Calculating External Costs of Transportation in Norway

Principles and Results

NECTAR Conference in Delft, October 1999

Knut S. Eriksen
Senior Research Economist
Institute of Transport Economics (TØI)
Oslo
Norway

EJTIR, **0**, no. 0 (2000), pp. 9-25

Received:1999/2000
Accepted: August 2000

Transport activities are known to have substantial negative external effects. One of the reasons for trying to value these effects is that the cost to society of using a specific transport mode should be reflected in the price that is paid by the transport user and thus form the basis for a transport tax policy.
Previous calculations of marginal external costs of transport at the Institute of Transport Economics (TØI) as well as the methods employed are in many cases outdated and need revision. Therefore it has been decided to update the methods as well as the estimates.
External effects included in this analysis are: a) emissions to air, b) noise, c) traffic accidents, d) wear of infrastructure and e) congestion. External costs are seen as related to transport volume, intensity of the effect, degree of harm of the effect and unit cost of harm.
The assumptions of these relations will be discussed. One problem with the shape of the cost function is whether the effect (e.g. noise) can be said to be proportional to the transport volume.
In estimating the unit costs mainly willingness-to-pay (WTP) methods will be applied.
The marginal external costs of each mode or vehicle type is compared to what is actually paid at the margin by these modes in taxes and charges that are related to transport volume.
Small vans and passenger cars internalise approximately their external cost in the form of traffic charges. Airplanes pay a lot more than their external cost because they cover the total cost of the CAA (Central Aviation Administration). Buses, passenger trains and cargo vessels pay a very small part of external costs in the form of traffic related charges.

1. Introduction

Transport activities, like other economic activities, will affect persons or enterprises other than those taking part in the activity. These are called external effects and include effects for persons and businesses that cannot themselves influence the activity through the market. The most common external effects that are usually ascribed to transportation are pollution, noise and traffic accidents.

The cost to society of transport activities includes private costs plus costs related to external effects. Here we want to focus on the marginal external effects, that is to say costs resulting from an increase by one unit in the transport activity of a certain mode.

Several previous calculations of the costs to society of external effects of transportation activities have been carried out in Norway. The first attempt to cover all transport modes and the *costs* of most important external effects was carried out Eriksen and Hovi (1995). Before that most studies concentrated on the physical aspects of external effects, e.g. the physical amount of pollution of certain gases. Methods of calculating the prices of non-market goods (or rather bads) that have been developed through the last decades have made it possible to try to calculate the actual costs of these effects.

The present study aims to calculate the marginal external effects of transportation activities in Norway. The external effects included are:

- emissions to air
- noise
- accidents
- infrastructure wear
- congestion

Unlike the study from 1995 congestion costs are included in the present study. This is due to the fact that the methods of estimation have been improved. Only external effects resulting directly from transport activities are included. Indirect effects like the effects of building infrastructure or manufacturing of vehicles are not included. One important aim of the study is to compare the marginal external costs of transportation activities with traffic-related charges and taxes that are related to transport activity.

The study was initiated by the Norwegian Ministry of Transport as part of their input to the National Transport Plan 2002 – 2011. This plan includes all transport modes and all infrastructure investment and other policy plans for this eight year period. The reason is that the Ministry wanted to investigate what tax policies stimulates an efficient use of environmental and infrastructure resources in the transport sector. The Ministry of Transport and the Ministry of Fishery[1] and the Civil Administrations of Road, Air and Rail have financed it as a joint venture.

The report of the project was published in December 1999 (Eriksen, Markussen & Pütz 1999).

[1] Responsible for harbours and costal shipping.

2. Marginal or average costs?

As mentioned above this study will focus on the *marginal external costs* of transportation activities. We are looking upon the effects of increasing the transport activity by one unit under a short time horizon, which implicates that we are looking upon the *short-term* marginal external costs.

Alternatively we might look at the *long-run* marginal external costs. In this we can calculate the effects of a long-run traffic increase. This means that transport capacity and transport capital is increased to an optimal level. However, the task of calculating this is not an easy one, and it may lead us into problems of delimitation. What are the effects of transportation itself, and what would be the effect of the investment in infrastructure? If congestion cost exceeds investment cost, it is an indication that investment in better infrastructure should be carried out.

Some related studies focus on *total* or *average* external costs as the main concept. That is to say all the costs and benefits associated with external effects of transportation and not only the effects on the margin. This might be a heavy task, as external effects that are caused by fixed (non-traffic related) activities in the transport sector should also be counted.

Theoretically it makes a difference whether one is looking at average or marginal costs. Comparing average external costs with average taxes paid by the providers of a transport mode may probably tell us something about fairness and whether the transport providers pay a *fair* share of the sector's external costs compared to what other transport modes are paying. This probably goes back to the view that the economic agent should bear *all* cost that he brings upon society and not only the traffic volume related costs. This way of seeing things is to some extent reflected in laws and official planning documents, at least in Norway. Also in the EU 'Green Paper' titled *Towards fair and efficient pricing in transport* (European Commission 1996) one may find traces of this view.

In the present analysis we want to focus on *efficiency* in the transportation sector. This means that we want to compare marginal costs with marginal taxes. In other words traffic related taxes and charges should be compared to marginal external cost. Thus the sector will get a signal to be efficient. This means *internalisation* of external cost. That means that external costs are reduced to an optimal level.

3. Externalities

As mentioned above an externality is an unwanted side effect of production or consumption. A more precise definition after Baumol (from Verhoef (1996)) is:

> An *external effect* exists when an agent's utility or production function contains a real (non-monetary) variable, whose actual value depends on the behaviour of another agent, who does not take this effect of his behaviour into account in his decision making process.

This means that only physical external effects are included. Indirect economic effects through the market should not be counted as external effects. Price effects of change in economic behaviour should thus not be included.

In the present analysis we confine ourselves to the short-term external effects. This among other things means that external costs of the infrastructure itself or production of vehicles or other means of transportation are not included.

4. Methods of calculation

4.1 General

The methods of calculation are mainly based upon the following simplified formula:

*[External cost] = [unit cost] * [degree of harm] * [intensity] * [transport volume]*

The formula is most easily explained when emission cost is taken as an example. Starting from the last element of the expression, *transport volume* means vehicle kilometres or passenger-/ tonne-kilometres performed by a certain mode of transportation. Only domestic transport is counted. This is also the case for air- and sea transport. *Intensity (of effect)* is the physical measure of the effect relative to transport volume, e.g. emission of SO_2 per vehicle kilometre. This is converted into concentrations per cubic metre of air. *Degree of harm* (degree of damage) is related to the size of the effect, e.g. number of deaths or cases of illness due to emission of particles. The *unit cost (of harm)* is the cost that is inflicted on society resulting from a certain 'harm', e.g. the cost per death or per case of illness.

The formula may also be applied to other external costs than emissions, in which case the formula may be simplified, for instance in that the degree of harm is not measured as the cost is related directly to the physical effect. This may apply for instance to noise.

External cost is not necessarily proportional to transport volume. Neither degree of harm nor intensity of effect need to be constant, but may vary with transport volume. As an example the harmful effects of local emissions may depend upon certain threshold values being exceeded. Below this threshold the effect is considered to equal zero, but will increase progressively above this level. On the other hand: in heavy traffic noise from an additional car will hardly be felt, while in low traffic periods it may be clearly annoying.

The valuation of unit costs is based upon three main methods:

- *The willingness to pay (WTP)*. By this one usually means people's (or society's) willingness to pay to avoid or to reduce certain unwanted environment effects. Also peoples' willingness to accept (WTA) a certain worsening of environment conditions belongs here. WTP and WTA are often measured by means of different interview technique e.g. *conjoint analyses*.
- *Damage costs*. The calculation of damage costs implied by different kinds of transport activity depends upon the establishment of *dose-response functions*, which will link a certain physical effect to a certain damage of health or environment. The cost of this damage often will have to be valued by means of WTP-methods, since several of the cost elements often do not have a market price. The damage cost method therefore can not stand entirely on its own as a valuation method.

- *Indirect valuation*. Measures to avoid ruining the environment are often implemented by the state or local authorities. The costs of these measures can be taken as the society's willingness to pay to preserve the environment from a specific threat. If this method is cost-efficient it will lead us to the *shadow price* of the environment resource. That is the cost of changing the society's boundary for this recourse.

All these methods are different ways of measuring the society's valuation or WTP/WTA for a non-market resource. Theoretically this method is satisfactory since it measures the value for the average economic agent of increasing or decreasing the size of a factor by one unit. The difficulty lies in measuring this in the best possible way.
The first of these methods measures the WTP in a direct way. This may be appropriate if people know the consequences of changing e.g. the emission of a certain substance by one unit. However, this is not always the case. But if it is possible to establish a good dose-response function and to measure the WTP to avoid a certain dose, the Damage cost method will probably be better. Indirect valuation has been criticised for confirming earlier political decisions. In lack of better alternatives we have applied this method as well.
The way to deal with the elements of the formula will be treated in the following part of the document.

4.2 Emissions to air

Local and regional emissions
Most emissions are closely related to *fuel consumption*. This is the case for local and regional emissions as well, but in some cases the relationship is more complicated. Driving conditions like the temperature of the engine plays an important role. For some substances the *distance driven* under varying conditions is the most important factor. The physical emissions to air from road traffic are calculated in the Norwegian 'Road Emission Model'. (Bang *et al.*, 1999).
Numerous different substances stemming from transportation activities influence local and regional environment. Since it is not possible to put a price on each of these components, we have chosen some components that are considered important, both regarding physical amount and damage effects. The substances included in the valuation are:

- Sulphur dioxide (SO_2)
- Nitrogen oxides (NO_X)
- Volatile organic components (VOC and NMVOC)
- Particles with diameter less than 10 μm in diameter (PM10).

Earlier studies of calculation prices of local emissions have mainly been based upon damage costs like Grupp (1986) and Hohmeyer (1988). Health costs include mainly hospital costs, other treatment and lost income. But there are early examples of use of WTP-studies, like Schulz (1995). Rosendahl (1996) combines dose-response functions with WTP-studies to include the cost of deaths caused by particle emissions.
We build our unit cost estimates upon different sources. If possible we base our estimates on WTP studies, preferably combined with dose-response functions (damage cost analyses). For SO_2 we build upon an unpublished study by The Norwegian Pollution Control Administration (SFT). The results are published in Christensen *et al.*, (1997). The main

effects are on health, on plants and corrosion damages. Marginal cost of SO_2-emission are by use of damage cost methods assessed to NOK[2] 50 - 90 (EUR 6 – 11) per kg in densely populated[3] and NOK 8 – 25 (EUR 1 – 3) in sparsely populated areas

For NO_X, VOC and particles (PM10) we apply the 'recommended' values from a meta study from The Conference of European Transport Ministers (ECMT) under OECD (ECMT 1998). This study puts together the results of numerous studies performed by different methods, most shadow price methods. From these ECMT finds an average price for NO_X and VOC of 8 Euro (NOK 66) per kg in densely populated areas and 4 Euro (NOK 33) per kg in sparsely populated areas. The strength of this analysis by ECMT is the number of separate analyses included. The fact that the estimates have found widespread use makes it easier to compare results with other studies eg. the 'SAS study' (COWI *et al.*, 1999). The weakness is that we do not know exactly what methods that have been applied, but apparently the estimates are mainly based on shadow price methods.

For particles (PM10) the same report finds an average value of 70 EURO (NOK 580) in densely populated areas and 0 in sparsely populated areas. A Norwegian study by Rosendahl (1999) indicates that the damage cost function is rapidly increasing by the concentration of particles in the air. As long as the concentration is not exceeding certain threshold values the damage is assumed to be zero. Taking the average values of Rosendahl's estimates for the different population concentrations we set the unit cost of particles to NOK 1700 per kg in the bigger towns and NOK 200 (EUR 25) in smaller towns. For sparsely populated areas the cost is 0. On average these estimates are of the same size as in the ECMT-study.

Global emissions

The most important gases contributing to the greenhouse effect apart from water vapour are carbon dioxide, methane, nitrous oxide ('laughing gas') and ozone. The emission of these gases may be converted into CO_2-equivalents.

Many approaches have been tried to calculate the economic implications of global warming. It is however hard to have any real knowledge of the many supposed harmful effects of the emission of greenhouse gases. Attempts of this have been made as part of the ExternE project (Eyre *et al.*, 1998). Expert assessments of damage costs have lead to cost estimates in the interval NOK 125 to NOK 350 per tonne. It is however in our view difficult to overlook all consequences of future global warming. Therefore we have chosen to base our calculation on shadow costs.

The consequences of Norway joining the Kyoto treaty is that the nation has an obligation to stabilise emissions on 1990-level by the year 2010. By means of the macro-economic equilibrium model GODMOD (Jensen & Eriksen 1997 and Jensen 1998) we have at TØI calculated the shadow prize of CO_2-emissions (and equivalents) CO_2 to fulfil this treaty. In the model this is equivalent to the tax-rate that must be levied upon the emission of CO_2 to make the economy change so that the obligation is fulfilled in the year 2010. Here it is assumed that other countries as well fulfil their part of the treaty. Another central assumption is that there is no trade in quotas of CO_2. The tax is introduced gradually, and the rate for the year 2000 is NOK 370 (EUR 45) per tonne CO_2. This does not permit tradable quotas, which would probably reduce the rate drastically. See Holtsmark and Hagem (1998) who find a rate

[2] NOK 8,00 is equal to 1 Euro.
[3] Population concentration with more than 200 inhabitants and less than 50 metres between buildings.

of NOK 110 (EUR 13,5) per tonne CO_2. As a consequence of the fact that all electricity in Norway is produced by hydro-electric power-stations, railways produce very little emissions.
The report from the International Panel for Climate Change (IPCC 1999) suggests that emissions from air transport in the troposphere are more harmful to the climate than emissions at ground level. This has not been taken into account for the study.

4.3 Noise

We measure the physical side of noise as the number of people disturbed by noise and unwanted sounds. The level of noise may be assessed from the average sound levels caused by different transport modes, in populated areas. The measure is decibels (dBA). Theoretically it is possible to link the change in traffic that is necessary for a certain change in dBA and thereby the subjective change in the noise level for the people affected by noise.
To calculate this in practice we have to make many simplifications. By means of stated preference analyses the WTP for a certain reduction in the subjective discomfort is assessed. This may be transformed into the willingness to pay for a reduction in noise level, which is converted into a certain traffic reduction. The validity of these estimates rests upon whether people - in an interview situation - are really able to distinguish between smaller and bigger reductions in noise levels and whether the WTP is the same per unity for smaller and bigger noise changes.
For *road transport* we have applied a study by Sælensminde & Hammer (1994). The value is here found to be NOK 1170 (EUR 145) per year for a noise reduction of 20%, among people that are bothered by noise, which represents a traffic reduction of 52,3%.
For *railway transport* a hedonic price approach is chosen. Vågnes & Strand (1996) made a survey for an area close to the railway passing through the eastern part of Oslo. They found that an average apartment increased its value by 10% when the distance to the railway track was doubled. For an average apartment this under certain conditions gives a value of NOK 1100 (EUR 137) per person for reducing railway noise to half its level.
Noise from *air traffic* is a nuisance to people living close to airports. Thune-Larsen (1995) found that the WTP among people bothered by noise is valued to NOK 1000 (EUR 125) per person for reducing the noise level by 50%. This represents a traffic reduction of 90%.

4.4 Congestion

When there is road congestion, one extra vehicle causes costs, in the form of time and driving cost, not only to themselves but to other road users as well. The total *marginal congestion cost* is equal to the total time and driving cost that is charged on the whole system from one extra vehicle entering the system.
At the two Norwegian transport research institutes, TØI and SINTEF, network models that simulate the traffic network of large Norwegian cities are built and maintained. Road users are assumed to minimise travel cost or travel time, and the origin-destination matrix is supposed to be fixed. Grue, Larsen, Rekdal & Tretvik (1997) have used these models to calculate the extra congestion cost over a 24-hour period to be NOK 0,94 (EUR 0.12) per vehicle km for the Oslo area. For the Trondheim area the congestion cost per km is calculated to be NOK 0,80 (EUR 0.10) on the basis of Grue & al[4].

---

[4] The transformation to cost per vehicle km has been done by us.

On average for bigger cities we will have an average congestion cost of NOK 0,90 (EUR 0.11) per vehicle km over a 24 hour period. Taking into account that buses and lorries need more space than passenger cars, we get an average cost of NOK 0,85 (EUR 0.11) per 'passenger car'-unit.

Due to lack of relevant surveys we neglect the congestion costs of smaller towns and other densely populated areas, assuming that apart from a few bottlenecks, congestion costs in these areas are of very moderate size.

4.5 Accidents

Traffic accidents can be said to have three types of cost:

- Costs of loss of human life and reduced health condition
- Lost income and expenses due to accidents
- Material costs

The parties that bear these costs are injured persons, their family members, vehicle owners, private third parties and the public sector. The costs for all these parties together make the total social costs of traffic accidents.

Elvik (1993) assessed the cost of loss of a statistical life and of injuries of different severity in a meta study of numerous WTP surveys. From this the cost of the loss of a statistical life is, e.g. assessed to be NOK 17,7 millions. It is subject to debate whether production loss and the relatives' welfare loss due to the accident should be included.

The accident cost should be divided into *internal* and *external* costs. Elvik (1994) has calculated the external part of accident costs in road transport based on the facts that the different road user groups play an unequal part in accidents where two or more vehicles are involved. All accident costs are classified according to type of vehicles involved and whether costs are external or internal. Self-inflicted accidents are always considered internal. Accidents with two or more vehicles are split up in internal and external part according to size of vehicle. This way of dividing accident costs into internal and external cost is of course subject to debate . According to Jansson (1994) accident externalities caused by additional vehicles in the road traffic system may take the form of:

1. increasing accident risk for other vehicles
2. increasing accident risk for unprotected road users
3. accident spill over effects on the rest of the society, including net output losses, ambulance transport, hospital treatment and so on

Items 2 and 3 here will always be positive. The question is whether item 1 is so too. Does the accident risk for existing vehicles increase when an extra vehicle is added? Vitaliano and Held (1991) find that the net external effect is negligible based on New York State data. The reason is probably that increasing congestion will influence driving behaviour. It seems that Vitaliano and Held have left out item 3 and possibly also item 2. Congestion is not an important feature of Norwegian road traffic.

Fridstrøm (1999a, b) finds indications that there exists a 'trade-off' between congestion and accident externalities, leaving the net effect close to zero, at least for small vehicles. He also argues that external effects due to item 3 may be more important than often believed since

insurance and public health care cover significant parts of accident costs. Fridstrøm estimates elasticities of accidents and traffic volumes for heavy and light vehicles.
Fridstrøms results may be generalised to all vehicle groups. However, we chose the more traditional approach described above[5]. This means that even the smallest vehicles, like motorcycles, have external accident costs, consisting of costs to pedestrians, etc. and administrative costs.
The calculation shows that external accident costs in road transport are 42% of total accident costs. The size of the external part is much larger among large vehicle types than among smaller ones.
For the other transport modes *railway, sea* and *air* most of the costs are internal. The calculations are based on Hagen (1997) and Minken & al (1999). The external costs here consist of deaths and injuries of non-travellers and of the part of traveller's death and injury costs that fall on relatives and on the public sector. For these modes the external part is small, but the cost of each accident is usually large.

4.6 Wear of infrastructure

Infrastructure wear depends on traffic in a complicated way. Wear is a function of type of infrastructure traffic volume, weight of vehicle, speed, vehicle type, way of operation etc. The form and parameters of such a model is not easy to determine. Actually we have to rely on accounting data, which means that we have to assume that the cost functions is linear.
All infrastructure costs are split into *fixed costs*, *transport-related costs* and *volume-related costs.* Suppose the level of maintenance is just sufficient to keep a constant standard of infrastructure. All amounts in the accounts should be split according to this. Then all maintenance cost should be divided over all users of infrastructure according to traffic volume.
For *road transport* the transport volumes of different vehicle types are known. We do not have much knowledge about the relationship between vehicle weight and number of axles and road wear. We have to rely on the quite old study AASHO (1974). From this the wear of each vehicle axle on the infrastructure is the vehicle weight per axle raised to a power. The size of the exponent has been fixed to 2.5, which has been common in similar Norwegian studies. Thus all vehicles can be transformed to passenger car units.
For *railway transport* gross tonne-kilometres, which include the weight of the train is the key to distribute the maintenance cost of the sector between passenger trains and freight trains. Even though it is probable that freight train carriages wear down infrastructure faster than passenger train carriages do, we assume that wear is the same.
When it comes to *air transport* broadly the same principles are applied. There are however more variable costs than just maintenance costs, like traffic control, security etc. Variable costs are distributed according to aircraft size measured by number of seats.
Infrastructure costs are not calculated for *sea transport.* The part of maintenance costs that is traffic volume dependent is assumed to be negligible.

[5] The original plan was to apply Fridstøm's method. Unfortunately, due to lack of time and resources, this could not be implemented.

4.7 Summary of unit costs

The following table summarises the *basic* unit cost. The unit costs are common for all modes except for noise costs, which are specific for each mode. It is not possible to give unit costs for infrastructure wear.

Table 1. Estimation methods and basic unit costs after type of external cost (Euro)

	per unit	*estimation method*	Big cities	Other built-up areas	Rural areas
			Local emissions		
SO_2	kg	WTP	8.75	8.75	2.12
NO_X	kg	meta-analysis	8.25	8.25	4.12
VOC	kg	meta-analysis	8.25	8.25	4.12
PM10	kg	WTP	212.5	25	0
			Global emissions		
CO_2 (and equivalents)	ton	shadow price	46.25	46.25	46.25
			Noise		
Road transport	20%*	WTP	146.25	146.25	0
Rail transport	50%*	hedonic price	137.50	137.50	0
Air transport	50%*	WTP	125.00	125.00	125.00
			Accidents		
Statistical death	case	WTP + mat **	2 150 000	2 150 000	2 150 000
Very serious injury	case	WTP + mat **	860 000	860 000	860 000
Serious injury	case	WTP + mat **	282 000	282 000	282 000
Light injury	case	WTP + mat **	24 000	24 000	24 000
			Congestion		
Passenger car unit	km	simulations	0.105	0	0

* Reduction in 'subjective' noise.
** Material and administrative costs

5. Some results

External costs
As seen from figure 1 motorcycles have the highest external cost per passenger kilometre. Large accident costs and emission costs are the most important explanations. The external part of the accident costs for motorcycles is low, but the accident risk is extremely high compared to other vehicles. The fact that there are few passengers per vehicle contributes to the high external cost per passenger kilometre. Passenger ships have the second highest costs, mainly due to very high emission rates. Passenger trains have the lowest costs per passenger kilometre, mainly due to very low emission costs.

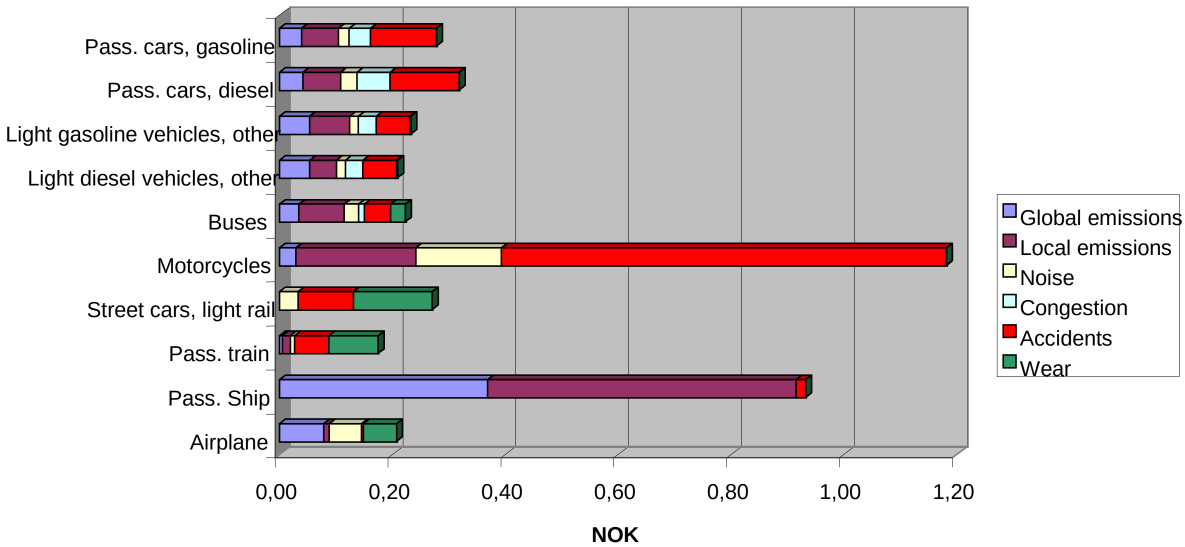

Figure 1. Marginal external costs per passenger km.

From figure 2 it is seen that the light goods vehicles have the highest external cost per tonne kilometre mainly due to low capacity and low load factor. Freight trains and cargo vessels (tankers included) have the lowest external cost per tonne kilometre due to their large carrying capacity.

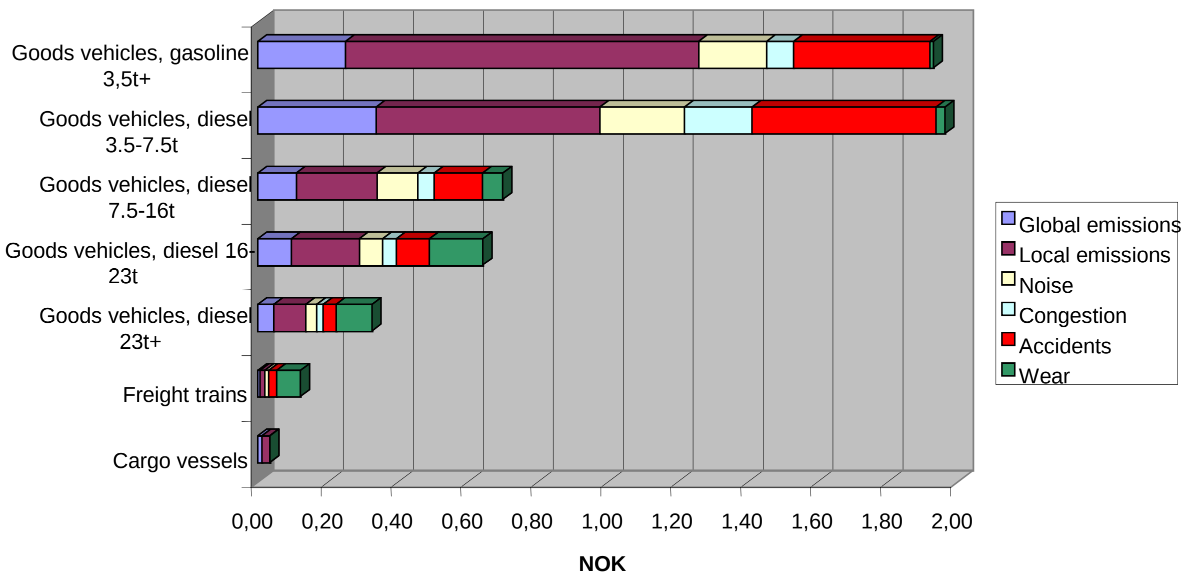

Figure 2. Marginal external costs per tonnekm.

Comparing external costs to charges

We have compared external marginal costs to what is actually paid in taxes and charges on the margin, that is to say taxes and charges levied on transport volume in some meaning of the word, either fuel consumption, kilometres driven, number of trips etc (traffic charges).

Both taxes to the Treasury and charges to the administrative provider of infrastructure services to the transport performer are included. These charges may have the form of payment for infrastructure use. If these public services are privatised, these charges are not included. This is the case for harbours, which are owned partly by local municipalities and partly by private interests. A possible privatisation of airports and railway infrastructure would thus lead to a reduction in charges paid to the state from air and rail.

Looking at figure 3 we can see that air transport pays nearly twice its marginal external costs as marginal taxes and charges. This is mainly because ‘user’ charges to CAA are included. These user charges are not only meant to cover wear of infrastructure, but also investments and administration cost. Apart from that only light gasoline driven vehicles (combined-cars and small vans) pay more traffic charges than their external costs. The reason why vans and combined-cars pay higher charges is that they use more fuel per kilometre, and the fuel tax is considerable.

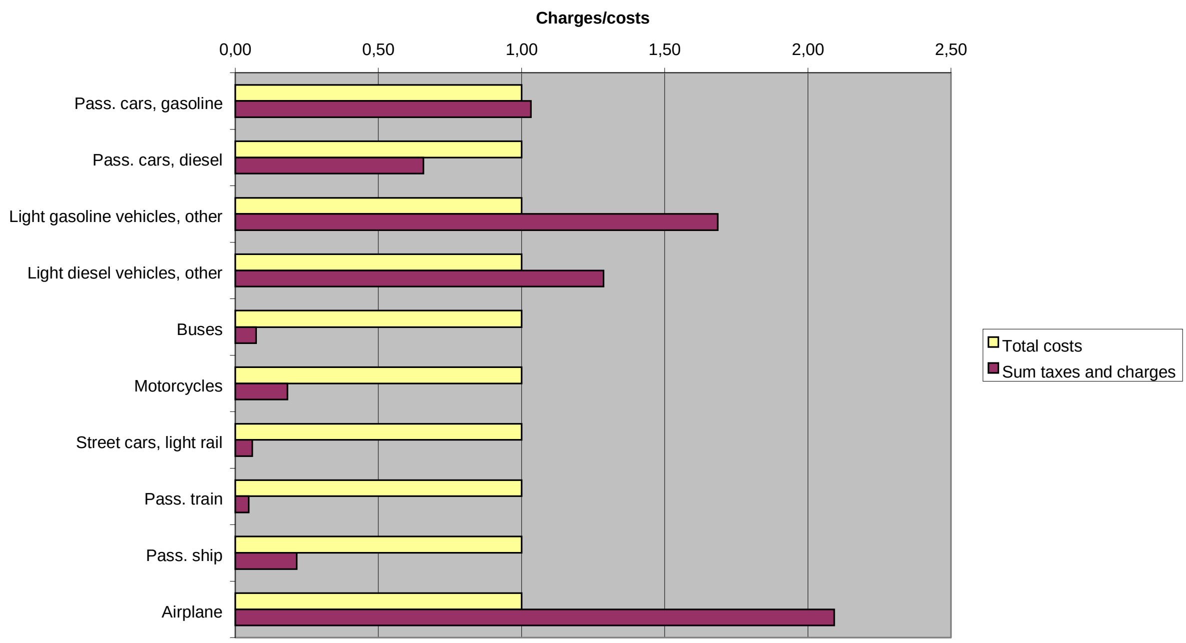

Figure 3. Marginal charges relative to external costs. Passenger traffic.

None of the goods transport modes pay their external costs in the form of traffic charges. This is seen from figure 4. The smallest goods vehicles pay the highest fractions. Cargo vessels pay the lowest fraction of their external costs. This is probably due to especially low charges, as they compete with foreign shipping trade. If it had not been for user charges to the infrastructure provider, freight trains would have paid the smallest fraction of all.

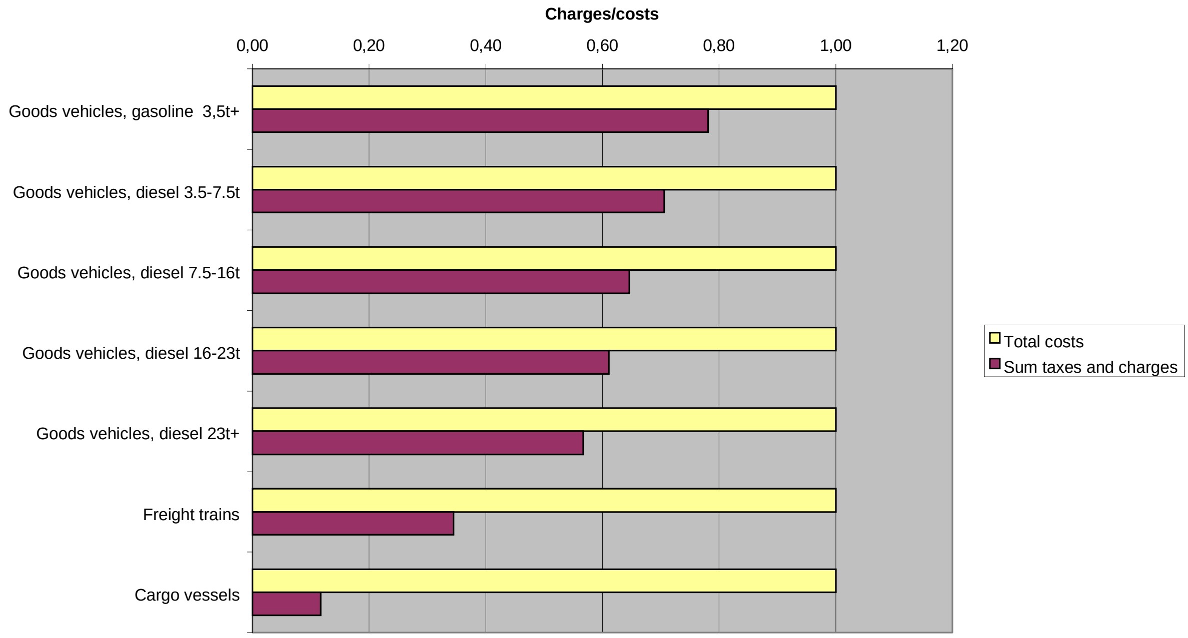

Figure 4. Marginal charges relative to external cost. Goods transport.

Big cities, built-up areas and rural areas

The geographic dimension of external costs is shown in figures 5, 6 and 7. As may be seen local emission cost is much higher in big cities than elsewhere mainly due to the effect of particles in densely built-up areas. Also by our definition congestion costs only exist in bigger cities.

As may be seen the external costs are about twice as high in big cities as in other built-up areas and five to six times as high as in rural areas. Per vehicle kilometre heavy goods vehicles and buses have the highest external costs both in big cities as well as in built-up and rural areas. Gasoline-driven passenger cars have the smallest external costs per km in big cities, while diesel driven passenger cars have the lowest external costs in rural areas.

Charges per vehicle kilometre are about the same level in big cities and other urban areas, and about ¾ of this in rural areas (not shown in figures).

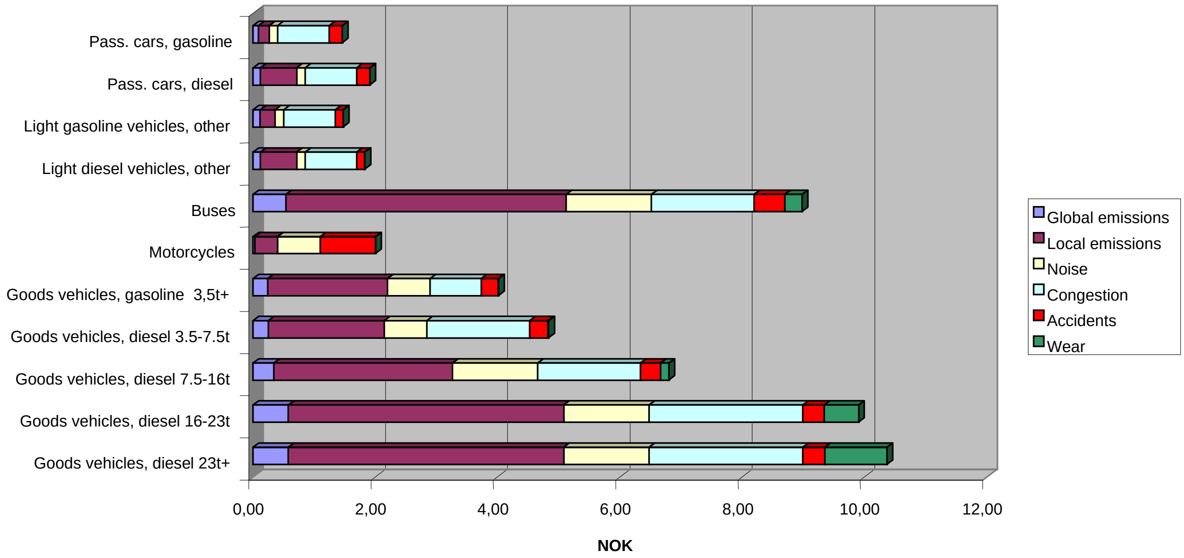

Figure 5. Marginal external costs per vehicle km.

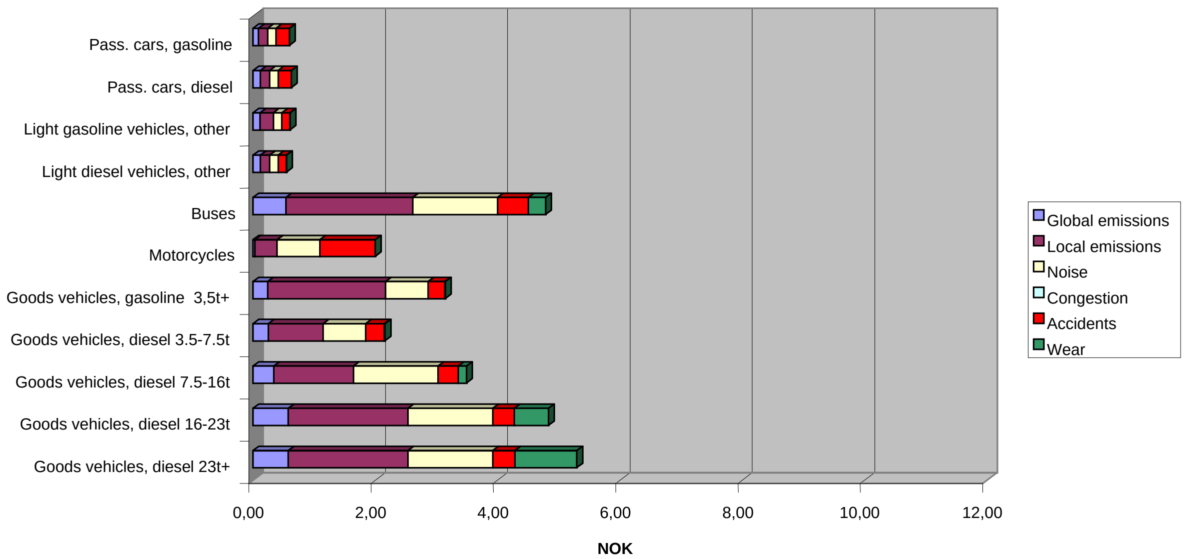

Figure 6. Marginal external costs per vehicle km. Built-up areas.

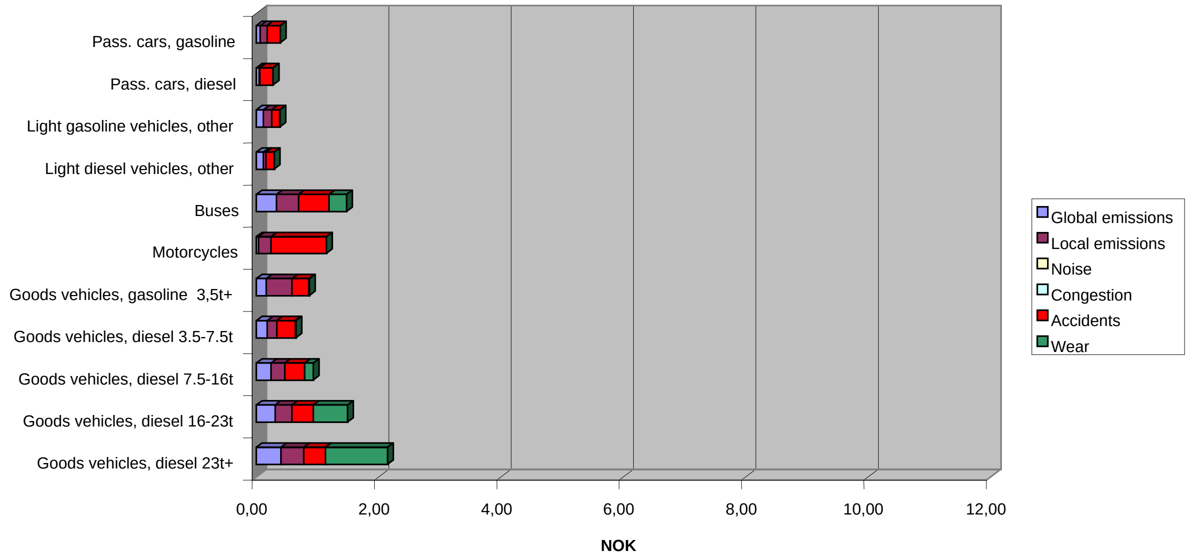

Figure 7. Marginal external costs per vehicle km. Rural areas.

6. Conclusions

In this survey we have only included cost elements of which we have reasonably reliable knowledge. The uncertainty of the physical amounts may be as large as the uncertainty of the estimates of unit prices. Elvik *et al.* (1994) estimated the relative uncertainty of the unit cost applied in the 1995-analysis as varying between 16 and 30%, which leads us to 95% confidence intervals of approx. 40-60% around the point estimate. The confidence intervals are based on sample sizes and estimation methods applied in the 1995 survey. This means that referring to the formula in 4.1 they have estimated the uncertainty of unit cost and (depending on the method) partly also the degree of harm. The uncertainty of the physical amounts is not discussed in the paper. Since in most cases similar methods have been applied this time, we judge uncertainty in the 1999 study to be in the same size order.

Our survey shows that passenger cars and other smaller vehicles have large external costs, both in total and per passenger kilometre. These vehicles, however, pay most of their marginal cost to society as traffic charges. Air transport pays charges that far exceed its external cost. However, these charges are meant to cover the CAAs total costs. Buses, passenger trains and cargo vessel pay a very small part of their external costs.

Even though passenger cars pay nearly their external costs, and buses and trains do not, it would probably be wrong to conclude that charges on these transport modes ought to be quadrupled or so. We must remember that the external costs we have calculated here are marginal. If such increases were carried through without other changes, most commuters would start using their cars and thus increase total external costs drastically. It would be better to analyse the problem by means of transport models.

One ambition of this project has been to improve the methods from 1995. Here we have succeeded only partially. Congestion costs are included by the use of transport models. We have also succeeded in calculating emission costs in a better way both for global and local emissions, among other things by use of damage cost functions for particle emissions. This has enabled us to split up the external costs by three levels of population density.

There are several points where the study might be improved in the future. One difficulty that still remains is to get a better grip of *marginality*. It is easy to use average variable cost as a substitute for marginal cost, since in many cases we do not know the exact form of the cost function. Especially for accidents Fridstrøm (1999a) offers some new possibilities. He finds a relationship between external costs from traffic accidents, traffic volume and transport capacity of roads. This means that dense traffic reduces the risk of traffic accidents, and thus the external marginal costs in densely populated areas may be reduced or even—in special cases—negative.

Another suggestion for further research is to apply the results of the IPCC (1999). This would acquire a new approach since greenhouse gases will have a different impact depending upon in what part of atmosphere the gases are emitted.

Of course the results of this study are very uncertain. However there is no fixed truth in this field. All we can hope for is that our estimates are moving in the right direction, helping the authorities to achieve a better policy concerning taxes and charges aimed at stimulating an efficient use of resources in the transport sector.

References

AASHTO (1974) *AASHTO Interim Guide for Design of Pavement Structures 1972.* American Association of State Highway and Transport Officials.

Bang, J., Flugsrud, K., Holtskog, S., Haakonsen, G., Larssen, S., Maldum, K., Rypdal, K. and Skedsmo, A. (1999) *Utslipp fra vegtrafikken i Norge.* Oslo, Statens Forurensingstisyn (State Pollution Control), SFT-report 99:04.

Christensen, P., Elvik, R. and Hagen, K. (1997) *Hva koster helse-, miljø- og sikkerhets-problemer det norske samfunn?* Oslo, Transportøkonomisk institutt, TØI-report 377/1997.

ECMT (1998) *Efficient Transport for Europe. Policies for internalisation of external costs.* Paris, European Conference of Ministers of Transport.

Elvik, R. (1994) The external Cost of Traffic Accidents: Definitions, Estimation and Possibilities for Internalisation. *Accident Analysis and Prevention.* Vol 26. New York.

Elvik, R., Hammer, F., Johansen, K.W. and Minken, H. (1994) *Usikkerhet knyttet til enhetskostnader for ikke markedsomsatte goder i kjørekostnadsberegninger.* Oslo, Transportøkonomisk institutt, Working paper TØ/694 (revised).

Eriksen, K. and Hovi, I.B. (1995) *Transportmidlenes marginale kostnadsansvar*. Oslo, Transportøkonomisk institutt, TØI-working report 1019/1995.

Eriksen, K., Markussen, T. and Pütz, K. (1999) *Marginale kostnader ved transportvirksomhet.* Oslo, Transportøkonomisk institutt, TØI-report 464/1999.

Eyre, N., Downing, T., Hoekstra, R., Rennings, K. and Tol, R.S.J. (1998) *Global Warming Damages, Final Report to the EC.* Brussels, European Commission, September 1998.

Fridstrøm, L. (1999a) *Econometric models of road use, accidents and road investment decisions*. Oslo, Transportøkomisk institutt, TØI-report 457/1999

Fridstrøm, L. (1999b) The non-linear relationship between traffic volume and accidents and its implications for accident externality assessments. Paper submitted to the 2nd European Road Research Conference, Brussels June 7-9 1999.

Grue, B., Larsen, O., Rekdal, J. and Tretvik, T. (1997) *Køkostnader og køprising i bytrafikk.* Oslo, Transportøkonomisk institutt, TØI-report 363/1997.

Grupp, H. (1986) Die sozialen Kosten der Verkehrs. Teil 1 und 2. *Verkehr und Technik.* 9/1986 and 10/1986.

Hohmeyer, O. (1988) *Social costs of energy consumption.* Springer Verlag, New York.

Holtsmark, B. and Hagem, A. (1998) *Emission Trading under the Kyoto Protocol*. Oslo, CICERO Report 1998-01.

Jansson, J.O. (1994) Accident externality charges. *Journal of Transport Economics and Politics*. January 1994.

Jensen, T. and Eriksen, K.S. (1997) *GODMOD-3 – En makroøkonomisk modell for transportanalyser*. Oslo, Transportøkonomisk institutt, TØI-report 345/1997.

Jensen, T. (1998) *Alternativ transportteknologi. Reduserte utslipp fra transportsektoren.* Oslo, Transportøkonomisk institutt, TØI-report 413/1998.

Rosendahl, K. (1996) Helseeffekter av partikkelforurensing i Oslo. *in Økonomiske Analyser (Economic Analyses)* 5/96. Oslo, Statistics Norway.

Rosendahl, K. (1999) *Vurdering av skadekostnadsmetoden til bruk på vegprosjekt–en case-studie.* Oslo, Statistics Norway, Reports 99/5.

Sælensminde, K. and Hammer, F. (1994) *Verdsetting av miljøgoder ved bruk av samvalganalyse.* Oslo, Transportøkonomisk institutt, TØI-report 251/1994.

The European Commission (1996) *Towards fair and efficient pricing transport.* Brussels, EC Green Paper.

Thune-Larsen (1995) *Flystøyavgifter basert på betalingsvillighet.* Oslo, Transportøkonomisk institutt, TØI-rapport 289/1995.

Verhoef, E. (1996) *The economics of regulating road transport.* Edward Elgar, Cheltenham.

Vitaliano, D. and Held, J. (1991) Road accident external effects: an empirical assessment. *Applied Economics*, 23, pp. 373-378.