Road pricing is not always green

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Abstract

This paper analyses a tax reform, explicitly conceived by policy makers to be climate-friendly, that partly replaces a high vehicle registration tax by road user charging and allows for differentiation of the remaining registration tax by fuel efficiency. A tight microeconomic framework is proposed to analyze such a reform. For the case of Denmark, the analysis shows that the reform is likely to yield a significant and robust welfare gain. However, it seems not unlikely that CO_2 emissions may increase as a result of the reform.

1 Introduction

This paper analyses a tax reform that shifts the tax burden from the fixed costs of passenger car ownership to variable costs of car use. The analysis is carried out in a Danish context using a compact microeconomic framework that accounts for a variety of effects. The analysis indicates that the reform is likely to be welfare improving given the current high Danish registration tax. The main issues are the merits of more sophisticated congestion charging schemes in the context of such a reform and whether such a reform is likely to reduce the environmental costs of passenger car use.

The context for the analysis is that the Danish Parliament has agreed in principle on a green tax reform that shifts the tax on passenger cars from fixed to variable costs (Transportministeriet, 2009). The elements of the proposed reform are the following: i) the registration tax is reduced by at least 50%; ii) the registration tax is further differentiated to encourage sales of more fuel efficient cars; iii) a national road pricing system is introduced and the revenues from road user charging (RUC) replace the lost revenues from the registration tax.

The stated intention of the reform is to reduce CO_2 emissions from passenger cars. There are also other concerns that the reform can help address. First, the current Danish registration tax is very high. The average tax rate on new cars, including VAT, is 160%. There is pressure from the EU to reduce the registration tax as it is considered to be an obstacle to the inner market (EU Commission, 2005).

Another concern is that projections indicate that future traffic growth will substantially overtake the planned growth in infrastructure capacity (Infrastrukturkommissionen, 2008a). So the result will be a dramatic increase in congestion unless something else is done. Here road user charging (RUC) is seen as a way to manage demand and deal with the expected increase in congestion.

This paper proposes a welfare economic analysis of this reform using a small microeconomic model. The model is partial and is thus leaving out possible effects on other markets such as the labour market. It is calibrated to the present situation in Denmark and to income and fuel price elasticities for car ownership and use estimated elasticities from time series data. The model is explained in detail in section 2 below.

The main point of the model is that it provides a consistent microeconomic framework that represents both the extensive and intensive margin of car ownership and use. This is a crucial model property for an analysis of a policy reform that involves a large shift from fixed to variable costs. The model comprises a distribution of representative households, distinguished by their propensity to drive. The households choose between owning 0, 1 or 2 cars. Furthermore, the model represents a number of different types of car uses. These types distinguish kilometres driven in different geographical areas and by different time of day. The model comprises separate cost relationships for each type, such that different degrees of congestion and other external costs can be represented. The infrastructure is represented by traffic type specific volume-delay relationships. Thus, decreases in traffic volumes result in time costs reductions and thereby welfare improvements. The model allows different types of kilometres to be more or less substitutes as desired. The model takes differentiation of the registration tax into account by interacting with a car choice model that predicts the average car from the household choice between more than 1000 car makes, models and variants.

The results indicate that a reform can lead to a substantial welfare improvement. Most of this effect is due to the reduction in deadweight loss gained from the shift of the tax burden from the very high registration tax to a tax on kilometres. A comparatively much smaller gain can be obtained from differentiation of the road user charge.

Differentiation of the registration tax shifts the composition of the car fleet in a more fuel efficient direction. But the general reduction of the registration tax leads to upsizing of the cars and the combined effect on the fuel efficiency of the average car is predicted to be small. The isolated effect of reducing the registration tax is a larger car fleet and more kilometres driven in total. The isolated effect of the introduction of RUC is fewer kilometres driven per car and fewer cars. The combined effect depends on the elasticities implicit in the model. The calibrated model predicts an increase in the size of the car fleet and also an increase in the total traffic volume and the total fuel consumption. The increase in total fuel consumption is not large. Taking model uncertainty into account, the conclusion is therefore that the reform is more likely than not to increase CO_2 emissions and hence not be green.

In section 2 below the theoretical model is presented and in section 3 the transformation to a simulation model is described along with the main assumptions. Section 4 presents the analyses and the results are discussed in section 5.

2 Model formulation

The model is an extension of the empirical model described in Rouwendal and Pommer (2004). This provides a setup that allows the external and internal margins of car ownership and use to be integrated in a consistent microeconomic framework.

Consider a household which may own 0, 1 or 2 cars. Net household income is y and the annual net fixed cost of car ownership is c per car. A household owning n cars has $y\text{-}nc$ available for consumption of other goods. The household is able to consume kilometres of different types, indexed by k. The price per km including time cost is p_k for kilometres of type k.

The model is formulated in terms of indirect utilities for owning 0, 1 or 2 cars using the following convenient form.

$$V_0 = \frac{y^{1-\alpha}}{1-\alpha}$$

$$V_1 = \frac{(y-c)^{1-\alpha}}{1-\alpha} + \frac{1}{\beta}\sum_m \left(\sum_{k\in m} \exp[\mu_m(\delta - \beta p_k + \eta_k)] \right)^{1/\mu_m}$$

$$V_2 = \frac{(y-2c)^{1-\alpha}}{1-\alpha} + \frac{1}{\beta}\sum_m \left(\sum_{k\in m} \exp[\mu_m(\delta - \beta p_k + \eta_k + \gamma)] \right)^{1/\mu_m}$$

Households are utility maximizers and choose to own n cars if V_n is the largest indirect utility. The demand for kilometres of different types is derived below using Roy's identity. All other goods than cars and kilometres are treated as one homogeneous good. The parameters $\alpha > 0$ and $\beta > 0$ measure the sensitivity with respect to other consumption and the price of kilometres.

The first term in the indirect utilities indicates the utility associated with consumption out of remaining income when the fixed cost of car ownership has been paid. This term decreases with the cost of a car c and it decreases as car ownership increases. The decrease in utility resulting from owning a car is compensated by the second term, which captures the indirect utility associated with driving the car(s). The sum here reflects that there are different types of kilometres that can be demanded by the household. The nesting structure is explained below.

The terms involving $y\text{-}nc$ link net income with the fixed cost of car ownership. This means that the elasticities of car ownership and use with respect to the fixed cost of car ownership are determined from the corresponding income elasticities. This is crucial since the income elasticity of car ownership is easy to estimate empirically: income changes both over time and across households. In contrast, changes in the fixed cost of car ownership are rare and hard to correlate with changes in car ownership. Cross-sectional variation between households in the cost of the cars they have chosen is not appropriate to use since they all have the same cars available to buy and the observable variation is (mostly) due to household choice. Variation over time is hard to observe for a number of reasons. First, taxation of car ownership changes only very infrequently; second, at any time there are very many different cars available on the market; and third, since the quality of cars changes over time.

Large values of δ correspond to large demands for kilometres and hence for cars. The parameter δ is a household specific random parameter and represents household heterogeneity in a minimal way. It is necessary to have some heterogeneity in the model since otherwise all households would have the same number of cars. Allowing for heterogeneity ensures that the total demand for cars changes smoothly as a function of income and prices. Parameter δ is assumed to follow some continuous distribution where the location (mean) is fixed while the scale (proportional to standard deviation) is given by a parameter σ. The sign of δ is not restricted. The implementation of the model uses a logistic distribution for δ.

The parameters η_k set the location for δ with a different value for each type of traffic. The parameter $\gamma > 0$ is a location shifter, expressing that having two cars reduces the cost of driving one kilometre due to less restrictions on the use of cars. If there was not such an effect, then no household would choose to have two cars rather than one.

Roy's identity states that the demand for a good x with price p is given as a ratio of derivatives of the indirect utility and it is thus easy to derive closed form expressions for demand for kilometres of type k conditional on having 1 or 2 cars.

The choice of how many cars to own is partly determined by the heterogeneity parameter δ. A household with low δ will not own a car, a household with intermediate δ will own one car and a household with large δ will own two cars. Closed form expressions for these thresholds are easily derived such that the shares of households with 0, 1 and 2 cars can be computed from the cumulative distribution function of δ.

The different types of kilometres k are gathered in groups m. The parameters μ_m measure the willingness to substitute kilometres within these groups. In the case where $\mu_m=1$, the contribution to utility from kilometres driven reduces to the sum. In this case kilometres of different types are complements, since an increase in the cost of one traffic type implies that driving in general becomes more expensive; this will lead to a reduction in car ownership and thus fewer kilometres of all types.

Larger values of μ_m lead to substitution between traffic types within group m. This feature is useful to model substitution, e.g., between peak and off-peak travel in the same geographical area.

2.1 Welfare economic analysis

The model is used to perform welfare economic analysis of tax reforms concerning passenger cars. This section outlines the principles underlying this analysis. The welfare economic analysis comprises three main elements. The first is the direct consequence for households. This is analyzed using the microeconomic model as explained below. The second element is the consequences that occur as a result of changes in net government revenues. The third element is the externalities. These include noise, accidents, air pollution, climate change and delays to trucks and vans.

The direct welfare consequences for households are computed as the equivalent variation comparing an ex ante situation without reform to an ex post situation with reform. The equivalent variation is the change in ex ante household income that makes the household indifferent between the ex ante and the ex post situations. This measure replaces the utility change of a reform with an equivalent income change. It is useful when the marginal utility of income is not constant, such that there is not a linear relation between utility change and the equivalent income change.

The utility for a household with a specific value of δ is equal to the indirect utility for the chosen number of cars. The choice of the number of cars as well as the conditional indirect utilities depend on δ. Therefore the average indirect utility is $E(V_n) = E\left(V_0 1_{\{n=0\}} + V_1 1_{\{n=1\}} + V_2 1_{\{n=2\}}\right)$.

The effect through a net change in government revenues is neutralized by only considering revenue neutral reforms. Thus for each reform of the registration tax, the level of the RUC is adjusted until the net government tax revenue is the same as in the ex ante. The model keeps track of a range of different taxes. This is described below in section 3.2.

The model accounts for a range of externalities. Some externalities are handled through constant marginal costs for each of the types of kilometres. These externalities are noise, accidents, local air pollution, and climate change. The model accounts for congestion both for the passenger cars of households and for other traffic, represented as trucks. The delay for passenger cars is included through the utility of households. The delay for trucks is assumed to be the same per vehicle kilometre as for passenger cars. It is evaluated using a value of time for trucks. The implementation of externalities in the model is described in section 3.2.

3 Implementation of simulation model

The model is implemented in Ox (Doornik, 2009) for an average Danish household in a single year. Data are generally obtained from a catalogue of unit prices published by the Danish Ministry of Transport (Transportøkonomiske enhedspriser, 2009) or from national statistics. All figures refer to the year 2010. The model is implemented in steady-state, showing the implications for equilibrium in a world of constant income and prices. The income y is the average disposable household income.

Aggregate traffic, the total traffic volume, is divided into six types as a rough approximation to a likely structure for a national RUC system. There is first a split into three groups and each group is further split into two types. Group 1 is called corridors and comprises essentially the Danish highway network. Type 1 comprises the times and places in the corridors where current (ex ante) traffic is congested, where congestion is defined as flow above 80% of capacity. Type 2 comprises the remaining traffic in corridors. Group 2 represents the urban region surrounding Copenhagen, the capital of Denmark. Traffic is split between peak and off-peak into types 3 and 4 according to the time of day. Here peak is defined as driving in the time intervals 7 to 9 am and 3 to 6 pm. Group 3 represents the residual; that is, traffic outside the corridors and the capital region. Type 5 is urban traffic and type 6 is rural.

The model allows specification of a substitution parameter μ_m within each group. Setting μ_1 and μ_2 to values larger than 1 creates substitution between different time periods within the corresponding groups. μ_3 is set to 1 since the traffic types in group 3 are not separated in time, but physically separated and substitution therefore is less relevant.

The price of kilometres p_k is the sum of three components: the time cost, the variable cost of kilometres and the road user charge. The time cost per kilometre is computed as the product of a unit value of travel time for private cars and the travel time per kilometre. The travel time per kilometre is given by volume-delay relationships that relate the average travel time per kilometre of a given type to the traffic volume of that type. It is of interest to discuss the computation of these relationships as they determine amount of congestion in the model.

The corridors (group 1) are divided into about 15,000 links. The computation of the aggregate volume-delay relationship uses the annual traffic volume on each link, a distribution of the annual traffic volume on the hours of a year, link capacity and a volume-delay relationship relating travel time on the link to capacity and hourly traffic. Every combination of link and hour is evaluated separately to see if traffic is above 80% of capacity, which is where speeds begin to decrease more steeply. Then the link-hour com is assigned to type 1 if traffic is above 80% of capacity and to type 2 otherwise. This division into types is done only once and maintained in the model afterwards. For each type the average travel time per km is then computed for proportional changes in traffic volume in all link-by-hour combinations. There are more than 100 million of these link-by-hour combinations. The result is an aggregate volume-delay relationship that relates average travel time per kilometre to aggregate traffic volume for proportional changes in traffic that maintains the current distribution of traffic across time and place.[1]

For group 2 (Copenhagen) the volume-delay relationships are computed using a detailed assignment model for the Copenhagen region (Jovicic and Hansen, 2003). The relationships express the change in travel time per kilometre resulting from a proportional change in demand in all OD-relations. For the residual group 3 it is assumed that there is no congestion and hence the volume-delay relationship is flat.

The fixed cost of car ownership c as well as some of the characteristics of the average car are produced using a car choice model. It is a multinomial logit model and predicts market shares for all new cars available on the Danish car market distinguishing more than 1000 different combinations of car make, model and variant. The data for the model comprise all new car registrations in Denmark during one year (Trafikministeriet, 2004) and the model has been calibrated to 2007. Car choice alternatives are described in terms of price, annual cost, fuel consumption and type, weight, engine size, and acceleration. Given a registration tax regime, the car choice model is used to compute characteristics of the average new car. In steady state this is taken to represent also the average car. Specifically, the car choice model produces the average price of new cars, split into a tax part and a resource cost, an average annual tax, and an average fuel consumption per kilometre. The car choice model also predicts the share of petrol and diesel cars in the fleet. The price of new cars is annuitized using an interest rate of 5% over the average lifetime of new cars, which is taken to be constant at 18 years.

3.1 Calibration

The model parameters α, β, γ, η and σ are calibrated such that the model prediction for the base year meets a number of targets as well as possible according to a criterion defined below. The targets are the shares of households with 1 and 2 cars according to national statistics, the annual distance driven in total and split into six types of kilometres, and price and income elasticities of the number of cars

[1] A concern regarding the aggregate volume-delay relationships for the corridors is whether they capture all the congestion that is present. The link specific relationships do not take into account the congestion arising in relation to bottlenecks like highway approaches and exits.

and the annual distance driven. The elasticities are derived from aggregate time series models for kilometres and cars estimated on Danish data (see Infrastrukturkommissionen, 2008b; the model has been updated with more years of data.) The targets are presented in the first column of Table 1.

Table 1 Calibration

	Target	Model	Weight
Share of households 1 car	0.46	0.4597	10
Share of households 2 cars	0.11	0.1132	10
Total km per year	11400	11400	10
Type 1: Km corridors congestion	61.4	61.7	5
Type 2: Km corridors residual	2845	2859	5
Type 3: Km Copenhagen congestion	432	432	5
Type 4: Km Copenhagen residual	829	848	5
Type 5: Km small cities	1476	1467	5
Type 6: Km rural areas	5759	5731	5
Elasticity No. cars wrt. income	0.63	0.64	1
Elasticity Total km wrt. income	1.06	0.94	1
Elasticity No. cars wrt. fuel price	-0.36	-0.43	1
Elasticity Total km wrt. fuel price	-0.92	-0.65	1

There are more targets than there are parameters, so the model cannot meet all targets perfectly. It would be possible to introduce more parameters into the model. The associated cost would be that the additional parameters would lack a clear interpretation.

The fit of the model to the targets is measured by a weighted sum of logarithms of the ratios of model predictions to targets: $\sum_t w_t [\log(\text{model}_t / \text{target}_t)]^2$, which emphasizes relative differences. This is important since there are large differences in the numerical size of targets. The weights are set to ensure that car ownership and km travelled are predicted close to the targets, while less emphasis is put on the elasticities. This reflects the degree of confidence we have in the various numbers, where car ownership and distances are observed, while the elasticities are uncertain statistical estimates.

Table 1 indicates the weights used as well as the results of the calibration. The shares of households owning 1 and 2+ cars as well as the distances by type are reproduced almost perfectly. The largest deviations occur for the elasticities relating to the fuel price. The elasticity of total kilometres with respect to the fuel price is (numerically) higher than the target, while the elasticity of the number of cars with respect to the fuel price is lower than the target. The fuel price enters the model through the parameter β. It would thus seem that the calibrated value of β balances these two targets. Changing β up or down would improve the model relative to one target but would bring the model further away from the other.

No basis is available for calibrating the μ_m and they have instead been fixed at values (2,2,1). The resulting substitution pattern is roughly that a cost increase during the peak in groups 1 and 2 will cause a third of the decrease in traffic during the peak to appear off-peak, while two thirds disappear.

3.2 Accounting

The model keeps track of all tax revenues for the government as well as a number of externalities. The main taxes to keep account of are the registration tax and the RUC as these are the taxes that are changed in the reforms. However, the change in behaviour resulting from reform affects also the revenues from other taxes. The annual tax per household is affected by the number of cars as well as the composition of the car fleet. There is also a fuel tax and VAT on fuel as well as various other taxes that enter into the marginal cost of kilometres. These are affected by the total kilometres driven as well as by the average fuel efficiency of the fleet. Finally, the total expenditure by households on transport changes as a result of reform. There is a consequent change in the other direction of the expenditure on other goods. The price of other goods generally includes VAT at the rate *v=0.25*. Therefore the change in government revenues through this channel is *0.25/1.25* times the change in expenditure on transport.

The model computes the marginal external cost (MEC) associated with kilometres of each type. The volume-delay relationships are used to compute the MEC of congestion imposed on other passenger cars. The same volume-delay relationships are used to compute the congestion cost imposed on trucks and vans. This uses the assumption that the delay per vehicle kilometre is the same for these vehicles as for passenger cars.

Standard unit values are used to compute the MEC associated with noise, accidents and local air pollution for each type of kilometres. These values take into account that noise and local air pollution is more expensive in urban areas than in rural areas, and that accidents are more likely in urban areas and least likely on highways.

The climate cost per kilometre is computed using the predicted average fuel consumption per kilometre, taking the split between petrol and diesel cars into account. The unit price per ton CO_2 is *29 EUR* reflecting the expected price of tradable EU emission permits (Energistyrelsen, 2009).

The model enables comparison of the MEC with the marginal tax and RUC per kilometre. This information is important in order to design efficient RUC that avoids distortion between different types of kilometres.

Table 2 summarizes the MEC and marginal taxes described in the model for the base scenario. The MEC of congestion (1) is high during peak periods and in Copenhagen. It is 0 by assumption for the residual types 5 and 6. The MEC of congestion imposed on trucks (2) is comparable to that imposed on passenger cars. In corridors it is even higher, due to the large share of heavy traffic in the flow. The MEC associated with local environmental externalities, noise, accidents and local air pollution (3) follow a fixed pattern across types and are the same for all scenarios. Noise and accidents are significant in urban areas. The cost associated with CO_2 emissions (4) is small in comparison to the other costs.

The tax component of variable costs is constant across types. The result is that some types of kilometres are taxed above the MEC while others are taxed below. Row 6 gives the sum of the MEC minus the marginal tax. It is positive when the MEC is greater than the marginal tax and negative otherwise. The numbers indicate that an additional RUC is well motivated in urban areas and in corridors during peak periods.

It is not the case that economic efficiency requires that the MEC and the marginal tax rate are equal. A first approximation to an optimal marginal tax may be that it should cover the MEC and in addition contain a component that corresponds to the general rate of VAT. It is certainly true that economic efficiency requires that the MEC minus the marginal tax rate should be equal across types.

Table 2 Marginal external costs and taxes, DKK per km – base scenario

	Type 1 Corridors peak	Type 2 Corridors off-peak	Type 3 Copenh. peak	Type 4 Copenh. off-peak	Type 5 Urban	Type 6 Rural
1: MEC congestion cars	0.42	0.02	0.87	0.24	0	0
2: MEC congestion heavy	0.58	0.03	0.58	0.21	0	0
3: MEC noise, accidents, air	0.11	0.11	0.62	0.61	0.62	0.14
4: MEC CO_2	0.03	0.03	0.03	0.03	0.03	0.03
5: Tax in variable costs	-0.55	-0.55	-0.55	-0.55	-0.55	-0.55
6: Sum	0.60	-0.36	1.56	0.56	0.11	-0.37

4 Analyses

We apply the model to a base scenario and three different policy scenarios.

- A base scenario reproduces the current situation.
- Scenario A reduces the registration tax by half and sets a uniform RUC on kilometres to neutralize the effect on government revenues including 893 DDK per household to the costs of the system.[2] A RUC of about 0.55 DKK per km would offset the change in registration tax before behavioural response. The reduction in registration tax has, however, self-financing to a large degree because households buy more and larger cars and because they drive more when the RUC is small. The RUC that leads to revenue neutrality is 0.22 DKK per km.
- Scenario B also reduces the registration tax by half and neutralizes the effect on government revenues, but by a RUC that is differentiated such that the MEC of kilometres less marginal taxes is the same across types of kilometres. The differentiated RUC that achieves revenue neutrality follows the degree of congestion and the distinction between urban and rural areas in the marginal external environmental costs.
- Scenario C is similar to scenario B, but strengthens existing incentives in the registration tax to buy more fuel efficient cars. This is done by increasing the fees for cars driving less and rebates for cars driving more than a threshold value for kilometres per litre.[3] The reduction of the registration tax is the same as in scenario A and B. The RUC is differentiated in the same way as in scenario B.

Table 3 displays the resulting RUC rates for the 6 types of traffic. The RUC in scenario A is 0.22 DKK per km. This is a moderate rate when compared to the present fuel tax of almost 0.50 DKK per km. When the RUC is differentiated to equalise the marginal external cost less marginal taxes, the RUC becomes considerably higher during peak periods and in urban areas where noise and air pollution justifies high rates.

Table 3 RUC levels, DKK per km

Type	Base	A	B	C
Type 1 corridors congestion	0.00	0.22	0.62	0.62
Type 2 corridors residual	0.00	0.22	0.08	0.08
Type 3 Copenhagen congestion	0.00	0.22	1.72	1.71
Type 4 Copenhagen residual	0.00	0.22	0.97	0.96
Type 5 small cities	0.00	0.22	0.54	0.53
Type 6 rural areas	0.00	0.22	0.06	0.05

Table 4 shows the model prediction of the number of cars per household. The number of cars is predicted to increase by almost 20% from the base to scenarios A, B and C. An increase of this magnitude is plausible as the level of car ownership in Denmark is low compared to other countries.[4]

Table 4 Cars per household

	Base	A	B	C
Share with 0 cars	0.43	0.34	0.34	0.34
Share with 1 cars	0.46	0.50	0.50	0.50
Share with 2 cars	0.11	0.16	0.16	0.16
Cars per household	0.69	0.82	0.82	0.82

[2] The annualized costs are estimated to 2.5 billion DKK including administration costs and VAT. With 2.8 million households this implies costs per household of 893 DKK.

[3] The fee is increased from 1000 to 2000 DKK per km per litres below the threshold and the rebate is modified from 4000 to 2000 DKK per km per litres above. The threshold value is increased from 16 to 18 km per litre for petrol cars and from 18 to 20 km per litre for diesel cars.

[4] In 2007 there were 354 cars per 1000 inhabitants in Denmark. Corresponding figures for other countries are 556 (Germany), 467 (UK and Sweden) and 494 (France), see Eurostat.

Even though the number of cars increases a lot, the annual distance driven per household increases only moderately (see table 5). The increase is about 2% from the base. In scenario A the increase is smaller for traffic types with more congestion and a little larger for types with no congestion. The differentiated RUC in Scenarios B and C means significant traffic reductions in the congested traffic types, especially in Copenhagen where the RUC is high. We find minor traffic reductions in urban areas in group 3 with a moderate RUC. There is a distinct traffic increase in rural areas and non-congested corridors where externalities are small and the driving charges are almost zero.

The average fuel efficiency deteriorates about 1% in all policy scenarios due to upsizing of cars such that CO_2 emissions increase about 3% The CO_2-differentiation of the registration tax in scenario C turns out to have very little effect. Emissions of CO_2 per kilometre are only reduced from 143 grams in scenario A and B to 142 grams in scenario C. This is still above the 141 grams in the base scenario.

Table 5 Kilometres and CO_2 per household

	Base	A	B	C
Total km	11398	11619	11578	11596
Type 1 corridors congestion	62	63	49	49
Type 2 corridors residual	2859	2915	3040	3044
Type 3 Copenhagen congestion	432	438	279	281
Type 4 Copenhagen residual	848	864	728	730
Type 5 small cities	1467	1496	1359	1360
Type 6 rural areas	5731	5843	6123	6131
CO_2 ton	1.612	1.660	1.655	1.652

Table 6 keeps account of all taxes paid by the household. The increase in the number of cars owned implies an increase in the revenue from the annual car tax. The decrease in the registration tax is counteracted by higher car sales and upsizing of the cars and the registration tax revenue is only reduced by around 30%. The RUC revenues reflect the RUC rates and the traffic volumes. The change in traffic patterns influences the results since traffic is reduced where the RUC rates are high. The fuel tax revenue mainly reflects the moderate increase in total traffic, but is also increased a bit by the upsizing of the car fleet which implies fewer kilometres per litre. This is also true in scenario C where the registration tax is further differentiated to encourage fuel efficiency. According to the car choice model this improvement is very moderate. The VAT revenues from other goods are decreased as the expenditure on transport is increased and hence the expenditure on other consumption is reduced.

Table 6 Taxes per household, DKK

	Base	A	B	C
Annual car tax	1897	2318	2313	2308
Registration tax	5724	4065	4055	4066
RUC	0	2501	2523	2510
Tax in variable costs (fuel)	6234	6355	6332	6342
VAT change	0	-491	-475	-478
Total	13855	14748	14748	14748

As shown in table 7, speeds decrease slightly in scenario A as a consequence of the increase in traffic. The differentiation of the RUC in scenarios B and C has a clear impact on speeds, which improve most where there is most congestion.

Table 7 Speeds, km per hour

	Base	A	B	C
Type 1 corridors congestion	99.8	99.4	104.8	104.8
Type 2 corridors residual	112.3	112.3	112.2	112.2
Type 3 Copenhagen congestion	46.6	46.4	52.0	52.0
Type 4 Copenhagen residual	53.7	53.6	54.4	54.4
Type 5 small cities	54.0	54.0	54.0	54.0
Type 6 rural areas	54.0	54.0	54.0	54.0

Table 8 summarizes the welfare economic evaluation of the scenarios as differences relative to the base scenario. The equivalent variation summarizes the effect for the households, measured in monetary terms. It includes the change in travel times, which is not an externality from this point of view. Households experience a large welfare gain from these reforms. The main reason is that there is a large gain from reducing the deadweight loss associated with the currently high registration tax on new vehicles. The welfare consequences for society in general comprise also those effects of change in local environmental externalities, CO_2 emissions and the change in the delay imposed on heavy vehicles. In scenario A these factors all contribute to a welfare loss, which is however less than 10% of the gain to households. The net result is a substantial welfare gain.

The differentiation of the RUC in scenario B leads to a small reduction of the direct welfare gain for households measured by the equivalent variation. This is however compensated by the externalities, which now contribute a net gain rather than a net loss as in scenario A. There is now a gain regarding the local environmental externalities, noise, accidents and local air pollution, and also regarding the delay imposed on heavy vehicles. This occurs as traffic shifts away from types of kilometres with high external costs towards types with lower external costs. The loss to climate is almost as large as in scenario A as there is still an increase in total fuel consumption. As must be the case, the net welfare gain is higher in scenario B than in scenario A. The gain from differentiation of the RUC (Scenario B vs. A) is 237 DKK per household per year. This is relatively little, both compared to the welfare gain obtained in scenario A and maybe also compared to the cost of running a differentiated RUC system.

The results for scenario C are very similar to those for scenario B. The main conclusion is that the additional differentiation of the registration tax according to fuel consumption does not lead to a noticeable decrease on CO_2-emissions.

Table 8 Welfare economic evaluation, DKK per household per year

	A vs. base	B vs. base	C vs. base
Equivalent variation	1236	1130	1187
Externalities	-74	269	263
Local environment	-55	162	158
Climate	-10	-9	-9
Heavy vehicles	-9	115	114
Total	1162	1399	1450

5 Conclusion

There seems to be three general conclusions from the analysis carried out above of the three reform scenarios.

- Partly replacing the Danish registration tax by a RUC in a revenue neutral way is likely to be welfare improving. The main contribution to welfare improvement is the reduction in the deadweight loss associated with the current registration tax.
- The benefits from differentiating the RUC according to time and place that can be identified by the model are small in comparison.
- The total traffic volume as well as the total fuel consumption is predicted to increase slightly. This could be interpreted as saying that they stay roughly constant.

The first conclusion is uncontroversial. It is perhaps more surprising that the benefit from differentiating the RUC is so small in comparison. Part of the explanation is that it is more the benefit from reducing the registration tax that is large than it is the benefit from differentiating the RUC that is small. Still, the benefit from differentiation is to a large extent a consequence of the shape of the volume-delay relationships implemented in the model. There is reason to believe that these do not reveal the full extent of congestion, especially in group 1, where only a small share of traffic seems to take place at more than 80% capacity utilisation.

Another relevant and important omission of the model is that it only allows for limited substitution of trips over time of day. The analysis of bottleneck congestion by Vickrey (1969) and Arnott, de Palma and Lindsey (1993) shows that there may be substantial welfare gains associated with changes in trip timing. The present model is not able to reveal such welfare gains.

So it would seem that the model underestimates the welfare gains that can be achieved by differentiating the RUC. Recall that the system cost is assumed to be the same in all scenarios. In reality it is likely to be higher for a differentiated charge than for a flat charge. So it is not unlikely that the present analysis is not able to justify differentiation.

The third conclusion will be surprising to many. It is also awkward for policy makers as climate issues are high on the agenda and the reform is sold as being climate-friendly. But there is nothing to preclude a revenue neutral reform that shifts the tax burden from fixed to marginal costs of car use from leading to an increase in car travel. Nevertheless, it is of interest to investigate the robustness of this conclusion.

The parameter β measures the sensitivity with respect to the variable cost of distance. Recall that the main deviations from the calibration targets involved the fuel price elasticities. We computed two alternative model calibrations removing one of these two targets from each one calibration. The calibrated model matched the other target well in both cases. Then we recomputed scenario A with the recalibrated model. The increase in the total traffic volume is now between 1.5% and 3.9% compared to 1.9% in the main calibration. The increase in CO2-emissions is now between 2.6% and 5.0% compared to 3% in the main calibration. So the above conclusions are robust with respect to this change.

An omission of the model that is especially relevant for the climate discussion is the effect of congestion on the average fuel efficiency. Barth and Boriboonsomsin (2008) show that various ITS strategies can achieve large reductions in CO_2-emissions by smoothing traffic flow and reducing severe congestion. It is reasonable to think that a reduction in congestion that may follow from a differentiated RUC also will lead to improved fuel efficiency.

Inevitably, there are many more ways in which the model simplifies and where it can be discussed whether important effects are omitted. One example is that our analysis ignores composition effects. It is based on an average household driving an average car and does not take into account that different households drive different cars and in different places. In return for this simplification we have obtained a tight micro-economic framework that has allowed us to describe a number of effects.

An interesting issue that could be dealt with more adequately in future research is that the model takes the average lifetime of cars to be exogenous, whereas it would ideally be determined endogenously in the model. Theory does exist to explain the lifetime of cars (Parks, 1977) based on failures that occur following some stochastic process. At each failure, the owner must decide whether to repair or scrap the car. This decision depends on the cost of the repair and the remaining value of the car. It remains an open question how this theory can be integrated in a model that accounts for the household decisions regarding ownership and use of cars. It is a fundamental question to ask since accounting for the lifetime of cars is necessary to link the level of ownership to the volume of car sales and hence the revenue from the registration tax.

6 References

Arnott, R. A.; de Palma, A. and Lindsey, R. (1993). A structural model of peak-period congestion: A traffic bottleneck with elastic demand. American Economic Review 83 (1):161-179.

Barth, M. and Boriboonsomsin, K. (2008) Real-World CO2 Impacts of Traffic Congestion. 87th Annual Meeting of the Transportation Research Board, Washington, D.C., U.S.

Doornik, J.A. (2009). An Object-Oriented Matrix Language Ox 6, London. Timberlake Consultants Press.

Energistyrelsen (2009): Forudsætninger for samfundsøkonomiske analyser på energiområdet, maj.

EU Commission (2005). Proposal for a Council Directive on passenger car related taxes. 2005/0130 (CNS).

Eurostat Statistics http://epp.eurostat.ec.europa.eu.

Infrastrukturkommissionen (2008a). Danmarks Transportinfrastruktur 2030. Sammenfatning, januar 2008.

Infrastrukturkommissionen (2008b). Langsigtet fremskrivning af vejtrafik – Indikation af fremtidige problemområder. Baggrundsrapport.

de Jong, G.; Kouwenhoven, M.; Geurs, K.; Bucci, P. and Tuinenga, J. G. (2009). The impact of fixed and variable costs on household car ownership.

Jovicic G. and C. O. Hansen (2003). A passenger travel demand model for Copenhagen. Transportation Research Part A. Vol. 37, No 4.

Nielsen, O.A. and Majken Vildrik Sørensen (2008). The AKTA Road Pricing Experiment in Copenhagen. Chapter 6 in Road Pricing, the Economy and the Environment. Springer Berlin Heidelberg.

Parks, R. W. (1977): Determinants of Scrapping Rates for Postwar Vintage Automobiles. Econometrica Vol. 45 No 5, pp. 1099-1115.

Rouwendal, J. and Pommer, J (2004): An Indirect Utility Model of Multiple Car Ownership and Use. Tinbergen Institute Discussion Papers.

Trafikministeriet (2004): Bilvalgsmodellen 2002, marts 2004. Prepared by Cowi.

Transportministeriet (2009): Aftale mellem regeringen (Venstre og De Konservative), Socialdemokraterne, Dansk Folkeparti, Socialistisk Folkeparti, Det Radikale Venstre og Liberal Alliance om: En grøn transportpolitik, 29. januar 2009.

Transportøkonomiske enhedspriser, 2009.
http://www.dtu.dk/upload/institutter/dtu%20transport/modelcenter/transportoekonomiske%20enhedspriser/transportoekonomiske%20enhedspriser%20vers%201%202%20aug09.xls

Vickrey, W.S. (1969): Congestion theory and transport investment. American Economic Review 59 (2):251-261.