Summary:

Marginal external costs of road transport

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TØI has revised the estimates of the marginal external costs of road transport in Norway. External costs related to greenhouse gas emissions have not been included. Costs caused by accidents has been revised in this latest version of the report. Road transport is estimated to produce external costs of approximately 0.54 NOK/km. The estimates vary from 1.51 NOK/km in large urban areas to 0.60 NOK/km in small urban areas and 0.25 NOK/km in rural areas. The average external cost is 4.78 NOK/litre for vehicles using petrol and 6.53 NOK/litre for vehicles using diesel. The costs caused by accidents constitute the largest proportion of the total external costs, but external costs related to local air pollutants and congestion also play a significant role, especially in large urban areas. The marginal congestion cost for private cars is estimated to 5.35 NOK/km. The estimates indicate that there are only minor differences in the marginal external costs of electric cars compared to cars which runs on petrol as long as the effects of greenhouse gas emissions are not included. This result follows because the local effects of exhaust gas emissions contribute to a very small share of total external cost for petrol cars.

Introduction

The concept external costs – or negative externalities – refers to cases where one agent's actions affect other agents negatively, i.e., the agent's actions inflict costs upon others. Road transportation is associated with a number of external costs such as noise, congestion, infrastructure damages, and health and environmental damages.

Economic appraisals make up the foundation for critically evaluating policy-actions and instruments in the transport sector. Hence, there is a need for representative estimates of the full costs of road transport, including the external costs. Many of the existing estimates of external costs of road transportation in Norway are outdated, and it is doubtful whether they still are representative for the present day's costs. The purpose of this report is therefore to present new estimates of the external costs that better reflect the current situation.

It is difficult to quantify the external costs of transportation. This is because the costs vary i) among different vehicles, ii) depending on where and when the transport occurs and iii) depending on contextual factors such as climatic conditions. A detailed analysis on how all these factors affect the magnitude of the external costs is beyond the scope of this current project. We will therefore consider three regional dimensions (large urban, small urban and rural areas), and will only consider the temporal dimension whenever it is appropriate (in particular related to congestion and noise).

The external costs that are being estimated are related to:

- Local air pollutants (NO_X and PM_{10})
- Noise
- Accidents
- Congestion
- Infrastructure damage
- Winter operation
- Barrier effects
- Health
- Nature impacts

Barrier effects, health, and nature impacts are in grey print because we do not estimate these costs, but instead include a thorough discussion on each of them.

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Methodology

Local pollutants

Road traffic pollution is caused by fuel combustion (exhaust gas emissions), road and tyre damages, and wear and tear on brake bands. The vehicles contribute to raising dust and dirt deposited along the road, irrespective of whether the particles are attributed to the road transport itself, to wood-burning, or are transported across vast distances. Air pollution affects peoples' well-being and health. It also negatively influences the flora, buildings, and roads and other types of infrastructure, in addition to contributing to water pollution. The conventional approach to estimating marginal external costs of air pollution is the damage function approach.

Our approach is based on a previous study on appraising health implications due to air pollution. The value of premature death due to diseases caused by air pollution is set equal to 30 million (2012-NOK).The available valuations of health costs are related to NO_X, whereas it is NO_2 that is considered to be the primary cause of health damages. With new technology and development of new engines over time, the share of NO_2 in NO_X has also changed. It would therefore be best to use the share of NO_2 relative to NO_X reported in urban environment studies to appraise NO_2, but because of lack of sufficient data we had to relate costs to NO_x. Calculated abatement costs related to international agreements regarding reduced emissions of NO_x was added to the health cost of NO_X.

Damage costs for PM_{10} are separated into the costs for small ($PM_{2.5}$) and large particles ($PM_{10-2.5}$). Since much of the available information suggests that small particles cause more severe health damages than large particles, it is tempting to weigh the damage costs for PM_{10} to allow the damage costs for small particles to be higher than the damage costs for large particles. Based on the results of a new study undertaken in Stockholm (which suggest that small and large particles contribute equally to damage), and indications suggesting that separation between small and large particles may be inaccurate, we decided not to weigh the damage costs for small and large particles differently.

There are few recent studies on the population's exposure to air pollution. In particular, there is little information about exposure in urban areas.

Several national and international studies show that the population in urban areas in Europe suffer from air pollution. There is no information in the urban environment studies which indicates that the implications of air pollution for peoples well-being are less important than the implications of noise emissions. We have applied dose-response functions to "translate" a reduction in damage due to noise pollution into a reduction in damage due to air pollution. There should, however, be carried out empirical studies to identify the willingness to pay for avoiding air pollution as there are only a few international studies on this subject. As a consequence of these uncertainties, we have chosen to emit costs due to reduced well-being in the main results.

Noise

External costs due to road traffic noise are estimated on the basis of *i*) Statistics Norway's mapping of persons who are exposed to road traffic noise in Norway, *ii*) international dose-response relationships (Miedema, 2002; Miedema and Oudshoorn, 2001), and *iii*) the unit value per annoyed person from the "Values of Time, Safety and Environment in Norwegian passenger transport" study (Magnussen et al., 2010b). Marginal external costs are calculated on the basis of Statistics Norway's simplified noise emission model and Andersson and Ögren's (2013) method.

Noise costs are calculated dependent on whether the transport takes place in large urban areas or small urban areas and dependent on vehicle categories. The marginal external costs are only assumed to differ across the aggregate categories light and heavy vehicles. The reason being that this vehicle classification is consistent with Statistics Norway's simplified noise emission model. The marginal external costs are estimated to 0,02 NOK/km for light vehicles, and 0,11 NOK/km and 0,13 NOK/km for heavy vehicles in small and large urban areas, respectively. The report presents additional calculations that emphasize variations in marginal noise costs between night and day and across speed categories.

Accidents

Our estimation of external marginal costs of road accidents is based on the methodology developed within the EU project UNITE (Lindberg 2001, see also Kjeldsen et al. 2013). This methodology sums traffic volumes, physical externalities, and system externalities from collisions between different road user types (e.g., car against heavy vehicles, or against MC), as well as within road user types (e.g., car against car) and single accidents; it also sums over injury severities. The physical externality and traffic volume externality are determined by the injury distribution between different road user types, the risk of injury due to collision between road user types (for different injury severities), the risk elasticity, and the accident cost (i.e., ex ante risk valuation and ex post costs). The system externalities are determined by the risk of injury due to collision between road user types and the ex post costs (medical costs, administrative costs, etc.). In our main calculations we sum marginal external costs for three levels of injury: slight injuries, serious/severe injuries, and fatalities. The data comprises seven road user types and distribution of injuries in collisions between them, during the period from 1998 to 2012; the road user types are cars, vans, buses, heavy vehicles (trucks and lorries), MC (light/heavy motorcycles and mopeds), bicycles and pedestrians. Risk elasticities are differentiated with respect to collisions between road user types (Fridstrøm 1999, 2000, 2011), but not with respect to injury severity. Ex ante risk valuation and ex post costs are based on the latest economic valuation study for the Norwegian transport agencies (Samstad et al. 2010, Veisten et al. 2010a), adjusted to the new official ex ante mortality risk valuation (VSL) equal to 30 million NOK (NOU 2012).

Our estimated marginal accident costs are more or less within the same order of magnitude as previous estimates for Norway (Eriksen et al. 1999, ECON 2003, Maibach et al. 2008). Previous studies have not included estimates for cycling and walking. Our results show that they are negative, which may be related to “safety in numbers”, i.e., that increased cycling/walking can help reduce the risk to other cyclists/pedestrians and possibly even other road users, as well as the fact that cycling/walking yield very low level of injury to other road user types. For MC our main estimate is close to zero, thus considerably lower than the comparable estimates in previous studies, while for heavy goods vehicles our estimates of external marginal costs are somewhat higher than in the previous studies. These differences may be due to changes in the traffic on Norwegian roads – an increase in the share of heavy goods vehicles and a significant reduction in accident risk for MC. For heavy goods vehicles, buses, vans and cars, the traffic volume externalities and physical externalities dominate the total marginal external costs, while system externalities dominate for MC, bicycle and pedestrians. Marginal cost estimates for the “vulnerable road users” (particularly for bicycle) are very sensitive to changes in the input values. Variations in the risk elasticities will affect the sign of the marginal cost estimate for MC, bicycle and pedestrian –for MC, also accident cost variations will affect the sign. The estimated marginal external costs for cars, vans, buses and heavy goods vehicles are more robust with respect to changes in the input values.

Congestion

Our estimates of marginal congestion costs are derived on the basis of a method by Mayeres et al. (1996), where an exponential function is used to represent the relationship between traffic volumes and delays. The congestion model is implemented using data on travel times and traffic volumes from PROSAM’s accessibility study (*Fremkommelighetsundersøkelse for bil i Oslo og Akershus*) and counting of vehicles at the Oslo city limit (Bygrensetellingen). Values of time collected from the “Values of Time, Safety and Environment in Norwegian passenger transport” study and the Norwegian Public Roads Administration’s Handbook 140 are further used to calculate the external congestion costs.

The congestion costs are assumed to be non-negligible for large urban areas only, and are assumed to vary across the aggregate categories light and heavy vehicles only. We do not consider detailed calculations for each vehicle type to be of major importance for the accuracy of the estimated congestion costs, and we do not have access to data which would allow us to undertake such estimations. The marginal external congestion costs in large densely populated areas are estimated to 5.35 NOK and 10.71 NOK for light and heavy vehicles, respectively.

Infrastructure damage

The costs of infrastructure wear and tear are calculated on the basis of The Norwegian Public Roads Administration's expenditures on maintenance in the period 2000-2008. The maintenance costs related to road transport are estimated to 3.6 cent/km (2012 NOK – cent referring to 1/100 NOK, one *øre*).

The infrastructure costs are distributed across vehicle categories in the same way as in Eriksen et al. (1999), where it is assumed that the vehicles' contributions to damage are proportional to their axel weights raised to the power of 2.5. The infrastructure costs are thereby estimated to 0.1 cent/km for private cars and 76.4 cent/km for heavy freight trucks. The results from an on-going project at VTI may provide the foundation for revising these estimates.

Winter operation

The marginal external costs related to winter operation are primarily related to the use of calcium chloride. It influences both the natural environment, the infrastructure, and the vehicles due to corrosion. VTI estimates that that the costs due to corrosion caused by calcium chloride amount to 1500 NOK per vehicle per year in Sweden. Translated to Norwegian conditions, this implies a cost of approximately 10 cent/km. Our estimate is derived based on the assumption that about 50 percent of the calcium chloride usage can be attributed to the traffic volume. Hence, the marginal external cost is 5 cent/km.

Barrier effects

Marginal external barrier effect costs have not, to our knowledge, previously been estimated for Norwegian road transport. There exist cost estimates from European studies, termed as "additional costs in urban areas"; adding two cost components: *i*) a "separation cost" for pedestrians, due to (increased) delay (due to motorised traffic) when crossing roads, and *ii*) a "compensation cost" for (increased) requirements for infrastructure facilities for cycling (Schreyer et al. 2004, ARE 2006, Maibach et al. 2008). For this type of marginal external effects in road transport, there is still a lack of a well-developed methodology. Moreover, there is still a much weaker data fundament for the extent and distribution of cycling/walking on Norwegian roads than for motor vehicles, also including the motor vehicles' impact on pedestrians' and cyclists' time spent in crossings and their experiences of barriers (or insecurity) due to motorised traffic. A calculation based on time loss costs (separation costs) seems, operationally, to be the simplest approach to carry out. Estimates of external barrier costs based on the costs of measures (compensation costs) for cycling (and walking) facilities seem to have weaker theoretical foundation for marginal external cost estimation. Moreover, although cycling and walking represent quite different modes of transport, it seems not obvious to apply the differentiation of time loss for pedestrians and infrastructure facility needs for cyclists; both pedestrians and cyclists might face a time loss (in crossing) due to the barrier that the motorised traffic represents. Both cyclists and pedestrians may also experience insecurity, a psychologically felt barrier due to the motorised road traffic. There is lack of data measuring how many potential cyclists/pedestrians are refrained from biking/walking due to barrier effects / insecurity, or how many cycling/walking journeys that are cancelled due to barrier effects / insecurity. Although lack of data also remains a problem for the actual cycling/walking taking place, it is easier to base calculations on the (published literature on) actual cycling/walking, although we might omit some of the barrier effects. If we focus on actual cycling/walking, we might assume that the time loss (mobility restraints on cycling/walking) and insecurity (subjectively experienced obstacles) constitute two different barrier effects on cycling/walking due to motorised traffic (and the infrastructure built for motor vehicles). In an appendix we show a few test calculations of marginal external barrier costs, where one is based on the estimation of the time loss (separation costs) for pedestrians/ cyclists, and the other is based on the estimation of insecurity costs for cyclists/ pedestrians due to crossings of roads with motorised traffic as well as due to sharing road space with motorised traffic. However, as indicated, as we find that we still lack a well-developed and validated methodology for this type of marginal external effects, we have not included the results from these test calculations in the final result tables on marginal external costs in Norwegian road transport. Although setting the marginal external barrier cost to zero most likely will be erroneous, underestimating true costs, we do not find a sufficiently strong fundament for proposing another positive cost estimate.

Health

Marginal external costs due to sedentary motorised transport, instead of physically active transport (cycling/walking), have not been calculated previously neither for Norwegian road transport nor internationally. Although we find that the calculation of such marginal external health costs lacks a developed methodology, we find it highly relevant to take the starting point that people through their choice of transport mode also potentially impact on society’s health costs due to a sedentary lifestyle. Changing some of the car, bus and MC trips to cycle trips or walks could potentially yield a positive health effect associated with reduced risk of serious illness and premature death. One way of estimating marginal external sedentary costs takes the point of departure in the ex post health cost reduction due to cycling/walking for transport. There is however a significant challenge related to estimating the share of motor-vehicle based person kilometres that actually yield sedentary health costs, that is, the extent to which a switch of a person km from motorised to cycle/walk yields a net positive health effect and if the net effect (per km) remains the same for larger changes. Some cyclists/pedestrians might get sufficient physical activity from their transport, but some of those using motorised transport might also get enough physical activity from non-transport based exercise. In an appendix we show some test calculations that are based on the health cost reduction for cyclists/pedestrians, somewhat mirroring the sedentary costs of motorised transport. We show how the estimated marginal external sedentary costs vary with the extent of shift from motorised to physically active transport (whether the scope of the shift is given by an assessment of health improvement potential or given by political objectives). However, as indicated, there is a need for further methodological development and empirical testing for estimating the marginal external sedentary costs. We have therefore not included these estimates in the final result tables for the marginal external costs in Norwegian road transport. Although setting the marginal external sedentary cost to zero is likely to underestimate true costs, we do not find a sufficiently strong fundament for proposing another positive cost estimate.

Nature impacts

Environmental problems caused by infrastructure and road traffic is not only related to local air pollution and road operations. Road operation and maintenance, as well as the road use, produce runoff of heavy metals and other pollutants to the surrounding soil and water. Moreover, infrastructure and traffic will seize land and thus affect the land-use and the areas surrounding roads or being traversed by roads. Thus, effects of road transport on nature comprise habitat loss, habitat fragmentation, and habitat degradation (due to pollution), none of which has been previously calculated for Norway. There are cost estimates from European studies (ARE 2003, Maibach et al. 2008), and in an appendix we review these types of calculations and discuss some methodological development.

Results

Our estimates are summarized by the tables S.1 and S.2, which report marginal external costs per km and litre fuel according to vehicle class, fuel type, and weight class (in 2012-NOK). The average for all vehicle types is weighted with respect to the estimated number of vehicle kilometres per vehicle type (and fuel and, for freight trucks, also weight class).

Table S.3 reports the marginal external costs in tonne kilometres for the three heaviest vehicle classes.

Table S.4 reports the marginal external costs according to population density and for rush-hour traffic in urban areas with more than 100 000 inhabitants. Marginal external costs for electric cars are also reported. The average for Norway is weighted with respect to the estimated number of vehicle kilometres in the different geographical areas.

Table S.1 Marginal external costs of road transport in Norway apart from greenhouse gas effects according to vehicle class, fuel type, and weight class. 2012-NOK/km.

Vehicle type	Fuel	Weight class	Air pollution	Noise	Congestion	Accidents	Infrastructure damage	Operations	Sum
Private cars	Petrol		0.06	0.01	0.08	0.17	0.00	0.05	0.37
Private cars	Diesel		0.10	0.01	0.08	0.17	0.00	0.05	0.41
Private cars	LPG		0.05	0.01	0.08	0.17	0.00	0.05	0.35
Other light vehicles	Petrol		0.09	0.01	0.08	0.20	0.00	0.05	0.43
Other light vehicles	Diesel		0.17	0.01	0.08	0.20	0.00	0.05	0.51
Motor cycles, mopeds	Petrol		0.01	0.05	0.04		0.00	0.05	0.15
Bus	Diesel		1.15	0.07	0.24	0.15	0.22	0.05	1.87
Bus	CNG		0.61	0.10	0.37	0.21	0.22	0.05	1.55
Freight trucks	Petrol		0.42	0.03	0.11	1.00	0.01	0.05	1.59
Freight trucks	Diesel	<= 7.5 ton	0.33	0.03	0.11	1.09	0.01	0.05	1.62
Freight trucks	Diesel	7.5 - 14 ton	0.44	0.03	0.11	1.17	0.10	0.05	1.90
Freight trucks	Diesel	14 - 20 ton	0.52	0.03	0.11	1.25	0.42	0.05	2.38
Freight trucks	Diesel	> 20 ton	0.75	0.03	0.11	1.29	0.76	0.05	3.00
Average (all motor vehicles)			0.14	0.01	0.08	0.23	0.03	0.05	0.54
	Petrol		0.06	0.01	0.08	0.16	0.00	0.05	0.36
	Diesel		0.19	0.01	0.09	0.28	0.06	0.05	0.68
	LPG		0.05	0.01	0.08	0.17	0.00	0.05	0.35
	CNG		0.61	0.10	0.37	0.21	0.22	0.05	1.55

Table S.2 Marginal external costs of road transport in Norway apart from greenhouse gas effects according to vehicle class, fuel type, and weight class. 2012-NOK/litre fuel

Vehicle type	Fuel	Weight class	Air pollution	Noise	Congestion	Accidents	Infrastructure damage	Operations	Sum
Private cars	Petrol		0.83	0.10	1.04	2,22	0.01	0.65	4,85
Private cars	Diesel		1.74	0.12	1.34	2,85	0.01	0.84	6,90
Private cars	LPG		0.50	0.08	0.85	1,81	0.01	0.53	3,77
Other light vehicles	Petrol		1.12	0.10	1.03	2,58	0.04	0.65	5,51
Other light vehicles	Diesel		2.05	0.09	0.96	2,42	0.04	0.61	6,17
Motor cycles, mopeds	Petrol		0.27	1.19	1.05	0,00	0.00	1.32	3,83
Bus	Diesel		3.20	0.19	0.67	0,42	0.60	0.14	5,22
Bus	CNG		1.22	0.21	0.73	0,53	0.43	0.10	3,94
Freight trucks	Petrol		1.76	0.14	0.49	4,48	0.02	0.22	7,12
Freight trucks	Diesel	<= 7.5 ton	2.34	0.22	0.77	7,63	0.08	0.35	11,38
Freight trucks	Diesel	7.5 - 14 ton	2.14	0.15	0.53	5,63	0.51	0.24	9,21
Freight trucks	Diesel	14 - 20 ton	2.02	0.12	0.43	4,88	1.65	0.19	9,29
Freight trucks	Diesel	> 20 ton	1.53	0.06	0.23	2,63	1.56	0.10	6,12
Average (all motor vehicles)			1.51	0.12	0.90	2,50	0.38	0.55	5,96
	Petrol		0.83	0.13	1.02	2,12	0.01	0.67	4,78
	Diesel		1.86	0.10	0.83	2,67	0.58	0.48	6,53
	LPG		0.50	0.08	0.85	1,81	0.01	0.53	3,77
	CNG		1.22	0.21	0.73	0,43	0.43	0.10	3,20

Table S.3 Marginal external costs per vehicle kilometre and tonne kilometre for freight transport in Norway apart from greenhouse gas effects according to weight class.

Weight class	NOK/km	Cargo	NOK/tonnekm
7.5 - 14 ton	1,90	1.9	0.99
14 - 20 ton	2.38	4.2	0.56
> 20 ton	3.00	10.7	0.28
Sum	2.91	9.7	0.30

Table S.4 Marginal external costs apart from greenhouse gas effects according to fuel type, vehicle type and population density. Kr/km.

Vehicle type	Fuel	Weight class	Large urban areas (+100')	Congestion urban areas	Small urban areas	Rural areas	All Norway
Private cars	Petrol		1,08	6,28	0,43	0,14	0,37
Private cars	Diesel		1,25	6,58	0,46	0,15	0,41
Private cars	LPG		1,02	6,00	0,41	0,14	0,35
Other light vehicles	Petrol		1,20	6,23	0,47	0,19	0,43
Other light vehicles	Diesel		1,54	6,76	0,53	0,20	0,51
Motor cycles, mopeds	Petrol		0,43	3,32	0,17	0,05	0,15
Bus	Diesel		4,69	17,13	1,32	0,42	1,87
Bus	CNG		2,70	12,88	0,81	0,33	1,55
Freight trucks	Petrol		5,03	14,93	2,63	0,82	1,59
Freight trucks	Diesel	<= 7.5 ton	5,11	15,75	2,74	0,83	1,62
Freight trucks	Diesel	7.5 - 14 ton	5,92	16,96	3,13	1,00	1,90
Freight trucks	Diesel	14 - 20 ton	6,84	17,88	3,74	1,38	2,38
Freight trucks	Diesel	> 20 ton	8,44	20,30	4,44	1,80	3,00
Average (all motor vehicles)			1,51	7,07	0,60	0,25	0,54
	Petrol		1,06	6,06	0,42	0,14	0,36
	Diesel		1,85	7,78	0,74	0,32	0,68
	LPG		1,02	6,00	0,41	0,14	0,35
	CNG		2,70	12,88	0,81	0,33	1,55
	Electric		0,98	5,93	0,41	0,14	