External Costs of Transport

Accident, Environmental and Congestion Costs in Western Europe

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Summary

Aim and methodology

This study is an update and extension of a former UIC study on external effects (1995). It aims at improving the empirical basis of external costs of transport based on the actual state of the art of cost estimation methodologies. The following dimensions are considered:

- Cost categories: Accidents, noise, air pollution (health, material damages, biosphere), climate change risks, other environmental and non-environmental effects and congestion.
- Countries: EUR 17 (EU member states, Switzerland, Norway).
- Base year: Detailed results for 1995 and rough estimate for 2010 (trend development, mainly based on emission trend forecasts of an EUROSTAT project TRENDS).
- Differentiation of transport means:
  - Road transport: Private car, motorcycles, bus, light goods vehicles, heavy goods vehicles,
  - Rail transport: Passenger and freight,
  - Air transport: Passenger and freight,
  - Waterborne transport: Inland water transport (freight).
- Functional and regional differentiation:
  - Urban and interurban passenger traffic,
  - Short and long distance freight traffic,
  - Application for point to point relations (two passenger and freight corridors).

Two study outputs can be distinguished:

- Total and average costs per country and means of transport: National cost accounts for the base year considered reflect the importance of each cost component. The results are mainly of statistical value. National average values can be – at least in some cases – a basis for pricing strategies and for socio-economic evaluation of infrastructure investments.
- Marginal costs per means of transport and traffic situation reflect the additional costs per additional unit of transport. They represent a European average which could be used as basis for the dimensioning of pricing instruments according to the approach of Social Marginal Costs Pricing, as the European Commission proposes in its White Book on 'Fair Payment of Infrastructure Use'.

Throughout the whole report, congestion costs are treated as a separate issue, since their relevance and measurement is quite different from the ones of other costs categories, especially in regard to total costs. Three different approaches were used; they different values from 0.5% to 3.7% of GDP.

The following table presents the costs categories considered and the methodologies used.

Type of effect	Share of total costs (EUR 17 1995 in %)	Cost components	Most important assumptions
Accidents	29%	Additional costs of - medical care - opportunity costs of society - suffer and grief.	- A value of human life of 1.5 million Euro is considered. - Average costs are equal to marginal costs. There is no specific relation between vkm and accident rates assumed. - Insurance payments are considered in order to estimate external cost components.
Noise	7%	Damages (opportunity costs of land value) and human health.	- The valuation approach is based on a willingness to pay for silent space above 55 dB(A). - Average costs are estimated by a top-down approach based on ECMT data. - Marginal costs are estimated by a modelling approach.
Air pollution	25%	Damages (opportunity costs) of - human health - material - biosphere.	- The results are based on a new and consistent data basis for emissions for all countries (TRENDS/Eurostat). - Health costs are based on a WHO study estimating health costs for France, Austria and Switzerland. - Building damages, crop losses and forest damages are based on results of Swiss expert studies. - Marginal costs are computed by the ExternE model. In order to be compatible with the top-down approach for total and average costs, building damages are adjusted.
Climate change	23%	Damages (opportunity costs) of global warming.	- The data basis is TRENDS. - A unit cost value of 135 Euro per tonne of CO_2 is considered. - Marginal costs are assumed to be equal to average variable costs. - The unit costs of air transport are doubled in order to consider the specific risks of emissions in higher altitudes.
Nature and landscape	3%	Additional costs to repair damages, compensation costs.	- A repair cost is used, estimating the desealing costs for different types of infrastructure. - A reference level (unspoilt nature) of 1950 is assumed. - The effects are not relevant for social marginal costs, since these costs are infrastructure related.
Separation in urban areas	1%	Time losses of pedestrians.	According to the methodology used in Germany (EWS), time losses are estimated based on random samples of different type of cities.
Space scarcity in urban areas	1%	Space compen-sation for bicycles.	- According to the methodology used in Germany (EWS), time losses are estimated based on random samples of different types of cities. - The effects are not relevant for social marginal costs, since these costs are infrastructure related.
Additional costs from up- and downstream processes	11%	Additional environ-mental costs (air pollution, climate change and risks)	- Based on the energy consumption, additional costs for precombustion, production and maintenance of rolling stock and infrastructure is estimated. - For nuclear risks, a shadow price of 0.035 Euro per kWh is assumed, based on willingness-to-pay studies for risk aversion.
Congestion	not taken into account for %.	External additional time and operating costs.	- Use of a traffic model to compute marginal and average costs. - Time values are derived from EU research projects (PETS). Three approaches: - Net welfare loss for road transport facing an optimal congestion tax, - Revenues of an optimal tax, - Time losses relative to a better level of service.

Table S-1: Overview of external costs being considered and of the most important methodological assumptions.

Total and average costs

Accident and environmental costs 1995

The following figures present the results for total and average costs for 1995. Total external costs (excluding congestion) amount to 530 billion Euro for 1995, being 7.8% of the total GDP in EUR 17. Accidents are the most important cost category with 29% of total cost. Air pollution and climate change costs amount to 48%. Whereas the costs for nature and landscape and the urban effects considered are of minor importance, upstream effects (11%) are quite significant, due especially to the fact that they are strongly related to air pollution and climate change. The most important mode is road transport, causing 92% of total cost, followed by air transport, causing 6% of total external costs. Railways (2%) and waterways (0.5%) are of minor importance. Two thirds of the costs are caused by passenger transport and one third by freight transport.

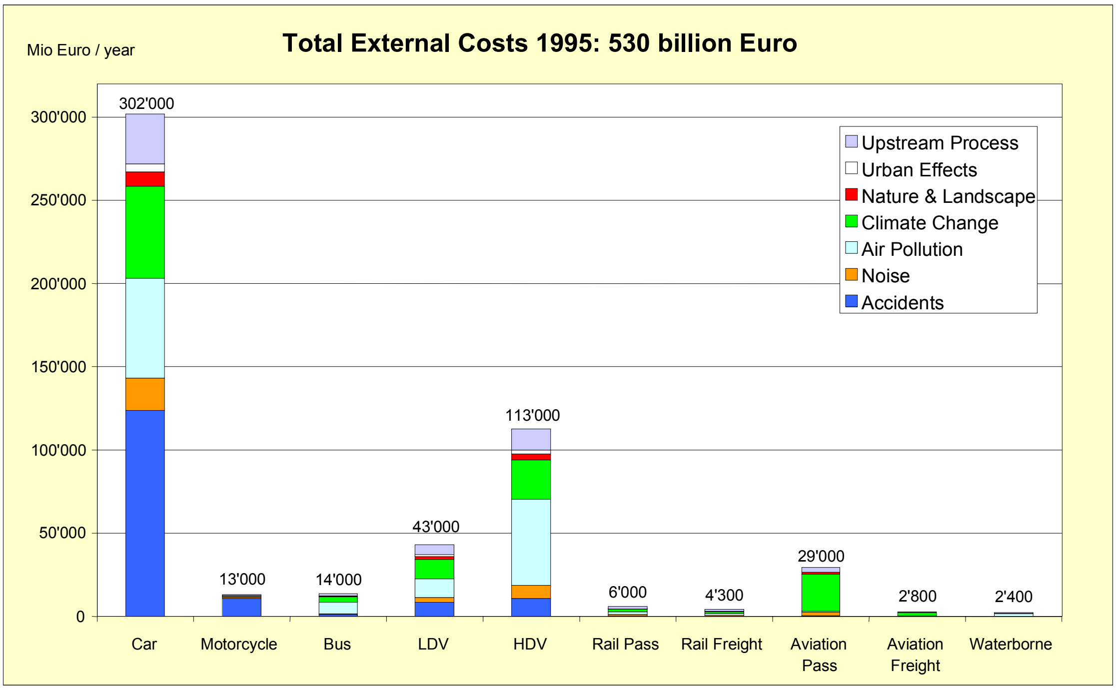

Figure S-1: Total external costs of transport 1995 (EUR 17) by transport means and cost category. Road transport is responsible for 92% of total external costs.

Average costs are expressed in Euro per 1'000 pkm and tkm. Within the **passenger transportation** sector, passenger cars reach 87 Euro. Railway costs amount to 20 Euro, which is 4.4 times lower than costs for the road sector. Most important for the railway sector are the effects on climate change, noise and air pollution. In aviation the predominant effect is climate change.

In the **freight sector**, the average costs of air transport are significantly higher than the costs of all other means of transport. This is due especially to the fact, that freight load (in tonnes) differs from mode to mode. Aeroplanes for example transport high quality freight of low specific weight. The costs for HDV (heavy duty vehicles) amount to 72 Euro per 1'000 tkm, which is 3.8 times higher than the cost for railways.

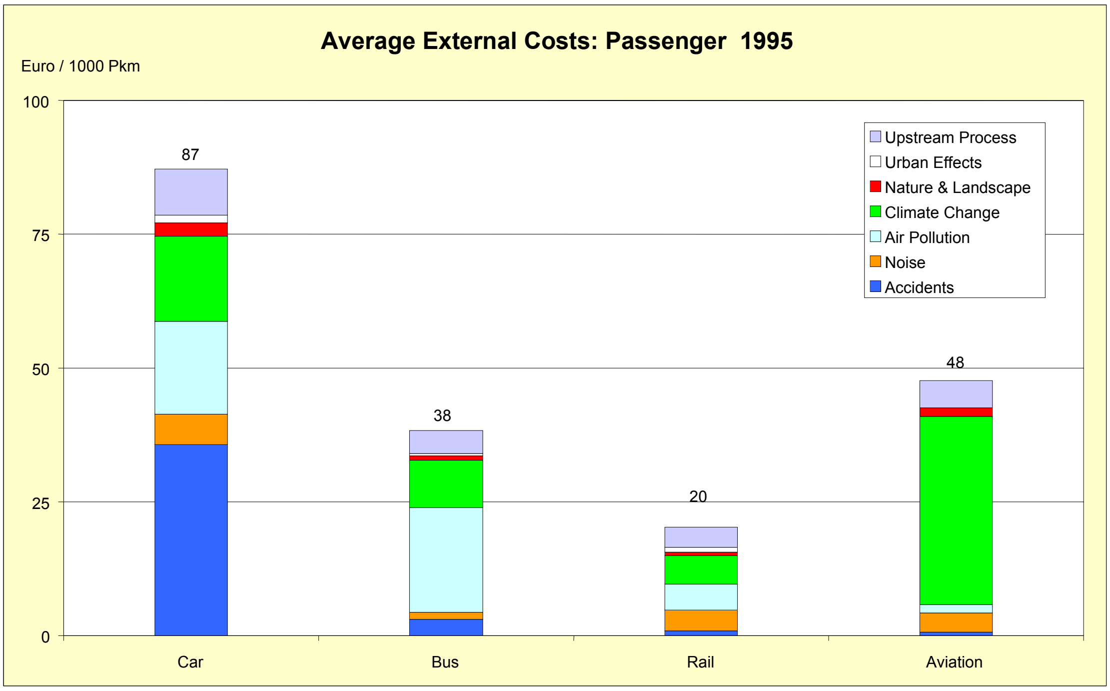

Figure S-2: Average external costs 1995 (EUR 17) by means of transport and cost category: Passenger transport (without congestion costs).

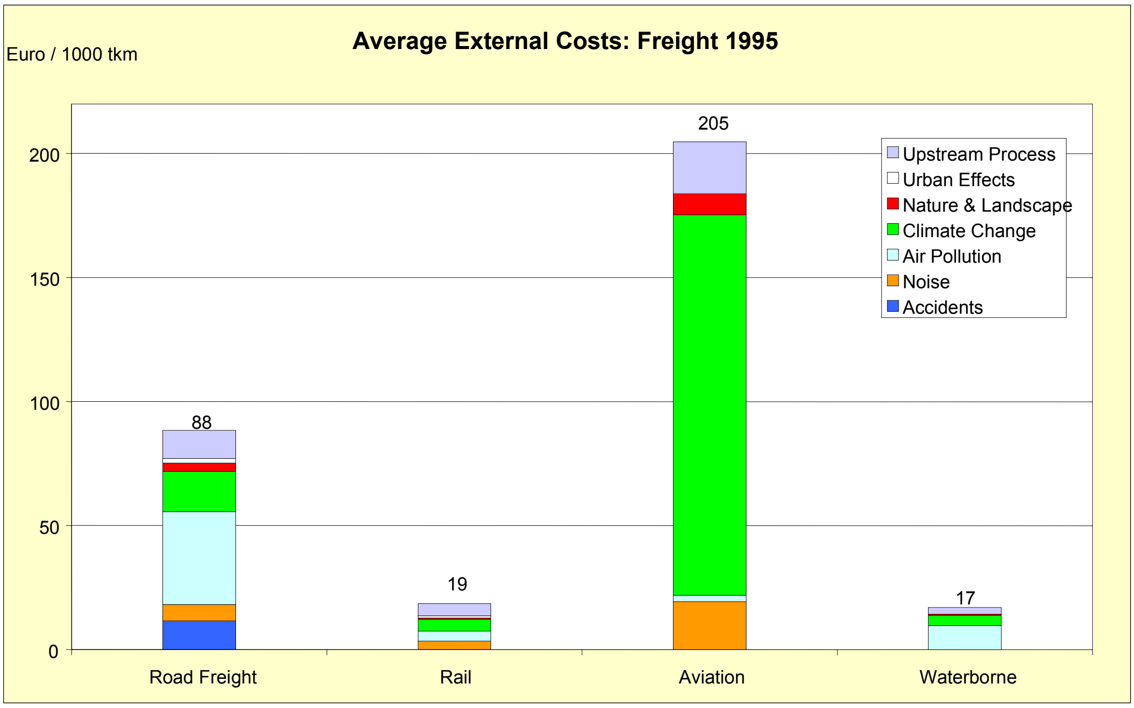

Figure S-3: Average external costs 1995 (EUR 17) by means of transport and cost category: Freight transport (without congestion costs).

The new values are significantly higher than the values estimated for 1991 (IWW/INFRAS 1995). A detailed comparison is difficult, firstly because a new and more consistent database was used. Secondly, additional cost categories were estimated; they amount to 15% of total costs. Thirdly, the values for air pollution (esp. impacts on health) and for climate change risks increased with the new approaches were used.

Trend forecast to 2010

Total costs will increase by 42% between 1995 and 2010. A major factor is transport growth and the increased valuation of environmental damages.[1] The highest growth rates will take place in the aviation and road sectors.

Average costs will also mainly increase. Expected technical improvements will not outweigh the growth in traffic:

1 The following growth rates of pkm/tkm were considered:
- Road + 26% (cars) +30% (HDV)
- Rail + 26% (passenger) + 0% (freight)
- Air +108% (passenger and freight)
- Waterways no change
- GDP (used for the adjustment of unit costs to consider increased valuation): +39%.
- The expected developments of emissions for the road sector are based on TRENDS.

- There will be an increase of 8% in road passenger transport. Due to improved technology, the costs for air pollution will decrease. Road freight costs will increase by 15%. Major increases have to be expected for climate change costs, since energy savings are not proportional to traffic increase.
- Rail costs will decrease by 2% for passenger transport. For freight transport an increase of 14% is expected, mainly due to increased costs of climate change.

Within air transport, average costs will increase by 16% for passengers and 18% for freight. In contrast, external costs for waterborne transport will decrease by 34%.

Marginal costs and comparison with average costs

The following table shows the values (the ranges, respectively) for all cost categories and means of transport in comparison with the average values. The ranges are quite significant, since different vehicle categories and traffic situations are considered.

Marginal Costs (Average Costs)	Road					Rail		Aviation		Water-borne
[Euro per 1000 Pkm/Tkm]	Car	MC	Bus	LDV	HDV	Pass	Freight	Pass	Freight	Freight
Accidents 1)	11-54 (36)	79-360 (250)	1-5 (3.1)	44-163 (100)	2.3-11 (6.8)	0-1 (0.9)	0 (0)	0-1 (0.6)	0 (0)	0 (0)
Noise	0.2-21 (5.7)	0.6-53 (17)	0.1-7.5 (1.3)	5.3-496 (36)	0.6-52 (5.1)	0.2-23 (3.9)	0.1-1.6 (3.5)	2.3-17 (3.6)	17-87 (19)	0 (0)
Air Pollution 2)	5-17 (17)	14 (7.9)	4-25 (20)	28-118 (131)	14-50 (32)	2-24 (4.9)	1-6.8 (4)	0.8-2 (1.6)	0.8 (2.6)	4.5 (9.7)
Climate Change	12-25 (16)	9.6 (14)	5.5-11 (8.9)	125-134 (134)	15-18 (15)	4.2-8.9 (5.3)	4.2-5.3 (4.7)	36-42 (35)	117 (154)	4.7 (4.2)
Nature & Landscape	0-1.8 (2.5)	0-1.8 (2)	0-1.3 (0.8)	0-23 (23)	0-8.9 (2.2)	0-0.8 (0.7)	0-0.3 (0.5)	0-2.9 (1.7)	0-8.5 (8.5)	0-0.5 (0.5)
Urban Effects	10.7-11.7 (1.5)	6.7-7.4 (1.1)	3-3.2 (0.5)	75-83 (12)	8-9 (1.3)	0 (0.9)	0 (0.9)	0	0	0
Upstream Process	3.3-6.7 (8.6)	2.7-5.4 (6.0)	2.8-6.5 (4.3)	40-72 (69)	4.2-8.8 (8.7)	1.1-9.8 (3.8)	0.4-3.4 (5)	4.1-4.6 (5)	18-23 (21)	0.6-1.4 (2.6)

1) Average of countries considered.
2) Values for specific traffic situations in Germany, adjusted to European average.

Table S-2: Marginal costs by cost category and means of transport (the ranges reflect different vehicle categories (Petrol, diesel, electricity) and traffic situations (urban-interurban).
The values in brackets denote average values as shown in figures S-2 and S-3.

The ranges of marginal costs are based on different traffic situations. In urban areas for example, marginal costs are considerably higher than for interurban transport. Road passenger transport costs amount to 113 Euro per 1'000 pkm in urban areas and

34 Euro for interurban transport. For HDV, the figures are 91.5 Euro per 1'000 tkm (urban) and 40 Euro (interurban), respectively.

Comparing marginal and average costs, the following general conclusions can be drawn:

- For accidents, figures are based on the assumption that the average of marginal costs is equal to average costs. The figures' range results from differences between countries. Urban transport values for cars are about 4 to 5 times higher than those for motorways and up to 1.5 times higher than those for country roads.
- For noise, average costs are well above marginal costs, since additional costs decline with increases in traffic. However, the important night time noise is not considered within the range of marginal costs. The values at night are more than double daytime values.
- For air pollution, average values are in principle similar to marginal values. Constant dose-response-relations are assumed. However, different cost estimation approaches have been used. Thus, a complete comparison is not possible. There are also considerable differences between different vehicle categories. For example a EURO 3 car in urban areas causes about 4 times lower costs than today's average car. Diesel trains cause 7 to 10 times higher costs than electric trains.
- For climate change, average costs are equal to marginal costs. The ranges result from different vehicle categories. Marginal costs per pkm of urban petrol cars for example are about 30% higher than the costs for interurban traffic. Diesel trains cause up to double the climate change costs of electric trains.
- For nature and landscape, average costs are close to maximum (long run) marginal costs. In the short run however, no marginal costs will occur, since the costs are infrastructure related and thus not relevant for social marginal cost pricing approaches.
- For urban effects, only marginal costs of separation are relevant, being above average because of a progressive increase with the amount of traffic. In addition the average values presented in table S-2 reflect national averages, whereas the marginal costs are related to specific urban traffic situations.
- For upstream effects, short-run marginal costs are only related to precombustion processes such as production, transportation and storage of fuels.[2] Therefore they are lower than average costs which include also vehicle and infrastructure related processes. Thus, average costs are close to long-run marginal costs.

All marginal values reflect existing situations. In order to deduce optimal prices and transport taxes respectively, the reaction of transport users to the price changes has to

2 Note that the emissions of electricity production (mainly for the railways) are considered within the air pollution and climate change costs.

be considered as well. For this reason, general optimisation model applications should be used. Thus optimal prices are usually slightly below the values presented here.[3]

Average costs can be used as approximate values for marginal costs for mean traffic situations.

Congestion costs

Total congestion costs are defined according to economic welfare theory as the costs arising from an inefficient use of the existing infrastructure. Due to the specification of the road traffic congestion and the three different approaches used, congestion costs are treated separately throughout this study.

For the EUR-17 countries, total and average road congestion costs, the revenues expected from their internalisation via road pricing systems and an "engineering" measure of additional time costs have been estimated on the basis of an extended network analysis for the year 1995. Due to the chosen welfare-economic approach, congestion costs by definition only appear for transport modes where single users decide on the use they make of infrastructure. Consequently, rail and air traffic are not affected by this kind of congestion. A comparison of the three congestion-related measures is presented by the following figure.

3 These applications are carried out in ongoing EU-research projects (e.g. TRENEN).

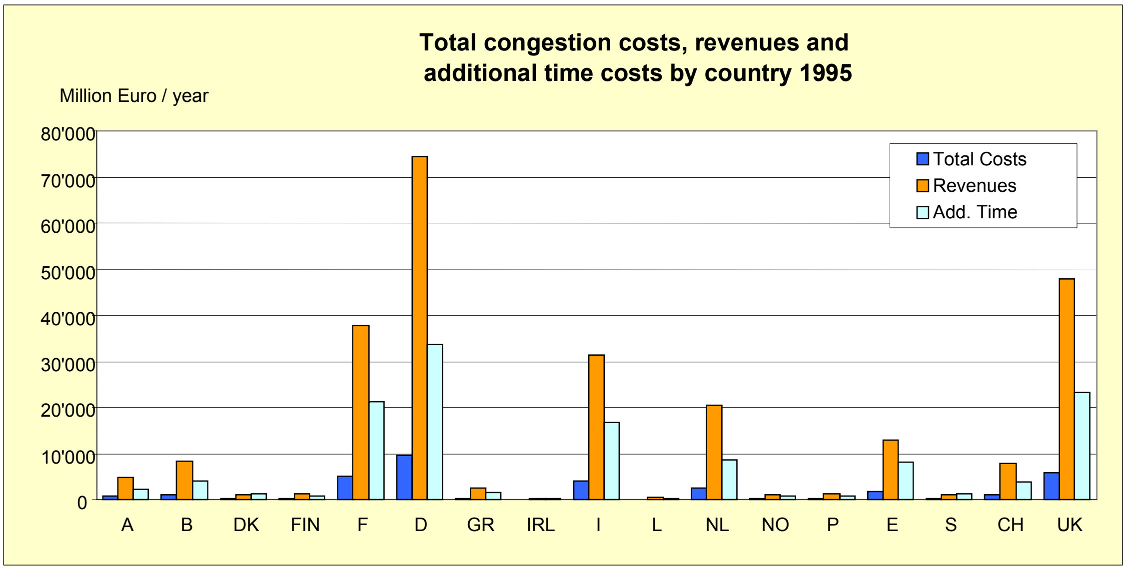

Figure S-4: Congestion costs: Results by country for 1995 (in billion Euro 1995)
- Total costs: Reduction of consumer surplus (dead weight loss) for road users compared to optimal congestion pricing-
- Revenues: Revenues from optimal congestion pricing,
- Additional time and operating costs relative to a non congested traffic situation.

On the basis of reduced consumer surplus, the external costs of road traffic congestion are estimated approximately 33.3 billion Euro for 1995, which corresponds to a share of Europe's GDP of 0.5%. Road congestion costs are not equally spread across Europe. As expected, the big industrial countries along the "blue banana" (UK, France, Germany and northern Italy) contribute by far the most to total road congestion costs in the EUR-17 countries.

A rough estimate concludes that 70% to 80% of total congestion costs and revenues in passenger transportation result from urban traffic while the remaining share of costs occur in long-distance travel. In freight transport the share of urban congestion is considerably lower; it is estimated to range between 25% and 45% within the EUR-17 countries.

The forecast of traffic demand to 2010 shows a dramatic increase of total congestion costs of 142% to 80.2 billion Euro p.a. Congestion on the inter-urban road network is estimated to rise of 124%, while on urban roads an increase of 188% is expected. However, these estimates assume that road infrastructure capacity remains constant, which is most likely not true for Europe's major road infrastructure bottlenecks.

The two other approaches show the following results for 1995:

- Revenues from optimal congestion pricing amount to 254 billion Euro (3.7% of GDP).
- Additional time costs amount to 128 billion Euro (1.9% of GDP).

Marginal external congestion costs per vehicle kilometre are defined as the difference between the marginal social costs which a user imposes on the whole system and the private costs perceived by him. They are evaluated on the basis of speed-flow diagrams and are presented by road type as a function of lane occupancy. The following table shows the most important values.

Marginal congestion values (Euro / 1000 km)	Marginal values per vkm SRMC	Charge	Av. DWL	Marginal values per pkm / tkm SRMC	Charge	Av. DWL
Passenger car on motorway						
- relaxed traffic	11	11	0′	6	6	0
- dense traffic	1′980	1′000	78	1′040	529	41
- congestion	2′030	1′480	195	1′070	778	102
Passenger car on rural road						
- relaxed traffic	37	37	0	20	20	0
- dense traffic	1′250	803	2	660	423	1
- congestion	1′950	1′690	28	1′030	888	15
Passenger car on urban road						
- relaxed traffic	26	26	0	19	19	0
- dense traffic	2′710	1′590	60	1′900	1′140	43
- congestion	3′100	2′210	179	2′210	1′580	128

Table S-3: Short-run marginal external costs (SRMC), optimal user charges and average dead-weight-loss (DWL) of road congestion for passenger cars.

Corridor estimates

Our corridor estimates aim to present a set of examples of the magnitude of short-run marginal costs in particular traffic situations to allow a comparison between different passenger and freight travel alternatives. To achieve this goal, four European border-crossing corridors were selected. They constitute two passenger routes (long distance: Paris–Vienna and short distance: Paris–Brussels) and two freight relations (combined Alpine-crossing: Cologne–Milan and uni-modal harbour-hinterland shipments: Rotterdam–Basle). For each corridor three modes (road, rail and a multi-modal alternative) considering corridor-specific rolling material and loading factors, were selected. For the inter-modal transport alternatives (passenger air, combined rail-road freight) all involved transport means are considered (i.e. including terminal or airport access by road).

Following the structure of the report, accident-, environmental- and other transport-external costs on the one hand and marginal external congestion costs and road user charges on the other hand are presented separately in the corridor estimates summarised in table S-3. Since only short-run marginal costs are considered, infrastructure related costs (like nature and landscape, most of the upstream effects) are neglected. The marginal cost calculations are based on a differentiated description of travel routes by road and rail, taking into account local characteristics such as the type of land use, population density, type of infrastructure and traffic conditions. The corridor-wise results are expressed in Euro per pkm/tkm to mark different route lengths and different vehicles used in intermodal transport chains (see fig. S-6 for accident and environment costs).

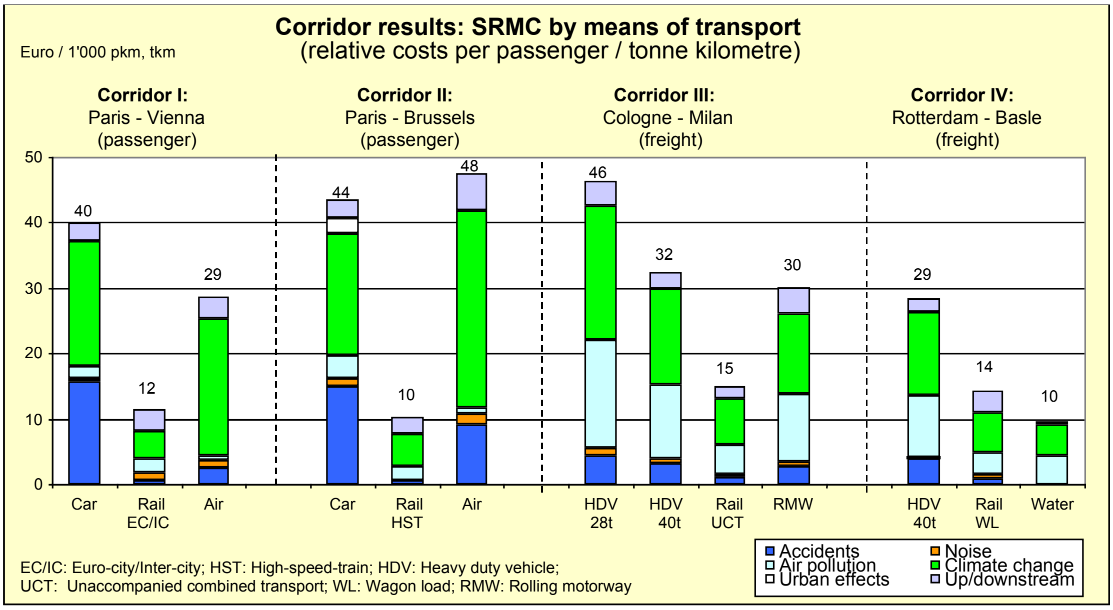

Figure S-5: Corridor results: Accidents and environmental costs for different means of transport

Comparing the corridor results with the average costs in passenger and freight transport (figures S-2 and S-3) the following observations can be made:

- For all uni-modal travel alternatives (passenger and freight) short-run marginal costs are 40–60% below average costs. This is mainly due to three facts:
  (1) the regressive cost function for noise emissions,
  (2) the neglected long-run cost elements and
  (3) the relatively high road safety standards in the countries considered.
- This decrease does not hold for the costs due to the emissions of CO_2, which – in contrast to average costs – dominates all other cost components because CO_2-emissions are not influenced by vehicle technologies nor is the economic valuation sensitive to the type of area.
- Due to the comparatively high external costs of road transportation, the intermodal travel alternatives air (passenger) and rolling motorway services show a rather unfavourable picture compared to unimodal rail transport. The relative external costs calculated are close to those of pure road transport.
- In freight and scheduled passenger transportation, vehicle loading factors may vary significantly and thus the average marginal costs per passenger or tonne kilometre show a wide range of uncertainty. The comparison between different passenger and rail services shows that this effect is more important than the technical standard of the rolling stock used.

The marginal external congestion costs in road and air passenger transport clearly dominate the environmental externalities presented in figure S-6. While congestion costs are about two times higher in the long-distance corridor Paris–Vienna, the short-distance route from Paris to Brussels (corridor II) with its high share of urban roads shows a ratio of 6 for road and 4.7 for air transport.

Uncertainty ranges

The most important sensitivities are the risk value being important for nearly all cost components, the minimal noise level (55 dB(A)), the consideration and procedure of air pollution costs (esp. material damages and biosphere) and the unit costs for climate change. Compared to the previous study (IWW/INFRAS 1995) one can state that the range of uncertainty has decreased, due to more robust data and more in-depth knowledge on several cost components.

Note, however, that the sensitivity ranges vary to both sides. Thus, the cost levels could be higher or lower. Note as well that the sensitivities can outweigh one another. The overall range of uncertainties could even be lower than the uncertainty range for one individual cost component. Thus we can conclude that the primary assumptions chosen in this study represent a 'best guess'. There is no systematic under- or overestimation of the results.

Concluding remarks

Estimations of external costs on a European scale face several challenges. Firstly, a solid and comparable data basis is needed for all countries and all means of transport. Secondly, robust dose response functions and valuation principles for different cost categories are necessary in order to produce defendable results. Although the situation in comparison with previous studies has significantly improved, it is still important to interpret the results in an appropriate manner.

Most important are the relations between different means of transport. In spite of several uncertainties, the relations remain stable and show the level of specific external costs. Within passenger transportation, railways are still the means of transport with the lowest level of external costs. For freight transport rail and waterborne transport are about equal.

The comparison also shows the relevance of different cost categories. Not surprisingly, the better known externalities (accidents, noise) remain rather stable, whereas the risks of air pollution and climate change have led to increased costs. It is important that natural science research in to emission data and cost estimation has improved significantly in these areas during the past few years. Especially for air pollution related health costs and future climatic changes which are rather recent research fields. New risks may possibly be added and integrated in cost estimations in future.

If we consider the trend, total and average costs will increase, despite improved productivity and technology. Although this might be surprising at first sight, there are three main reasons for it. Firstly, the trend of traffic growth will hold and will increase total pollution levels in many areas. Secondly, willingness to pay (for environmental protection) will increase. Willingness to pay will increase with incomes and will lead to higher unit values. Although it is difficult to say what degree this will be the case, the direction is very clear. Thirdly, we have to consider that productivity will increase in future for all transport means, but in different directions. There are some specific effects to consider which might offset the positive impacts. In passenger transportation for example, increased motorization and new forms of (more individual) leisure transport might lead to lower occupancy rates and increasing average costs. In freight transportation, similar effects are possible with increased degrees of globalisation.

In this report average costs and marginal costs are compared. The definition of marginal costs plays a major role in this comparison. Whereas it is very obvious that marginal costs differ from average costs for congestion and noise, because dose response and cost functions are not linear, it is rather difficult to conclude anything like that for other cost components. There are, however, two other elements which became visible making this comparison. Firstly, the marginal cost approach – being mainly a bottom-up approach – is very appropriate to provide differentiated results for different types of vehicles and different traffic situations, in order to make the range of costs visible. Secondly, it is helpful to distinguish between short-term impacts (directly related to the amount of traffic) and long-term impacts (which consider production and life cycles as well). This is especially true for nature and landscape and of up- and downstream processes.

It is also important to read, understand and interpret the results in a 'top-down manner'. The general statements made above are very robust and should help to provide a sound basis for further cost estimations and for policy implications (especially in the field of pricing). However, it has to be considered that the aggregated results are much more robust than the desegregated results, for example for specific countries or for specific traffic situations, since these values were derived from aggregated results. Thus, the more detailed the results are, the more illustrative they should be considered.

The study has shown the strengths and weaknesses of the estimation of external costs which is useful for future studies. We conclude the following major issues should be treated in more depth:

- **National accounts and marginal costs for different traffic situations**: For these two data sets the purpose of the estimation and the approach employed is quite different. Whereas the former can be used as statistical and strategic information on national level, the latter is directly relevant for pricing issues. The comparability of the approaches employed should be improved. More information is needed on the shape of the cost curves varying with the most important factors of influence.
- **Risk values**: Being one of the most critical assumptions in estimating external costs, the definition of risk values needs a lot of accurate evidence, including political and societal discussions of risk.
- **Air pollution costs**: More research is needed in the field of particulate matter (modelling, relevance of different particulates) for the estimation of health costs.

The other cost elements (especially building damage, damage to the biosphere) have to be improved by new estimations of dose-response relationships.

- **Costs of climate change risks**: In-depth discussions are necessary on the question of the target level to be chosen as this is the main element of cost uncertainties.
- **Congestion**: Although there is enough evidence to estimate marginal congestion costs, the relevance of total (external) congestion costs is still not finally determined.
- **Other external costs**: Upstream effects are in certain cases considered especially for fuel production and for electricity production used by electric trains. Due to lack of scientific data, electricity used for vehicle production by example is not considered. Although their relevance is quite limited compared to the main cost categories, it is important to include them more accurately in future in order to communicate their levels properly.