The marginal cost of road- and rail-infrastructure use in Europe – latest estimates and European legislation

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Abstract

This paper summarise the result from studies on the external marginal cost for road and rail transport made in the European GRACE project. The project includes studies on the marginal infrastructure cost, cost of congestion and scarcity, accident, air pollution, greenhouse gases and marginal noise cost. This paper focuses on the estimates of the marginal infrastructure cost and is based on 8 original studies made across Europe. The paper reveals a structure on the cost elasticity that depends on cost category and mode of transport. The paper presents result on the marginal renewal cost from both econometric studies and studies based on a lifetime approach. The elasticity is highest for renewal measures on road infrastructure and lowest for operation of road infrastructure with a number of elasticities in the rail sector in between. The result suggests that the marginal infrastructure cost at average is below the average cost for both rail and road infrastructure.

Introduction

Marginal cost base pricing of infrastructure use has been on the agenda of the European transport policy in over a decade. The policy is most developed in the road and rail sector and two pieces of relevant new legislation have been adopted, the new 'Eurovignette' directive for charging of heavy goods vehicles (EU, 2006) and the directive (EU, 2001) for charging of the use of railway infrastructure. Both directives demand more accurate estimates on the social marginal cost.

A number of projects funded by the European Commission and other organisations such as European Conference of Ministries of Transport (ECMT) and International Railways Union (UIC) have presented estimates of the social marginal cost. The project UNITE[1] financed by the European Commission presents a number of case studies on the social marginal cost in Europe. A general conclusion is that the variability in all estimates has been very large. Some argues that the estimates are too uncertain for a policy development. However, (Quinet, 2004) suggests, in a meta-analysis, that the observed variability is due to recognizable differences in studies and that the variability can be explained. The main reasons for the variability according to Quinet are the area investigated - urban, metropolitan or rural - the GDP of the country in question and if the studies really tries to estimate the marginal cost and not the average cost.

To improve the estimates on the social marginal cost and to support policy makers in developing sustainable transport systems by facilitating the implementation of such pricing and taxation schemes that reflect the costs of infrastructure use the GRACE project (Generalisation of Research on Accounts and Cost Estimation[2]) has been initiated by the

[1] UNIfication of accounts and marginal costs for Transport Efficiency (http://www.its.leeds.ac.uk/projects/unite/)
[2] www.grace-eu.org

European Commission. The project covers five major areas of research; i) case study research to address gaps in the existing level of knowledge of marginal social costs for road, rail, air and waterborne transport; ii) development and refinement of methods to enable the use of transport accounts as monitoring instrument for the implementation of transport pricing reform in an enlarged Europe; iii) research on the appropriate degree of complexity in transport charges, iv) guidance on the marginal social cost of the different modes of transport in specific circumstances and on simple and transparent methods for determining charges and finally v) modelling of the broad socio-economic impacts of pricing reform.

This paper summarise the result from case studies on the external marginal cost for road and rail transport made in the European GRACE project. The costs considered in the project include infrastructure cost, cost of congestion and scarcity, accident, air pollution, greenhouse gases and noise cost. This paper focuses on the estimates of the marginal infrastructure cost. The reasons for this focus are twofold; first, previous studies (e.g. UNITE) have shown that the knowledge on marginal infrastructure cost is less developed than could have been expected and, secondly, the legislation discussed above includes explicitly references to the infrastructure cost.

The remaining part of the paper is organised as follows; section 2 summarise the methodology while section 3 presents the economic data used in the Case studies. Section 4 presents the results in the form of elasticities and section 5 the marginal costs. Section 6 offers some conclusion.

2. Methodology

The short-run marginal infrastructure cost related to an additional vehicle or train consists of four components; first, the increased wear of the infrastructure leading to additional routine maintenance, secondly, the damage to the infrastructure leading to earlier future periodic maintenance. A third component is the increased cost inflicted on other vehicles/trains. Fourthly, congestion or scarcity cost, and corresponding peak load pricing, is in many sectors a necessary part of understanding and developing cost allocation or pricing principles in the transport sector. The case studies in GRACE presented here focus on the two first categories; routine maintenance (including operation) and renewal cost.

Infrastructure operation, for example snow removal, is defined to have a very short time horizon and is undertaken to keep the infrastructure open and functioning for traffic. Maintenance activities have a longer time horizon and are preventive measures to avoid degradation. Finally, renewal activities have a longer time horizon and are undertaken to bring the infrastructure back to its original condition[3].

Two distinct approaches have been used; an econometric approach and a lifetime approach. In the econometric approach a cost function is estimated to describe the variability of costs as a function of infrastructure characteristics, geographical, climate information and finally traffic volumes. The observed correlation between traffic and cost is then the base to estimate the marginal cost. In this approach information on expenditure is collected over a number of years. The observation unit is in some cases a single road or rail segment while other studies

[3] In European standards (EN 13306:2001) 'maintenance' is defined as *'combination of all technical, administrative and managerial actins during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function'*. Both the measure maintenance and renewal in the table is thus a part of the general maintenance term.

use information over a larger network, usually a Maintenance Delivery Unit (MDU) where the maintenance work has been contracted out. The expenditure is expressed separately for the different measures related to operation, maintenance or renewal. In some cases the expenditure information is constructed from physical information on measures taken. To fix the idea we use a double log functional form:

$$\ln(C_i) = \alpha + \beta_1 \ln(Q_{Ai}) + \beta_{11} \ln(Q_{Ai})^2 ... + \beta_2 \ln(Q_{Bi}) + \beta_{21} \ln(Q_{Bi})^2 + \gamma \ln(I_i) + \delta \ln(P_i) \qquad (1)$$

Where

- C_i is the cost per annum for section or zone i;
- Q_i is outputs for section or zone i ; here in terms of traffic with vehicles of different types (A and B). Above is also a squared term included;
- I_i is a vector of fixed input levels for section or zone i – these include the infrastructure variables i.e. track length, track quality or pavement type etc;
- P_i is a vector of input prices.

The marginal cost can be derived as the product of the average cost (AC) and the cost elasticity ε. In the example above we included the square of the traffic variable Q_A which means that the elasticity with respect to vehicle type A is non-constant if β_{11} is non-zero.

$$\varepsilon_A = \frac{dC}{C}\frac{Q_A}{dQ_A} = \frac{d \ln C}{d \ln Q_A} = \beta_1 + 2\beta_{11} \ln(Q_A) \qquad (2)$$

The average cost is simply the cost C divided by the relevant output variable Q. However, the average cost will depend on the traffic volume Q. Usually this is expressed as the mean in the sample.

$$MC = \varepsilon AC = \varepsilon \frac{C}{Q_A} = \left[\beta_1 + 2\beta_{11}\ln(Q_A)\right]\frac{C}{Q_A} \qquad (3)$$

Two additional observations should be highlighted. First, while the theoretical specification above includes different outputs in terms of different vehicles the reality is more problematic. In general, the correlation between different outputs is so strong that the econometric model can not distinguish between the effect from, for example, different vehicle types. This means that we a priori need to decide on only one output variable to use in a study. Secondly, input prices are often assumed to be constant between sections or areas and thus not included in the studies.

The duration model, or engineering approach, is based on the lifetime of a piece of infrastructure and is used to calculate renewal cost. This approach does not require expenditure information but lifetime information. A lifetime or duration function is estimated as a function of infrastructure characteristics, geographical and climate information and traffic volumes as in the econometric approach. The change in the lifetime as the traffic changes will affect the present value of the future renewal costs and is thus the basis for the marginal cost calculation. The basic assumption is that the length of an interval between two renewal measures depends on the aggregate of traffic that has used a certain section. Existing literature (Newbery, 1988) focuses on road and assumes that the number of standard axles that can use a road before the pavement has to be renewed is a design parameter of road construction. (Lindberg, 2002)) however makes use of the fact that the number of standard axles which the road can accommodate after all is a function of the actual, not the predicted traffic volume. Adding or subtracting vehicles to the original prediction will therefore affect the timing of a reinvestment and there is, consequently, a marginal cost associated with variations in traffic volume.

The lifetime of a pavement – the number of years between resealing – (T) is a function of the constant annual number of vehicles that pass the infrastructure (call it Q_A) and the strength of the infrastructure where Θ denotes the number of vehicles the infrastructure can accommodate and m indicates the climate dependent deterioration:

$$T = \left[\frac{\Theta(Q)}{Q_A} \right] e^{-mT} \tag{4}$$

Each renewal of the infrastructure has a cost of C. The first renewal takes place at year 0. We can then calculate the present value of an infinite number of renewals as (5) where r is the relevant discount rate. If we examine a road in use year t, the next overlay will take place T-t years ahead. Consequently, the present value will depend on the time left until next overlay (6).

$$PVC_o = C(1 + e^{-rT} + e^{-r2T} \ldots + e^{-rnT}) \qquad \lim_{n \to \infty} PVC_o = \frac{C}{(1 - e^{-rT})} \tag{5}$$

$$PVC_t = e^{-r(T-t)} \frac{C}{(1 - e^{-rT})} \tag{6}$$

We explore the present value for roads with different ages which are equally distributed (7).

$$PVC_{Average} = \frac{1}{T} \int_0^T e^{-r(T-t)} dt \frac{C}{(1 - e^{-rT})} = \frac{C}{rT} \tag{7}$$

And finally, we study the effect of annual traffic on the cost, and we will therefore examine the properties of the annualised present value (ANC), which for an average road can be expressed as (8).

$$ANC_{Average} = r\,PVC_{Average} = \frac{C}{T} \tag{8}$$

The marginal cost caused by shortening the renewal intervals due to higher traffic loads can be obtained by differentiating the annualised present value of the infrastructure with the annual traffic volume. By using the deterioration elasticity ε – the change of lifetime due to higher traffic loads (equation (8)) – and the definition of average costs AC=C/QT the marginal costs for an average road $MC_{Average}$ can be expressed simply as 10.

$$\varepsilon = \frac{dT}{dQ}\frac{Q}{T} \quad . \tag{9}$$

$$MC_{Average} = -\,\varepsilon\, AC \tag{10}$$

3. The Case studies

The case studies explore the marginal cost of motorways in Germany (Link, 2006) and a broader set of roads in Poland (Bak et al., 2006) and Sweden (Haraldsson, 2006). Lifetime model is developed to analyse the renewal costs on Swedish roads (Haraldsson, 2006). The same approach is used on Swedish railways (Andersson, 2006b). An econometric approach is used on railways in Sweden (Andersson, 2006a), Great Britain (Smith and P.Wheat, 2006) and Switzerland (Marti and Neuenschwander, 2006)[4].

a. Road infrastructure

[4] A study with a different approach is made in Hungary

The German study includes one production cost oriented study and one study focused on the influence of traffic. The studies are based on detailed physical information of renewal measures on (West) German motorway sections during 20 years. The database consisted originally of 1830 sections but only sections where renewal has taken place during the period were included in the database (221 sections). Based on unit costs for each type of construction[5] a database on renewal expenditure was constructed. The annual data was summed up over the period which resulted in a cross-sectional database of 221 observations of total renewal expenditure over the period 1980 to 1999.

The cost data in the Swedish econometric study is based on the Swedish National Road Administrations accounting system. The observation unit are 145 small areas, so called Maintenance delivery units (MDU), which were established by the Road Administration when maintenance contract were procured on the market. This means that information on actual maintenance and operation expenditure by MDU can be found directly in the accounting system. The study is focused on maintenance for paved and gravel roads, winter operation as well as ordinary operation of paved and gravel roads. The database covers the period 1998 to 2002. For the lifetime approach the basic database is extensive: it includes observations on every completed renewal interval in the Swedish national road network from 1928 to 2005 but only data from 1950 and onwards has been used.

In Poland a database with all sections of national roads where renewal works have been conducted between 2002 and 2004 has been used. Renewals include rebuilding, strengthening, refurbishing or modernization. The final database consists of 264 sections with an average length of 6 km. For these sections also maintenance cost has been added. All of the

[5] Bituminous concrete, bituminous mastic asphalt, bitumen binder, mastic asphalt with crushed materials, cement concrete, thin layer, others.

studies relay on common measures of traffic volumes based on AADT for some broad vehicle categories.

b. Rail infrastructure

The collected information in the Swedish econometric study includes operation, maintenance and renewal costs on 185 track sections over the period 1999 to 2002 and originates from the Rail Administration accounting system. The traffic variables have been the most difficult information to collect and include information on gross tonnes and number of trains per section by passenger and freight trains over the four years.

Following the idea of lifetime analyses developed for the road sector the second Swedish case study endeavours to apply this same approach to the railway sector. Two data samples from the track information system have been matched; the first from 1999 and the second from the end of 2005. Changes between these years can be identified through changes in the infrastructure information and with information of the year when the track is laid, an age variable for each observation.

The data used in the Swiss study is from the whole railway network of Switzerland including all main lines divided into almost 500 sections. Some defined track sections are maintained by other countries, are marshalling yards etc and this result in 371 useful observations (track sections) per year for the years 2003 to 2005. Within a detailed set of cost categories the Swiss railway separates between short-run maintenance costs ("Contracting A") that arise yearly and long-run costs which arise periodically and have the characteristics of renewal costs ("Contracting B"). Due to the fact that the data base is only available since 2003, the estimation of renewal costs is based on a relatively short time period of three years.

In the study from Great Britain cross section data from Network Rail for 53 Maintenance Delivery Units (MDUs) for 2005/06 is used. 67% of total maintenance expenditure is available at the MDU level. The remaining expenditure (33% of the total maintenance budget) includes maintenance of electrification and plant equipment and other expenditure and can not be allocated to individual MDUs.

4. Cost elasticities

The cost-elasticity with respect to the traffic-output describes the relationship between average cost and marginal cost such that Marginal Cost = Elasticity *Average Cost. The figure below summarises the estimated (average) elasticities in the econometric case studies for road and rail infrastructure. The elasticities are divided into renewal (R), maintenance (M) and operation cost (O).

Figure 1 about here

The elasticity for road infrastructure cost decreases as the measure changes from renewal to maintenance and to operation. The average elasticity for renewal cost is between 0.58 and 0.87, for an aggregate of renewal and maintenance cost the elasticity is between 0.48 and 0.58 while the elasticity for only maintenance and operation are from 0.12 to zero. The table below summarise the function for the elasticities based on equation 2 (except for the duration model). The result supports the general idea that operation (i.e. snow removal) is not a relevant base for marginal cost based charges. An observation that needs more research is the form of the function. The German study suggests that the elasticity increases with traffic volume while the Swedish study points at a decreasing function. The polish study shows a constant elasticity.

Table 2 about here

The elasticity for rail infrastructure cost is lower than the elasticity for road and doesn't show the same difference between different measures. The average elasticity is between 0.26 and 0.30 for an aggregate of renewal and maintenance, for maintenance it is between 0.20 and 0.24 and for operation or short term maintenance it is 029 to 0.32. The functions from the railway studies show a higher degree of similarity than the road studies.

Table 3 about here

The majority of the studies suggest that the elasticity decreases with increased traffic. Thus highly used infrastructure has a lower elasticity than low volume infrastructure. All elasticities reported above are from the average traffic in the studies.

5. Average and marginal cost

The marginal cost can be calculated as the product of the average cost and the elasticity. Although the elasticity is constant the average cost is not and it falls with increasing traffic volume. Consequently, the marginal cost decreases with increasing traffic.

a. Road infrastructure

Applying the elasticity on the average cost per goods vehicle kilometre in the German study (1.59 €/vkm) results in a marginal cost of 0.08 €/HGV-km at very low traffic volume increasing to 1.87 €/HGV-km on roads with the highest traffic volume. Evaluated at the average traffic volume the cost is 1.39 €/HGV-km. In Poland, evaluated at the average traffic volume, the renewal and maintenance average cost is 0.27 €/vkm (for all vehicles) and the marginal cost 0.13 €/vkm. The corresponding number for renewal only is 0.21 €/vkm and the MC is 0.12 €/vkm. Observe that the Polish study is related to all vehicles not only HGVs.
The Swedish econometric study reports a significant difference between the marginal cost of paved and gravel roads. The former have a marginal cost of 0.032 €/HGV-km and the latter almost ten times higher marginal cost, 0.24 €/HGV-km. An aggregate of renewal and maintenance suggests an average cost of 0.040 €/HGV-km. The model for operation cost does not show a significant marginal cost and it can then be assumed to be zero.

The table below summarise the average and marginal cost for the road case studies. Observe that the mean traffic volume is very different between the studies with the highest traffic volume in the German study and the lowest in the Swedish study (see previous table).

Table 3 about here

Based on a unit cost of 7.05 €/m^2 pavement an average cost over a pavement interval can be estimated to 0.028 €/vkm. Applying the elasticities and a correction factor following the choice of a Weibull distribution on these average costs suggests a marginal cost of 0.0013 €/vkm with an interval from almost zero to 0.004. The reason for this low marginal cost in this approach is of course the low elasticity. Previous research has assumed that this is due to a weather/climate effect but this study can reject any such influences. One possible explanation not further analysed in the study is that the responses from the Road authority are such that the unit cost per m^2 differs depending on traffic volume. If a higher volume is expected a more expensive pavement measure is taken.

b. Rail infrastructure

The average and marginal cost in the Swedish and Swiss studies are rather similar, regarding both average cost and marginal cost. The marginal cost related to maintenance is in Sweden 0.31 €/1000GTkm and in Switzerland 0.45 €/1000GTkm. Adding renewals to the maintenance increases the marginal cost to 0.70 €/1000GTkm in Sweden and 0.97 €/1000GTkm in Switzerland. In addition, the Swedish study finds a marginal cost for operation which is 0.054 per trainkm. The study from Great Britian reports both higher average costs and marginal costs compared to the other studies. The maintenance marginal cost is estimated to 1.2 €/1000GTkm.

Table 4 about here

The Swedish case study on lifetime of railways generated results that are consistent with the econometric studies. There is a significant and price relevant cost related to rail renewal in line with what has been found in econometric studies of renewal cost data. A marginal costs for freight and passenger trains is estimated separately in the range of € 0.00012 – 0.00028 per gross tonne kilometre. Somewhat surprisingly, the marginal cost for passenger trains is higher than freight trains, but a possible explanation to this is higher quality demands for passenger trains.

6. Conclusion and discussion

This paper summarises 8 Case studies on the marginal infrastructure cost made in the European GRACE project. Each study contains interesting information and the summary in this report cannot cover all topics presented in these studies. However, we have tried to present the general picture and the common results. Below four areas are discussed, i) methodology, ii) elasticity, iii) differentiation, and iv) marginal cost.

Most of the studies use an econometric approach and collect paneldata. However, a minority of the studies use paneldata models. In two studies a duration model is used where a function of the lifetime of a road pavement or railtrack is estimated. The result can be used to derive a marginal renewal cost. The rail study gave results in line with the econometric study and supported the conclusion drawn from the econometric studies that there indeed exists a marginal cost related to renewal on railways. The result was similar between the two approaches. However, the road study suggested a very low effect of traffic on the observed lifetime of a pavement. A possible explanation with some support is that the authority predicts the higher traffic volume when deciding on the pavement thickness. The marginal cost is thus not found in observed lifetime but in the increased cost of the measures taken.

The cost-elasticity with respect to the traffic-output describes the relationship between average cost and marginal cost such that Marginal Cost = Elasticity *Average Cost. The elasticity for road infrastructure cost decreases as the measure changes from renewal to maintenance and to operation. The elasticity for rail infrastructure cost is lower than the elasticity for road and doesn't show the same difference between different measures. In addition, the majority of the studies suggest that the elasticity decreases with increased traffic. Thus highly used infrastructure has a lower elasticity than low volume infrastructure. All elasticities reported are for the average traffic in the studies. However, one study reports increasing elasticities and is supported by other studies (Lindberg, 2002). A possible explanation is that studies control for infrastructure technology in a different way; better roads with lower marginal costs also have more traffic. And this change in quality is not controlled for in all studies.

The table below summarise some other studies on the share of road infrastructure cost that can be attributed to traffic load (standard axles). It can be compared to the elasticities reported from the GRACE case studies. The table includes both rehabilitation (renewal) and routine maintenance. The load shares come in a number of different forms but they are below 1 (or equal to). The load share seems to be higher for rehabilitation than for routine maintenance which reinforces the conclusion from the GRACE case studies.

Table 5 about here

The operation or short term maintenance is related to total trainkm or total vehiclekm while the renewal and maintenance are usually related to gross tonnekm or HGVkm. Few of the studies have been able to test which type of traffic predominantly influences the infrastructure cost. In general, this has been decided a priori based on other information. However, one study (Great Britain) conducted a test on the difference between additional trains of the same weight or additional weight of the same number of trains but could not find any significant difference. The Swedish study suggested a huge difference between the marginal cost on gravel roads and on paved roads.

The marginal cost follows from the elasticities and the average costs. The marginal cost on roads has a huge variability depending on the huge variability in average cost. The cost on German motorways is 1.39 €/HGVkm for renewal only. The corresponding cost for all Swedish paved roads is 0.032 €/HGVkm and 0.12 €/vkm in Poland. The Swedish result for gravel roads is 0.236 €/HGVkm. Aggregating renewal and maintenance generates a marginal cost of 0.040 €/HGVkm in Sweden and 0.13 €/vkm in Poland. Infrastructure operation costs do not vary with traffic volume according to the Swedish case study. The marginal cost in the rail sector is 0.00070 €/Gtkm in Sweden for renewal and maintenance and 0.00097 €/Gtkm in Switzerland. Maintenance only has a cost of 0.00031 €/Gtkm in Sweden and 0.00045 €/Gtkm in Switzerland. The marginal cost in Great Britian is estimated to 0.0012 €/Gtkm. Operation has a marginal cost of 0.054 €/trainkm in Sweden.

In the railway sector the difference between different studies from other research projects are not as big as for the road sector. One explanation could be that the technology is more homogenous and easier to control which makes studies less vulnerable to the problem with unobserved variables. Another, less positive, explanation could be that studies are less common in the railway sector and still starts from a similar approach. The table below summarise a number of current studies.

Table 6 about here

In addition to these studies on marginal infrastructure cost the GRACE project contains case studies for all other cost categories discussed in the introduction. Together with other information, the project contributes to the knowledge of the marginal external cost of road and rail traffic and will facilitate a more informed discussion on future legislation.

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Figure 1 Cost elasticity with respect to traffic for road and rail infrastructure

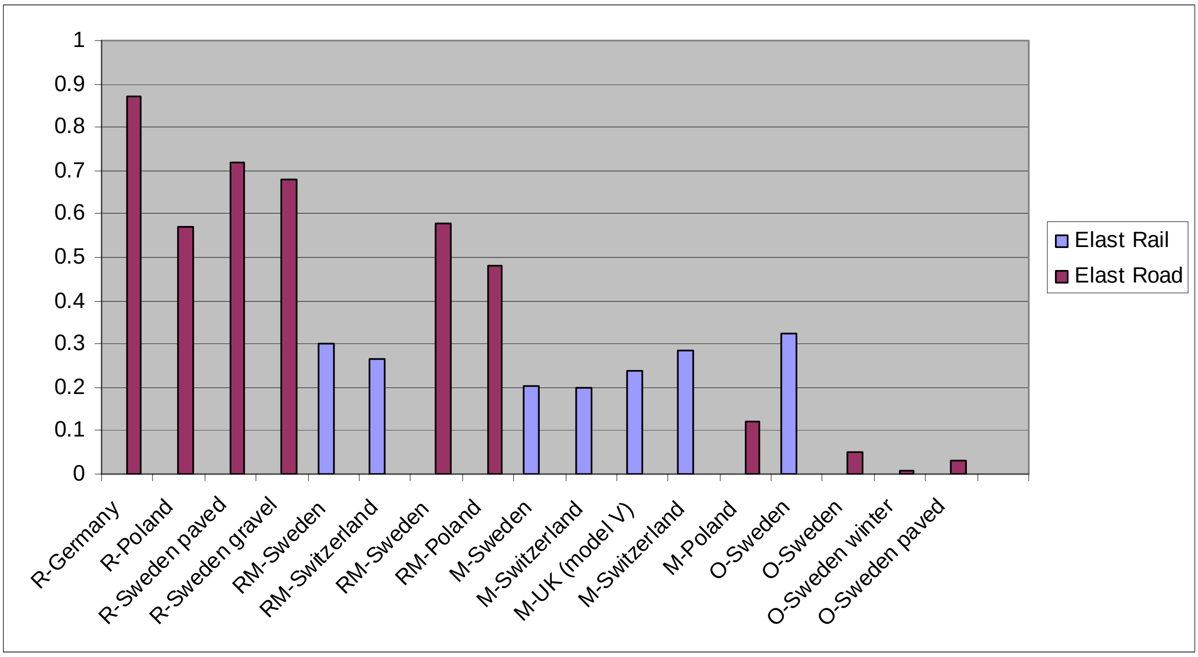

Table 1: Road elasticities

	β_1	β_{11}* lnQ	β_2* lnX	Mean Q	Elasticity	Output (Q)	Interaction term X
Renewal							
Germany R	0.15	0.38	-0.26	5002	**0.87**	HGV	Passenger cars[C)]
Poland R	0.57			8592 [1403][A)]	**0.57**	AADT	No
Sweden R paved	4.95	-0.38		87594 [158][B)]	**0.72**	HGVkm in region	No
Sweden R gravel	0.68			718 [5][B)]	**0.68**	HGVkm in region	No
Sweden duration model					**0.039[DE]**	HGV	No
Renewal and Maintenace							
Sweden R+M	3.3	-0.24		88313 [125] [B)]	**0.58**	HGVkm in region	No
Poland R+M	0.48			8592 [1403][A)]	**0.48**	AADT	No
Maintenace/Operation							
Poland M	0.12			8592 [1403][A)]	**0.12**	AADT	No
Sweden O	0.147	-0.007		869962 [1232][B)]	**(0.05)**	vkm in region	No
Sweden O winter	0.21	-0.0152		869962 [1232][B)]	**(0.007)**	vkm in region	No
Sweden O paved	0.495	-0.034		859463 [1554][B)]	**(0.03)**	vkm in region	No
Sweden O gravel	1.11	-0.136		10498 [69][B)]	**(-0.09)**	vkm in region	No

Note: DE=Deterioration elasticity,
[A)] Average HGV traffic
[B)] Output measure expressed per km road.
[C)] Mean volume 26632
(In parenthesis)= non significant estimates

Table: 2 Rail elasticity

	β_1	β_{11}*ln Q	β_2*lnX	Mean Q	Elasticity	lnQ	Inter-action term (X)
Renewal							
Sweden (duration)					**0.109**[DE]	GT Freight	
					0.146[DE]	GT Passenger	
Maintenance and Renewal							
Sweden	1.567	-0.0844		7445989	**0.302**	Grosse Tonnes	
Switzerland (A+B)	0.265				**0.265**	Grosse Tonnes	
Maintenace							
Sweden	1.47	-0.0844		7445989	**0.204**	Gross Tonne	
Switzerland (A)	0.200				**0.200**	Gross Tonne	
Great britian (model V)	5.834	-0.1818		4809570	**0.239**	Gross Tonne	
Switzerland (part of A)	0.285				**0.285**	Gross Tonne	
Operation							
Sweden	3.314	-0.79	0.0495	15499	**0.324**	Trains	lnQ*lnQ

DE=Deterioration elasticity; GT=Grosse Tonne

Table: 3 Average and marginal infrastructure cost in the road sector

	AC	MC	Outputvariable
	€/Xkm	€/Xkm	Q
Renewal			
Germany R	1.590	1.390	HGV
Poland R	0.210	0.120	All veh
Sweden R paved	0.036	0.032	HGV
Sweden R gravel	0.415	0.236	HGV
Sweden duration model	-	0.0013	HGV
Reneval and Maintenace			
Sweden R+M	0.059	0.040	HGV
Poland R+M	0.270	0.130	All veh
Maintenace/Operation			
Poland M	Na	na	All veh
Sweden O	0.024	(0.002)	All veh
Sweden O winter	0.015	(0.001)	All veh
Sweden O paved	0.003	(0.001)	All veh
Sweden O gravel	0.066	(0.010)	All veh

Table: 4 Average and marginal infrastructure cost in the rail sector

	AC	MC	Outputvariable
	€/Xkm	**€/Xkm**	**X**
Renewal			
Sweden – duration model		0.00028	Gross Tonne (Passenger)
		0.00012	Grosse Tonne (Freight)
Maintenance and Renewal			
Sweden	0.00285	0.00070	Grosse Tonnes
Switzerland (A+B)	0.00364	0.00097	Grosse Tonnes
Maintenace			
Sweden	0.00209	0.00031	Gross Tonne
Switzerland (A)	0.0022	0.00045	Gross Tonne
Great Britain (model V)	0.00451	0.00124	Gross Tonne
Switzerland (part of A)	0.00133	0.00038	Gross Tonne
Operation			
Sweden	0.153	0.054	Trains

Table: 5 Load shares on road infrastructure

Study	Year	Flexible	JCP	CRC	Composite
Rehabilitation [6]					
Li et.al. (2001)	1995-1997	0.28	0.78		0.38
Indiana HCAS	1984	0.42	0.78		0.38
ARRB Study (Australia)		0.88	0.88		0.88
Federal HCAS	1997	0.84-0.89	0.78-0.86		0.84-0.89
Routine maintenance[7]					
Li et.al. (2002)	1995-1997	0.257	0.357	0.632	0.28
Indiana HSC Approach	1984	0.21	0.54	1.00	0.29
Ontario study	1990	0.25-0.33			

Note: HCSA = Highway Cost Allocation Study; JCP=joint concrete pavement, CRC=continuously reinforced concrete and Composite

[6] Source: Li et.al (2001)
[7] Source: Li et.al. (2002)

Table: 6 Results from other studies compared against the estimated models

Study (maintenance costs only) / Model estimated	**Country**	**Marginal Cost Estimates (Average) Euro per Thousand Gross Tonne-km**	**Elasticity of cost with respect to tonne-km**
Johansson and Nilsson (2004)	Sweden	0.127	0.169 (average)
Johansson and Nilsson (2004)	Finland	0.239	0.167 (average)
Tervonen and Idstrom (2004)	Finland	0.18	0.133-0.175
Munduch et al (2002)	Austria	0.55	0.27
Gaudry and Quinet (2003)	France	Not reported	0.37 (average)
Andersson (2005)	Sweden	0.293 (pooled OLS model) 0.272 (random effects model)	0.1944 (average pooled OLS model) 0.1837 (average Random effects model)
Booz Allen & Hamilton (2005)	UK	Approx 1.5	Proportion of maintenance cost variable with traffic: 0.18; 0.24 for track maintenance