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UNIfication of accounts and

marginal costs for Transport Efficiency

Deliverable 10
Case Studies on Marginal Infrastructure Costs

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Authors: Heike Link (DIW), Max Herry, Norbert Sedlacek (Herry), Gunnar Lindberg, Per Johansson, Jan-Eric Nilsson (VTI), Christoph Schreyer, Markus Maibach (INFRAS), Pauline van Donselaar, H. Carmigchelt (NEI), Jan-Owen Jansson, Robert Ericsson (EKI), Bryan Matthews, Chris Nash (ITS), Veli Himanen, Tiina Idström (Transplan), Dimitrios Tsamboulas, Dimitris Korizis, Angeliki Kopsacheili (SYSTEMA) with contributions from partners

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Executive Summary

The UNITE project is designed to support policy makers in the development of pricing and taxation policies for the transport sector. It proceeds along three streams of research activities, namely (i) the estimation of the full social costs and revenues of all transport modes (pilot accounts), (ii) the estimation of marginal costs of infrastructure provision and use, and (iii) the integration of pilot accounts and marginal costs. This deliverable refers to the second stream of research activities aimed at providing new methodological and empirical knowledge on the analysis of marginal costs. Its focus is on the estimation of marginal infrastructure costs.

This deliverable presents the findings of a series of case studies dealing with the estimation of marginal infrastructure costs. These case studies analysed both link-based infrastructures such as road and rail links and terminal infrastructure such as airports and ports. They included two case studies on road infrastructure covering Germany, Switzerland, Austria and Sweden, two case studies on rail infrastructure covering Sweden, Finland and the UK, two case studies for seaports in Sweden and Greece, one airport case study in Finland and one case study on inland waterways in the Netherlands and Germany. The case studies applied different methodological approaches ranging from literature and data review, gathering of expert opinions, cost disaggregation approaches to econometric analyses and engineering approaches. Table 1 gives an overview on the scope of the case studies and the methodologies applied. In contrast to existing studies and policy documents (for example Newbery 1989, European Commission 1998) which mainly assume marginal infrastructure costs to be related to wear and tear only, this deliverable also contains case study results on staff costs varying with traffic volume.

The purpose of this deliverable was

- to analyse whether the methodologies outlined in Link and Lindberg 2000 are suitable for estimating marginal infrastructure costs,
- to compare different methodologies for estimating marginal infrastructure costs,
- to provide quantitative results for marginal infrastructure costs,
- to analyse whether and how far the case study results can be generalised to other contexts,
- to discuss the experience from the case studies concerning requirements to data quality,
- to identify the sensitivity of the methodologies applied in the case studies.

Table 1
The marginal infrastructure cost case studies of UNITE

Country	Modes covered	Scope	Methodological approach
Germany, Austria, Switzerland	Road	Motorways	Econometric analysis (Translog approach with the ratio between AADT of trucks and passenger cars applied for Germany, log-linear models with one traffic category applied for Austria and Switzerland)
Sweden	Road	All roads	Engineering approach
Sweden, Finland	Rail	Total network, Tracks only	Econometric analysis (Translog approach)
UK	Rail	Total network Tracks only	Review of Railtrack's engineering modelling approach and of several studies conducted for the Rail Regulator
Finland	Aviation	Airport of Helsinki	Cost disaggregation and econometric analysis (linear and cubic models)
Sweden	Maritime	Baltic seaports	Queuing model, econometric analysis (log-linear model), long run marginal cost approach
Greece	Maritime	Mediterranean Sea ports	Data review, descriptive analysis
Netherlands, Germany	Inland waterways	Rhine	Data and literature review, expert opinions, descriptive analysis

The analyses presented in this report were able to achieve the majority of these goals. The feasibility of the two main methodologies (econometric analysis and engineering approach was tested. Both approaches produced sensible results. Methodological difficulties (high multicollinearity) arise with the econometric approach if in a translog cost function different vehicle categories are considered as explanatory variables. The ideal input data for these models are axle-load km. If this is not available, the translog approach is only applicable with ratios between vehicle categories' traffic volume as independent variables. The case studies indicate that the "one" ideal methodological approach to estimate marginal infrastructure costs does not exist. Econometric approaches are based on observed behaviour of costs and cost drivers. It is obvious that the actual or observed costs do not always follow technical needs resulting from the use of infrastructure, i.e. do not necessarily reflect true marginal costs. In comparison, marginal costs derived with engineering-based methods are built on measured technical relationships, but which are not necessarily reflected in actual spending.

Both engineering-based and econometric approaches require detailed data (cross-sectional) on costs spent for infrastructure, on physical conditions of infrastructure and on cost drivers such as traffic volume, climate conditions, age of infrastructure, maintenance standards and maintenance history. The experience from the case studies is that the input data needed both for econometric and engineering-based analysis is often not available in a sufficient quality. However, first attempts were made to construct the respective databases and it seems that it is worthwhile to spend efforts doing this.

The case studies provided evidence that for rail tracks and road infrastructure it is mainly the cost of maintenance, repair and renewal that vary with traffic volume. For terminal infrastructure such as ports and airports it is staff costs which varies in the short run with traffic. For rail tracks and road infrastructure the main cost drivers identified are traffic load, especially measured by weight indicators such as gross-tonne km and axle-load km, infrastructure characteristics such as number of bridges, tunnels, electrification etc., age of infrastructure and maintenance history. For terminal infrastructure where staff costs form the major category of marginal infrastructure costs the traffic load (measured as throughput in ports and as aircraft movements and departing/arriving passengers at airports) is again the main cost driver. In addition, the case studies provided evidence that the season, the weekday and the salaries' arrangement have to be considered for analysing operation costs of terminal infrastructure.

Both the econometric and the engineering based case studies mostly provided results which are consistent with the u-shaped marginal cost curve suggested by neoclassical economic theory. However, in many cases the detected non-linearities were rather weak in the relevant range of traffic variables (examples are the results for rail tracks in Sweden and Finland, but also the road results for Switzerland and Austria). No uniform result was obtained with respect to the question which branch of the “u” describes marginal infrastructure cost behaviour. The analyses for the Swedish and Finnish rail network, the results for Swiss roads and the long run marginal cost approach for Swedish seaports identified a cost shape which follows the falling branch of the “u”. Other case studies such as the analysis of motorway renewal costs for Germany, the stevedoring cost analysis for seaports and the analysis of staff costs in relation to departing international flights at Helsinki airport provided evidence for the increasing part of the “u”. The Swedish and Austrian road case studies identified degressively growing marginal costs. These obvious differences of cost functions between modes can be caused either by methodological differences or by real differences of cost behaviour, or by a combination of both.

The comparison between the road and rail results seems to indicate that rail maintenance is a decreasing cost activity while for road the opposite is true. This means that for rail the network utilisation is at a level where additional trains do not cause more maintenance than it is anyway necessary to perform. The fact that the Swedish and Finnish rail networks are among those networks with low utilisation supports this interpretation. The opposite situation is true especially for the German motorways where additional vehicles cause increasing marginal costs. It remains open whether the decreasing marginal cost curve for Swiss roads can be similarly explained like the rail results, or whether methodological problems are responsible for this result.

All case studies except the inland waterway study and the Mediterranean port study provided quantitative estimates of marginal infrastructure costs. The marginal cost estimates for road and rail infrastructure costs are summarised in table 2. While for rail the estimates are of a similar magnitude, the road results show a considerable variance. For other modes there is only few empirical evidence except for the airport and seaport case studies. The marginal costs of inland waterway infrastructure were estimated to be zero, referring to the Rhine waterway. For the Helsinki airport it was estimated that the marginal airport operating costs amount to one person-hour per aircraft movement or – expressed in monetary terms - € 38 for an extra aircraft movement. Marginal stevedoring costs for the Swedish port of Uddevala were estimated to be in a range of 1.5 up to 1.7 SEK per ton of throughput.

In most cases it was not possible to analyse the sensitivity of model assumptions and estimated parameters. An exception was the Swedish road study where a qualitative assessment of model assumptions was performed. As it was to be expected, transferability and generalisation of the case study results proved to be the most difficult issues. In general, it is not recommended to transfer output values or unit values (such as costs per sqm of road surface or rail tracks) to other context or countries. The same is true for output functions especially estimated with econometric approaches since the estimated functional forms differ too much, even within one individual mode. Examples which underline this are the Swedish stevedoring cost analysis where two functional forms fit the data, and the Finnish airport case study where for a separate cost category (staff costs for international departing flights) a different functional form than for total costs analysed was estimated.

Table 2
Marginal cost estimates for road and rail infrastructure costs

Mode					
Road	**Country**	**Unit**	**Mean**	**Trucks**	**Passenger cars**
	Germany1)	€ Cents/vkm	-	0.05 ... 2.70a)	-
	Austria2)	€ Cents/vkm	0.16	2.17b)	0.07b)
	Switzerland3)	€ Cents/vkm	0.67 ... 1.15	3.62 ... 5.17	0.42 ... 0.50
	Sweden4)	€ Cents/vkm	-	0.77 ... 1.86	-
Rail	**Country**	**Unit**	**Mean**	**Main lines**	**Secondary lines**
	Sweden5)	€ Cents/gross-tkm	0.013	0.0088	0.097
	Finland5)	€ Cents /gross-tkm	0.017	0.029c)	0.045d)

1) Marginal renewal costs. –2) Marginal costs of maintenance and renewals. –3) Marginal costs of maintenance (operational and constructional) and upgrades & renewals. Calculated from the minimum and maximum values for all cost categories. –4) Marginal costs of renewals. –5) Marginal maintenance costs.

a) Marginal costs obtained from a model with the ratio between trucks and passenger cars where the AADT of passenger cars was fixed at the minimum and maximum observed value in the sample. –b) Based on log-linear regression model with vehicles-km of 2 vehicles classes. The model was statistically insignificant. –c) Refers to electrified lines. –d) Refers to non-electrified lines.

Sources: Annex A1 (Link 2002), A1b (Schreyer et al. 2002), Annex A1c (Herry and Sedlacek 2002), Annex A2 (Lindberg 2002), Annex A3 (Johansson and Nilsson 2001), Annex A4 (Nash and Matthews 2002).

A preferable generalisation approach is the transfer of the overall methodology, e.g. to apply the econometric or the engineering approach to data of the region/country or context at hand. However, both approaches require a large amount of data which is often not available. Therefore, at least for those types of costs and modes where the detected non-linearities are not very strong it seems to be possible to transfer cost elasticities, i.e. the ratio between the marginal and average costs. This would be the case for rail track maintenance costs and for road maintenance costs. However, given the somewhat different results of the German and the Swedish renewal cost case studies more research on renewal costs is recommended. The same is true for airports and seaports where only empirical evidence for one case study site is available.

The evidence on the cost elasticity for road is mixed. The Swiss analyses yields a cost elasticity for maintenance and renewals/upgrades in the order of 0.8 while for Austria a somewhat higher elasticity would be obtained. The Swedish engineering approach for renewal costs produces an average cost elasticity of 0.4 (with variations from 0.1 to 0.8). The cost elasticities for rail are more consistent and are in the magnitude of 0.14 to 0.17 for the econometric studies and of 0.2 to 0.3 from the engineering approach reviewed in the British rail study.

Summarising up, it is obvious that estimating marginal infrastructure costs is a field with much less empirical evidence than in particular the estimation of marginal environmental or congestion costs. Against this background this report has presented new methodological and empirical results which, however, would need a broader research basis when it comes to generalisation. Especially for those modes where evidence from only one application (for example airports, seaports, inland waterways) or from applications with too similar and not typical contexts (for example the rail case studies for two networks with low traffic density) is available, more studies would be desirable. Studies which apply both the econometric and the engineering approach to the same data set would be of great interest for a methodological comparison.

1 Introduction

The UNITE project is designed to support policy makers in the development of pricing and taxation policies for the transport sector. It proceeds along three streams of research activities, namely (i) the estimation of the full social costs and revenues of all transport modes (pilot accounts), (ii) the estimation of marginal costs of infrastructure provision and use, and (iii) the integration of pilot accounts and marginal costs. This deliverable refers to the second stream of research activities aimed at providing new methodological and empirical knowledge on the analysis of marginal costs. Its focus is on the estimation of marginal infrastructure costs.[1]

A rich body of literature on estimating production functions including the respective cost functions of rail companies and airlines does exist. However, much less attention has been paid to estimating cost and cost causation relationships separately for transport infrastructure. The research summarised in this deliverable was therefore aimed at closing this gap and at providing both methodological and empirical evidence on cost functions and marginal costs of transport infrastructure.

This deliverable presents the findings of a series of case studies dealing with the estimation of marginal infrastructure costs. These case studies analysed both link-based infrastructures such as road and rail links and terminal infrastructure such as airports and ports. They included two case studies on road infrastructure covering Germany, Switzerland, Austria and Sweden, two case studies on rail infrastructure covering Sweden, Finland and the UK, two case studies for seaports in Sweden and Greece, one airport case study in Finland and one case study on inland waterways in the Netherlands and Germany. The case studies applied different methodological approaches ranging from literature and data review, gathering of expert opinions, cost disaggregation approaches to econometric analyses and engineering approaches. In contrast to existing studies and policy documents (for example Newbery 1989, European Commission 1998) which mainly assume marginal infrastructure costs to be related to wear and tear only, this deliverable also contains case study results on staff costs varying with traffic volume.

The objectives of the case studies were the following:

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[1] Further deliverables are dedicated to marginal cost analysis for environmental burden, congestion, accidents and supplier operating costs.

- to analyse whether the methodologies outlined in Link and Lindberg 2000 are suitable for estimating marginal infrastructure costs,
- to compare different methodologies for estimating marginal infrastructure costs,
- to provide quantitative results for marginal infrastructure costs,
- to analyse whether and how far the case study results can be generalised to other contexts,
- to discuss the experience from the case studies concerning requirements to data quality,
- to identify the sensitivity of the methodologies applied in the case studies.

This deliverable is organised as follows: Chapter 2 summarises the state of the art of cost function analysis paying special attention to the few existing studies dealing with transport infrastructure costs. Chapter 3 briefly describes the methodological approaches applied in the case studies. Chapter 4 is designated to the case study results. Chapter 5 presents overall conclusions and discusses generalisation issues. A detailed description of all case studies can be found in the Annexes A1 to A8.

2 State of the Art Review of Cost Function Analysis for Infrastructure Costs

Although traditionally in economics a rich body of literature on production functions and cost functions can be found, both methodological and empirical studies analysing cost functions purely for infrastructure networks and terminals are rare. Generally, the background for all existing studies has rather been the question of regulating or deregulating industries than estimating cost functions for pure infrastructure. Early examples of cost studies are Lardner 1850, Lorenz 1916 and Ripley 1921. These early studies mainly dealt with the question of cost variability, the problem of allocating joint and common costs and attempts of measuring returns to scale. All these early studies referred to the rail industry but similar questions were later on analysed for other modes too. While the early works used simple linear cost functions the subsequent research moved to Cobb-Douglas production functions (see for example Keeler 1974) and in a next step to flexible functional forms such as the generalised Leontief function and the translog function (Christensen et al. 1973). Berndt and Khaled (1979) proposed a generalised box – cox specification which includes both the generalised Leontief function and the translog function as special cases. This stream of literature experienced with the contestability theory and the conceptual foundations for multiproduct cost functions including scope economies a new stimulus. Another stream of cost function research was motivated by the question how to measure and to compare productive efficiency across firms over time. Examples of this stream are conventional approaches of firm and time effect models (for examples Caves et al. 1984) and frontier cost functions (for example Bauer 1990, Grabkowski and Mehdian 1990, Talvitie and Sikow 1992).

Methodological and/or empirical studies on transport infrastructure costs were only performed in central European countries such as Germany, Austria, Switzerland and France where the public interest in infrastructure cost accounting as a source of general information for the public partly motivated by intermodal fairness considerations did exist. However these studies were full cost studies and included only in a few cases regression analysis with mainly longitudinal data on costs and on traffic volume. Examples for such regression analyses are a German study on road and rail infrastructure costs (see BMV 1969), an Austrian road study which estimated functional relationships between costs and used indicators such as vehicle kilometres, gross vehicle weight kilometres, length vehicle kilometres, and duration of road use (see Herry et al. 1993), and studies performed in France. More recently, a Swedish study has dealt with estimating a cost function for rail maintenance costs. This study (Johansson and

Nilsson 1998) used cross-sectional data of three different years for maintenance costs and for cost drivers such as infrastructure characteristics, track quality and gross tonne-kilometres. These few examples refer to road and rail only. So far no cost function study for waterborne transport or aviation infrastructure exists. Certainly, this is due to a missing general interest in the topic of infrastructure cost functions so far. Congestion costs, environmental costs and accident costs play for example in the road sector the major role. On the other hand, the situation can also be explained by the fact that most studies and policy documents assume that marginal infrastructure costs refer mainly to cost elements such as maintenance and repair of infrastructure. Indeed, these are the relevant components for policy-makers when setting prices for infrastructure use in the road and rail sector. They play a minor role for terminal infrastructure (airports, seaports) where it is rather staff cost that varies with traffic volume[2].

Beside the econometric approach, engineering methods are applied to estimate cost functions. In contrast to econometric studies they use mostly bottom-up approaches. The most known example for this stream of research is the AASHO Road Test (see Highway Research Board 1961) which derived within an engineering experiment a relationship between road damage and axle weight. The so-called fourth power rule indicates that doubling the axle weight increases road damages by a factor of 16. If road infrastructure costs are then assumed to be proportional to road damages this damage function can be translated into a cost function.

Finally, studies exist which distinguish between fixed and variable costs. Usually they allocate top-down percentages of costs varying with traffic volume to different cost categories based on empirical, engineering and expert judgement. An overview of such studies in the field of road transport is given in DIW et al. 1998. Such studies can be seen as the first step in estimating cost functions. By dividing total costs into fixed and variable costs they provide the necessary a priori information on the relevant part of total costs to be included in the estimation of marginal costs.

Table 1 summarises these existing studies on infrastructure cost function analysis and categorises them by the approaches used. One possible categorisation is the distinction between bottom-up and top-down estimation. Regarding the type of information and data

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[2] Although currently not being the main interest for transport pricing, marginal costs of seaports or airports as a basis for pricing of service providers can serve as useful information in the context of monitoring competitional distortions between seaports or between airports.

used, cost functions can be estimated by using observed data on the one hand, and by applying theoretical and experimental relations (usually engineering knowledge on the relation between infrastructure damage and traffic volume) on the other hand. Bottom-up approaches consider in a first step the costs of so-called basic packages (for example construction costs of infrastructure for the least demanding vehicle category). In a stepwise approach the additional costs caused by successor categories are added. If these successor categories are defined in a sufficiently detailed way, the bottom-up approach could be considered as a discrete (or incremental) approach to the first derivative of a cost function, e.g. to the marginal cost function. While this approach typically analyses single infrastructure sections or lines and generalises the results afterwards, top-down approaches start from observed total costs or total cost components and try to identify a functional form for the total costs and marginal costs. Cost function analysis which uses empirical observed information on cost behaviour can be based either on cross section analysis or on regression analysis based on time series. In the former case, different sections of infrastructure are compared and infrastructure costs are analysed according to traffic volumes, vehicle weight, design parameters etc. In the latter case the change of traffic volumes and weights and the related development of costs and time is analysed.

From the available, very limited number of studies it is not possible so far to conclude on the most appropriate methodological approach. Therefore, the case studies presented in this report applied a broad range of possible approaches briefly summarised in chapter 3.

Table 1
Approaches of existing studies on marginal infrastructure costs

Classification criteria	**Approach**	**Characteristics of approach**	**Scope**	**Advantages**	**Disadvantages**	**Examples**
1. Functional form	Cost function	Estimation of a total cost function and derivating the marginal cost function, either by econometric methods or engineering background	Whole network, network parts, single sections/lines	Theoretically and empirically adequate approach (first best approach)	High data requirements	BMV(1969) Johansson and Nilsson (1998) Herry et. al. (1993)
	Single cost figure	Linearity assumption for total cost function, pragmatic breakdown approach of variable cost categories to marginal costs	Whole network, network parts, single sections/lines	Less information necessary, easier (second best approach)	Linearity assumption not confirmed	DIW et. al (1998)
2. Direction of approach for estimating cost functions	Bottom-up	Starting point are costs of basic package, additional costs of successor vehicle categories are stepwise added (discrete approaching of a continuos cost function)	Single lines/sections	can be done experimentally, real world characteristics, use of engineering knowledge	Generalisation from single sections/lines to whole network complicated, only rough approach to marginal concept	TRL et al. (1996) AASHO-Road test
	Top-down	Starting point are real occurred total costs, functional relationship elaborated by econometric analysis of costs and cost drivers (influence factors)	Whole network, network parts, single sections/lines	Easier to elaborate, generalisation better		BMV (1969) Johansson and Nilsson (1998)
3. Type of information used	Empirical/ accounting cost information	Observed costs either from official statistics or from road authorities (ex-post information)	Whole network, network parts, single sections/lines	Information in principle available		BMV (1969) Johansson and Nilsson (1998)
	Experiment-based or simulated engineering information	Observed or theoretical/simulated engineering relationships	Single lines/sections	Proper reflection of engineering knowledge	Generalisation often difficult, experiments often heavily disputed	TRL et al. (1996) AASHO-Road test

Source: DIW.

3 Methodology

3.1 Scope of the marginal cost case studies

The starting point for all case studies summarised in this report were such parts of infrastructure costs which can be identified to vary with traffic volume. In accordance with the terms of reference of the UNITE project, a short run marginal cost approach was applied. An exception is the Baltic seaport case study (Sweden) where in addition long run marginal cost behaviour is also analysed. For link-type infrastructure such as roads, rail tracks and inland waterways, we consider the costs of maintenance, operation and renewals as the most important cost categories that vary with traffic volume. These types of costs formed the major dependent variables in the respective case studies although it has to be mentioned that not all of these cost types were available as input data for the cost estimation. For terminal infrastructure such as seaports and airports a somewhat different situation had to be taken into account. While the costs of maintenance, operation and renewal can be considered to be driven mainly by other factors than transport volume, it is staff costs that are influenced by traffic volume. Consequently, these case studies paid special attention on the question whether and to what extent staff costs vary with traffic volume.

No case study on urban public transport was performed. This is clearly a gap which needs to be closed in future research. At this stage one could assume that infrastructure for railbound public transport such as metro and tram might have similar cost structures and cost drivers to rail infrastructure. This means that at the current stage of research the results from the rail cost case studies have to be generalised to metro and tram infrastructure. Buses are to be treated within the road mode. Furthermore, we have to mention that freight reloading facilities, railway stations and intermodal freight terminals were not analysed within the case studies. They might be characterised by cost functions similar to other terminal infrastructure such as airports and seaports studied in this report.

While the road and rail case studies refer to whole networks or whole network types (motorways as a total network, all rail tracks) the case studies for aviation, inland waterway and maritime shipping treat special case study sites such as the airport of Helsinki, the port of Norrköping, and the river Rhine.

3.2 Overview on the methodological approaches applied in the case studies

All case studies summarised here have sought to elaborate functional relationships between cost causers and the development of infrastructure costs. In contrast to many existing studies and policy documents we have explicitly not assumed a linear cost curve with variable costs being equal to marginal costs. The fact that some of the econometric case studies estimated linear cost curves is mostly due to the failure of other approaches, caused by insufficient data quality (for example not enough disaggregation of vehicles by weight or axle-load in the road case studies).

As outlined in chapter 2 there are different methods for cost function analysis available. The case studies summarised in this report used econometric approaches for road, rail, Swedish seaports and airports while the Swedish road case study chose an engineering approach. For Mediterranean seaports, for the inland waterway case study and for the British rail case study the disaggregation level and the quality of available data was neither sufficient to apply econometric methods nor to perform engineering based analyses. Table 2 summarises the methodological approaches and their fields of application.

Table 2
The marginal infrastructure cost case studies of UNITE

Country	Modes covered	Scope	Methodological approach
Germany, Austria, Switzerland	Road	Motorways	Econometric analysis
Sweden	Road	All roads	Engineering approach
Sweden, Finland	Rail	Total network, Tracks only	Econometric analysis
UK	Rail	Total network Tracks only	Review of Railtrack's engineering modelling approach and of several studies conducted for the Rail Regulator
Finland	Aviation	Airport of Helsinki	Cost disaggregation and econometric analysis
Sweden	Maritime	Baltic seaports	Queuing model, econometric analysis, long run marginal cost approach
Greece	Maritime	Mediterranean Sea ports	Data review, descriptive analysis
Netherlands, Germany	Inland waterways	Rhine	Data and literature review, expert opinions, descriptive analysis

4 Cost functions and marginal infrastructure costs – results from the UNITE case studies

4.1 Road

Two sets of case studies covering four countries dealt with estimating cost functions for road infrastructure. For three countries (Germany, Switzerland, Austria) an econometric approach was applied, i.e. the case studies built on observed development of costs and cost drivers such as traffic volume, climate conditions etc. A fourth case study (Sweden) used an engineering approach to estimate marginal infrastructure costs by analysing how the intervals for pavement renewal are shortened depending on the traffic load.

4.1.1 Econometric studies on road cost functions in Austria, Germany and Switzerland

Aims of the case studies

For Germany, Switzerland and Austria econometric studies were performed. The envisaged starting point for these three studies was to analyse cost behaviour and its dependence on cost drivers by using the flexible functional form of the translog-function. This approach was discussed in Link and Lindberg 2000 and will thus not be described in detail here. The main questions to be answered were:

- whether the translog-functional approach is feasible for estimating an infrastructure cost function,
- whether the application to available data can provide statistically significant results which can be sensibly interpreted,
- whether the results obtained with this method differ compared to other approaches.

Input data

All three case studies used observed data on cost behaviour, but the cost categories included and the disaggregation of data differed considerably (see table 3):

- In the Swiss data set all types of infrastructure expenditures such as construction costs of new motorways, upgrading costs, renewal costs, constructional maintenance costs and operational maintenance costs were separately available and provided an opportunity of analysing separately individual expenditure categories. Furthermore, the Swiss case study used two data sets which differed regarding data disaggregation and time horizon. The first data set contained infrastructure expenditures for 23 cantons covering the period from 1985 to 1998. By pooling together the cantonal data finally about 320 cases for a longitudinal regression analysis were available. The second data set covered constructional maintenance costs for 127 motorway sections for four years covering the period from 1997 to 2000. However, given an average renewal cycle of 12 years only at about 10 % of all sections constructional maintenance costs occurred in one of these four years. Therefore, the data was added up and then used for a cross-sectional regression analysis.

- For Austria, originally data on maintenance and renewal expenditures for each motorway covering the period from 1990 to 2000 was available. This data, however, also included partly new construction which had to be sorted out in order to obtain a data set comparable to that of Switzerland. Since the data was characterised by high fluctuation over the observation period due to the cyclical nature of renewal expenditures, it was summed up over the years. Thus, the total number of observations finally used for the regression analysis was only 38.
- For Germany, only data on larger renewal measures was available, meaning that only the rather cyclical part of road expenditures could be analysed. Due to the extraordinary extent of renewal measures in East Germany after the German Unification it was for the purpose of the UNITE case studies only sensible to use the data for West Germany. This data covered originally 1837 sections of West German motorways and covered for all these sections at least 20 years, partly reaching back even to the fifties and sixties. The cyclical character of renewal expenditures led to similar problems as those observed in the Swiss data set, meaning that only for a small percentage of motorway sections renewal expenditures could be observed in one year. Therefore, the expenditure data was aggregated for the period from 1980 to 1999. Furthermore, due to the fact that the independent variables had a higher aggregation level than the dependent variable, the final data set contained instead of originally 1837 cases 224 cases.

The availability and quality of data for the cost drivers assumed to be important for explaining the cost behaviour also differed between the three countries. Both for Switzerland and Austria only traffic related data was available while for Germany also data on further influence factors such as age, maintenance history and climate were obtained. The disaggregation of traffic data by vehicle type and vehicle weight was also characterised by considerable differences. A description of input data on cost drivers used in the case studies is given in table 3 and can be summarised as follows:

- Both the longitudinal data set and the cross-sectional data for the Swiss motorways contained mileages as well as estimated gross ton kilometres and axle load kilometres. The longitudinal data set used mileage data for four different vehicle categories (car, van, truck, bus) which was taken from a traffic model for 1995 and adjusted to the missing years before and after by using growth factors. The cross-sectional data set contained mileages derived from the automotive vehicle counting stations on the Swiss national road network and was disaggregated into four vehicle categories (based on vehicle length, see table 3). The corresponding input data on gross tons and axle loads was calculated by using a study on axle load equivalences which was based on the results of one Weigh-in-Motion station (WIM-station) at the Gotthard alpine crossing.
- Similar traffic data was used for the Austrian case study. Mileage data was based on automotive vehicle counting stations and further disaggregated into 10 vehicle categories. By using national Austrian studies input data on gross ton kilometres and axle load vehicle kilometres was calculated. The Austrian case study had also access to data on the length of tunnels and bridges per motorway section and on the age of each section. However, this data was not used for the econometric analysis.
- The German case study used mileage data disaggregated into passenger cars and goods vehicles[3] derived from the automatic vehicle counting stations at the German national road network for 400 motorway sections for the years 1990-1999. This, however, means that the independent variables “passenger car mileages” and “goods vehicle mileages” correspond only to the last half of the time period covered by the dependent variable. There are two reason justifying this approach: On the one hand, data for the time before 1990 is not available in electronic form. On the other hand, this data refers to many less motorway sections than the data from 1990 onwards meaning that the number of cases to be included into the regression analysis would fall dramatically.[4] Further cost drivers included into the regression analysis contained the number of lanes per motorway section,

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[3] Disaggregated traffic data for vehicle categories such as light goods vehicles, heavy goods vehicles with trailer, heavy goods vehicles without trailer, busses was only available for three single years (1990, 1993 and 1995) and only for a few federal states in Germany.

[4] However, we also tried a regression analysis by including a second traffic variable reflecting the increase of mileage driven by passenger cars and goods vehicles from 1980-1990.

the age of each motorway section at the beginning of the analysed period and the expenditure spent on renewals at each motorway section before the period of analysis. Finally, climate data from 260 climate stations in Germany was obtained and allocated to the motorway sections. This data referred to the number of days where temperature changed from below 0°C to above 0°C. Additionally, the number of days with snowfall was available.

It has to be mentioned that the econometric analyses performed were unique for each country. Consequently, it was first necessary to built up the data bases and to adjust them to the needs of regression analysis. Given the data situation in each country and the time and labour budget available within the UNITE project it has to be stated that for none of the three countries could an ideal or almost ideal data set actually necessary for the econometric analysis be obtained. Furthermore, it has to mentioned that data inquiries in a number of other European countries (U.K., Sweden, Spain) were not successful. It seems that especially detailed data on road expenditures per road section is not available.

Table 3
Description of the input data used for the econometric analysis of motorway costs in Germany, Switzerland and Austria

	Germany	**Switzerland**	**Austria**
1. Cost data (dependent variable)	• data on larger renewal measures for 1837 motorways sections over 20 years • past expenditures on larger renewal measures (before 1980) • no data on running maintenance and operation expenditures	• data on construction costs, upgrading costs, renewals, constructional maintenance and operational maintenance for 23 cantons from 1985 to 1998 (data set I) • data on constructional maintenance for 127 motorway sections from 1997 to 2000 (date set II)	• data on maintenance and renewal expenditures including (partly) new construction for 46 sections from 1987 to 2004 • new construction estimated and sorted out
2. Data on cost drivers (independent variable)			
Use data	• average daily traffic volume and mileages from counting stations for passengers cars and freight vehicles (400 cases) from 1990 to 1999 • no modelling on further disaggregation or axle-load km	• mileages, estimated gross-tonne-kilometres and axle-load kilometres for 4 vehicle types (car, van, bus, truck) • for data set I: based on a 1995 model and adjusted by growth factors • for data set II: disaggregation based on counting stations and modelling results	• mileage based on counting stations for 6 vehicles categories for 1985, 1990, 1995 • final data set generated from this counting information and from a forecast • gross-tonne km and axle-load km calculated based on Austrian studies
Road characteristics	• length of sections • number of lanes • age of sections	• length of sections	• length of sections
Maintenance information	• past expenditures (before 1980) on larger renewals	• none	• none
Climate	• number of days where temperature changed from below zero to above zero from 260 climate stations	• none	• none
3. Cases used for the econometric analysis	224	• data set I: 320 • data set II: 424	38

Sources:, Annex A1a (Link 2002), Annex A1b (Schreyer et al. 2002), Annex A1c (Herry and Sedlacek 2002).

Methodological approach

It was only sensible to apply the translog approach for Germany. The data for Austria and Switzerland contained more disaggregated traffic data which caused serious multicollinearity problems for the translog approach. Further data on other explanatory variables was missing. Therefore, both studies used instead log-linear regression analysis and estimated single equations, each of them including one of the traffic variables.

The translog-model used for the German data had the following form:

$$\begin{aligned} \ln C_i = {} & c + \sum_{j=1}^{8} \alpha_j BL_{ij} + \alpha_9 Cpast_i + \beta_1 \ln l_i + \beta_2 \ln\left(\frac{u_{1i}}{u_{2i}}\right) + \beta_3 \ln age_i + \\ & \frac{1}{2}\left(\beta_4 \ln^2\left(\frac{u_{1i}}{u_{2i}}\right) + \beta_5 \ln^2 age_i\right) + \\ & \frac{1}{2}\left(\beta_6 \ln\left(\frac{u_{1i}}{u_{2i}}\right) + \ln age_i\right) \end{aligned} \qquad (1)$$

where

i: index for motorway sections

c: constant

C : sum of renewal costs from 1980 to 1999, expressed as costs per km at 2000 prices

Bl_j: dummy variable for the federal state where section i is located (j=1...10)

Cpast: renewal costs before 1980 (categorical variable with 0, 1, 2, 3)

l: number of lanes

u_1: annual average daily traffic volume of passenger cars

u_2: annual average daily traffic volume of goods vehicles

age: age of motorway section.

Note, that the dependent variable is the sum of renewal expenditures covering the period from 1980 to 1999 while the traffic variables are only summed up from 1990 to 1999. The data does not contain any price effects since the cost information was obtained by evaluating physical renewal measures with unit costs at 2000 prices. However, possible changes of technologies for renewal measures are neglected with this approach. Furthermore, it has to be mentioned that the traffic variable as explanatory factor was constructed as the proportion between the AADT[5] of goods vehicles and the AADT of passenger cars. The reason for this were serious multicollinearity problems (variance inflation factors between 15 and 56) which occurred in the translog models with separate variables for the AADT-values for goods vehicles and passenger cars. The construction of an explanatory variable $\frac{u_{1i}}{u_{2i}}$ solves these multicollinearity problems. However, it complicates the derivation of marginal costs. Due to the fact that instead of two ß-parameters only one ß-parameter for the ratio $\frac{u_{1i}}{u_{2i}}$ is estimated, marginal costs can only be derived with respect to the ratio.

The Swiss case study contains two types of log-linear regression analysis. A first one was based on a longitudinal approach of the form

$$\ln C_t = c + \beta \ln u_t \qquad (2)$$

with u: traffic variable, tested for several data such as mileage and gross-tonne kilometres
c: cost variable, tested for different types of costs such as operational maintenance cost, constructional maintenance cost and upgrade & renewal costs.

A second type of regression analysis was performed as cross-sectional analysis of a similar form, but also including a dummy-variable for sections with maintenance expenditures below a certain level.[6]

The Austrian case study applied a similar approach to the Swiss one by using the aggregated maintenance and renewal expenditures over 10 years in a cross-sectional analysis.

Table 4 shows the parameter estimates for the translog model (1) as it was applied to the analysis of renewal costs for German motorways. The model fit with R^2=0.21 was rather low. However, all statistical properties (absence of autocorrelation in the residuals, normality of

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[5] AADT = Annual average daily traffic volume.

[6] The introduction of this dummy variable was aimed at considering sections with maintenance performed below average. However, it is rather difficult to define a “normal” or average amount of maintenance measures. Although the introduction of the dummy variable increased the R-square considerably the reader should interpret this model rather cautiously.

residuals, homoscedasticity, no multicollinearity) required for OLS-estimation were fulfilled. Most of the parameters are significant at 5 % or at least at 10 % critical level.

Table 4
Regression results for the translog model for German motorway renewal costs

	Coefficients	Standard deviation	t-value	Significance level
constant	-1.555	0.182	-8.524	0.000
α_1	1.799	0.651	2.763	0.006
α_2	-0.917	1.387	-0.661	0.509
α_3	1.172	0.481	2.438	0.016
α_4	0.714	0.373	1.913	0.057
α_5	1.308	0.611	2.141	0.033
α_6	1.536	0.528	2.911	0.004
α_7	0.851	0.251	3.394	0.001
α_8	1.165	0.300	3.876	0.000
α_9	-0.546	0.231	-2.366	0.019
β_1	1.869	0.558	3.346	0.001
β_2	1.306	0.313	4.174	0.000
β_3	0.480	0.255	1.877	0.062
β_4	1.486	0.780	1.905	0.058
β_5	0.507	0.927	0.547	0.585
β_6	-1.789	1.110	-1.612	0.108

Source: DIW Berlin.

The main influence factors for the renewal costs identified with the translog approach are the ratio between AADT trucks and AADT passenger cars, the age of motorways and the level of past maintenance. Furthermore, with one exception all dummy variables for the federal states were significant. It was not possible to identify what influence climate conditions have.

The case study identified a non-linear marginal cost curve with a progressively increasing shape. Marginal renewal costs for motorways increase progressively if the ratio between trucks and passenger car increases, or in other words, if the traffic volume of trucks grows faster than the traffic volume of passenger cars. This finding of a progressively increasing marginal cost curve for motorway renewals differs from the result presented in Annex A2 (Lindberg 2002) where a degressively increasing curve for marginal renewal costs of trucks is reported. One explanation for this difference is that the case study presented in Annex A2 used the absolute amount of traffic load while the German case study used the proportion between trucks and passenger cars.

Table 5
Regression results for Austrian and Swiss motorways

Model	N	R^2	Coefficients	Std-error	T-value	Significance
1. Austria	38	0.70				
Dependent Variable:						
Ln C 1)						
Independent Variables:						
constant			-7.233	2.374	-3.046	0.004
ln u			1.046	0.111	9.433	0.000
2. Switzerland						
Model I: 2)	322	0.65				
Dependent variable:						
ln C						
Independent variables:						
constant			1.315	0.565	2.329	0.20
ln u			0.686	0.028	24.385	0.00
Model II: 3)	316	0.34				
Dependent variable:						
ln C						
Independent variables:						
constant			1.065	1.117	0.954	0.341
ln u			0.715	0.056	12.718	0.000
Model III: 4)	98	0.26				
Dependent variable:						
ln C						
Independent variables:						
constant			-3.620	3.007	-1.204	0.232
ln ug			0.822	0.142	5.790	0.000
Model IV:		0.57				
Dependent variable: 5)						
ln C						
Independent variables:						
constant			-8.558	1.504	-5.690	0.000
ln u			0.550	0.077	7.191	0.000
Dummy			-2.169	0.230	-9.430	0.000
Model V: 6)		0.58				
Dependent variable:						
ln C						
Independent variables:						
constant			-7.631	1.328	-5.746	0.000
ln u			0.562	0.075	7.448	0.000
Dummy			-2.040	0.228	-8.930	0.000

1) Costs of maintenance and renewals. - 2) Time series based model with variables “operational maintenance costs” and “mileage of all vehicles”. - 3) Time series based model with “constructional maintenance costs” and “mileage of all vehicles”. - 4) Time series based model with variables “costs of upgrades and renewals” and “gross-tonne km”. - 5) Cross-sectional analysis with “operational maintenance costs” and “total gross-tonne km”. – 6) Cross-sectional analysis with “operational maintenance costs” and “total axle load equivalent-km”.

Sources: Annex A1c (Herry and Sedlacek 2002), Annex A1b (Schreyer et al. 2002).

Table 5 shows the results from the log-linear regression analysis for Austria and Switzerland. The models for Switzerland were tested on multicollinearity, normal distribution of residuals and on absence of autocorrelation of first order (Durbin-Watson test). None of the assumptions for OLS regression was violated.[7] However, it is open whether the same is valid for the Austrian data. With respect to the Austrian analysis it should also be borne in mind that with 38 cases the sample was rather small.

Figures 1 to 3 show the marginal road costs obtained by calculating the first derivatives of the cost functions. The shape of the three marginal cost curves are different. As can be seen (from figure 2), for Austria a degressively growing shape of the marginal cost function was derived while figure 1 shows that the Swiss data yield a decreasing shape. With the translog approach applied to the German data a progressively increasing shape of marginal costs with respect to the ratio between trucks and passenger cars was obtained (see figure 3). The results (except those for Austria) indicate that the costs for maintenance and renewals seem to follow the u-shape known from neo-classical theory. However, the results are ambiguous with respect to the part of the „u". Obviously, the Swiss results refer to the falling part of the „u" while the German results refer to the increasing one. The a priori expectation for the case studies was that costs increase progressively with axle loads as it is suggested by the AASHO road test. The results obtained for Germany confirm this assumption of the cost curve while the Austrian and Swiss results would reject this assumption. However, it should be borne in mind, that the cost curves for Austria and Switzerland are in the relevant range of traffic loads almost constant.

Note, that the marginal cost curve shown in figure 3 for renewal costs at German motorways refers to the ratio (r) between AADT of trucks and passenger cars. It is obvious that the derivative with respect to r is not the "usual" marginal cost we were aimed at deriving. Nevertheless, it allows some considerations if we fix the level for AADT of passenger cars at certain points such as the sample minimum, maximum and mean. It has to be mentioned, that fixing the AADT of passenger cars would also be necessary if a translog model with two separate variables for passenger cars and goods vehicles were used as a basis for deriving marginal costs. The reason for this is the interaction term between them which does not disappear when calculating the first deriviative. Having said this we can now analyse what an increase of r means and which consequences it has for the level of marginal costs. An increase of r can either be due to an increase of truck traffic while passenger car volume remains constant or due to a faster growth of truck traffic than passenger car traffic. In the first case

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[7] It is open whether autocorrelation of higher order does exist.

the marginal costs of additional trucks can directly be taken from (3) and from figure 3. Assuming for example a road section with the sample average AADT of passenger cars, the marginal costs of an additional truck in the allowed range[8] vary from 0.05 € Cent to 2.7 € Cent. At sections with the sample minimum AADT of passenger cars an additional truck causes marginal costs between 0.7 € Cent and 2.7 € Cent. At sections with the sample maximum of passenger cars the marginal cost of trucks ranges between 0.05 € Cent and 0.8 € Cent.

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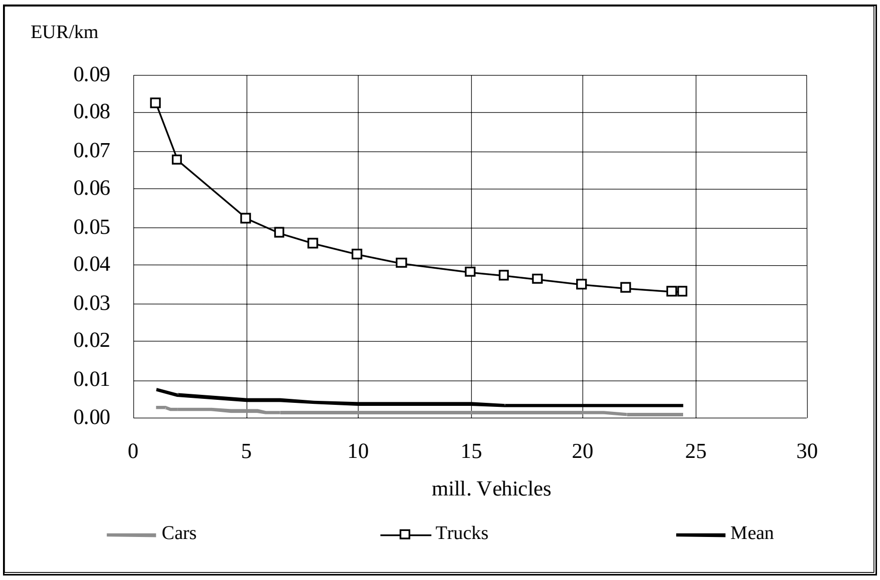
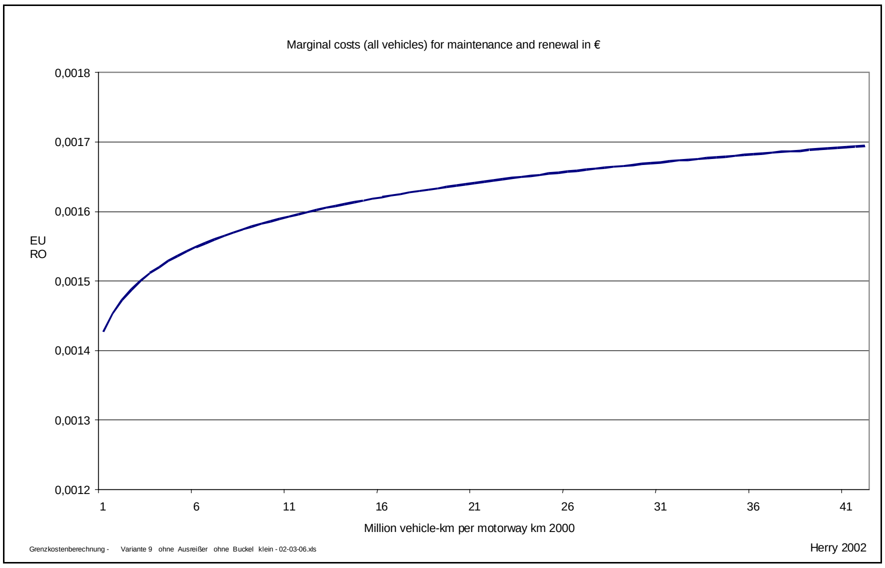
[8] The allowed range means that when fixing the AADT for passenger cars at a certain value and varying the AADT for trucks, the resulting ratio between the two has to lie between 0.03 and 0.44 (the minimum and maximum values for r in our sample).

Figure 1
Marginal costs of constructional maintenance for Swiss roads



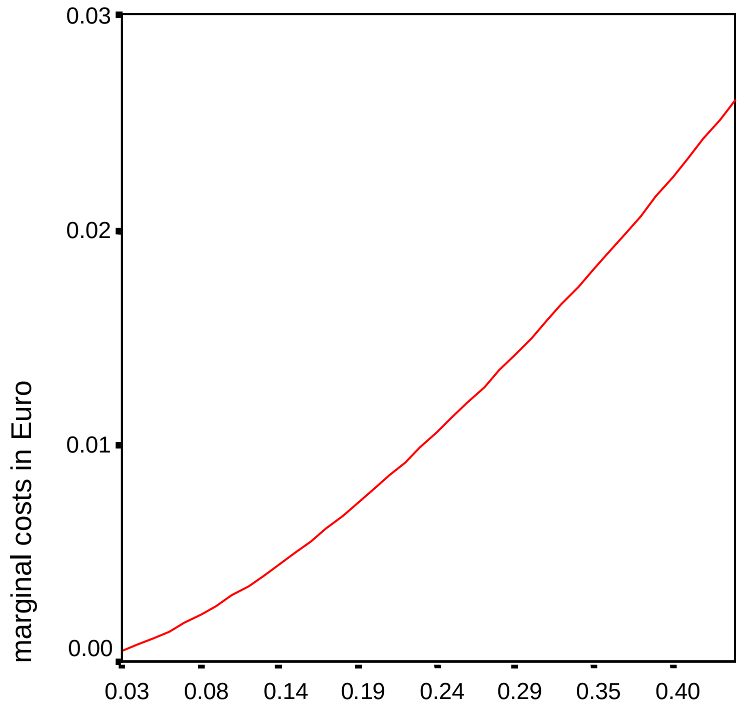
Source: Annex A1b (Schreyer et al. 2002).

Figure 2
Marginal costs of maintenance and renewal per total vehicle-km per motorway-km in Austria



Source: Annex A1c (Herry and Sedlacek 2002).

Figure 3
Marginal renewal costs of Germany motorways with respect to the ratio between AADT (average annual daily traffic volume) of trucks and passenger cars



Source: DIW Berlin.

Table 6 summarises the marginal costs for Swiss motorways estimated with the different variants of log-linear models for different categories of costs. Note, that actually with the log-linear models of the form shown in (2) it is not possible to properly estimate the marginal costs for different categories. Nevertheless in order to give an illustration, the Swiss case study applied two indirect methods. In the first method (statistical method) the estimates for gross-tonne km were used to calculate a proxy for marginal costs of different vehicle categories. In the second method, results from an engineering approach on the cost splits between different vehicle categories were applied to the marginal cost levels estimated within (2). Furthermore, the marginal costs of operating motorways were assumed to be the same for all vehicle categories. They amount to approximately 0.3 Cents per vehicle-km. Marginal costs for upgrades and renewals are in a range of 0.01 to 0.04 Cents per vehicle-km for cars and 0.3 to 0.6 Cents per vehicle-km for trucks. For marginal costs of constructional maintenance results obtained with the time series analysis and with the cross-sectional analysis are available. However, they are not directly comparable since within the latter case the vehicle category „trucks“ was further disaggregated. The cross-sectional analysis based on axle-load kilometres yielded lower figures for cars, but higher ones for trucks when compared to the results from time series based regression. The ranges of marginal costs for constructional maintenance estimated with the different approaches are 0.03 to 0.19 Cents per vehicle-km for cars, 3.02 to 8.00 Cents for trucks and 7.30 Cents for trucks with trailer/semitrailer.

Table 6
Marginal cost estimates for Swiss motorways (€/vkm)

		Cars	Trucks	Trucks with trailer/semitrailer	Mean
Operational maintenance costs	Statistical method	0.0027	0.0027	:	0.0027
Constructional maintenance costs	I: Time series based results				
	Statistical method	0.0019	0.0302	:	0.0037
	Engineering method	0.0014	0.0428	:	0.0039
	II: Cross-sectional results				
	Calculation based on...				
	total mileage (veh-km)	-1)	-1)	-1)	0.008
	gross ton-km	0.003	0.039	0.073	-
	axle load equivalent-km	0.0003	0.080	0.073	-
Costs for upgrade and renewals	Statistical method	0.0004	0.0062	:	0.0008
	Engineering method	0.0001	0.0033	:	0.0003

1) No cost allocation to different vehicle categories possible.
Source: Annex A1b (Schreyer et al. 2002).

Table 7 presents the results for Austria. Average marginal costs of maintenance and renewals for all vehicles amount to 0.16 Cent per vehicle-km. Just for the purpose of additional information, we also present the results of the statistically insignificant model. According to this model the marginal costs amount to 0.07 Cents per vehicle-km for vehicles below 3-5 t GVW and 2.17 Cents for vehicles above 3.5 t GVW. These results cannot be compared with those from Switzerland since the cost categories included and the vehicle categories differ.

Table 7
Marginal cost estimates for Austrian motorways (€/vkm)

Vehicle type	Marginal costs 1)
All vehicles 2)	0.0016
Vehicles <3.5 t GVW3)	0.0007
Vehicles >3.5 t GVW3)	0.0217

-1) Marginal costs of maintenance and renewals. -2) Based on log-linear regression model with total vehicle. -3) Based on log-linear regression model with vehicles-km of 2 vehicles classes. The model was statistically insignificant.
Source: Annex A1c (Herry and Sedlacek 2002).

Conclusions and generalisation

The three case studies aimed at estimating marginal road infrastructure costs by using an econometric approach clearly have to be seen as a first step in this field. The research done, including the efforts spent on gathering the necessary data bases, was unique for each of the three countries involved.

The studies yielded rather contradictory results. While the results seem to be in line with the traditional u-shape of cost functions they differed with respect to the question which part of the „u“ is reflecting the behaviour of road maintenance and renewal costs. In particular for the two mountainous countries Switzerland and Austria the expectation was that the type of cost function would be equal. This expectation was not confirmed by the regression results. However, the fact that for Switzerland a falling shape and for Austria an increasing shape was obtained might be caused by a too simple approach, but also by the rather small sample size for Austria. Furthermore, the different scope of cost categories and vehicle types applied to the case studies does not allow a direct comparison of the results. An important consideration when comparing the shapes of the curves for Austria and Switzerland is also the relevant range of these curves. This relevant range for both countries refers to traffic volumes from the middle of the horizontal axle up to the right-hand side (the average traffic volume for Switzerland is 10 million vkm, for Austria 4 billion vkm). In these areas the non-linearity of curves is rather weak and one could almost assume a linear shape. Thus, the observation of contradictory results eases considerably.

Based on the experience and results from the three case studies we can draw the following methodological conclusions:

1. As the German case study shows, the functional form of the translog-approach is a suitable tool for explaining cost development and for deriving marginal costs. The rather low R^2 is probably due to the nature of input data used (renewal data with cyclical character) and should not be over interpreted.[9]
2. Rather low R^2-values were a general problem with which the case studies had to cope. Obviously, the included variables were only able to explain rather low shares of the dependent variable. This indicates that further explanatory variables were missing,

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[9] Generally it has to be stated that with cross-sectional analysis a R^2 of not more than 50% is common (see Greene 2000).

especially for the Swiss and Austrian case studies. The rather low R²-values for the German regression analysis which had access to further data on cost drivers might be explained by the nature of the dependent variable which referred to renewal expenditures for the motorways only.[10]

3. For none of the three case studies an ideal type of traffic data, namely measures of axle-load km, was available. The studies used instead mileages for different vehicle categories which are by nature highly correlated. This caused serious multicollinearity problems and hampered the use of the translog approach for the Swiss and Austrian data. Furthermore, the Austrian and Swiss study used modelling results on gross-tonne km and axle-load km. The problem here is that the modelling assumptions are then reflected in the outcomes of the regression analysis, i.e. the results are not based on observed relationships but trather on modelled between costs and traffic volume.
4. If cross-sectional data on axle-load km are not available (which will be the case in many countries) and mileage data have to be used the multicollinearity problem can be solved by using the ratio between mileages of different vehicle categories (see the variable used in the German case study).
5. A further problem lies in the nature of an econometric approach itself. Since econometrics are based on observed cost figures the results necessarily reflect the spending behaviour of road authorities. Link and Lindberg 2000 discussed the fact that it is not feasible to assume road authorities act as cost minimizers. Consequently, the cost function can not be considered to be dual to production technology. All three case studies found evidence that road authorities do not only decide on expenditures on the grounds of necessity but rather in relation to budgetary reasons. This spending behaviour is certainly responsible for the low explanatory power of our regression models, too.

Summarising up the results from the three econometric case studies it seems to be obvious that the availability and quality of data have to be improved considerably in order to apply the flexible functional approach of a translog function.

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[10] The cyclical nature of this type of expenditure did not only cause problems in the road case study. Similar problems were also observed for an econometric study on rail infrastructure cost functions also described within this report (see Annex A3, Nilsson and Johansson 2002).

In general, it is possible to transfer the general approach of econometric estimation to road networks of other countries. However, the availability of disaggregated data on expenditures, traffic loads and other explanatory factors might be the bottleneck. Given the fact that the non-linearities detected for maintenance expenditures are not very strong in the relevant range of traffic loads it seems to be possible to transfer (i) the remaining (almost) linear shape of marginal costs, especially for ongoing maintenance, and (ii) in absence of other knowledge the elasticity MC/AC. The result of a progressively increasing marginal cost curve for renewal expenditures as obtained from the German case study differs from results obtained with an engineering approach in Sweden (see section 4.1.2). Therefore, we do not recommend a transfer of either the German or the Swedish result to other countries. More research is needed in this area.

4.1.2 Engineering case study for Swedish roads

Aims of the case study

A case study on marginal road infrastructure costs covering Sweden analysed how the marginal cost of pavement renewal is related to the amount of heavy goods vehicles. Starting point was the assumption that the length of an interval between two pavement renewals depends on the traffic load which went over a certain road section measured as standard axles. The case study dealt therefore with one major component of maintenance cost which makes around 30 % of total maintenance costs on Swedish roads.[11] Since this type of costs causes difficulties for econometric estimation (see Annexes A1a and A3) this case study choose a complementary approach and applied empirical information to engineering-based relationships.

Input data

The case study used data from the Swedish Long-term Pavement Performance Project within which each year a distressed survey was performed measuring the road depth and the longitudinal profile of roads. The data base contained information about the structural strength, the surface condition, the pavement structure, the climate conditions as well as traffic data on 639 sections of 64 different roads in the middle and south of Sweden. In addition, information on road substructure was taken from constructional drawings. The

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[11] The other components of maintenance costs include winter maintenance, traffic signs, road markings, grass and hedge cutting, sweeping and cleaning, drainage etc.

traffic variables were represented by average annual daily traffic (AADT) and by annual standard axles. The climate data included rain, snowfall and coldness measured in “negative day degrees” (Celsius). In order to express the physical measures of road condition in monetary terms, unit costs provided by the Swedish National Road Administration formed a further input data. These unit costs referred to the costs of an overlay which consist of the costs of pavement (including work) and the costs of necessary repair of substructure. They vary between 14.182 € per kilometre for narrow roads in the South up to 71.076 € per kilometre on the wider roads in the North with an average cost of 24.803 € per kilometre. Table 8 contains a description of the independent variables used for the case study.

Table 8
Description of independent variables used in the Swedish road engineering study

Measure of	Name	Symbol
Traffic	AADT Standard axles per year Proportion HGV	(Q)
Road construction	Thickness of base and pavement	
Strength	Measured deflection Surface Curvature Index 300 Tensile strength	(SCI)
Age	Year since construction	
Climate	Annual average coldness Annual accumulated coldness Annual rain and snowfall Annual accumulated rain and snowfall	

Source: Annex A2 (Lindberg 2002).

Methodological approach

Existing literature (Newbery 1988b, Small et al. 1989) assumes that the number of standard axles that can pass on a road before the pavement has to be renewed is a design parameter of road construction and thus independent of the traffic volume. In contrast to this assumption, the case study used new empirical knowledge which indicates that the number of standard axles which the road can accommodate is a function of the traffic volume (Wågberg 2001). It is assumed that the pavement has to be renewed when road condition has a too poor standard. This fact is expressed within a cracking index which consists of three elements, namely the crackled surface, the longitudinal cracking and the transverse cracking. For estimating these three elements of the cracking index, data from the Long-term Pavement Performance Project in Sweden was used. The finally estimated lifetime of a pavement is a function of the constant annual numbers of standard axles that pass the road and the strength of the road:

$$T = \left[\frac{\Theta(Q)}{Q} \right] e^{-mT} \qquad (3)$$

where

T = period between the overlays

Θ = number of 'standard axles' the pavement can accommodate

Q = annual traffic volume measured as 'standard axles'

m = climate dependent deterioration.

For simplification the climate influence was excluded from the empirical analysis. The change of lifetime due to higher traffic loads was expressed by a so-called deterioration elasticity

$$\varepsilon = \frac{dT}{dQ} \frac{Q}{T} \qquad (4)$$

The marginal costs caused by shortening the renewal intervals due to higher traffic loads were expressed by differentiating the annualised present value of the road with the annual traffic volume. By using the deterioration elasticity ε and an expression for the average costs AC, the marginal costs MC_{New} for a new road, an old road MC_{Old} and an average road $MC_{Average}$ were derived as shown in Table 9. For deriving the marginal costs for an average road it was assumed that the age of roads is evenly distributed over the whole network.

Table 9
Engineering based approach:
Expression of marginal costs for a new or old road and for an average road

(9) New road or old road	(10) Average road
$MC_{New} = MC_{Old} = -(rT)^2 \frac{e^{rT}}{(e^{rT}-1)^2} \frac{C}{TQ} \varepsilon = -\alpha \varepsilon AC$ (5)	$MC_{Average} = -\varepsilon AC$ (6)

with

$$AC = \frac{C}{\theta} = \frac{C}{QT} \qquad \text{Average cost} \qquad (7)$$

$$\alpha = (rT)^2 \frac{e^{rT}}{(e^{rT}-1)^2} \qquad (8)$$

r = interest rate

C = total costs.

The study shows that if a real interest rate of 3 or 4 % is applied the parameter α takes a value between – 0.95 and – 1.00. Consequently, the marginal cost is in this case approximately the same for an average road as for a new or old road. The decisive parameter for the relationship between the average cost (AC) and the marginal cost (MC) is the value of the deterioration elasticity. The so-called fundamental theorem developed by Newbery (see Newbery 1988) says that average cost is equal to marginal costs. However, the formal expression of marginal costs for new or old roads derived and average roads in the case study (see table 9) illustrates that this is only valid if there is no weather effect and if the number of standard axles the surface can withstand is constant, e.g. if the elasticity ε becomes negative unity. The empirical analysis performed in the case study provides evidence that ε is not equal to negative unity.

Finally, the basic assumptions of the engineering case study can be summarised as follows:

1. Climate conditions have no influence on the renewal interval.
2. The age of roads is equally distributed within the whole road network.
3. Pavement will be renewed if the cracking index has reached a certain terminal value.[12]

In contrast to econometric approaches which are based on observed cost behaviour, the approach chosen here can be characterised as an "ideal world" approach. Experience in several countries shows that maintenance and renewal measures do not always follow technical needs. This fact has to be borne in mind when interpreting the results.

Table 10
Marginal cost per standard axle (SA) on Swedish roads 1) (€ / 100 SAkm)

Standard axles per day and direction(Q/365)	**SCI 2)**						
	50	**75**	**100**	**125**	**150**	**175**	**200**
200	-	-	-	-	-	0.29	0.76
300	-	-	-	0.25	0.54	0.89	1.32
400	-	-	0.23	0.47	0.73	1.05	1.48
500	-	0.13	0.34	0.55	0.80	1.12	1.55
600	-	0.22	0.40	0.59	0.84	1.15	1.58
700	0.07	0.27	0.43	0.62	0.86	1.17	1.60
800	0.13	0.30	0.45	0.63	0.87	1.19	1.61
900	0.16	0.31	0.46	0.64	0.88	1.19	1.62

1) Calculated with an average pavement cost. – 2) Road surface curvature index.

Source: Annex A2 (Lindberg 2002).

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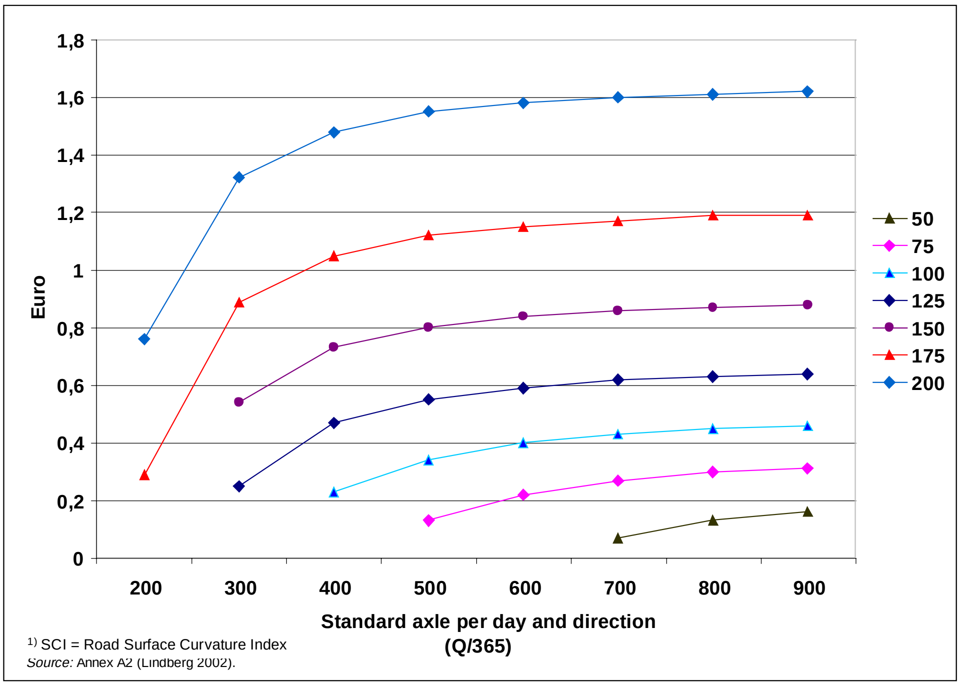
[12] This terminal value was set to S > 5 in the case study.

Figure 4
Shape of the marginal cost curve for road renewal costs with respect to standard axles in Sweden (€ / 100 SAkm)



$^{1)}$ SCI = Road Surface Curvature Index
Source: Annex A2 (Lindberg 2002).

Case study results

Based on the methodological approach summarised above the deterioration elasticity was estimated for given traffic loads expressed as standard axles per day and direction. This elasticity varies from – 0.1 on high quality roads with low traffic load up to – 0.8 on low quality roads with high traffic load (see table 3.3 in Annex A2). The empirical analysis has shown that the marginal costs depend on the road strength, the number of standard axles and the costs of a new pavement.

The modelling work and the available input data allowed to present two types of results on marginal costs:

1. By using an average pavement cost and the deterioration elasticity marginal costs per standard axle on roads with different roads strength were calculated. As can be seen from table 10 the marginal costs lie in a range of 0.07 € per 100 standard axle kilometres up to 1.62 € per 100 standard axle kilometres. The main result is that the marginal cost increases when the road strength is reduced.

2. In a second type of calculation the available information for a sub-sample of 249 road sections was used. For these sections an average lifetime of 11.8 years and an elasticity of – 0.43 was estimated (see table 11). The marginal costs per 100 standard axle kilometres were estimated to be 0.8 €, assuming an average overlay cost of 2.2 € per 100 standard axle kilometres. Charging these marginal costs to road users would yield a cost recovery rate of 36 %.

Table 11
Basic information, average cost and marginal cost for the Swedish road subsample

	Mean	Std.Dev.	Minimum	Maximum	Number of cases
SCI 1)	133.997	44.3632	55.5224	269.104	249
Vehicles (AADT) 2)	5131.57	2278	1290	10900	249
WIDTH (m)	11.7209	3.75126	7.5	20	249
Q (per day and direction) 3)	578.94	379.485	137	1320	249
OVERLAY COST (kSEK/km)	37.0	8.7	30.5	66.0	249
LIFETIME (year)	11.8103	3.11661	3.36859	16.9688	249
Deterioration elasticity	-0.431342	0.221295	-0.80211	-0.00908	249
Average costs (SEK/Sakm)	0.022	0.016	0.006	0.093	249
Marginal costs (SEK/Sakm)	0.008	0.0061	0.0002	0.038	249

1) Road Surface Curvature Index. – 2) AADT = Annual average daily traffic. – 3) Number of standard axles.
Source: Annex A2 (Lindberg 2002).

The estimated cost per standard axle were also be expressed as a cost per vehicle type. For this calculation data from the Swedish Road Administration on standard axles per vehicle type for four groups of goods vehicles was used. According to this calculation a marginal cost of 0.32 € per 100 vehicle kilometres for light duty vehicles (LDV) and of 1.86 € per 100 vehicle kilometres for the heaviest vehicles (HGV with trailer) was derived (see table 12).

Table 12
Standard axles per vehicle (VEF) and Marginal cost by vehicle type for renewal costs of Swedish roads

	VEF	€/100Vehkm
Light duty vehicles	0.4	0.32
Light duty vehicles with trailer	0.85	0.69
Heavy goods vehicles	0.96	0.77
Heavy goods vehicles with trailer	2.3	1.86

Source: Annex A2 (Lindberg 2002).

Conclusions and generalisation

The following considerations are important to interpret the results properly:

1. The assumed equal age distribution of roads in the network simplifies the expression of marginal costs but can be violated in many cases. As shown in the analysis the difference between an old and a new road depends on the parameter α. The case study has shown that if a real interest rate between 3 and 4 % is applied, the parameter α takes a value not far from unity, and consequently the costs for an old and a new road are similar. Note however, that the choice of an higher interest rate (for example an 8 % nominal interest rate at financial markets) would yield an α-value between 0.81 and 0.98.

2. As discussed, the engineering approach used in this case study assumes an optimal spending behaviour of road authorities. Due to budget constraints, however, the road authorities may not respond with a new overlay when the trigger value has been reached. Empirical evidence suggests that after the first trigger value has been passed the road starts to deteriorate quicker which indicates a higher elasticity and consequently higher marginal costs than presented in this study. This does not mean that the functional relationship developed for the marginal cost in this case study is not valid but with non-optimal renewal cycles the marginal cost estimation has to be based on new empirical data.

3. The engineering based relationships modelled in this case study assumed that if crack initiation in the wheel path has reached a certain trigger value the pavement has to be renewed. However, crack initiation is not the only deterioration that may trigger a major road work. On roads with high traffic volume and a high proportion of studded tyres rut depth becomes a serious problem, too. However, the available data did not allow to estimate a reliable model of the probability that the cracking index was the trigger for the decision on the road work.

4. The model does not include climate dependent deterioration since the empirical results from the Long-term Pavement Performance Project suggested that climate has no explanatory power. It can be sensibly assumed that especially for roads with low traffic load climate has a higher impact on deterioration.

5. A comparison with a top-down cost allocation study (see Vägverket 2000) has shown that with the engineering based approach substantially lower marginal costs are estimated. For roads with an AADT of 500 up to 2000 the result of the engineering approach makes 31 %

of the estimate obtained by using the cost allocation method. For the next category the engineering approach yields 24 % and for the category with an AADT above 8000 the estimate is 23 % of the results from the cost allocation study. However, it should be borne in mind that the results are not comparable since the estimates from the UNITE case study only covered the reconstruction and resurfacing costs while the cost allocation study included all road related costs.

6. The method presented in this case study can easily be generalised to other countries if the respective data is available. Methods to estimate the lifetime of pavements have been developed in research projects financed by the European commission (PARIS project). However, it is not clear whether long-term data on standard-axles per road section as well as on the quality measures is available in other countries.

4.2 Rail

In this chapter we summarise the results from two case studies dealing with the estimation of marginal rail infrastructure costs. The first study performed an econometric analysis of track maintenance costs in Sweden and of track maintenance and reinvestment costs in Finland. In a second case study evidence on the marginal costs of rail infrastructure use in the U.K. was examined by using results from the periodic review of rail infrastructure charges undertaken by the Rail Regulator in Britain in the period from 1997 to 2000 (ORR, 2000a). Both case studies were restricted to analysing marginal infrastructure costs related to track use while those costs referring to stations, marshalling yards and other facilities were excluded.[13]

4.2.1 Econometric studies for Sweden and Finland

Aims

By econometric analysis of cross-sectional data for Swedish and Finnish rail tracks the study was aimed at deriving insights on the spending behaviour for track maintenance and at providing evidence on scale economies with respect to traffic load. From the methodological point of view, one aim of the case study was to test whether the translog functional approach can be successfully applied to this field of cost function analysis.

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[13] The British rail infrastructure cost study also covered congestion costs and scarcity costs. These parts of the study will not be summarised in this report because they are out of scope of the marginal infrastructure costs.

Input data used

The analysis used cross-sectional data which referred for Sweden to the years 1994 to 1996 and for Finland to the years 1997 to 1999. The Swedish data contained information on track maintenance costs, track length, technical characteristics (number of switches, bridges and tunnels), a track quality index and a dummy variable for main and secondary lines. As a measure of track usage information about gross ton kilometres driven on the tracks was used. The finally analysed data set included 169 observations for 1994, 176 observations for 1995 and 175 observations for 1996. The maintenance costs referred to track-specific costs only, e.g. excluded common costs. The records account for about 1.6 billion SEK out of a total spending of 2.3 billion SEK in 1994. This makes 70 % of total maintenance expenditures (see Johansson and Nilsson 1998). Reinvestments were not included in this data set.

The structure of the Finnish data set was similar but not identical to that from Sweden. It comprised information for the period from 1997 to 1999 with 93 observations for both 1997 and 1998 and 92 observations for 1999, each of them relating to a track section. In contrast to the Swedish data set common costs were also allocated to the track sections. Furthermore, the Finnish data included information about spending on reinvestments such as track renewal. On the other hand the Finnish data set was less detailed than the Swedish one. For example, there was no information available about the number of bridges and tunnels. Instead the average speed allowed on a track unit was used as a proxy for quality, and a dummy variable on electrification was used instead of the dummy variable on main and secondary lines in the Swedish data set. A summary of the input data used for the econometric analyses can be found in Table 13.

Table 13
Description of input data used in the rail case study for Sweden and Finland

Variable		**Mean**			**Standard deviation**		
Sweden1)		**1994**	**1995**	**1996**	**1994**	**1995**	**1996**
Maintenance costs (current €)	C	641.711	594.728	608.338	644.985	528.290	486.201
Track length, km	Y	66.68	66.32	66.23	45.78	45.78	46.17
Number of switches	z_1	30.84	31.74	30.50	27.21	27.21	27.16
Number of bridges	z_2	15.46	15.49	15.89	12.70	12.70	13.18
Number of tunnels	z_3	0.48	0.47	0.58	1.40	1.40	1.85
Track quality index (1,...8)	z_4	5.18	5.41	5.65	1.88	1.88	1.80
Secondary lines	I	0.33	0.33	0.34	0.47	0.47	0.47
Gross tonne (the natural logarithm)	u	14.92	14.79	14.78	1.67	1.67	1.68
Finland2)		**1997**	**1998**	**1999**	**1997**	**1998**	**1999**
Maintenance costs (m FMK)	C	561.163	512.882	496.154	346.901	336.893	302.738
Re-investment costs (m FMK)	R	1.872.245	1.981.133	1.651.605	3.683.273	4.071.212	3.123.250
Track length, km	Y	80.63	80.62	81.22	45.18	45.21	45.01
Number of switches	z_1	45.01	45.00	45.47	31.86	31.88	31.68
Non-Electrified	I	0.57	0.57	0.52	0.50	0.50	0.50
Average speed	z_5	41.09	41.09	41.55	22.76	22.76	22.56
Gross tonne (the natural logarithm)	u	14.60	14.59	14.75	1.83	1.76	1.32

1) N=169 for 1994, N=176 for 1995, N=175 for 1996. 1995 price level. – 2) N=93 for 1997, N=93 for 1998, N=92 for 1999. 1995 price level.

Source: Annex A3 (Johansson and Nilsson 2001).

Methodological approach

As in the German motorway case study, the underlying methodological approach of the rail case study was the translog function proposed by Christensen et al. (1973) which provides the possibility of a flexible specification of the cost structure. The finally specified models for the Swedish and the Finnish data set are given in Table 14. They include as independent variables the track length, the utilisation level measured as gross tonnes, a vector of technical variables (number of switches, number of tunnels etc.) , and for the Swedish analysis a vector of dummy variables indicating the influence of districts. Note, that this model specification excludes the vectors of marginal prices for the input factors which were originally included in the translog cost function described in Berndt and Christensen (1972).[14]

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[14] Since both Sweden and Finland are fairly small countries with factor prices that are harmonised at large marginal prices are assumed to be equal a cross track units.

Case study results

In general the translog specification of the functional relationship between costs and explanatory variables provided a good basis for understanding the spending pattern on track maintenance. R-squares of 77 % for the full Swedish model, of 74 % for the restricted Swedish model (excluding bridges, tunnels and district dummies), and of 83 % for the Finnish data proved high explanatory power of this approach.

The estimated model (see table 14) for the Swedish rail network contained significant parameters with the expected signs for the parameters of main interest, namely for track length and track utilisation except the second order term for track length. Out of the other parameter estimates there were two insignificant parameters for the number of bridges, two insignificant parameters for the tunnel factor and one insignificant parameter estimate for the variable indicating main and secondary lines. The model specification for the Finnish data set (see table 14) yielded significant coefficients for track length, but the corresponding coefficient for traffic load was insignificant. Note, however, that the first order coefficient for traffic load had the expected sign and was significant at the 10 % level in a one-tail test. From this result one could conclude that obviously the spending behaviour in Finland does not respond to variations in traffic load in the same way as in the Swedish data.

The main results of the econometric analysis can be summarised as follows:

1. The methodological approach of a translog function provided excellent results with unusually high R-squares.
2. For the Finnish data set an attempt was made to also include the spending for reinvestment purposes. However, since only observations from three specific years rather than a long period of time was available this attempt failed. Only two variables were significant with the electrification dummy and the squared utilisation capturing most of the effect on the cost. An interpretation of the results obtained with this model seems not to be sensible.
3. The main result is that track maintenance seems to be a decreasing cost activity. The study confirmed the traditional “u” shape of cost functions, however, referring to the falling part of the “u”. The interpretation of this is that higher traffic loads lead to lower marginal maintenance costs.

4. Obviously, maintenance activities in Sweden and Finland are not very responsive to variations in traffic load. The cost elasticity with respect to track utilisation calculated for the Swedish network falls when traffic load increases and remains constant after exceeding a certain threshold of gross ton kilometres. The mean of this elasticity is 0.17 indicating decreasing average maintenance costs. Although for the Finnish data set this elasticity was only estimated with a lower precision than for Sweden it is below unity and the magnitude is with 0.167 very similar.
5. The analysis provided evidence that costs do not vary linearly with variation in traffic and track length. However, the detected non-linearities are not very strong.
6. The marginal maintenance costs shown in table 15 range from 0.117 SEK to 0.147 FIM in 1995. Note, that they were calculated as "average marginal costs" both for the network as a whole and for the main and secondary lines separately.[15] All estimated marginal costs are for the Finnish data higher than for Sweden.
7. The results indicate that with marginal cost pricing no more than 17 % of the annual maintenance costs in Finland and no more than 12 % of the maintenance costs in Sweden would be recovered.

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[15] For this purpose the track activity on each track section was weighted by dividing the gross tonne kilometres at each section by total gross tonne kilometres on the whole network.

Table 14
Parameter estimates for the translog approach applied to rail track maintenance costs in Sweden and Finland

Sweden1)				
	Equation2)		Equation3)	
Variables/Coefficients	Est.	t-value	Est.	T-value
α	-6.749	-3.924	-6.828	-4.210
α_{95}	-0.005	-0.093	0.000	0.003
α_{96}	0.013	0.241	0.005	0.292
I / ß$_I$	0.026	0.342	0.004	0.048
y / ß$^*_y$	2.338	5.943	2.023	5.589
u / ß$^*_u$	0.986	5.051	1.037	5.692
yu/ ß$^*_{yu}$	-0.104	-5.868	-0.096	-5.665
y^2 / ß$_{yy}$	-0.010	-0.294	0.023	0.786
u^2 / ß$_{uu}$	-0.014	-2.288	-0.017	-2.995
Bridge	0.005	0.708		
Bridge^2	0.000	-0.459		
Switches	0.011	3.601	0.010	3.462
Switches^2/100	-0.006	-1.184	-0.005	-1.169
INDX	0.210	2.290	0.269	3.022
INDX^2	-0.028	-3.145	-0.033	-3.773
Tunnel (factor in seven levels)				
1	-0.070	-0.604		
2	0.206	1.782		
3	-0.062	-0.461		
4	0.256	1.078		
5	0.626	2.423		
6	0.057	0.331		
R^2	0.767		0.736	
Finland4)				
	Maintenance Cost		With Reinvestments	
Variables/Coefficients	Est.	t-value	Est.	t-value
α	8.780	6.645	10.764	2.967
α_{98}	-0.104	-2.145	-0.036	-0.269
α_{99}	-0.139	-2.830	-0.051	-0.381
I / ß$_I$	-0.318	-4.936	-0.550	-3.102
y / ß$^*_y$	1.504	3.462	1.408	1.179
u / ß$^*_u$	0.167	1.501	-0.326	-1.065
yu/ ß$^*_{yu}$	0.001	0.071	-0.018	-0.341
y^2 / ß$_{yy}$	-0.104	-2.766	-0.078	-0.754
u^2 / ß$_{uu}$	-0.006	-1.519	0.026	2.234
Switches	0.010	4.460	0.012	1.889
Switches^2/100	-0.003	-2.264	-0.001	-0.379
SPEED	0.013	3.298	0.005	0.478
SPEED^2/100	-0.013	-3.287	0.009	0.809
R^2	0.827		0.498	

1) N = 520. -2) Full model. Included also 19 district dummies not reported here. -3) Restricted model. -4) N = 278.

Source: Annex A3 (Johansson and Nilsson 2001).

Table 15
Estimates of marginal maintenance cost for the Swedish and Finnish rail network in € Cent per gross tonne-km (at 1995 and 2000 exchange rates)1)

	Sweden		Finland	
	1995	2000	1995	2000
ALL	0.013	0.014	0.017	0.027
Main/electrified	0.0088	0.0099	0.013	0.020
Secondary/non-electrified	0.097	0.11	0.029	0.045

1) 1 Euro (ECU) was SEK 9.332 in 1995 and SEK 8.446 in 2000.

Source: Annex A3 (Johansson and Nilsson 2001).

Generalisation of results

The results for Sweden and Finland are a first attempt to estimate a cost function for rail infrastructure. Although there are similarities of results for these two countries there are also important differences. On the one hand the impact of traffic levels on costs is less distinct in Finland than in Sweden while on the other hand the marginal costs for track use are 90 % higher in Finland than in Sweden. Interpreting these similarities and differences and moreover generalising them to other countries has to consider that each country has his own features of network (with respect to track standard, track quality and climate conditions).[16] A transfer of the results presented here to other countries is also hampered by the fact that both case study countries have similar conditions (rather low traffic levels) and belong to the same climate zone.

However, given the positive experience with two countries it seems that the methodology, e.g. the translog approach itself, is transferable to other countries provided the necessary input data is available. Also the fact that maintenance is a decreasing cost activity seems to be transferable since it is in line with findings from existing literature on cost functions of rail companies as a whole. Note, that this result is different from the findings for road infrastructure, where the case studies (except the Swiss one) found that road maintenance and renewal is an increasing cost activity. Comparing the results for road and rail and interpreting the differences is difficult since no theoretical benchmark (any type of a priori assumption) does exist. However, the detected non-linearities are not very strong. This finding which

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[16] For example Finland has a different track gauge and heavier winter conditions than Sweden. Furthermore, the Finnish data set included also costs that were common for the rail administration.

shows similarities with the results for road infrastructure costs indicates that applying a linear cost curve might be a reasonable first attempt for such countries where other information is not available.

4.2.2 Review of marginal cost calculations for the British Rail Network

Scope and methodological approach

A second rail-related UNITE case study examined existing evidence on marginal cost calculation for rail infrastructure use arising from the periodic review of rail infrastructure charges undertaken by the Rail Regulator in Britain. This review was based on three main sources, namely on the marginal cost calculations performed by Railtrack itself, on a study performed by Booz Allen & Hamilton for the Office of the Rail Regulator, and on the decision taken by the Rail Regulator on the track exist charges.

Results

Britain’s railway infrastructure manager, Railtrack, applies an engineering approach to estimate track usage costs. Within this model the effect of an additional train on either the maintenance requirements of the track or on the life of the track asset is calculated. Unit costs are than applied to express these physical effects in monetary terms. The main input data used for the model are traffic data (train services, speeds, load of each service), number of axles and infrastructure data (track type, sleeper type, line speed by network segment). Railtrack’s modelling results indicate that between 29 % and 32 % of the overall level of expenditure on maintenance and renewals of tracks may be regarded as variable. Table 16 contains the estimates from the Railtrack model on asset usage costs and cost variability.

Table 16
Railtrack’s estimates of asset usage costs and cost variability for the British rail network

Asset type	Overall variable cost per year (€ at 2001 average exchange rate)	Percentage variability	Percentage of estimated total usage cost
Track	483m	50	77
Underbridges	64-80m	20	13
Signalling	24-32m	5	5
Electrification	24-32m	5	5

Source: Railtrack.

In contrast to the engineering based model the Rail Regulator put forward a top-down approach. In a study undertaken for the British Rail Regulator (Booz, Allan & Hamilton 1999), a review of international research on use dependent track costs was performed. The study found that between 30 and 60 % of track maintenance and renewal costs vary with the level of use. However, the review ranged from engineering studies to statistical analysis of past expenditures. Very high density railways as well as low density railways were studied, and the results were on the one hand obtained from predominantly freight railways (USA), while others were derived from predominantly passenger railways (Europe). Generally, it has to be stated that very little research into the variability of maintenance and renewal costs of structures, signalling and electrification equipment exists. The results of the Booz Allen & Hamilton Study on track access charges in Britain are summarised in Table 17. These results rely on a traditional accounting distinction between fixed and variable costs. However, the categorisation needed there is based on an extensive review of empirical evidence. Applying the percent variability estimates to the Railtrack figures of cost by cost category, the Booz Allen & Hamilton Study suggests, with a range of 21 % to 23 %, a somewhat lower level of cost variability than Railtrack. However, it has to be borne in mind that these figures rely heavily on judgement.

Table 17
Variable costs of rail track infrastructure in the U.K. (%)

	% variable	% by asset category
Track		38
Maintenance	30	
Renewals		
Rail	95	
Sleepers	25	
Ballast	30	
S&C	80	
Structures	10	10
Signals		2
Maintenance	5	
Renewals	0	
Electrification		24
Maintenance		
AC	10	
DC	10	
Renewals		
AC	35	
DC	41	

Source: Annex A4 (Nash and Matthews 2002).

A third source of insight into the level of marginal costs of rail infrastructure was obtained by analysing the Railtrack access charges finally derived by the Rail Regulator. The Regulator used a top-down-approach to estimate the overall variable costs by splitting Railtracks total maintenance and renewal costs into fixed and variable costs. In a next step, the results of the Railtrack model were applied to apportion the variable costs between vehicle types. Table 18 gives some examples of the resulting figures.

Summarising up, the approach taken by the British Rail Regulator is based on the assumption that average variable costs can be used to approximate marginal costs. The case study argues that in absence of other knowledge this assumption might be feasible, given the fact that another UNITE case study (see Johansson and Nilsson 2001, Annex A3) found only slight non-linearities. Note, however, that this other study is based on findings from 2 Nordic countries with rather low traffic flows and Nordic climate conditions.

Table 18
Typical examples of rail track usage charges for the U.K.
(€ Cent/vehicle km 1999/2000)

Diesel shunter (class 08)	4.2
Diesel loco (class 47)	102.8
Electric loco (class 90)	96.0
Passenger car (mk 3)	16.7
Diesel multiple unit (class 158)	16.7
Electric multiple unit (class 333)	
Powered car	24.4
Trailer car	19.1
Freight wagon	4.3 – 5.3 [1]

[1] p per gross tonne km.
Source: ORR (2000a, 2000b).

Conclusions and generalisation

Although the review was restricted to British sources some general conclusions can be drawn. First of all there seems to be very little empirical evidence on the level of usage related rail track costs. Second, the British Rail Regulator seems to prefer an engineering based approach for deriving use related track costs given the several caveats of statistical and econometric analysis such as the cyclical nature of renewal expenditures and the budget dependence of maintenance and renewal costs. However, the engineering based approach is dependent upon a great deal of detailed data and specific modelling work which may not be available in other countries. Third, the international review performed for the Rail Regulator suggested that usage costs, e.g. the variable costs, as a proportion of total maintenance and renewal costs tend to lie within a range of 20 % to 30 % under European conditions. Note, however, that this percentage has rather the character of a top-down recommendation and, moreover, it does not say anything on the functional form of marginal costs.

The British case study suggests the top-down approach for situations where no reliable data for econometric analysis do exist. With regard to transferability, the study recommends to transfer cost elasticities (here defined as the ratio of marginal cost to average cost) which would be in the range of 0.2-0.3 for European countries.

Generally, more statistical research similar to the one performed in Johansson and Nilsson 2001, but also simply on the percentage of total costs which vary with usage is necessary.

4.3 Inland Waterways

Scope

So far very little information has been available on marginal infrastructure costs of inland waterways. On the one hand, this may reflect missing interest in the area. On the other hand, the lack of cost function studies in this field may be a consequence of the assumption that cost elements such as maintenance and repair of inland waterways do not vary with traffic volume. Against this background, the UNITE project contained a marginal infrastructure cost case study for the river Rhine with the aim to explore the possibilities of cost function analysis for inland waterways. This case study which is summarised in Annex A8 (Donselaar and Carmigchelt 2001) comprised the areas along the lower and middle Rhine, ranging from the seaport of Rotterdam to the inland port of Mannheim.

Methodology

The Rhine case study was largely based on expert opinions. Due to the lack of sufficient statistical data (the data had a too high level of aggregation) neither an econometric analysis nor an engineering based analysis was possible. Furthermore, an important complication in calculating marginal infrastructure costs of inland waterway shipping is the fact that not all costs related to investments, maintenance and management of inland waterways are caused by inland shipping. Costs of water management, flood protection, soil pollution prevention, recreational facilities on embankments etc. cannot be attributed to inland shipping. For the Rhine case study it was estimated that these other costs make approximately 30 % of all annual expenditures.

Case study results

The case study concluded that the relationship between additional inland ship movements and infrastructure costs is for the Rhine virtually non existent and, thus the marginal infrastructure costs for the Rhine waterway stretch are zero. This main finding was supported by the following assembled qualitative information:

1. Literature review and a review of expert opinions support the thesis that maintenance costs of embankments and quays are not influenced by additional ship movements. Although damage can be caused to the embankment if the speed of a vessel is too high or if a large ship passes too close to the embankment, these types of costs relate rather to an improper use of the waterways. Therefore, they rather have to be regarded as a breach of shipping rules. With normal use of the waterways no additional costs of embankment maintenance would occur as a result of additional ships. However, it should be borne in mind, that for canal embankments a causal relationship exists between the use of the canal and maintenance costs. Such infrastructure was not studied within UNITE.
2. A review of expert opinions documented in Annex A8 revealed that there might be a very weak relationship between traffic volume and the maintenance cost of river depth. Dredging amounts may be influenced by differentiation in sediment patterns which may have different outcomes depending on traffic volumes. Due to lack of studies in this area it was not possible to identify whether additional ships would have a positive or negative impact on the amounts necessary to be dredged. The common opinion of experts consulted within the case study was that additional ship movements might increase the scouring effect of the waterway to a small extent allowing for a very small marginal external benefit.
3. The operation of locks and bridges may result in marginal costs as a consequence of the energy used for closing and opening a bridge or lock, and the staff needed for operation. However, for the Rhine stretch analysed in the case study no locks do exist. Consequently no such costs could be identified.

Conclusions and generalisation

The conclusion from the Rhine case study is that there are little or almost no marginal costs involved with inland waterway infrastructure costs. This is also supported by Transportation Research Board 1996. Note, however that the Rhine is a natural river. No other types of waterway infrastructure were studied within UNITE.

Some caution seems therefore to be necessary when generalising this conclusion. The situation could be somewhat different if locks would be necessary in the Rhine. In such a situation some of the labour and energy costs would certainly be variable. Given the lack of research in this area it is obvious that more theoretical, engineering-based and empirical knowledge is necessary.

4.4 Airports

While a considerable amount of literature exists on cost function analysis for airlines, marginal cost studies on airport infrastructures are very rare. For the few that are available only limited data is revealed. The UNITE project included one study in this area. This study refers to the airport of Helsinki-Vantaa and is described in Himanen et al 2002 (see Annex A5). It was aimed at describing and analysing the cost structure of infrastructure services and at deriving short run marginal costs for these services.

Scope

Airports are complex systems where different actors – airport authorities, custom and security authorities, airlines, and other private companies – provide various services in order to facilitate for both passenger and freight the interchange between air and surface transport. Airport services can be divided into aeronautical activities focussing on the operation of aircraft and non-aeronautical activities related to the movement of passengers and freight. Table 19 shows a detailed categorisation of the different services.

The case study focused on infrastructure services while other services, i.e. transport operator services, commercial services and public sector services were excluded. Cargo services related to non-aeronautical activities were excluded, too. Services for freight flights on the aeronautical side were included.

Table 19
Airport services and their customers and producers

	Customer	Producer	Service Category
AERONAUTICAL SERVICES			
Terminal Air Traffic Control Services (pure infra)			
maintenance and development of equipment,	AL	IM	I
approach control services and	AL	IM	I
tower control services.	AL	IM	I
Manoeuvring Area Services (pure infra)			
• maintenance and development of runways and taxiways,	AL	IM	I
• cleaning and prevention of the slippery condition,	AL	IM	I
• guidance systems of air and ground traffic,	AL	IM	I
• environmental protection and	OS	IM	I
• security and fire services of manoeuvring area.	AL	IM	I
Apron Area Services (mainly infra)			
• maintenance and development of apron area and machinery,	AL	IM	I
• aircraft parking,	AL	IM	I
• aircraft handling,	AL	AL	O
• bus transportation,	AL	IM	I
• environmental protection,	AL	IM	I
• security and fire services of apron area and	AL	IM	I
• control of vehicle traffic operations and safety.			
NON-AERONAUTICAL SERVICES			
Passenger services (partly infra)			
• maintenance and development of air terminals,	AP,AL,OC	IM	I,C,O
• check-in and gate services,	AP	AL	I,O
• passport check and customs services,	AP	IM,PS	P?
• guidance and information services,	AP,OC	IM	I,C,O
• baggage handling, delivery and trolley service,	AP	IM,AL	I
• security services.	AP	IM	I
Cargo services (partly infra)			
• maintenance and development of cargo terminals,	AL,OE	AL,OE	O
• freight handling services,	AL,OE	AL,OE	O
• mail handling services and	AL,OE	AL,OE	O
• customs services.	AL,OE	PS	P?
Commercial services (no infra)			
• shops, cafés, restaurants and kiosks,	AP,OC	IM,OE	C
• tax free shops,	AP	IM,OE	C
• hotels,	AP,OC	OE	C
• posts and banks,	AP,OC	OE	C
• auxiliary services (e.g. car rental),	AP,OC	OE	C
• conference rooms and	AP,OC	IM	C
• VIP-services together with advertising and media services.	AP,OC	IM	C
Ground transport services (partly infra)			
• development and maintenance of terminal land side exit and entry roads,	AP,OC,OE	IM	I
• parking services,	AP,OC	IM,OE	I
• taxi and public transport services and	AP,OC	OE	O
• car rental.	AP,OC	OE	C

Customers: AL = Airlines, AP = Air passengers, OC = Other customers, OS = Other society.
Producers: IM = Infrastructure manager (airport), AL = Airlines, OE = Other enterprises, PS = Public sector.
Service Category: I = Infrastructure service, O = Transport operator service, C = Commercial service, P = Public sector service.
Source: JP-Transplan Ltd.

Methodological approach

Starting point for the assessment of short run marginal costs was an approach of allocating costs to different services of the airport. Based on the results of this cost allocation approach, for each service and for all services together the number of personnel was put into relation to the number of aircraft movements and the number of passengers by means of a regression analysis. The main hypothesis tested with this approach was that with increasing numbers of aircraft movements and passengers a need for more personnel arises. The validity of this hypothesis is closely related to two questions:

- Is it possible to link the number of personnel providing services to the number of aircraft movements and passengers, i.e. do they happen at the same time period?
- Is it possible in practice to schedule staff according to demand?

The study performed several linear and non-linear regression analysis. Due to the fact that only data for one independent variable (the traffic output either measured in aircraft movements or in number of passengers) was available it was not sensible to apply a translog approach. Seasonal and calendar effects were modelled by introducing dummy variables. The fact that for each service and even within the same service different kinds of agreements on extra salaries for evening and night work do exist was considered by introducing a categorical variable which represented this information.

Input data used

The cost data used in this study included the following elements:

- total costs for the year 2000 per service and cost category including detailed descriptions on the content of these cost categories,
- detailed schedules for staff use which included both the airports own staff and that of contractors.

The traffic data used included:

- the observed number of departing and arriving flights,
- the observed number of departing and arriving passengers.

This data was collected for two sample weeks, one week during the winter season and the other week during the summer season.

Estimation results

A descriptive analysis of the data firstly showed that, when also considering services which were outsourced some 80 % of total airport costs were staff costs. Secondly, it was obvious that the number of personnel followed – though in a limited manner – the number of aircraft movements. This relationship refers both to a daily pattern over the week and an hourly pattern over the day. Thirdly, the inflexibility of agreed working times is responsible for the observation that the number of personnel parallels only in a limited manner the number of aircraft movements. One aspect of this are permanent contracts which hamper a too large change of the daily numbers of staff employed. Another aspect is that there are different kinds of agreements on extra salaries for evening and night work.

Based on these observations several linear and non-linear regression models were estimated. In a first set of regression models, linear relationships between the number of personnel in all services (and also separately in each service) and two different measurements of traffic (number of aircraft movements, number of passengers) were assumed. Apart from the traffic variable the models included two dummy variables representing the seasonal effect (winter/summer) and the weekend effect, and a categorical variable for the different agreements on salaries. Due to problems with auto-correlated residuals a model with correlated error terms of second order was also estimated. And finally, some non-linear regression analysis was performed and compared with the findings from the linear models. The results from these different types of analysis can be summarised as follow (see also tables 20-22):

Table 20
Estimation results for Helsinki airport: traffic volume represented by the number of aircraft movements

Model no:	Dependent variable	R^2	Number of aircraft movements		Additional		Weekends		Season		Constant	
	number of personnel in	%	β-coeff.	(t)	β-coeff.	(t)	β-coeff.	(t)	β-coeff.	(t)	β-coeff.	(t)
1	All services	90,5	1,239	(13,14)	-35,72	(-28,7)	-4,25	(-2,44)	-13,07	(-8,76)	116,4	(36,7)
2	Traffic Control Services	76,1	0,1566	(5,10)	-7,31	(-18,0)	-4,55	(-8,04)	0,71	(1,47)	17,5	(16,8)
3	Maneuvering Area Services	85,6	0,0388	(2,03)	-2,01	(-8,03)	0,56	(1,61)	-12,65	(-42,1)	26,8	(41,9)
4	Apron Area Services	81,2	0,0903	(6,63)	-3,65	(-20,3)	-2,03	(-8,09)	-1,32	(-6,16)	12,6	(27,3)
5	Passenger Services	85,1	0,7773	(10,47)	-22,24	(-22,7)	1,78	(1,30)	0,45	(0,38)	53,1	(21,3)
6	Ground Transport Services	44,0	0,1761	(9,56)	-0,51	(-2,12)	-0,06	(-0,19)	-0,25	(-0,87)	6,6	(10,6)
7	All services	64,8	3,10	(24,8)		_		_		_	39,1	(14,1)

Source: JP Transplan Ltd.

Table 21
Estimation results for Helsinki airport: traffic volume represented by the number of passengers

Model no:	Dependent variable	R^2	Number of passengers		Additional		Weekends		Season		Constant	
	number of personnel in	%	β-coeff.	(t)	β-coeff.	(t)	β-coeff.	(t)	β-coeff.	(t)	β-coeff.	(t)
8	All services	89,6	0,0144	(11,4)	-39,80	(-35,2)	-10,83	(-6,29)	-14,55	(-9,35)	130,9	(52,5)
9	Traffic Control Services	74,1	0,0015	(3,66)	-8,01	(-22,3)	-5,40	(-9,89)	-0,40	(1,07)	19,8	(25,1)
10	Maneuvering Area Services	85,4	-0,00004	(-0,16)	-2,39	(-10,9)	0,34	(1,00)	-12,70	(-42,1)	28,0	(57,9)
11	Apron Area Services	80,5	0,0010	(5,48)	-3,99	(-25,0)	-2,51	(-10,4)	-1,43	(-6,55)	13,7	(39,1)
12	Passenger Services	85,0	0,0098	(10,3)	-24,40	(-28,5)	-2,32	(-1,78)	-0,48	(-0,41)	61,0	(32,4)
13	Ground Transport Services	42,6	0,0022	(9,02)	-1,04	(-4,88)	-0,99	(-3,05)	0,46	(-1,58)	8,5	(18,0)
14	All services	47,0	0,0401	(17,2)		_		_		_	54,8	(17,9)

Source: JP Transplan Ltd.

Table 22
Comparison of linear models with and without modelling of correlated error terms[1] for Helsinki airport

	Coefficients	Standard deviation	t	Significance
1. Linear model with dummies				
Constant	116.437	3.176	36.659	.000
Number of aircraft movements	1.239	.094	13.145	.000
Categorical variable for payments[2]	-35.720	1.244	-28.716	.000
Seasonal dummy	-13.071	1.492	-8.760	.000
Weekend dummy	-4.247	1.738	-2.444	.015
2. Linear model with dummies and correlated error terms (lag 2)				
MA1	-.437	.0537	-8.145	0.000
MA2	-.344	.0555	-6.205	0.000
Number of aircraft movements	0.983	0.114	8.645	0.000
Categorical variable for payments[2]	-31.140	1.648	-18.890	0.000
Seasonal dummy	-13.189	2.443	-5.399	0.000
Weekend dummy	-5.256	2.684	-1.958	0.051
Constant	117.203	4.062	28.856	0.000

[1] Dependent variable: total number of personnel in all services. – [2] Expressed at three levels (0, 1, 2).

Source: JP Transplan Ltd. and DIW.

1. The linear regression models with dummy variables had the best explanatory power of all tested models. Variations in the number of total personnel were explained to 90 % by the independent variables. Those models which considered each service separately were characterised by lower but still quite good model fits, except for ground transport services where the R-square value remained below 50 %. The significance of the independent variables differed between the type of services. The number of aircraft movements was highly statistically significant in all equations except in manoeuvring area services where the number of personnel was predicted best by the season variable. The variable indicating different levels of salaries per time of day was statistically significant in all equations except in ground transport services. The season variable was statistically significant for manoeuvring services and apron area services which both are impacted upon by snow removal and slippery control in winter. The weekend variable was only statistically significant in half of the equations. When using the number of passengers instead of the number of aircraft movements as an independent variable similar results were obtained. A major difference was seen with the weekend variable which has more significance when using the number of passengers. This can probably be explained by the higher occupancy rates of aircrafts during weekends. Note, however, that all these results have to be seen against the background that problems with auto-correlated residuals occurred.

2. In order to solve the problem of auto-correlated residuals a model with correlated error terms containing two lags was estimated. When comparing the coefficients from the linear model with three dummies with those from the model with correlated error terms some changes can be identified. Interpreting the coefficients, however, is more tricky since the correlated error terms also depend on the independent variables.
3. For all regression analyses with only one independent variable (e.g. without considering dummy variables) the non-linear regression models yielded a higher R-square than the linear one. A cubic approach achieved the best model fit. Analysing the different types of services in detail we found that the cubic model had with 74 % the highest explanatory power for explaining the staff employed in passenger services against international departing flights (see table 22). Table 23 shows the parameter estimates for the cubic model.

Table 23
Comparison of the explanatory power of different functional forms for staff costs at Helsinki airport

Dependent variable	Independent variable	Linear	Linear with dummies	Cubic
Total staff	International departing flights	0.52	0.89	0.73
Passenger service staff	International departing flights	0.56	0.89	0.74
Passenger service staff	All departing flights	0.59	0.87	0.66

Source: Transplan Ltd. and DIW Berlin.

Before reporting the results on marginal costs, a discussion of these different methodological findings seems to be necessary. The regression analyses performed in the study provide two alternative results: One with a high R-square and a linear shape, adjusted by correlated error terms, and a non-linear model with a lower R-square. A decision between these two results has consequences for pricing since the linear model yields constant marginal costs while the non-linear model does not. The question what is the correct or best model given the aim of the UNITE project to derive marginal costs for the purpose of pricing cannot be answered within this study only. More evidence from future similar analyses of airport costs is necessary.

Table 24
Parameter estimates for the cubic model[1)] for staff costs at Helsinki airport

Parameter	Dependent variable	
	Total staff	Passenger service staff
b0	36.0117	10.1542
b1	22.2911	14.6369
b2	-1.761	-1.1264
b3	0.0444	0.0280

[1)] Model: $y= b0 + b1x + b2x^2 + b3x^3$.

Source: Transplan Ltd and DIW.

A second consideration seems necessary with respect to the role the dummy variables play in the estimation procedure. As can be seen in table 20 the three dummy variables add a lot to the higher R-square of the linear regression. This raises the question whether these dummies simply were necessary because the study had to cope with features of data caused by the way the data was collected (e.g. containing a summer and a winter week, collection of all weekdays and weekends). It might well be that with other types of data (for example only collected in winter season and only covering the period from Tuesday to Thursday) the need for dummy variables would be different. Also this question remains open in the study and requires further research.

If we choose the linear model with dummy variables as the basic model for deriving marginal costs, the marginal costs can be represented by the β-coefficient estimated for the number of aircraft movements. Figure 5 shows the total costs based on the linear model for different types of staff costs. From the analysis it can be concluded that an extra aircraft movement needs, on average, one person or more from the airport personnel. Expressed in monetary terms the marginal costs can be estimated to € 38 for an extra aircraft movement. However, it has to be borne in mind that monetary values cause more uncertainties and therefore marginal costs expressed in person hours should be preferred. The marginal cost estimate of € 38 for an extra aircraft movement corresponds well with earlier findings for US airports. Morrison and Winston 1989 report for maintenance, operation and administration of US airports marginal cost estimates of $ 22.09 per aircraft movement. If this figure is inflated to 2000 dollars (by using the index of landing fees published by the Air Transport Association[17]) and adjusted to

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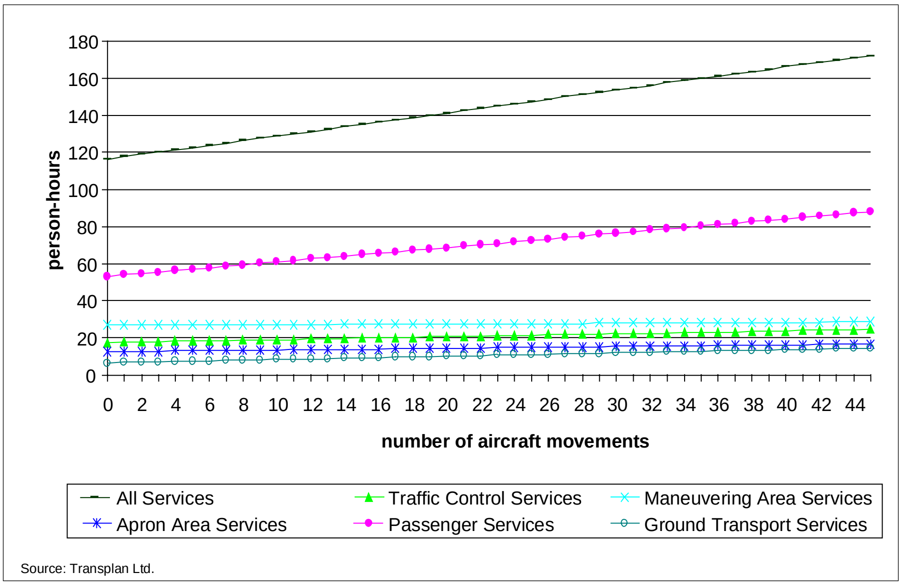
[17] www.airlines.org

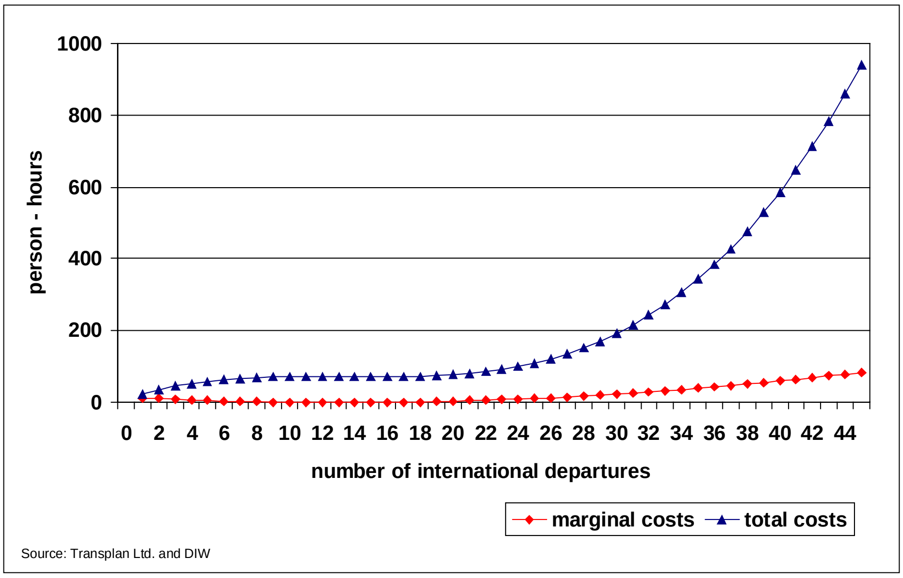
Euros, an estimate of € 32.97 per aircraft movement is obtained which comes close to the result for Helsinki airport.

Figure 5
Shape of the total cost curve for airport personnel – linear model for Helsinki airport



Source: Transplan Ltd.

Figure 6
Shape of the total and marginal cost curve for airport personnel – cubic model for Helsinki airport



Source: Transplan Ltd. and DIW

With the cubic model for the relationship between passenger service staff and the number of departing international flights, different results on marginal costs will be obtained (see figure 6). As discussed above, the study leaves open what would be the best functional form for describing the relationship between the number of personnel and the number of aircraft movements. In that respect it is also open if any model can satisfactorily explain that relationship during every hour of a day. The marginal cost estimated here can therefore be considered only as the best current estimate.

Conclusions and transferability of results

There are some aspects which have to be borne in mind when transferring the results from this study to other airports:

- According to Doganis 1996 major development programs push up the unit costs of airports. As many other airports, Helsinki-Vantaa was and is characterised by ongoing construction work (the construction of passenger terminals has just ended and the construction of a third runway is ongoing).
- For a comparison of airport costs the share of international passengers is important (see Doganis 1996). The fact that a non-linear regression model with a cubic form achieved the best model fit for departing international flights underlies this importance. The share of international flights in total aircraft movements is for Helsinki 59 %. This has to be borne in mind when transferring the results from this airport to other airports such as London-Heathrow, Frankfurt, Paris-Charles de Gaulle or Amsterdam-Schiphol, which have higher shares of international flights.
- When comparing the above results with those of other airports it should be borne in mind that the person hours used here include all outsourced activities. Except Air Traffic Control and Manoeuvring Area Services this refers to all types of services shown in table 19.
- Further differences to be considered are caused by varying accounting procedures used in different countries.
- Finally, possible differences in design and service standards have to be considered. Helsinki-Vantaa airport is characterised by a 24 hours operation and Nordic climate conditions.

It seems to be necessary to add some thoughts on the relevance of estimating marginal airport costs for pricing. Compared to the situation in road and rail, the question whether airports charge airlines appropriately is certainly not a major issue for pricing policy. However, the knowledge of marginal costs can be seen as a necessary information for monitoring the competitive and regulatory framework, especially within the context of competition between airports.

4.5 Seaports

Two case studies were performed within the UNITE project dealing with the cost structure and marginal costs of seaports. One of these referred to Swedish seaports in the Baltic Sea, the other one dealt with Mediterranean seaports. The Swedish study was an exception under two aspects. First, the study also analysed queuing and congestion costs. The results of these analyses are not presented in the main report since this deliverable is designated to evidence on infrastructure costs in the narrow sense. The interested reader can find the results on queuing and congestion costs in Jansson and Ericsson 2002 (see Annex A6). Second, the study follows a long run marginal cost approach by studying the so-called development costs of a seaport.[18]

There is not much literature on marginal cost pricing and cost analysis of port services. The existing empirical research on seaport and shipping cost functions carried out in Sweden and Israel is reported in Jansson 1974, Shneerson 1976, Jansson and Ryden 1979, and Jansson and Shneerson 1982a, 1982b, 1987. The relevant literature is mainly operation research in the form of queuing model applications to seaports and the corresponding statistical cost analysis refers both to cross-section analysis and time-series analysis.

In the short run, port infrastructure is given. The wear and tear from using this infrastructure is almost negligible (similarly as it was for airports). Therefore the short run marginal cost analysis for port infrastructure focuses on the direct cargo handling or stevedoring costs.

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[18] The term Development costs is used as an alternative for the long-run marginal costs.

4.5.1 The Swedish Seaport Study

The Swedish seaport study analysed queuing costs, congestion costs, stevedoring costs and development costs of seaports. We summarise here the findings on stevedoring and development costs since these are the relevant cost categories for infrastructure cost function analysis.

The input data used

The analysis of stevedoring costs referred to the port of Uddevala for which monthly data for the period from January 1973 to June 1976 was available. It was not possible to obtain more updated information. The data included amongst other, the total through-put of the port divided into twenty groups of commodities and the stevedoring costs expressed in total nominal wages paid every month. The stevedoring costs were deflated by using the rise of stevedoring charges rather than the rise of wage rates for stevedoring services[19]. Furthermore, it has to be mentioned that the 42 observations of throughput included one outliner.[20] The results from the analysis are reported both for using all 42 observations as well as for data excluding the odd far-out observation.

The analysis of development costs referred to the port of Norrköping. For this analysis time series of annual figures from 1962 to 1999 were obtained including the following categories:

- aggregate throughput of the port,
- investment expenditures in real terms (depreciated over 40 years)[21],
- total user costs as the sum of total transport costs of all exports and imports through the case study port,
- the number of employees,
- total labour costs in real terms.

Methodology

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[19] The rise of stevedoring charges was chosen in order to reflect both inflation effects and the effect of increased productivity of stevedoring labour.

[20] While all observations except the outlying one fell within a range of aggregate throughput between 65 000 and 170 000 tons the observations contained a figure for one month where a total throughput of 240 000 tons was handled.

[21] Excluding investments for petroleum facilities.

Starting point for the analysis of short run marginal costs was the expression of marginal costs as a sum of marginal producer costs MC_{prod}, marginal user costs and marginal external costs MC_{ext}:

$$MC = MC_{prod} + Q\frac{dAC_{user}}{dQ} + MC_{ext} \qquad (9)$$

where Q is the throughput and AC_{user} is the averages user cost.

The stevedoring costs which are relevant for short run marginal cost pricing form a major part of the marginal producer costs. To provide empirical evidence on the relationship between stevedoring costs and traffic volume a time series based regression analysis was performed. Within this analysis two alternative functional forms were analysed, the linear form and the exponential form.

The development cost analysis dealt with the problem of long run marginal cost indicating that capacity expansion over time is in focus. The implicit idea is that pricing policy should prevent over-expansion which might follow from not taking into account (i.e. excluding from the price) the costs of capacity development. The methodological idea was that by means of time series analysis the full effect on the costs of capacity expansion caused by growing demand could be estimated. However, two main problems related to this approach have to be borne in mind:

- There are user cost effects of investments in new capacity.
- Technological change and growing experience of the technology adopted during the long period of observation have to be considered.

While the first aspect refers rather to the problem which parts of marginal costs for different cost categories (user costs, producer costs, external costs) are price relevant the second aspect indicates a methodological problem of empirical estimation.

The functional form used for estimating the relationship between development costs, throughput, technological progress overtime and the learning by doing effect was:

$$\log TC = \log a + b \cdot \log Q + c \cdot \log Q_{cum} + d \cdot year \qquad (10)$$

with TC: long run total costs

Q: port throughput

Q_{cum}: cumulated port throughput

Beside the annual throughput, a further expression of traffic volume, the cumulative throughput Q_{cum} was included in this function. By this term it was hoped to reflect the effect of learning from experience. Economic literature (see for example Griffiths and Wall 2000, Pindyck and Rubinfeld 2001) usually refers to the term “experience curve” or “learning curve” when discussing firms cost savings over time as cumulative output increases. These cost savings differ from those arising from economies of scale[22]. Finally, by including the time as a separate term in the function the approach tried to control for technical progress over time.

Results

Both types of regression analyses were faced with the problem of only few observations (42 observations for the analysis of stevedoring costs and 38 observation for the analysis of port development costs). In addition, the data base for the stevedoring cost analysis referred to figures from the 70’s. These caveats have to be borne in mind when deriving policy conclusions. It would be preferable to perform similar analyses with more updated input data. However, the type of data needed is difficult to obtain and the case study had no access to better data. According to a literature review performed in the case study there is no similar study available in order to compare results.

Table 25
Result of regression analysis of the stevedoring costs on port throughput(1)
at the port of Uddevala

Form of regression equation	Number of observations	Constant	Throughput coefficient	t-value	$\overline{R}^2$
Exponential	41	0.101	1.23	8.47	0.60
Exponential	42	0.234	1.16	9.28	0.67
Linear	41	-13.369	1.658	9.66	0.69

(1) Dependent variable = stevedoring costs; independent variable = port throughput.

*Source: Annex A6 (*Jansson and Ericsson 2002).

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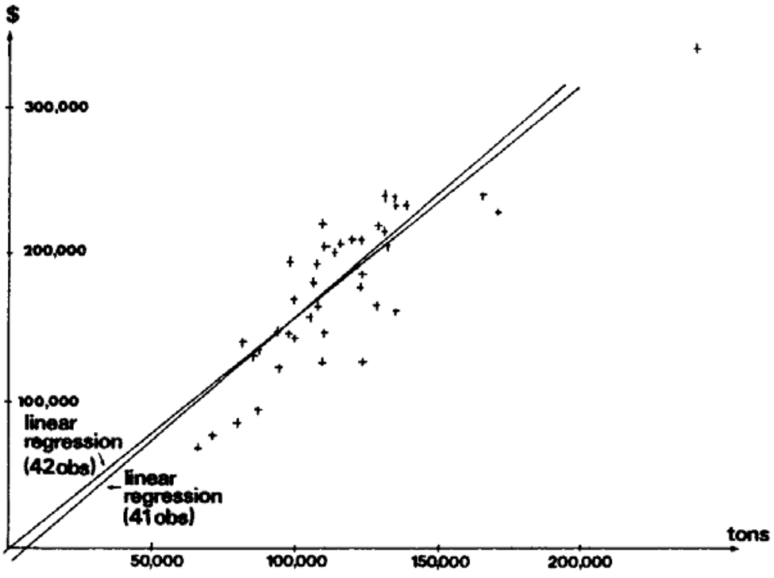
[22] Economies of scale arise when all factor inputs are variable and when the average cost of a firm has declined as a result of further inputs being adjusted.

Table 25 shows the results of the regression analysis for the stevedoring costs, both for the exponential and the linear approach. As can be seen from this table the R-squares range between 60 % and 69 %. While the result of the linear regression indicates that there is a strict proportionality between the stevedoring wage costs and the throughputs, the exponential regression indicates that elasticities between stevedoring costs and throughputs were greater than unity (1.23 if analysing 41 observations and 1.16 if analysing 42 observations). It seems impossible to draw any firm conclusion from these results. This problem is reinforced by visually analysing the scatter plot between stevedoring costs and throughput shown in figure 7.

Figure 7
Total stevedoring cost versus throughput for the port of Uddevala



Source: Annex A6 (Jansson and Ericsson 2002).

Table 26 presents the results of the regression analysis on development costs. All coefficients are statistically significant and have the expected signs. The approach was able to explain 86 % of the variance of total development costs. A major methodological problem with this analysis was the high correlation (0.912) between time and the logarithm of cumulative throughput indicating problems of multicollinearity. Dropping one or the other of the two variables of the equation, however, does not change the signs of the coefficients (for more details see Annex A6). The parameter estimates are only slightly affected and are still significant in both cases. The adjusted R-square reduces to 79 % when dropping the cumulated throughput and to 74 % when dropping the time factor from the equation. All three models were tested for absence of heteroscedasticity and autocorrelation. Both hypotheses on homoscedasticity and absence of autocorrelation in the residuals could not be rejected at the 10 percent critical value. Although the results refer to the 10 percent level only and despite the multicollinearity problem, the approach seems to be a good empirical estimation of the long run total cost-function given the fact that the autocorrelation problem is not a serious one.

The results of the regression analysis were used to calculate the ratio of price-relevant long run marginal cost to the port service producer average cost, MC/AC_{prod}. The elasticity of total (producer and user) costs with respect to throughput was found to be 0.59. Furthermore, the ratio between average user costs and average producer costs was derived from the empirical material and was calculated to be 1.17 (average value for all 38 years) and to 1.39 respectively (average value for the last 10 years only). Applying these ratios and the cost elasticity to calculate the ratio between marginal costs and average producer costs MC/AC_{prod} yields 0.11 and 0.02 respectively.

Table 26
Regression analysis of the total costs on port throughput, cumulative port throughput and time at the port of Norrköping

Model[1]	B	Std. Error	t-value	Sig.
Constant	32.883	3.291	9.991	0.000
LN_Q	0.590	0.060	9.905	0.000
LN_QCUM	-0.09234	0.021	-4.390	0.000
YEAR	-0.01031	0.002	-5.572	0.000

[1] Dependent variable = total costs; independent variables = port throughput,cumulative throughput and time.

Source: Annex A6 (Jansson and Ericsson 2002).

Conclusions and generalisation issues

Both for the analysis of stevedoring costs as a short run marginal cost and of development costs as a long run marginal cost the study results should be interpreted very cautiously due to the small number of observations. If we assume a linear shape of the stevedoring cost function we could conclude that short run marginal costs are constant within a range of 1.5 up to 1.7 SEK per ton of throughput. The exponential functional form which obtained similar explanatory power as the linear approach would lead to a cost elasticity greater than unity (between 1.16 and 1.23). The empirical evidence provided by the study is not sufficient to choose one of these functional forms.

The long run marginal cost, derived by the development cost analysis follows an exponential form with a cost elasticity with respect to throughput of 0.59. In order to interpret this result properly for the purpose of pricing decisions the issue of user cost effects of investments has to be revisited. Going back to the expression (9) it has to be borne in mind that the middle term is now a product of total throughput and of the change in the ship owners costs per ton. This is a result of an increase in throughput accompanied by the actual capacity expansion taking place. It turns out that this middle term will be a relatively large negative component of the price relevant marginal costs.

4.5.2 Mediterranean ports

A second seaport study was performed dealing with Mediterranean ports. In particular, this study focused on the largest Mediterranean port, the port of Piraeus.

Input data

The data situation for the Mediterranean ports seems to be complicated. Except for the port of Piraeus no official balance sheets were available. The study had to rely on existing data on investment financing reported to the European Community for the years 1995 to 1997. This data included port infrastructure investments broken down by several categories such as land purchase, maritime access, port infrastructure, port superstructure, infrastructure links, port maintenance work, port services and other port activities. This information was supplemented by data on freight turnover and sea container port traffic for Mediterranean ports belonging to the EU. More data was available for the port of Piraeus. Financial results (revenues, expenses and investments) for the years 1994 to 1997 were taken from the official balance sheet. A breakdown of costs into cost categories was available for the years 1997 and 1998. Furthermore, traffic data for the Piraeus port was also available for 1997 and 1998.

Methodology

Due to the insufficient data the opportunities of performing statistical analysis or engineering based cost analysis were restricted, in fact rather impossible. One part of the case study was designated to identifying those cost elements that vary with a volume of output in the short run. Furthermore, the case study tried a simplified approach of estimating short run marginal costs for the port of Piraeus by simply calculating the difference between the years 1997 and 1998. It is obvious, that this approach can lead to negative marginal costs.

Results

The study identified the following items of port costs being relevant for short run marginal costs, e.g. being costs that vary with the volume of output in the short run:

- temporary personnel and seasonally permanent personnel including overtime works,
- maintenance of port infrastructure such as dredging,
- supplies for port infrastructure and maintenance,
- special port services,
- maritime access, e.g. navigational means,
- traffic management at infrastructure links.

Due to the fact that the methodological approach of using the difference between two subsequent years does not seem to be an appropriate approach for estimating marginal infrastructure costs we do not report the results of this case study any further. The interested reader can find more details and the results in the Annex report on the Mediterranean seaport case study (see Annex A7).

5 Conclusions and generalisation

In this report we have presented results from a series of UNITE case studies dealing with estimating marginal infrastructure costs for different modes of transport. The case studies addressed both link-based infrastructure and terminal infrastructure. The case studies had to a different extent access to detailed data on costs and cost drivers. They employed different methodological approaches which mainly fall into two types, namely econometric analyses and engineering-based ones.

In chapter 1 we formulated six goals of the case studies which we recall here:

- to analyse whether the methodologies outlined in Link and Lindberg 2000 are suitable for estimating marginal infrastructure costs,
- to compare different methodologies for estimating marginal infrastructure costs,
- to provide quantitative results for marginal infrastructure costs,
- to analyse whether and how far the case study results can be generalised to other contexts,
- to discuss the experience from the case studies concerning requirements to data quality,
- to identify the sensitivity of the methodologies applied in the case studies.

The analyses presented in this report were able to achieve the majority of these goals. The feasibility of the two main methodologies (econometric analysis and engineering approach was tested. Both approaches produced sensible results. A quantitative comparison of different methodologies for estimating marginal infrastructure costs was not possible but the experience made with different approaches, and the requirements to data quality and disaggregation can qualitatively be compared. In most cases it was not possible to analyse the sensitivity of model assumptions and estimated parameters. An exception was the Swedish road study where a qualitative assessment of model assumption was performed (see section 4.1.2). All case studies except the inland waterway study and the Mediterranean port study provided quantitative estimates of marginal infrastructure costs. All case studies discussed issues of transferability and generalisation of results. As it was to be expected, these issues are the most difficult and critical ones.

After this general assessment of what was achieved in the case studies we discuss now the individual issues in more detail and draw conclusions.

Which methodology is most suitable ?

The case studies indicate that the “one” ideal methodological approach to estimate marginal infrastructure costs does not exist. Both the econometric analyses and the engineering-based case studies performed have obvious advantages but also caveats. Econometric approaches are based on observed behaviour of costs and cost drivers. It is obvious that the actual or observed costs do not always follow technical needs resulting from the use of infrastructure, i.e. do not necessarily reflect true marginal costs. In comparison, marginal costs derived with engineering-based methods are built on measured technical relationships, but which are not necessarily reflected in actual spending. They give rather an estimate of marginal costs under the assumption that all infrastructure assets are properly maintained and renewed. A direct comparison of results obtained with these two approaches was not possible since no case study had access to both types of input data. Further research needs to focus in particular on such a methodological comparison.

Both engineering-based and econometric approaches require detailed data (cross-sectional) on costs spent for infrastructure, on physical conditions of infrastructure and on cost drivers such as traffic volume, climate conditions, age of infrastructure, maintenance standards and maintenance history. The experience from the case studies is that the input data needed both for econometric and engineering-based analysis is often not available in a sufficient quality. Therefore, no recommendation can be made to prefer one approach over the other based on lower data requirements. However, first attempts were made to construct the respective databases and it seems that it is worthwhile to spend efforts doing this.

What are the relevant cost components and cost drivers ?

The case studies provided evidence that for rail tracks and road infrastructure it is mainly the cost of maintenance, repair and renewal that vary with traffic volume. For terminal infrastructure such as ports and airports it is staff costs which varies in the short run with traffic.

For rail tracks and road infrastructure the main cost drivers identified are traffic load, especially measured by weight indicators such as gross-tonne km and axle-load km, infrastructure characteristics such as number of bridges, tunnels, electrification etc., age of infrastructure and maintenance history. For terminal infrastructure where staff costs form the major category of marginal infrastructure costs the traffic load (measured as throughput in ports and as aircraft movements and departing/arriving passengers at airports) is again the main cost driver. In addition, the case studies provided evidence that the season, the weekday and the salaries' arrangement have to be considered for analysing operation costs of terminal infrastructure.

The shape of infrastructure cost functions

Neoclassical economic theory suggests a non-linear total cost curve with an u-shaped curve of marginal costs. Those case studies which had access to detailed data allowing the carrying out of either econometric or engineering-based approaches produced results which were mostly consistent with this. However, in many cases the detected non-linearities were rather weak in the relevant range of traffic variables (see for example the results for rail tracks in Sweden and Finland, but also the road results for Switzerland and Austria).

Except for the road sector there was no a-priori assumption (either from theory or from practice) for the area of the traditional "u"-shaped marginal cost curve which applies to the context studied in the case studies. For the road sector the AASHO-Road test suggests a progressively increasing cost curve, i.e. refers to the increasing branch of the "u". From the case studies there is no general answer on this question. The analyses for the Swedish and Finnish rail network, the results for Swiss roads and the long run marginal cost approach for Swedish seaports identified a cost shape which follows the falling branch of the "u". Other case studies such as the analysis of motorway renewal costs for Germany, the stevedoring cost analysis for seaports and the analysis of staff costs in relation to departing international flights at Helsinki airport provided evidence for the increasing part of the "u". The Swedish and Austrian road case studies identified degressively growing marginal costs. These obvious differences of cost functions between modes can be caused either by methodological differences or by real differences of cost behaviour, or by a combination of both.

The comparison between the road and rail results seems to indicate that rail maintenance is a decreasing cost activity while for road the opposite is true. This means that for rail the network utilisation is at a level where additional trains do not cause more maintenance than it is anyway necessary to perform. The fact that the Swedish and Finnish rail networks are among those networks with low utilisation supports this interpretation. The opposite situation is true especially for the German motorways where additional vehicles cause increasing marginal costs. It remains open whether the decreasing marginal cost curve for Swiss roads can be similarly explained like the rail results, or whether methodological problems are responsible for this result.[23]

Marginal cost estimates

Table 27 shows a summary of marginal cost estimates for road and rail infrastructure costs. As can be seen the variance between the road results is considerable. With respect to the cost components included it is possible to compare Sweden and Germany (both analysed renewal costs) and Austria and Switzerland (covering maintenance and renewal costs), although methodological differences and differences of the road types have to be taken into account, too.

Table 27
Marginal cost estimates for road and rail infrastructure costs

Mode					
Road	**Country**	**Unit**	**Mean**	**Trucks**	**Passenger cars**
	Germany1)	€ Cents/vkm	-	0.05 ... 2.70a)	-
	Austria2)	€ Cents/vkm	0.16	2.17b)	0.07b)
	Switzerland3)	€ Cents/vkm	0.67 ... 1.15	3.62 ... 5.17	0.42 ... 0.50
	Sweden4)	€ Cents/vkm	-	0.77 ... 1.86	-
Rail	**Country**	**Unit**	**Mean**	**Main lines**	**Secondary lines**
	Sweden5)	€ Cents/gross-tkm	0.013	0.0088	0.097
	Finland5)	€ Cents /gross-tkm	0.017	0.029c)	0.045d)

1) Marginal renewal costs. –2) Marginal costs of maintenance and renewals. –3) Marginal costs of maintenance (operational and constructional) and upgrades & renewals. Calculated from the minimum and maximum values of table 6 for all cost categories. –4) Marginal costs of renewals. –5) Marginal maintenance costs.

a) Marginal costs obtained from a model with the ratio between trucks and passenger cars where the AADT of passenger cars was fixed at the minimum and maximum observed value in the sample. –b) Based on log-linear regression model with vehicles-km of 2 vehicles classes. The model was statistically insignificant. –c) Refers to electrified lines. –d) Refers to non-electrified lines.

Sources: Annex A1 (Link 2002), A1b (Schreyer et al. 2002), Annex A1c (Herry and Sedlacek 2002), Annex A2 (Lindberg 2002), Annex A3 (Johansson and Nilsson 2001), Annex A4 (Nash and Matthews 2002).

The range between the minimum and maximum estimate for Germany is higher than for Sweden. A comparison between Switzerland and Austria shows considerable differences, too. However, this should not be overinterpreted since a rather small number of cases was

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[23] Due to multicollinearity problems the Swiss road study was not able to estimate a functional form with both passenger and freight variables in one equation.

available for Austria. For marginal maintenance costs of railtracks the case studies for Sweden and Finland produced marginal cost estimates of a similar magnitude. This is certainly due to similarities of data disaggregation and data quality and also due to comparable low traffic densities.

For other modes there is only few empirical evidence except for the airport and seaport case studies. The marginal costs of inland waterway infrastructure were estimated to be zero, referring to the Rhine waterway. For the Helsinki airport it was estimated that the marginal airport operating costs amount to one person-hour per aircraft movement or – expressed in monetary terms – € 38 for an extra aircraft movement. Marginal stevedoring costs for the Swedish port of Uddevala were estimated to be in a range of 1.5 up to 1.7 SEK per ton of throughput.

Transferability and generalisation

Given the fact that not much empirical evidence on infrastructure cost functions, and the associated marginal costs is available, it is necessarily a risk to recommend any generalisation of the few results or a transfer and adjustment to other contexts/countries. In general, it is not recommended to transfer output values or unit values (such as costs per sqm of road surface or rail tracks) to other context or countries. The same is true for output functions especially estimated with econometric approaches. The estimated functional forms differ too much, even within one individual mode. Examples which underline this are the Swedish stevedoring cost analysis where two functional forms fit the data, and the Finnish airport case study where for a separate cost category (staff costs for international departing flights) a different functional form than for total costs analysed was estimated.

A preferable generalisation approach is the transfer of the overall methodology, e.g. to apply the econometric or the engineering approach to data of the region/country or context at hand. However, both approaches require a large amount of data which is often not available. Therefore, at least for those types of costs and modes where the detected non-linearities are not very strong it seems to be possible to transfer cost elasticities, i.e. the ratio between the marginal and average costs. This would be the case for rail track maintenance costs and for road maintenance costs. However, given the somewhat different results of the German and the Swedish renewal cost case studies more research on renewal costs is recommended. The same is true for airports and seaports where only empirical evidence for one case study site is available.

In the following we give some values for the cost elasticity MC/AC. For road we have to conclude that this parameter is rather different for the German, Swiss, Austrian and Swedish road studies. The Swiss analyses yields a cost elasticity for maintenance and renewals/upgrades in the order of 0.8 while for Austria a somewhat higher elasticity would be obtained.[24] The Swedish engineering approach for renewal costs produces an average cost elasticity of 0.4 (with variations from 0.1 to 0.8). For the German case study results it is more complicated because we have estimated a stronger non-linearity. Necessarily we would obtain here a much broader range of estimates for the cost elasticity. Due to the progressive increase of the marginal cost curve the ratio between marginal costs and average costs takes values greater than 1 from a certain threshold of traffic volume onwards. The cost elasticities for rail are more consistent and are in the magnitude of 0.14 to 0.17 for the econometric studies and of 0.2 to 0.3 from the engineering approach reviewed in the British rail study. It needs to be mentioned that these cost elasticity estimates should be treated cautiously. If we argue that non-linearities are rather weak and derive on that basis a cost elasticity, we would actually need to fit a new linear model to the relevant, (almost) linear area of the cost function and estimate the new parameters.

Future research needs

The estimation of marginal infrastructure costs is a field with much less empirical evidence than in particular the estimation of marginal environmental or congestion costs. Against this background this report has presented new methodological and empirical results which, however, would need a broader research basis when it comes to generalisation. Especially for those modes where evidence from only one application (for example airports, seaports, inland waterways) or from applications with too similar and not typical contexts (for example the rail case studies for two networks with low traffic density) is available, more studies would be desirable. Studies which apply both the econometric and the engineering approach to the same data set would be of great interest for a methodological comparison.

A further component of infrastructure-related costs not considered so far is the user cost, which increases if roads or rail tracks are not sufficiently maintained. This component is not

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[24] However, the reliability of the Austrian result might be restricted by the small sample used.

an infrastructure cost in the common sense (as it was defined for UNITE) but it has consequences for the price-relevant marginal infrastructure cost. If infrastructure is badly maintained and the marginal infrastructure costs are estimated with an approach which assumes regular maintenance, than these marginal infrastructure costs are in fact over-estimated.

Glossary of Terms

AADT

Annual average daily traffic volume

AASHO factors

Factors which describe the impacts between axle-load and road deformation. The AASHO factors were yielded by the AASHO road test carried out in the US in 1958 in Illinois. The result of this test was that the road deformation increases with the fourth power of axle-load (4th power rule).

Annuity method

A financial-mathematical method for calculating the annual refinancing of investments. The annuities are calculated by using the formula:

$$a = u \bullet \frac{\frac{z}{100} \bullet \left(1 + \frac{z}{100}\right)^{d}}{\left(1 + \frac{z}{100}\right)^{d} - 1}$$

with:

a = annuity for the capital value

u = capital value

z = interest rate in percent

d = depreciation period (years) for the assets

In economic terms, the annuity value a is equal to the annual sum which, when discounted over the life of the asset (i. e. the depreciation period d) has a present value equal to that of the capital value u.

Average costs

Average costs are equal to the total costs of roads divided by a measure of output, such as vehicle-kms. They therefore show the costs of infrastructure provision per unit of traffic. They are particularly relevant for cost-recovery, since prices which are set equal to average costs will ensure that total costs are recovered from users. Average costs contain both fixed and variable costs. Due to this fact, they are usually calculated in order to get information on total infrastructure costs and - in combination with revenues - on cost recovery.

Axle weight-km

One of the factors used for allocating weight dependent road costs to vehicle types. They are obtained by multiplying the weight in tons on each axle with the mileage driven. The weight in tons on each axle can be derived either from the maximum gross vehicle weight or from the average gross vehicle weight.

Capacity costs

Capacity costs are those costs which occur due to the provision of infrastructure capacity independently of the level of traffic. They comprise shares of capital costs and running costs and are equal to the fixed costs. The term “capacity costs” is often synonymously used with the term “fixed costs”.

Capital costs

The capital costs comprise the consumption of fixed capital (→ depreciation) and the interest (→ interest). Capital costs represent a high share of total infrastructure costs and are different to the annual capital expenditures.

Capital value

The capital value is the value of fixed capital measured either as a gross or a net value. The *gross value* represents the capital value of all assets still physically existing in the capital stock. It can thus be considered as an equivalent of production capacity. The *net value* represents the value of assets minus the meanwhile consumed fixed capital (→ depreciation). The difference to the gross value is thus the loss of value due to foreseen obsolence and the normal amount of accidental damage which is not made good by normal repair, as well as normal wear and tear. Methods for estimating capital values are the direct method (→ synthetic method) and the indirect method (→ perpetual inventory concept).

Cost approach

There are two principal ways for elaborating infrastructure accounts: the cost-based approach and the expenditure-based approach. The cost approach is based on deriving capital cost from existing road capital values. This implies that investments with an expected lifetime of more than one year have to be capitalised (that means depreciation and interests have to be calculated).

Cost coverage

Cost coverage is the ratio between revenues and costs. It answers the question whether the costs are covered by the (respective) revenues.

Depreciation

Depreciation is an accounting charge for the decline in value of an asset spread over its economic life (life expectancy). The depreciation is a part of deriving capital costs from existing infrastructure capital values. In general there are two approaches to derive capital costs: (1) (→) The perpetual inventory method: (2) (→)The annuity method (see annuity-method).

Development costs

The term development costs is an alternative for long run marginal costs. While capacity is fixed in the short run, it is a variable production factor in the long run.

Engineering approach

A term used here to describe a method where economic theory is elaborated and it boils down so that the MC is dependent on a few parameters. Engineers estimate these parameters when roads are designed and the key to the approach is thus to find the best estimates of these parameters.

Expenditures

The annually spent money for infrastructure. They contain investments (comprising net-investments for the construction of new infrastructure and for enlargement as well as replacement investments) and running expenditure for maintenance, operation and administration/police.

Expenditure approach

One of the two principal ways for elaborating infrastructure accounts. It is based on using (annual) expenditures for investment, maintenance and operation. In this approach the annual investment expenditures are not capitalised.

Fixed costs

Fixed costs are equal to those costs, which are independent on the use of infrastructure, for example the (vehicle) mileage driven.

Fourth power law

This rule relates the road deterioration to axle weight. If the load is doubling the road damages increases by a factor 16 (=2^4).

GVW

GVW is the gross vehicle weight and contains the weight of the vehicle itself and the weight of the payload.

HGV

HGV means heavy goods vehicles.

Interest

Interest charges are part of the capital costs of infrastructure. They reflect the opportunity cost of capital (if not invested in infrastructure the funds could be invested elsewhere in the economy). The interest rate for infrastructure capital is usually comparable with the refinancing cost for governmental loans. The estimation of capital charges with a nominal interest rate (i.e. including a premium for inflation) is necessary if the capital value does not consider inflation rates (e.g. is calculated by the use of nominal investment costs = purchase costs). A real interest rate has to be used, if the capital values have been calculated at current prices.

Investment expenditures

They reflect the annual expenditures for infrastructure with durable character and a lifetime of more than one year (for example new construction of roads or reconstruction of road surface). These expenditures have to be capitalised with a depreciation rate and an interest rate reflecting the opportunity cost for the capital invested.

Lost assets

These are assets which are already amortised (e.g. which have exceeded their expected lifetime).

Maintenance

Maintenance costs reflect the costs which are necessary to maintain an existing infrastructure. We distinguish between

- ordinary maintenance, for example cleaning and winter maintenance, which is independent of infrastructure use and
- maintenance, which is dependent of the volume of vehicles or vkm (e.g. surface dressing). These latter maintenance costs are variable cost and weight dependent.

Operating expenditures

These are expenditures which are necessary to operate the existing transport infrastructure (administration, police, traffic signals, cleaning). These costs are running costs and thus do not have to be capitalised.

Perpetual-inventory method

This is a method to estimate the capital value from a time series of annual investment expenditures. Annual new investments are cumulated and - according to their remaining life time - a depreciation will be calculated. The sum of these annual remaining capital values is equal to the total amount of the capital value.

PCU (Passenger Car Unit)

PCU is used in order to standardise vehicles in relation to a passenger car. Speed and lengths differentials are most common.

PPP

PPP means purchasing power parity. PPPs are the rates of currency conversions which equalise the purchasing power of different countries. This means that a given sum of money, when converted into different currencies at the PPP rates, will buy the same basket of goods and services in all countries. In particular, PPPs are applied if figures for specific products or branches shall be expressed in foreign currency (for example in EURO or in US $) because in these cases the use of official exchange rates is not appropriate.

Purchase costs

The costs of buying a good or service.

Replacement value/cost

The cost of replacing a particular asset of a particular quality with an asset of equivalent quality. Replacement cost may exceed the original purchase cost because of changes in the prices of the assets.

Running expenditures

The costs necessary to keep a particular asset in operation, but which do not enhance the value of the asset. Running expenditures will be those annual expenditures necessary to ensure that the infrastructure provides an acceptable quality of service, but which do not maintain that quality beyond a limited period of time.

Running costs

These are equal to running expenditures.

SCI

Road surface Curvature Index

SNA

SNA stands for System of National Accounts, an international framework of definitions and methods for quantifying macroeconomic processes. Nucleus of SNA are the rules for the sector-specific accounts, the tables on production and consumption of GDP and the distributional issues of national income, the gross fixed capital formation by sectors and the input-output tables.

Standard axles

Road deterioration is heavily dependent on the axle load. As axle load may vary in a wide range a so-called ‘standard axle’ (often 10 tonne) has been defined. Functions are then estimated to relate road deterioration with standard axles.

Standard axle-km

Standard axle-km belong to the weight dependent factors used in cost allocation procedures. They are obtained by multiplying the mileage driven by a certain vehicle type with the standard axle. The standard axle is a measure of the relative road wear and is equal to the sum of the fourth power of the weight in tons on each axle, divided by 10 000 (see also AASHO factors).

Structural maintenance

Maintenance of a capital nature. A good example of structural maintenance is the reconstruction of road pavements and resurfacing. The benefits of this expenditure are received over a number of years, rather than just in the year in which the road pavement is improved.

Survival function

Survival functions are used in rather refined perpetual inventory models. The survival function g (i) is based on the assumption that the service lives of assets within an investment vintage are dispersed around the mean. g (i) explains then which share of investments within an investment-vintage still exists in the capital stock after i years. The survival function is characterised by a downwards slope of shares between 100 % (in the first year of investment) and 0 % (after exceeding the maximal lifetime of all assets in the investment vintage).

Synthetic method

One of the two main methods to value existing transport infrastructure (see also: perpetual inventory method). The synthetic method values infrastructure by estimating what it would cost to replace this infrastructure with assets of equivalent quality. The method therefore involves measuring the existing physical assets, in terms of road or rail length of particular types, bridges, etc, and then multiplying these measures of physical assets by unit replacement costs, such as the cost of constructing a motorway or rail line with the same physical characteristics as the existing one.

Total costs

The sum of capital costs and running costs. Total costs therefore give the total annual costs of infrastructure.

Variable costs

Those costs which vary with traffic levels. Examples of variable costs include wear-and-tear to road surfaces (caused largely by the passage of heavy vehicles), or to rail tracks.

Vehicle length-km

They belong to the factors used for allocating capacity costs in cost allocation procedures. They are yielded by multiplying the vehicle length of a certain vehicle category with the mileage driven by this category.

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