DET ØKONOMISKE RÅD
SEKRETARIATET

Optimal level of Multiple Types of Transportation with Several Externalities

Jens Hauch
Working Paper 1999:4

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

Peder Andersen
Head of Secretariat

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

To order, contact:

Danish Economic Council
Secretariat
Adelgade 13, 5.
1304 København K

Phone: 33 13 51 28
Fax: 33 32 90 29
E-mail: dors@dors.dk
Home page: www.dors.dk

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

Optimal level of MultipleTypes of Transportation with Several Externalities

Jens Hauch
The Secretariat of the Danish Economic Council and
Institute of Economics, University of Copenhagen

Working Paper 1999:4

Abstract:

There exist several types of transportation, each causing several externalities. E.g., both transportation of persons by cars and trains cause noise, accidents and emissions of CO_2.

Analysing a socially optimal situation by independently analysing the partial optimal level of each transportation type based on the marginal costs of reducing and the marginal value (negative) of the externalities it creates is not satisfying. The marginal value of an externality depends on its level. The marginal benefit from reducing this externality by lowering one kind of transportation is therefore dependent on emissions from other kinds of transportation. Here, the theoretical background for the problem is analysed and the rules for an optimal solution are found.

Estimating and running a partial equilibrium model based on a valuation in monetary terms of externalities for Denmark shows that the optimal level of transportation requires reductions in transportation. Compared with a world without taxes on transportation, there are significant welfare gains from reducing transportation to the optimal level. The existing tax system on transportation improves welfare relative to a system without taxes, but is still inoptimal. There are significant efficiency costs of reducing the number of taxes, but the major part of the welfare gain can be achieved with only one optimal tax. If administrative costs are taken into account, a single tax might be preferred to multiple taxes. If uncertainty is introduced, pricing instruments should be preferred for quantity instruments. This is caused by damage curves with relatively small slopes and corresponds the Weitzman result.

Keywords: Transportation, energy, pollution, externatities, valuation.

JEL: Q2, Q4.

Table of contents

1. Introduction[1,2]

The amount of transportation has increased dramatically in the recent years. This has, seen from a social point of view, both beneficial and damaging consequences. The possibility of transportation gives households larger freedom in choosing between commodities and in choosing address. Firms have improved possibilities for attracting qualified employees and must compete in larger markets, which might reduce the deadweight loss from imperfect competition.

Transportation gives, however, also rise to several externalities that are not taken into account by the agent. These externalities include air pollution, noise, accidents etc. Furthermore, transportation increases wear and tear on the infrastructure. The user of transportation does not generally pay such costs directly, and they do therefore not affect the transportation decision.

The transportation level chosen by the agent might therefore differ from the choice made by a social planner who takes also externalities into account. Transportation regulation can therefore be necessary for achieving the socially optimal level.

To analyse this we will develop a partial equilibrium model for the Danish transportation markets. It solves for optimality when negative externalities are taken into account. There might be effects on the rest of the economy from large changes in transportation. In general, such macro effects depend on the possibility for substituting between transportation and other inputs in production/consumption. In the partial model presented here, these effects are assumed to be reflected in the demand for transportation.

Economic regulation methods can in many cases ensure that reductions of externalities from transportation take place at lowest possible costs. We will here concentrate on economic regulation methods.

Economic regulation of damage should in principle relate directly to the damage to give the right incentives. Carbon dioxide will optimally be regulated by a tax

1) An ealier version of this paper has been published, see Hauch (1996).

2) The views posed in the paper are not necessarily shared by the Chairmanship of the Danish Economic Council. The author would like to thank Jan V. Hansen, Peter Brixen and Jørgen Birk Mortensen for many helpful comments and clarifying discussions. This paper is largely based on data found by Danish Economic Council (1996), but the transportation model and the results are, however, not a part of the work by Danish Economic Council (1996) and the author is solely responsible for the paper and problems and mistakes it may contain.

on carbon dioxide. There is, however, a proportional relation between fuel use and emission of carbon dioxide. For a specific car there is also a proportional relationship between fuel use and kilometres driven.[3] I.e., we can create a mapping from driven kilometres to carbon dioxide emissions. In this case, regulating carbon dioxide emissions optimally by a tax per driven kilometre is possible.

For other externalities this mapping is less realistic and only if the physical capital is taken as given. If the physical capital can change, also the mapping can change: if catalytic converters are introduced, the sulphur dioxide emission per fuel use is lowered, i.e. the emission per kilometre is lowered and the mapping is changed. In this paper it is never the less assumed that such mappings can be created between the level of each externality from each transportation type to the level of that transportation type, i.e. we take the physical capital as given. Externalities can therefore in the model only be reduced by reductions in the transportation level.

There is a possibility that the connection between externalities and driven kilometres can change when regulation is introduced. E.g. if increased taxes imply less congestion and by that change the average fuel efficiency due to changed driving speed. Such changes can not be taken into account in this model.

The externalities might differ between cities and rural areas as the level of transportation and the damage from externalities might be different. This means that an optimal regulation of transportation should implement different shadow values depending on geographical location, time of day etc. Such aspects will not be taken into account in this paper. This is important to remember below, where we introduce differentiated road pricing. In this model road pricing can only be primitively differentiated between transportation types not between regions. I.e. an important possibility of differentiated road pricing is not modelled.

The present model should because of the above weaknesses not be interpreted as a policy tool, but rather as an example of how environmental effects can be included in a model, which also includes economic effects of regulation. The model does not solve for optimality in a long run steady state, but shows in principle what should have been done in the base year for optimality to have been obtained through transportation reductions, taking all physical capital as given. Use of the model results in real world policy making is therefore limited.

---

3) At least for the same type of driving at the same type of road.

In Section 2, the model is presented. In Section 3, the data needs and calibration of the model are described. In Section 4, results are presented. We analyse the first best case and the case where the number of available regulation tools are more limited. We also carry out sensitivity analysis of the results to analyse their robustness and to determine which economic regulation instrument is optimal. In Section 5, the paper is rounded off with conclusions.

2. The Model

Assume there exist J types of transportation and I externalities. Equation (1) defines the marginal damage MD_i of an externality as a function of the level of the externality, E_i. Note that it is implicitly assumed that the damage from one externality is not directly correlated with the level of other types of externalities.

$$MD_i = MD_i(E_i) \qquad i = 1,.....,I \tag{1}$$

One example of this relationship is the damage, in monetary terms, of one extra kilo of sulfur dioxide as a function of the emission of sulfur dioxide.

Equation (2) defines the total damage of an externality, TD, as the area under the *MD* curve.

$$\int_o^{E_i} MD(E_i)dE_i = TD(E_i) \qquad i = 1,.....,I \tag{2}$$

Equation (3) gives the size of externality E_i, in physical terms, as a function of the contribution to this externality from the different types of transportation, x_j.

$$E_i = E_i(x_1,.....,x_J) \qquad i = 1,...,I \tag{3}$$

An example of this relationship is the emission of sulfur dioxide, which is given by the sum of emissions from each type of transportation, where those emissions are given by the emission coefficients. In that case, (3) has a very simple linear form. In other cases, this relationship is not linear. E.g. the increase in the noise level from one extra car measured in decibels is dependent on the total level of noise, and the functional form is more complex. This relationship represents the critical assumption of a mapping, mentioned in the introduction, between the level of a transportation type and the level of externalities from this transportation type.

Equations (1) and (3) can be written as (4)

$$MD_i = MD_i(E_i(x_1,....,x_J)) \qquad i = 1,...,I \tag{4}$$

Equation (5) gives the demand for transportation type *j* as a function of its price.[4]

$$x_j = D_j(p_j) \qquad j = 1,...,J \tag{5}$$

Representing the demand for transportation (5) also gives the private costs of giving up transportation, i.e. (5) represents the marginal cost curve of transportation reductions and by that emission reductions.

Equation (6) is the "supply" of transportation type *j*. This equals the marginal user costs, MUC_j, of x_j and the externality tax t_j on x_j. *MUC* is assumed to be independent of the level of transportation for each transportation type. Authorities are assumed to implement only constant unit taxes. These two assumptions imply that the supply curve for each type of transportation is horizontal.

$$p_j = t_j + MUC_j \quad , \quad j = 1,...,J \tag{6}$$

Consumer's private surplus of transportation x_j, CPS_j, is defined in the following way:[5]

4) By including only the own price as explanatory endogenous variable we have restricted ourselves. It is probable that also the price of other transportation types will influence the demand for a transportation type. We will see below, however, that the mistake we make by assuming no cross prices dependence is probably small. The solution method we use in the model is based on the social surplus, which can generate theoretical problems by including cross price elasticities, see below. One advantage of this restriction is that the social surplus has the same value as equivalent variation.

5) When there is more than one market in which prices are shifting, the use of changes in consumer's surplus as an indicator of the change in welfare resulting from a shift in prices may be problematic, Auerbach (1985). The problem is that consumer's surplus does not come from an underlying utility function. The consequence is path dependence in calculating *CS*: as more prices are changing, the order in which the different consumers surpluses are calculated becomes important. There are conditions under which the problem is not present: the utility function should be quasi linear, Varian (1992). This condition is restrictive and will not generally be satisfied. In the model presented here, the condition will be fulfilled by setting all cross price elasticities equal to zero.

$$CPS_j(x_j) = \int_{p_j}^{\infty} [D_j(p_j)]\,dp_j - x_j p_j \qquad j = 1,...,J \tag{7}$$

Consumer's private surplus (*CPS*) equals the total private surplus of transportation since the *MUC* is horizontal, and the producer's surplus therefore equals zero. Note that *CPS* does not take the externalities into account, it only focuses on the private value of transportation. Because the supply curve for transportation is horizontal, the producer's surplus equals zero.

To find the optimal level of transportation, we need a criteria function that maximizes the total social surplus, *SS*, of transportation. The difference between *CPS* and *SS* is that the latter takes the existence of externalities into account, along with tax revenues. In the case with only one type of transportation, *SS* equals the area under the *MC* curve minus the area under the *MD* curve. In the general case, we look at J types of transportation and thereby have J instruments to regulate. There exist *I* externalities. It is not possible, if $I > J$, to achieve any combination of *I* externalities. It is therefore not possible, in general, to ensure that the usual optimization criterion, $MD(E_i) = MC(E_i)$, is achieved for $i = 1,...,I$. We instead maximize the total social surplus using the J transportation levels as instruments.[6]

The social benefit from transportation type j $SB_j(x_j)$ is defined in (8).

$$SB_j(x_j) = CPS_j(x_j) + (P_j(x_j) - MUC_j)x_j \qquad j = 1,...,J \tag{8}$$

We get the following criteria function (9).

$$\max_{x_1,...,x_J} \left[\sum_{j=1}^{J} SB_j(x_j) - \sum_{i=1}^{I} TD_i(E_i(x_1,...,x_J))\right] \qquad j = 1,...,J \tag{9}$$

---

[6] Several other solution methods could have been used instead of maximizing social surplus. The optimal way would be to include damage from externalities directly into the utility function of a representative consumer in a general equilibrium model. This solution would, however, imply much data work. The results from such a model would probably not be much more valid than the results from our model as one would still be left with highly uncertain damage functions. The solution could also be based on an objective function including the indirect utility of a representative consumer and the value of externalities defined as in our model, see Borger and Swysen (1995).

The problem is solved by finding the necessary first order conditions, which gives the following result,

$$\sum_{j=1}^{J} \frac{\partial SB_j(x_j)}{\partial x_{j^{\bullet}}} = \sum_{i=1}^{I} \frac{\partial TD_i(E_1,\ldots,E_I)}{\partial E_i} \cdot \frac{\partial E_i(x_1,\ldots,x_J)}{\partial x_{j^{\bullet}}}, \qquad j^{\bullet} = 1,\ldots,J \quad (10)$$

The interpretation of the result is the following: the sum of marginal consumer's private benefits plus the marginal tax revenue shall equal the sum of marginal damages for each type of transportation. It is not possible to solve (9) for one type of transportation without paying attention to the other types: marginal damage from one type of transportation depends on the level of the other types of transportation.

It is from (10) possible to get the resulting optimal tax for each transport types reflecting the shadow value of transportation in optimum. Those shadow values will only by coincidence be equal. If the optimal transportation level should be achieved by taxing transportation, using the same tax for all types of transportation would therefore not be possible. We will see below, however, that the loss from using only one tax might in practice be limited.

3. Model Calibration

The model is calibrated for 1993. The data can be separated into two groups, data used for estimating the demand functions in one group, and data used for damage functions in the other group.

Costs of reducing transportation

The benefits of transportation (or the costs of reducing transportation) are reflected by the demand for transportation. The demand functions are based on empirical work by Brixen (1996). The functional form used in demand is the following:

$$x_j(p_j) = \gamma_j \, p_j^{\alpha_j} \qquad j = 1,\ldots,J \quad (11)$$

The demand depends on own price as the only endogenous variable. The γ's are level constants calibrated from 1993 data. All parameters other than transportation prices that might affect the demand for transportation are assumed constant at the base year level. They could be parameters such as the income level, changes in comfort in transportation, technological changes etc. They are assumed reflected by the calibration of the γ's.

The transportation types analysed here are domestic transportation on land, i.e. transportation by cars, vans, buses, trains and trucks. A set of own price elasticities can be calculated from Brixen (1996). The estimated elasticities are shown in Table 1.

Table 1 Transportation data, 1993

Transportation type	Transportation level	Existing taxes and subsidies	Own price elasticity
	million person per ton km.[a]	DKK per person per ton km.	
Cars	57060	0.16	-0.54
Buses	9502	-0.19	-0.55
Person trains	4798	-0.65	-0.55
Vans	480	2.73	-0.42
Trucks	9047	0.22	-0.92
Freight trains	502	-0.70	-0.5[b]

a) Person km. for cars, buses and person trains. Ton km. for vans, trucks and freight trains.
b) Guesstimated.
Source: Brixen (1996), Danish Economic Council (1996, p. 142) and own calculations.

The reported elasticities are elasticities for the level of transportation when variable transportation costs are changing. For public transportation, such variable costs are the ticket prices/freight prices and Brixen's estimated elasticities are used directly. For cars and vans, the elasticities are calculated using estimations from Brixen.

The, by far, largest transportation type for persons is cars. This indicates that the effect of leaving out cross price elasticities is minor. If transportation should be moved in substantial amounts from, e.g., (polluting) cars to (perhaps less polluting) buses, the bus transportation elasticity of car user costs should be very high. Very high elasticities are not supported empirically, see Brixen (1996). I.e., realistic cross price elasticities will only imply small movements from car transportation to bus transportation by changes in car prices. By that, the influence of including these elasticities into the model will also be minor. The same argument holds for freight transportation where trucks are the dominant transportation type.

In Denmark several taxes on transportation exist. Existing taxes are reported in Table 1. Net taxes on private transportation are positive, while public transportation is net subsidized. We want the model to solve for optimum, i.e. the modelled user costs should not include existing distortionary taxes. We consequently subtract existing taxes from observed user costs of transportation.[7]

The seemingly high tax on vans is a result of the calibration of this composite transportation commodity. Vans only transport small amounts of freight, but are also used for person transportation. Calculating the tax as either on person transportation or freight transportation will always seem strange as the service from vans is a composite of these.

Damage Functions

To include damages from externalities into an optimizing model, it is necessary not only to measure the damage in physical terms, but also in monetary terms. Though very interesting, the choice between valuation methods will not be dealt with here, while a good overview of the different principles can be gained by reading Freemann (1985). There should be no doubt that the existing valuation methods contain serious problems that may or may not be solved in the future. These problems will also be present in a model based on those methods.

Estimation of the damage functions in this paper is based on work done by the Danish Economic Council (1996) and Larsen (1996). The used valuation methods are based on several different techniques, but when possible direct methods have been used. Key data are shown in Table 2.

---

7) We will not add subsidies to observed user costs of public transportation. The argument for this is that the subsidies reflect public preferences for giving everybody a possibility of being transported, not subsidies to increase externalities. I.e., a subsidy is given to public transport for other reasons than externalities.

Table 2 Data on externalities, 1993

Externality type	Total costs	Emissions
	Million DKK	1000 tons
Accidents	13829	-
Noise	4980	-
Wear and tear	673	-
Nitrogen oxide	9172	98
Sulphur dioxide	495	9
Particulates	399	4.3
Hydro carbon oxide	2546	98
Carbon dioxide	2020	10096

Source: Danish Economic Council (1996) and Larsen (1996).

For the emission of the air pollutants nitrogen oxides, particulates and hydro carbon oxide, the marginal damage is assumed to be a linearly increasing function of the level of emission, passing through the origin and through the present levels of emission and marginal damage. This is, of course, a very rough approximation.

When it comes to carbon dioxide and sulphur dioxide, marginal damage is assumed to be constant at the present level. The reason for carbon dioxide is not a general assumption that the marginal damage is constant, but reflects that the damaging effects of carbon dioxide is a function of the global level of carbon dioxide to which Denmark only contributes marginally. Assuming that the damage from the Danish emissions is equal to the marginal global value is therefore reasonable, no matter what the change in the Danish emissions is.

A further assumption is that emission coefficients for air pollution are constant and therefore that the emissions of the different kinds of air pollutants are linearly increasing with the level of the different types of transportation. This is, as discussed above, a critical assumption.

The marginal damage from noise is assumed to be a constant function of the transportation level. This assumption, though valid for small changes in the transportation level, is not without problems, see Larsen (1996).

The marginal damage from wear and tear of roads is for each transportation type assumed to be a constant function of the use of each transportation type. This is not an unreasonable assumption.

The marginal damage from accidents is assumed to be constant as a function of the number of accidents, which is reasonable. But the number of accidents is not a linear function of transportation level. The Danish Economic Council finds based on work by the Danish Road Directorate that the total number of accidents is exponentially increasing with transportation level by a power of 0.6. Consequently, the marginal number of accidents is a decreasing function of the transportation level for each type of transportation. This means that the marginal damage from accidents will be a decreasing function of transportation level.

It can be discussed whether accidents should be included directly into the model as we have done. It can be argued that the risk of accidents are already implemented into the costs of transportation seen by the consumer and by that reflectet by the demand for transportation. This is possible the case for the potential pain and suffering on the person that makes the transportation decision. It is, however, doubtful whether this person takes the increased damage risk imposed on other persons into account. The costs of medical treatment are neither taken into account by the person that makes the transportation decision because of the health insurance. I.e. some of the damage costs may be internalised, some may not. We have chosen to include all as they are hard to separate.

4. Results

Two scenarios are analysed. In one of them, differentiated road pricing is used as regulation instrument. In the other, the effect of using a uniform fuel tax is analysed. By comparing the value of the objective function in these two scenarios, one can get an impression of the cost of restricting oneself to using only one tax. This cost gives the upper level of the administrative costs that could be used extra to run a system of diffrentiated road pricing compared with only one fuel tax.

We also carry out a sensitivity analysis on the location of the marginal cost curve for transportation reductions. We use this to determine the optimal choice of economic regulation instrument.

Differentiated Road Pricing

The first scenario analyses the effect of introducing a system of differentiated road pricing, which in our model is the first best solution to the planner's problem. Authorities can use one road price for each type of transportation. As previously described, using one tax for each type of externalities is impossible as the number of transportation types puts linear restrictions on the number of instruments. The results are summarized in Table 3.

Table 3 Optimal transportation with differentiated road pricing, 1993 prices

Transportation type	Change in transportation level	Shadow value	Shadow value	Maximum tax[b]
	Per cent	DKK per person per ton km[a]	DKK pr. l. fuel	DKK per l. fuel
Cars	-20.2	0.42	10.1	11.00
Buses	-22.5	0.21	10.7	11.50
Person trains	-24.9	0.31	16.1	17.25
Vans	-18.2	8.70	4.6	5.25
Trucks	-7.3	0.52	7.9	8.50
Freight trains	-4.5	0.37	11.0	12.50

a) Person km. for cars, buses and person trains. Ton km. for vans, trucks and freight trains.
b) Calculated by Danish Economic Council (1996).
Source: Own calculations.

It is seen that in optimum all road prices are positive.[8] This means that the existing taxes do not take external effects of transportation sufficiently into account. Vans seem to be heavily taxed, it should be noted though that the reason for this is a very low load factor, which is seen when the tax is measured in DKK per litre fuel. Here vans are taxed at a rate lower than the other types of transportation.

In Table 3, "maximum taxes" calculated by Danish economic Council (1996) are also reported. The maximum taxes are calculated as the marginal damages in 1993

---

8) Remember that public transportation in optimum is assumed to receive a subsidy for social reasons. The net result, calculating both social/regional subsidies and environmental taxes, is around zero for buses and freight trains. For person trains there will be a net subsidy of 1.6 bill. DKK a year. This implies, however, still higher net taxes than the present.

from each type of transportation. If the aggregate marginal damages from externalities are increasing functions of the levels of transportation, maximum taxes will represent an upper limit of taxes. If all marginal damages of transportation were constant, the maximum taxes would equal optimal taxes.

It can be seen that the shadow values calculated per litre fuel are only a little lower than the maximal levels calculated by Danish Economic Council (1996). Even though the transportation level in optimum is lower than the base year level, one could not be sure that the optimal taxes should be lower than the maximum taxes as the marginal damage of accidents is a decreasing function of transportation level. This is, however, dominated by the increasing marginal damages of other externalities.

The resulting effects on levels of externalities are given in Table 4.

Table 4 Optimal change in levels of externalities

Externality type	Change in externality level
	Per cent
Accidents	-11.8
Noise[a]	-9.9
Wear	-15.1
Nitrogen oxide	-18.5
Sulphur oxide	-17.4
Particulate	-16.0
Hydro carbon oxide	-19.7
Carbon dioxide	-18.0

a) The reported number is not the change in noise level, but the change in damage from noise.

Source: Own calculations.

The levels of all externalities should be at least 10 per cent lower than the base year level. The largest reductions should be in the damages from air pollution. All air pollutants should be reduced by at least 16 per cent.

Uniform Taxes

The uniform tax scenario gives the consequences of implementing *one* optimal tax on fuel.[9] This scenario differs from the differentiated road pricing scenario as authorities now are limited to use only one tax. They have by that a reduced number of instruments, and it should be expected that the outcome is less efficient than when differentiated road pricing could be used. If the costs of implementing a single tax system are small compared with the difference in administrative costs between running a system of differentiated road pricing and a system of uniform fuel taxes, then a single tax system should be preferred to differentiated road pricing. The result of the uniform tax scenario is shown in Table 5.[10]

Table 5 Effects of one optimal fuel tax, 1993 prices

Transportation type	Change in transportation level	Shadow value	Shadow value
	Per cent	DKK per person / ton km.[a]	DKK per l. fuel
Cars	-18.6	0.40	9.5
Buses	-20.2	0.18	9.5
Person trains	-16.8	0.18	9.5
Trucks	-9.6	0.63	9.5
Freight trains	-3.9	0.32	9.5

a) Person km. for cars, buses and person trains. Ton km. for vans, trucks and freight trains.
Source: Own calculations.

By comparing the first column in Table 5 with the first columns in Table 3, it is seen that the consequences for the transportation level of only using one tax are minor. The optimal tax should be 9.5 DKK per l fuel in this scenario. This means that trucks will be more heavily taxed than under multiple taxes, while the other transportation types will be taxed less than optimally.

9) In this scenario we are very restrictive with respect to regulation instrument. In the real world, taxes on fuel are differentiated for different types of fuel. If this was included here, the performance of regulating fuel prices would improve. We are, however, interested in the one fuel scenario as it represents an extreme case.

10) Vans are excluded from the fuel tax scenario. This is due to analytical problems with vans when a fuel tax is used as instrument.

The small changes in transportation levels when only one tax is used indicate that the costs of restricting oneself to one tax might be minor. In Table 6, costs of applying different kinds of tax systems are presented.

Table 6 Costs of different tax systems compared with the case of optimal taxation, 1993 prices

Tax system	Costs compared with optimum[a]
	Million DKK per year
Uniform fuel tax	39
No regulation	7760
Present taxes	2169

a) Vans are for the comparability not included in any of these scenarios.
Source: Own calculations.

From Table 6 we can see that a system of differentiated road pricing gives large welfare improvements compared with a situation without regulation, about 7.7 billion DKK a year.

The present tax system for transportation is costly compared with the optimal taxation, amounting about 2 billion DKK extra a year, which is about 2 per cent of gross output in transportation. Comparing the present system with a situation without taxes on transportation, it can be seen, however, that the present taxes are better than a system with no taxes, and therefore represent a step in the right direction.

A uniform fuel tax on transportation leads, as expected, to additional costs compared with the optimal situation. These costs are around 39 million DKK a year. When deciding which of those systems that should be preferred, considering administrative costs is important. These are not included in the model. If the administrative costs of running a system with differentiated road pricing are less than 39 million DKK more than running a system with a single fuel tax, then the differentiated road pricing system should be preferred. Otherwise, a single fuel tax should be preferred.

The small difference in performance of differentiated road pricing and a uniform fuel tax is surprising. The main explanation for this result is the small difference between externalities from different transportation types. In Table 3 the optimal road pricing is calculated as a shadow value per litre fuel. These shadows value are not very different which indicate small difference in externality level per litre fuel used for different transportation purposes.

It should, however, be remembered that the differentiated road pricing used here is primitive. In real world there will be an opportunity to differentiate road prices between regions. This will improve the advantage of differentiated road pricing towards a uniform fuel tax.

Sensitivity on Reduction Costs

Here we will carry out a sensitivity analysis concerning the location of the marginal abatement cost curve. There is a twofold purpose of this analysis. First, we want to analyse the quantitative changes to the result if the location of the cost curve is different, i.e. a traditional sensitivity analysis. Second we will use the result to decide upon the optimal regulation instrument, tradeable permits or taxes (see below for a discussion of the interpretation of tradeable permits in our case). By that we can quantify the Weitzman result for the choice of instrument under uncertainty, see Weitzman (1974).

We are in the real world facing large uncertainty about the location of both the cost curve and the damage curve. When there is uncertainty about the location of the damage curve, the loss from applying wrong standards or taxes are equal, see Weitzman (1974). It does therefore not matter which instrument we use when the uncertainty is on the location of the damage curve. When we face uncertainty about the location of the abatement cost curve, the optimal choice of instruments depends on the relative slope of the marginal cost curve and the marginal damage curve. If the damage curve has a relatively small slope, taxes are the preferred instruments, while standards are preferred if the damage curve has a relatively large slope.

To decide optimally upon the choice of instrument we should therefore concentrate on the case with uncertainty about the location of the marginal cost curve. We will therefore not carry out sensitivity analyses concerning the location of the damage curve. It is, however, important to remember that the location of the damage curve is highly uncertain, which can imply high welfare losses, although they are the same for standards and taxes.

We have modelled the costs of reducing damage as the cost of reducing different kinds of transportation. This may, as mentioned above, not be cheapest way to reduce damage. It is therefore possible that the real costs of reducing damage are lower than the costs we have used in the model. To analyse the consequence of this we will assume lower reduction costs than we have used above.

Technically, we will introduce lower reduction costs by assuming numerically higher own price elasticities in demand for transportation. By that, the reduction curves become less curved than the original curves. The high elasticity curves will consequently be lower as it is calibrated in the same base point as the original curves.

This way of changing the location of the cost curve is slightly different from in the Weitzman articles. There, the uncertainty is additive, i.e. it does not change the slope of the curve. Here, the slopes of the curves are changing, i.e. also the relative slopes between the curves change. The optimal choice of instruments can therefore in the theory depend on the level of uncertainty. In our model the relative slope between the original curves will, however, below be seen to be so different that the optimal choice of instruments is the same within a large range of elasticities.

In the sensitivity analysis we assume that all own price elasticities are numerically 0.2 higher than the original own price elasticities shown in Table 1. We will take the scenario with multiple road pricing as the starting point. The result is shown in Table 7.

Table 7 Optimal transportation with multiple taxes and high elasticities, 1993 prices

Transportation type	Own price elasticity	Change in transportation level[a]	Shadow value	Shadow value
		Per cent	DKK per person/ton km.[b]	DKK per l. fuel
Cars	-0.74	-25.6	0.41	9.8
Buses	-0.75	-28.4	0.20	10.3
Person trains	-0.75	-31.6	0.30	15.5
Vans	-0.62	-25.1	8.51	4.5
Trucks	-1.12	-8.4	0.51	7.7
Freight trains	-0.70	-6.0	0.36	10.5

a) Compared with scenario with base year taxes.

b) Person km. for cars, buses and person trains. Ton km. for vans, trucks and freight trains.

Source: Own calculations.

Comparing the changes in transportation level in Table 7 with the changes in transportation level in Table 3, we see that the optimal transportation levels are lower in the case with higher elasticities. This is not surprising as the costs of reducing transportation are lower. If we, on the other hand, compare the tax levels we see, that they are only slightly changed compared with the tax levels in Table 3. This indicates that the damage curves have a relatively small slope.

We will consider a price instrument and a quantity instrument as in the Weitzman tradition. The price instrument is in our case road pricing. The straightforward interpretation of the quantity instrument is tradeable driving permits, which is not the most realistic instrument in the real world. We will instead interpret the quantity instrument as a composition of instruments that limits the quantity of transportation, e.g., less train departures, less roads, lower speed limits, car less Sundays etc. We will assume that these measures are composed optimally given the target.

With a small slope of the damage curves as indicated above, the Weitzman theory tells us that the best instrument under uncertainty is probably the price instrument.

Assume that the high own price elasticities in Table 7 are correct, but that the planner falsely believes that the own price elasticities in Table 1 are correct. What loss would occur if the price instrument was used for achieving the false optimum and what would be the loss if the quantity instrument was used? The result is shown in Table 8.

Table 8 Costs of applying prices versus quantities for wrong abatement cost curves, 1993 prices

Regulation instrument	Cost
	Million DKK per year
Price instrument	13.9
Quantity instrument	190.8

Source: Own calculations.

We see that the cost of applying a wrong price instrument is much smaller than the cost of applying a wrong quantity instrument. This result corresponds to the Weitzman theory.

This is a very robust result with respect to changes in own price elasticities. Scenarios have been made with own price elasticities within a range of 0.2 numerically lower and 10 numerically higher than the original elasticities. In all these scenarios, the pricing instrument is preferred.

5. Conclusion

We have developed a model for calculating optimal level of multiple types of transportation taking several externalities into account. We have applied the model in analysing the optimal Danish transportation level in 1993.

The empirical foundation of the model contains several weaknesses. First, the estimation of the damage from externalities is highly uncertain. Second, the mapping from transportation level to externality level is based on an assumption on fixed physical capital, which is obviously not the case in future policy making. For that reason the result is interpreted as the 1993 optimal level. Third, the model is based on a rough modelling of the demand for transportation where the own price is the only endogenous variable influencing demand. The error from this is, however, probably minor and dominated by the other large uncertainties. The results from the model should therefore in policy making primarily be used as qualitative indications of the optimal policy, while the specific levels should only be taken as very rough estimates.

The model shows that the optimal level of transportation is lower than the present level, especially for public transportation. In optimum, public transportation should face positive taxes, though they should be lower than taxes on private transportation. All externalities should be reduced significantly in optimum compared with the present situation. The largest reductions should be in air pollution.

There are significant welfare gains from reducing transportation to the optimal level compared with the level in a world without regulation of transportation. This is a result that would be expected ex ante as externalities are not taken into account in the decision of transportation level in a situation without taxes. The existing tax system improves welfare compared with a system without regulation, but is still inoptimal. There are therefore possibilities of improving the regulation system.

It is shown that the efficiency costs of reducing the number of regulation instruments are significant, but the major part of the welfare gain can be achieved with only one optimal tax. A system with one tax can achieve 98.2 per cent of the potential gain of regulating transportation. One will, of course, want to get the last 1.8 per cent of the potential gain (39 mill. DKK a year), but administrative costs are not included in the model. If the costs of this system could be reduced by more than 39 million DKK a year by only using uniform taxation, then this would be preferred to a system with differentiated road pricing.

We also made a sensitivity analysis on the location of the marginal cost curve. We changed the location by assuming numerically higher own price elasticities in demand for transportation. We found that this changed the optimal transportation level significantly, while the optimal taxation changed only slightly. This indicates that the marginal damage curves have relatively low slopes. The Weitzman theory tells us that a pricing instrument should be preferred if one faces uncertainty on the location of the marginal cost curve. We quantified this theoretical result and found that the loss of applying wrong standards would be much higher than the cost of applying wrong taxes.

References

Auerbach, A. J. (1985): The Theory of Excess Burden and Optimal Taxation. In A. J. Auerbach and M. Feldstein (eds.) (1985): *Handbook of Public Economics, vol. 1*. Elsevier Science Publishers B.V. Amsterdam.

Borger, B. and D. Swysen (1995): *Optimal Pricing and Regulation of Transport Externalities: A Welfare Comparison of Some Policy Alternatives*. Paper presented at International Institute of Public Finance 51 st Congres, Lisbon, 21-24 august 1995.

Brixen, P. (1996): *Dansk transport: Estimationer og en prognose,* Danish Economic Council, working paper 1996:6. Copenhagen.

Danish Economic Council (1996): *Dansk Økonomi Forår 1996*. Copenhagen.

Freemann, A. M (1985): Methods for Assessing the Benefit of Environmental Programs. In A. V. Kneese and J. L. Sweeney (eds.) (1985): *Handbook of Natural Resource and Energy Economics*. Elsevier Science Publishers B.V. Amsterdam.

Hauch, J. (1996): Optimal Level of Multiple Types of Transportation with Several Externalities. In IAEE and DES (1996): *Transport, Energy and Environment.* Conference Proceedings. Regional European Conference 3-4 October, 1996. Copenhagen.

Larsen, M. (1996): *Transportens eksterne omkostninger,* Danish Economic Council, Working Paper 1996:4. Copenhagen.

Varian, H. R. (1992): *Microeconomic Analysis*. W.W. Norton Company. New York. London.

Weitzman, M. L. (1974): Prices vs. Quantities. *The Review of Economic Studies, XLI.*