

# MODELLING THE EFFECTS OF A DISTANCE-DEPENDENT ROAD PRICING SCHEME

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The growth in traffic in Denmark in recent years has created increasing interest in using financial incentives to control the extent and distribution of traffic. In 1997, the Danish Transport Council published a report on payment systems on roads which concluded that the theoretically optimum payment system would be a road pricing system by which road users pay a tax per kilometre, depending on where and when they drive.

In order to gain more knowledge about the advantages and disadvantages of such a system, the FORTRIN Programme was launched. One of the core objectives of the FORTRIN Programme was to analyse the traffic effects of a variable road pricing system. This paper describes how the traffic effects of a variable road pricing system have been analysed by means of model predictions.

In Denmark, the proceeds from standard charges constitute more than two thirds of the total tax proceeds from passenger cars. Part of or all of these proceeds could be replaced by road pricing, and the effects of such a reorganisation of the duty structure have therefore also been analysed.

International experience with effects of road pricing systems and reduction of standard charges has been examined. Variable road pricing systems for cars are still at the development stage and are not in operation anywhere in the world. However, several countries have made model predictions of the effect of variable road pricing. On the other hand, experience is very limited as far as modelling of a restructuring of standard charges is concerned. This is due to the fact that few countries have standard charges as high as the Danish charges.

## TYPE OF MODEL

There have not been enough resources in the FORTRIN Programme to establish a model specifically for modelling a variable road pricing system, and the calculations are therefore made on the basis of existing Danish traffic models.

A significant reorganisation of the duty structure must be presumed to signify great changes in people's transport behaviour. The most suitable model type for describing such changes is an activity-based model which has each individual's trips in one day as its starting point. In this model, the drivers' trips in one day are modelled as a whole, on the basis of background variables such as age, income, and car ownership. The PETRA model is a model of this type (1).

Another model type which can be used for the modelling of variable road pricing is a sequential disaggregated model, starting from the individual trips. Based on the generation

and the attraction of the different zones, the trips are distributed between the zones. The trips are distributed between various means of transport and possible routes between the destinations. One model of this type is OTM (the Orestad Traffic Model) (2).

These two model types are used in the model predictions. Both types have advantages and disadvantages. The development of activity-based models in Denmark is still at a very early stage. In the PETRA model, the results are not calibrated to correspond to data observed as yet. The data basis of PETRA is traffic survey data from 1995.

The development of sequential disaggregated models is taking place at a very high level in Denmark. OTM is based on very extensive research work. One advantage of the model is that it lays out the calculated traffic on the road network so that it is possible to make very detailed analyses of the effect of a tariff structure. In the model, however, it is not possible to model changes in the size of the fleet of cars. The data basis for OTM is traffic survey data from 1997 to 2000 and SP analyses.

Another difference between the models is that PETRA is a nationwide model, whereas OTM covers solely the Copenhagen region.

One result of the differences mentioned is that there is a very big difference in sensitivity to changes in the variable costs in the two models. From an overall evaluation of the data basis of the models, the model specifications and a comparison with foreign model predictions of road pricing, it is estimated that the results of OTM are the more credible ones.

## **ASSUMPTIONS**

There is no practical experience with variable road pricing, but there is quite detailed knowledge about the correlation between petrol price and the road users' behaviour. The calculations therefore assume that drivers will react to road pricing in the same way that they react to other variable costs of driving (the petrol price, for example). In practice, it could be expected that the drivers will react more strongly to road pricing because the price of the individual trip is continuously shown on a display in the car.

The model predictions also assume that road users show rationality in their travel behaviour so that the total variable driving and time costs are minimised. This will certainly be the case to a certain extent.

## **SCENARIO**

The model predictions are based on a tariff scenario differentiated by zone, road type, time of day, and car type. The scenario is called the goal orientation scenario, and the overall goal is to improve the local environment and reduce CO<sub>2</sub> emissions (3). The kilometre rates in the scenario vary from DKK 0.20 to DKK 1.45. The average tariff level for cars in the goal orientation scenario corresponds to an increase in the variable costs of car driving of about 50%.

## RESTRUCTURING OF DUTIES

The existing traffic models cannot model the effects of a restructuring of duties where an introduction of variable road pricing takes place together with a reduction in the standard charges. In the case of such a restructuring, car ownership will be affected, and no account can be taken of that in the models for the time being.

In order to evaluate the effects of a restructuring of duties, we have therefore used an elasticity model which describes the correlations between car price, car taxes, the size of the fleet of cars, annual driving, etc. Elasticities are suited primarily to evaluating marginal changes, while the restructuring of duties is a significant change. Therefore, the results of the model are subject to great uncertainty.

## MODEL RESULTS

In the following, the effects of a variable road pricing system are evaluated, on the basis of the model predictions in FORTRIN. The results are divided into two sections. In the first section, the results of calculations with the goal orientation scenario are presented, where the variable road pricing is modelled as an extra charge without a reduction in the standard charges. In the following section, the results of a major restructuring of duties are presented.

### Effect of Variable Road Pricing

The results mentioned are found from the calculations with OTM and PETRA. International experience is also used where relevant.

- *The Total Number of Trips*

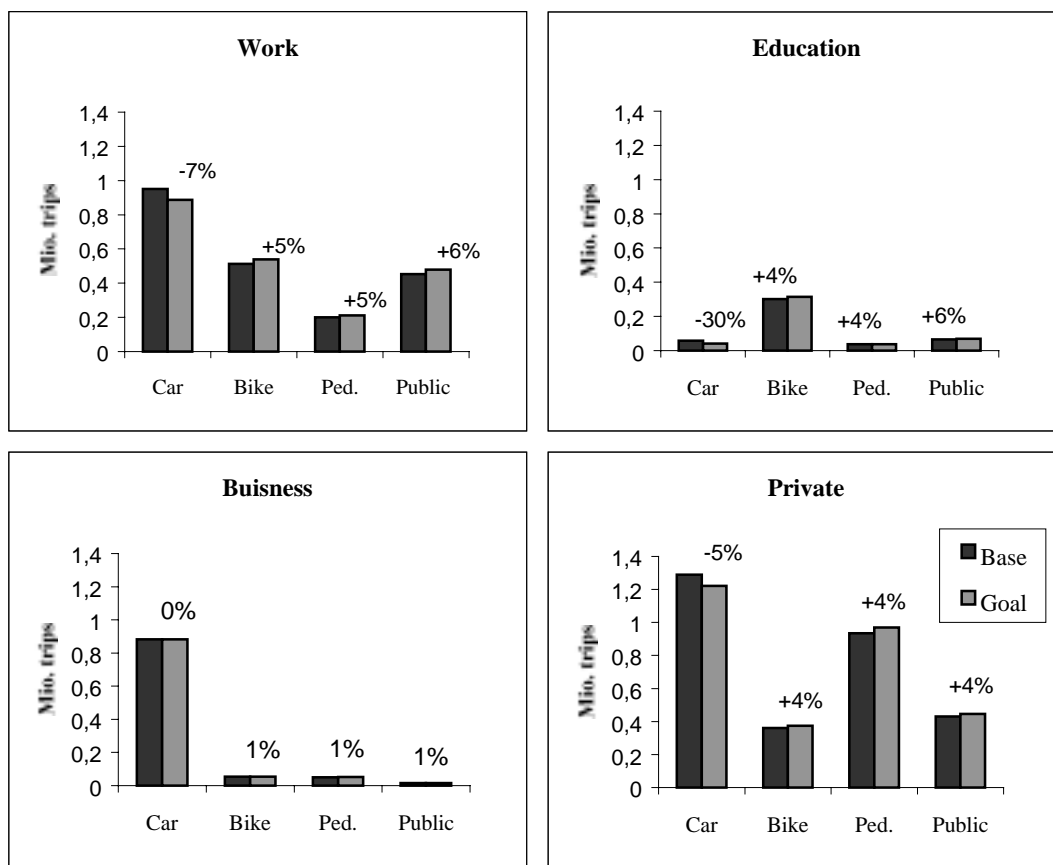
The total number of trips is expected to fall with increased variable costs of the trips. In the OTM, it is possible to model cancellations of trips only for private trips (leisure, shopping, etc.). The model, however, predicts only marginal changes. In PETRA, it is possible to model changes in number of trips for all trip purposes, but it also only gives marginal changes. It does not seem likely that the total number of trips will change only marginally if the average transport costs increase by 50%. It must be expected that the least necessary trips will be deselected.

- *Distribution on trip purpose*

In the OTM model the number of trips is analysed for different trip purposes. The number of trips for the different trip purposes is shown in figure 1. The trip purpose education is most effected by road pricing. Business trips is least affected.

- *Number of Car Trips*

Both models give a reduction in the number of car trips. As the total number of trips is changed only marginally, most trips are shifted to other means of transport. In OTM, a reduction in the number of car trips of 5% is predicted.



**Figure 1. Number of trips distributed on trip purpose and mode in the goal orientated scenario compared with the base scenario**

- *Car Traffic Work*

With higher variable costs of car driving, a reduction in car traffic work is expected. The OTM model predicts a fall in traffic work in the Copenhagen region of 10%, and PETRA predicts a fall in nationwide traffic work of 24%. It is estimated that the results of the OTM model are the most credible ones, but also that the model is relatively conservative. It is therefore estimated that the effect of a variable road pricing system based on the goal orientation scenario will be a reduction of the traffic work in the Copenhagen region of 10% to 15%.

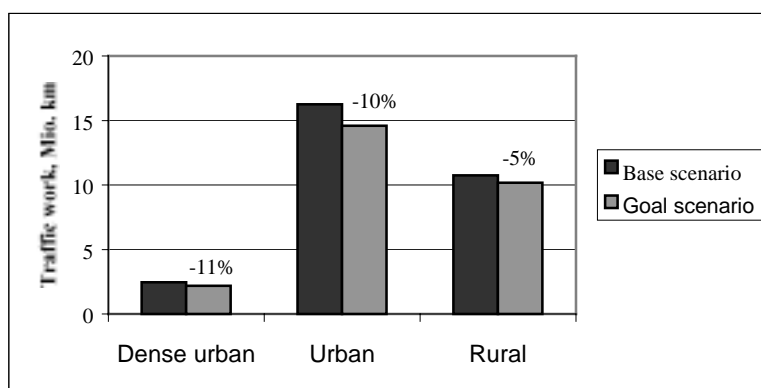
It is possible to analyse the changes in traffic work in OTM for every road section in the model. The relative change in traffic work for the Copenhagen area is shown in figure 2.



**Figure 2. Relative change of traffic work in the network modelled in OTM 4.0**

- *Differentiation of Tariff by Zone*

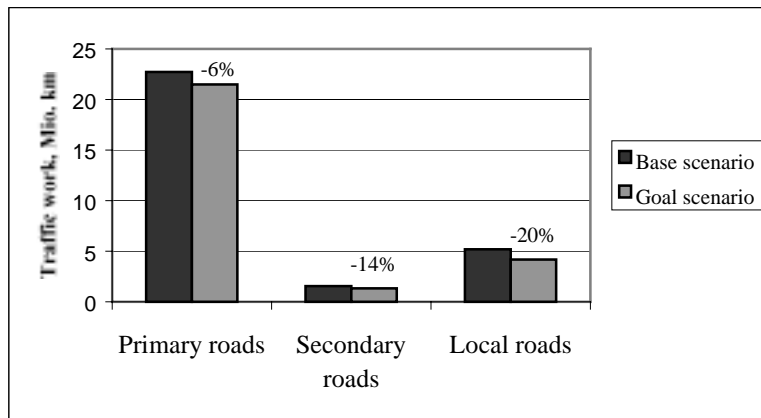
The model predictions show that a differentiation of the tariffs by area has a clear effect on the choice of route. The modelled effect of the goal orientated scenario on traffic driving in different zone types is shown in figure 3. The traffic work is reduced 10% in the urban areas, but only 5% in the rural areas.



**Figure 3. The effect of road pricing in the Copenhagen area on traffic work for different zone types**

- *Differentiation of Tariff by Road Type*

The model predictions show that a differentiation of the tariffs by road type has a clear effect on the choice of route. The modelled effect of the goal orientated scenario on traffic driving on different road types is shown in figure 4. The traffic work is reduced 20% on the expensive local roads but only 6% on the cheaper local roads. In certain cases, the division into road types may mean that detours will be made, as the road users tries to avoid to drive on the road types with high charges.



**Figure 4. The effect of road pricing in the Copenhagen area on traffic work for different road types**

- *Differentiation of Tariff by Time*

The effect of introducing variable road pricing which is differentiated over time cannot be illustrated with the existing Danish traffic models. Experience from Trondheim, among others, shows that traffic will change as some road users shift their trips to a cheaper time of day.

- *Differentiation of the Tariff by Car Type*

It is expected that a differentiation of the tariff by car type will motivate consumers to acquire car types with a low road pricing rate. It is possible to provide only a rough analysis of this effect in the OTM model. It is thus possible to make a division into only two car types (passenger cars and vans or lorries). The effect is obtained only on choice of route and has not been examined in detail.

- *Selection of Means of Transport*

As the number of car trips is reduced and the total number of trips is changed only marginally, trips are shifted to other means of transport. The OTM model predicts an increase in the number of trips on public transport of 5% and an increase in the number of bicycle trips and walks of 4%. PETRA predicts a somewhat bigger increase, corresponding to the greater reduction in the car traffic work in PETRA. As the results of the OTM model are estimated to be the most credible ones, it is estimated overall that the number of walks, bicycle trips, and public transport trips will rise by about 5% at the tariff level used.

- *The Rate of Car Occupancy*

An introduction of variable road pricing will probably mean that driving together will be more widespread. In the OTM, it is not possible to model changes in the rate of car occupancy as the occupancy rate is exogenously given in the model. In PETRA, an increase in the rate of car occupancy is modelled at 5%.

- *The Size of the Fleet of Cars*

With increasing variable costs, it will be more expensive to have a car, and it is therefore expected that the size of the fleet of cars will be reduced. It is not possible to calculate changes in the fleet of cars in OTM. In PETRA, car ownership is calculated, but the model's sensitivity to changes in the variable costs is very small in proportion to recognised elasticities.

- *Localisation*

In the model predictions of both OTM and PETRA, a great deal of the reduction in car traffic work derives from a reduction in the average trip distance. The models thus predict that people generally will elect trip purposes closer to their home (for example, shopping, leisure activity, work place). In the longer term, it must be expected that people will also select their residence location so that the transport distances are reduced.

### **Effect of a Reorganisation of the Duty Structure**

In this section, the results of the calculations of the effects of a restructuring of duties are presented. The effects expected have been found from an elasticity model, and the results are subject to great uncertainty.

- *The Size of the Fleet of Cars*

According to the elasticity model, a reduction of the standard charges will mean that more cars are bought. This is also true when account is taken of a restructuring of duties where the reduction in the standard charges corresponds to a variable tax. When restructuring totally from standard to variable charges, the model predicts 1.5 times as many cars in the Danish fleet of cars as today.

- *Car Traffic Work*

According to the elasticity model, car traffic work will not increase if the duties are restructured on a proceeds-neutral basis, despite the increased fleet of cars. The model even predicts a fall in traffic work in case of a total restructuring of duties.

- *Selection of Means of Transport*

The elasticity model does not operate with alternative means of transport, and from the model it can therefore not be estimated whether the reduction in the car traffic work will correspond to an increase in the traffic by public transport, bicycle, and walking.

- *Rate of Car Occupancy*

Changes in the rate of car occupancy cannot be illustrated from the elasticity model. In the model, an increase in the fleet of cars is calculated on the basis of a restructuring of the duties. With more cars in the Danish fleet of cars, more people will have access to a car, and it may be expected that the rate of car occupancy will be lower.

## RECOMMENDATIONS

On the basis of FORTRIN's results, the following recommendations are made:

- Better knowledge about the road users' behavioural reactions to variable road pricing must be obtained. This is particularly true of deselection of trips, changed destinations, and shifting of trips in time.
- If the objective is a nationwide road pricing system, knowledge should be obtained about regional differences in road users' behavioural reactions to variable road pricing.
- Before the tariff structure is fixed, it should be analysed whether the duty structure will have any unintentional effects (detours, among others).
- On the basis of the increased knowledge about the road users' behaviour, models have to be (further) developed which can describe the traffic effects of variable road pricing. Particular importance should be attached to developing models which can describe a shifting of trips over time as well as cancellation of trips.
- A model has to be developed which can calculate the size of the fleet of cars as a function of a total restructuring of duties, in which road pricing is introduced while one or more of the standard charges are abolished at the same time. The results from such a model can be used as inputs to the further calculations of the traffic effects, for instance in the OTM model.
- With a traffic model which can calculate both the effects of a reduction of the standard charges and an introduction of variable road pricing, it is possible to assess the effects of various restructurings of duties on proceeds. Such a model can be used to determine the charges in a proceeds-neutral solution.

## ACKNOWLEDGEMENT

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