution elasticities between transport and consumption on the one hand and between car and non car on the other were chosen so the model reflects 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 and non car is 0.35, while the own price elasticity of non car (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 cost not just the variable cost.[19]

The substitution between peak and non-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 more ad hoc as we have not been able to locate relevant empirical studies. The substitution elasticity was set such that a reduction in the wage (after transport cost and income tax) in Copenhagen by one percent would reduce the commuting to Copenhagen from Greater Copenhagen with a half percent. 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 violated even for large changes in the substitution parameters.

4. Model simulations

In this section we first discuss the analysed regulatory instruments. Then we present the results. After this the importance of the uncertainties of 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 systems, a kilometre based system and a toll ring. The largest congestion problems in Denmark are in the capital area. Therefore we focus on road pricing in Copenhagen and a toll ring around this area.

[19] With respect to the own price elasticity of non car use this is higher than the estimate at -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.

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 in the analysed scenarios. Therefore, the results do therefore not correspond to a first best situation but is probably closer to a realistic situation.

We focus on two instruments:

- A kilometre based road pricing system in Copenhagen of 4 DKK per kilometre in peak and 2 DKK per kilometre in non peak
- A toll ring around Copenhagen with a fee of 40 DKK per passing in peak and 20 DKK in non peak

The tax levels for the toll ring are chosen approximately equal to twice the Stockholm tax level. This is done as our simulations indicate that high taxes are needed to achieve a welfare gain. The reason is the high fixed costs that are necessary for running the systems. The level of the kilometre based tax is chosen such that the revenues of the two systems are of approximately the same size. The main difference between the two systems is that the fixed costs of the toll rings are smaller and that the toll ring does not directly affect the cost of car trips both starting and ending 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 increase the labour supply and thereby production and total welfare. We assume that the public consumption is unchanged i.e. all the net revenue is recycled to the consumers. We analyse three types of recycling:

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

The income tax reductions is constructed such 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 experiences the largest reductions in income tax.

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

Results
Table 1 summarizes the results of the two instruments with the different recycling schemes.

Tabel 1Annual welfare gain of alternative road pricing systems in Copenhagen combined with different types of recycling the revenue.

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

Source: Own calculations with ASTRA.

It appears from the table that there is a welfare reduction using road pricing at the given level, though the loss is only small when revenue is used to reduce income tax. Thus, the gain of 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 382 million DKK if the revenue is used for reducing income taxes. The toll ring is preferred to a kilometre based system because of the lower fixed costs.

The difference between the welfare gain from a kilometre based system and a toll ring is larger than the difference in system costs. This could be a surprise as road pricing can be targeted more precisely. However, the larger recycled revenue with a toll ring stimulates the labour supply more via 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 and 2 % in non peak. 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 oppositely directed 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 most effective because of the stimulation of labour supply. Increased labour supply c.p. increases the transport and by that congestion and other externalities. These negative effects are, however, dominated 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 either. Congestion is reduced less as the commuting tax deduction makes commuting more attractive. That is, the positive effects from the toll ring are reduced. The redistribution between consumers with high transport consumption and consumers with low transport consumption is, however, smaller with increased commuting tax deduction or subsidies to public transport than with income tax reductions.

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

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

	Copenhagen	Greater Copenhagen	Rest of Denmark
	Change, million DKK		
Welfare	139	93	11
Revenue from taxation	980	1350	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 Other Capital area, to	-6.2	1.9	1.7
From Rest of Denmark, to	- a)	0.2	0.0
Speed (car in Copenhagen)			
Peak	1.60	0.17	0.00
Non peak	0.13	0.02	0.00
Traffic (car in Copenhagen)			
Peak	-6.17	-0.63	0.00
Non peak	-2.42	-0.38	-0.02

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

The largest welfare gain is achieved by the consumers living in Copenhagen. They are most affected by the toll ring as they experience the largest reduction in congestion and receive the largest reduction in income tax but 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 for labour supply and reduces mobility. However the effect of recycling the revenue to reduce income taxes increases labour supply and so does the increased speed. The total effect is an increased labour supply.

The total positive labour supply is composed of regional differences. The interregional commuting is reduced, while the intraregional commuting is increased.

Traffic is only reduced by six percent in the peak and two percent in non peak. This implies an increase in speed of two percent in the peak but almost no change in speed in non peak. That is quite limited changes.

Other types of transport are affected in several ways: There is a substitution away from cars towards the other types of transport – the substitution effect. The increased price of car transport decreased the demand for car transport, which reduces the demand for all transport commodities – the income effect. The increased labour supply increases the total demand including demand for transportation. The demand for bus transport is furthermore affected by the reduced congestion stemming from the fewer cars. It is assumed that busses are not taxed at the toll ring, and there will be an increase in the demand for bus transport.

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 does not increase transportation correspondingly. This could be the case if the working time per day is increased or if the increased labour supply comes from increased skills or increased effort. Also changes in the consumer choice of residence can reduce the transport. Assuming a labour supply elasticity at 0.1 increases the welfare gain of a toll ring with reduced income taxes to 290 million DKK 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 million DKK	
Speed flow function (dspeed/dflow)	29	564
Consumers elasticity of substitution be-		

tween:		
Transport – other consumption	210	322
Car – non car	235	260
OD choice, commuting	140	561
OD choice, leisure	231	268
Peak – off peak	203	296

Source: Own calculations with ASTRA.

It is clear from the table that changes in the assumed elasticities of substitution in the consumers demand system affects the resulting welfare changes from a toll ring. However, none of the alternative specifications changes 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 higher flexibility in either demand or speed flow relation implies larger 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 is similar to the structure used in the existing literature but extended somewhat. This structure with very deep nests implies, however, that transportation types are generally complements. Other demand structures could result in larger substitution between types of transport. It is, however, a large task to change the structure of the demand system as the connection between commodity consumption and time use implies that the standard stepwise modelling of the CES functions cannot be used. Thus, this is a subject for further work on the model.

The road tax levels are chosen on the basis of the Stockholm experiences. This is, however, not the levels that maximize welfare in the model. Varying the tax used in the model indicates that the tax that maximizes the welfare gain is larger than the 20 and 40 DKK used in table 1. There are, however, costs that are not included in the model. A toll ring will create a more separated labour market with larger matching problems and less labour market competition. Also the commodity markets will be more separated which can reduce competition. These negative effects are expected to increase with increasing fees. Higher fees than used in table xx are therefore not necessarily suitable even though this is indicated by the model.

Both road pricing and investments in infrastructure reduces congestion. Infrastructure investments reduce the marginal value of road pricing and vice versa. This implies that the two instruments could not be viewed separately but should be included simultaneous in a model analysis. This is theoretically possible in ASTRA, but requires that the link between relevant potential infrastructure investments and how they affect the speed-flow relationship is known. This knowledge can be obtained with traffic models but requires several detailed analyses, which have not systematically been carried out yet. The analyses with ASTRA are made for a fixed amount of infrastructure. This implies that the ASTRA results overestimate the potential gain from road pricing if the amount of infrastructure is lower than the optimal and underestimate the gain if the amount of infrastructure is higher than optimal, see De Borger and Wouters (1998) and Proost (1997).

Finally a fully open economy is assumed. This may not be too realistic. A more detailed description of the effect on industries, trades and services and the 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 of both road pricing systems.

Supplementary analyses

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

Technological development will probably reduce the costs of kilometre based road pricing. The necessary GPS technology is already installed in several new cars and 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 will be 361 million DKK, 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 gasoline 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.[20] Analyses in Danish Economic Council (2006) indicate that the average taxation of cars are less than the marginal value of externalities in urban areas but larger in rural areas. Transport should be taxed both because of the externalities (a Pigou argument) and because of the public revenue (a

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[20] Cross border trade in gasoline can, however, reduce the gain from increased gasoline taxes. This effect is not included in the model.

Ramsey argument). Car transport in urban areas is therefore under taxed but it is uncertain for rural areas.

Analyses with ASTRA indicate that an increase in the taxation of cars by 0.5 DKK per kilometre will result in a welfare loss of 219 million DKK per year if the revenue is used to reduce income taxes. Lower taxes will also give a welfare loss while a very small tax increase will give 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 of these subsidies may therefore be beneficial using the same arguments as for cars. Analyses with ASTRA shows, however, that reduced subsidies of public transport of 0.5 DKK per kilometre only creates a welfare gain of 7 million DKK per year, i.e. almost no gain. The gain will, however, increase if the subsidises are 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 reduces 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-benefits analyses of specific infrastructure investments. If an investment increases α by one percent traffic will increase. This will generate more traffic and in equilibrium the average speed will only increase by 0.9 pct. In total this will lead to an annual increase in welfare by 701 million DKK. Assume that investment has a life time of 30 years and that the rate of discount is 3 percent. Then there will be a positive welfare gain if it is possible to increase α by 1 percent by investments with a net present value of 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.

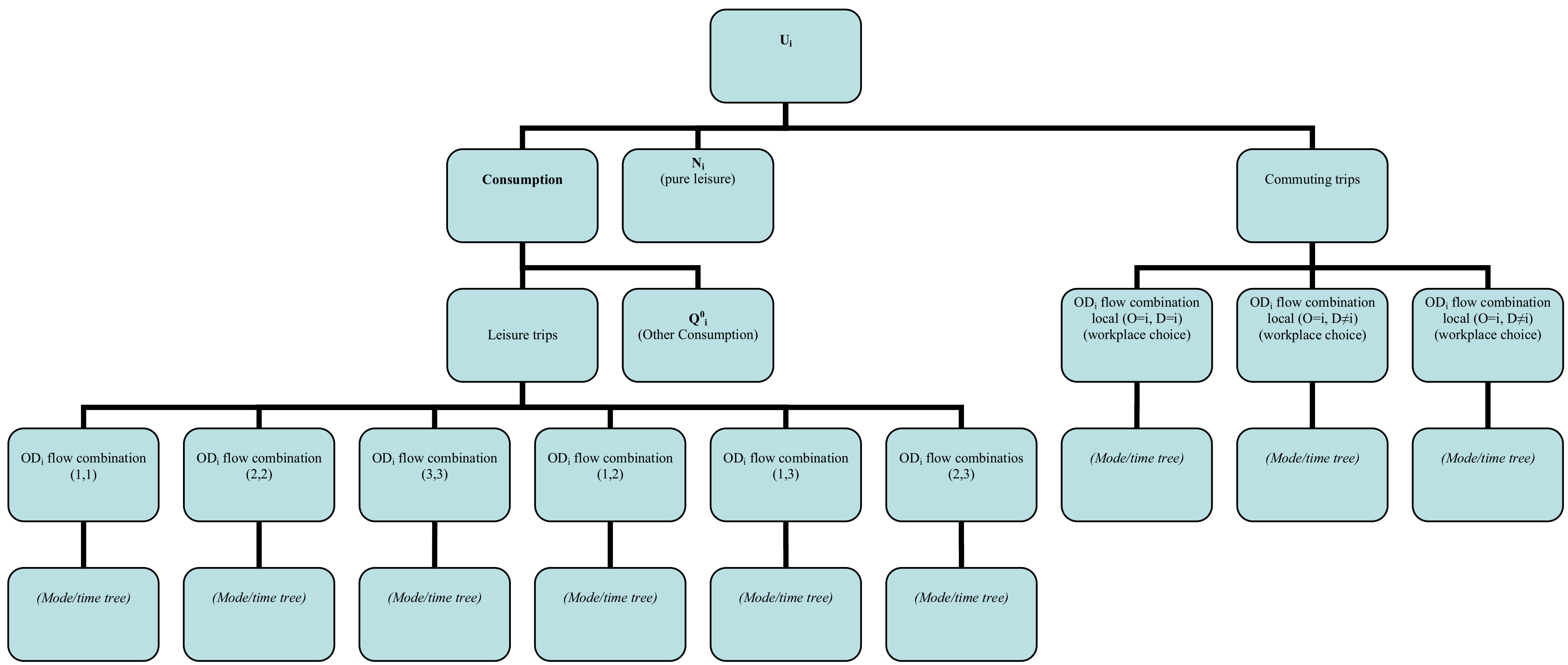
5. Conclusion

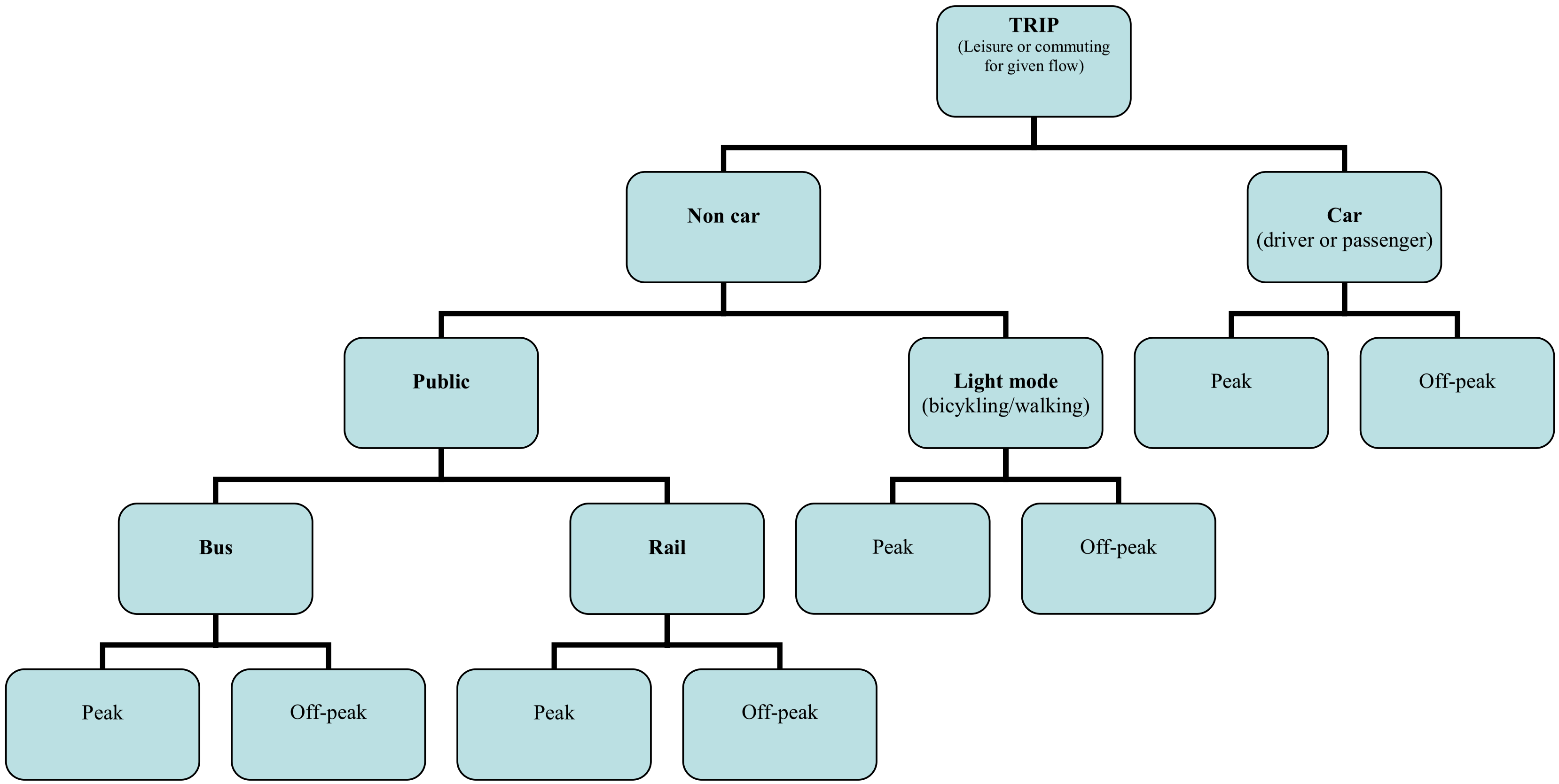
We have constructed a model for transport in Denmark with special focus on regulation of congestion and the derived labour market effects.

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

A kilometre based road pricing gives a negative welfare effect in the standard specification of the model. Alternative specifications of the model generate in some cases a positive gain, 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. The price of the necessary GPS technology that is needed for the kilometre based road pricing system is expected to be reduced over time. In this case, the road pricing instrument may of course become the overall best instrument.

Appendix A Consumers utility nesting structure





Note: This Tree is included for each OD-Combination

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.[21] The applied marginal external cost (not including congestion) can be seen in table B.2.

[21] 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, because infrastructure cost are not either 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 Consumer price and production costs of modes, DKK per km. (2003 price level).

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

	Consumer price	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
Commuting 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.

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