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Annex A1 a

Deliverable 10
Road Econometrics – Case Study on Renewal Costs of German Motorways

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Road Econometrics – Case Study motorways Germany

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1 Introduction

One component of optimal prices for road use, although not the most important one is the marginal cost of road infrastructure. While extensive studies on congestion charges and environmental charges are available much less attention has been paid to the estimation of marginal road infrastructure costs. Econometric studies on cost functions for roads are rare. The few existing sources on the relationship between costs and cost causers such as Newbery 1988a, Newbery 1988b, Newbery 1989 provide theoretical attempts to the problem but lack the empirical evidence. Other studies such as Talvitie and Sikow 1992 analyse rather the productive efficiency of highway construction by means of frontier cost functions. Existing cost allocation studies in Germany, Switzerland, Austria and Sweden as well as in other countries elaborated within the context of road accounts are usually based on expert opinion and judgement.

The study described in this annex report was aimed at closing this gap. It focuses on analysing renewal costs of German motorways during the period 1980-1999. This annex report is one of the three reports presenting the results of econometric analysis of cost behaviour on motorways in Germany, Switzerland and Austria. Since data inquiries such as the U.K., Sweden and Spain failed an extension of the analysis to other countries was not possible.

This annex report is organised as follows: Chapter 2 describes the input data used. Chapter 3 discusses the results of the descriptive data analysis and chapter 4 describes the methodological approach. Chapter 5 presents the results of the econometric analysis of motorway renewal costs while chapter 6 describes the marginal cost estimation. Chapter 7 discusses generalisation issues and concludes.

2 Description of input data

2.1 Dependent Variable

The main data source was an extensive survey on renewal measures on German motorways carried out by ASTRA (see ASTRA 2001). The data base collected within the survey was made available for the UNITE project. It contained a description of renewal measures (length of measure, type of measure, material used, thickness of layers concerned) for almost 2000 road sections of the German motorway network. The data is disaggregated for different road layers and covers all measures taken within the last 20 years, in most cases even reaching back to the 50's and before. Due to the fact that the East German road network experienced after the German re-unification a phase of extraordinary high maintenance and renewal expenditures, only the data referring to West Germany was selected for this case study. In order to obtain expenditure data the physical description of the measures had to be expressed in monetary terms. This working step was carried out by one of the leading engineering consultancies in the field of pavement management systems in Germany (SEP Maerschalk). Unit costs at 2000 prices for each type of construction were used. This approach excludes per se the price effects as a cost driver from the cost function analysis. However, possible changes of technology for renewal measures are neglected with this approach.

It was not possible to obtain any disaggregated data on expenditures for operation and ongoing maintenance. Data inquires at all road administration offices in the federal states of Germany yielded that the respective data bases are under development but not yet available. The German motorway case study was therefore an analysis of renewal costs which are characterised by two features:

1. They contain to a large part measures which are investments rather than running expenditures.
2. Their spending behaviour over time follows a cyclical pattern.

The second characteristic forms a problems for an econometric analysis because the data base contained only for a small percentage of motorway sections renewal expenditures in one year. This problem was solved by aggregating the annual expenditure data for the period from 1980 to 1999.

Note furthermore, that the renewal data did not include measures related to the renewal of bridges or tunnels, but only replacements of the different layers of the motorway. This and the fact that renewals contain to large part investive measures and only to minor part maintenance measures makes a direct comparison with available figures on motorway expenditures complicated. Using a study on the replacement of assets a German motorway in the 90's (Kunert and Link 1999) it can be concluded that the data on renewal expenditures used for the econometric analysis in the study amount to a fraction of about 70 % of replacement expenditures.

2.2 Independent Variables

A set of explanatory variables was constructed, containing the annual average daily traffic volume (AADT) of passenger cars and goods vehicles, the number of lanes, the age of motorways, the expenditures before the analysis period and climate conditions. Table 1 summarises these variables.

The traffic data was disaggregated into three groups: for all vehicles, passenger cars and goods vehicles[1]. It was derived from the automatic vehicle counting stations at the German road network for about 400 motorway sections for the years 1990 to 1999. Data for the time before 1990 was only available in paper format and its transfer to electronic form would have caused a considerable expense of labour and time. In addition this data before 1990 refers to much less motorway sections than the data from 1990 onwards. A backward extension of the traffic data with less cases would mean to include much less observations into the regression analysis than using data from 1990 onwards[2]. Note, that since the 90's about 600 automatic vehicle counting stations have been expected to deliver data on mileages of vehicle categories. However, due to failures of the devices and other reasons several gaps in the data had to be closed. Minor gaps (for example one missing year when all other years were available, missing shares of goods vehicles for one or two years when all other data was available) were closed. Major gaps, however, were not filled in with estimated values since

[1] 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.

[2] However, we tried also regression analysis by including a second traffic variable reflecting the increase of mileages driven by passenger cars and goods vehicles from 1980-1990. This analysis failed due to high multicollinearity problems.

supplementing too much missing data (for example exploding few existing data to all other sections) would bias the regression analysis.

The level of renewal expenditures in the period of analysis depends also on the maintenance and renewal practice in the past. This fact was considered by introducing two variables, one reflecting the renewal expenditures before the analysis period and another one indicating the age of the motorway section.

For analysing the influence of climate conditions data from 260 climate stations in Germany was obtained and allocated to the motorway sections covered by the analysis. According to literature road damages due to climate conditions are mainly caused by the changes of temperature from below 0 to above 0. Therefore, we constructed a variable "number of days with temperature change from below 0 to above 0" and in addition a variable indicating the number of days with snowfall. The hypothesis behind this latter variable was that if snow falls thawing salt is used which damages the road surface.

Table 1
Description of input data

	Germany
1. Cost data (dependent variable)	• data on larger renewal measures for 1837 motorways sections in 20 years • past expenditures on larger renewal measures (before 1980) • no data on running maintenance and operation expenditures
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
Road characteristics	• length of sections • number of lanes • age of sections
Maintenance information	• past expenditures (before 1980) on larger renewals
Climate	• number of days where temperature changed from below zero to above zero from 260 climate station • number of days with snowfall
3. Cases used for the econometric analysis	224
Source: DIW Berlin.	

3 Descriptive analysis

Table 2 shows the minimum and maximum values for the variables used and the mean and standard deviation. Note, that we report here average annual daily traffic volumes for the years 1990 and 1999. For the regression analysis, however, we used an aggregated variable from 1990 to 1999 (see section 2.1). Furthermore, we do not report the descriptive statistics for the age variable in table 2. The reason for that is that there are a considerable number of sections which were constructed from 1990 onwards, e.g. at the beginning or during the analysis period. In order to avoid losing cases (due to problems with logarithms for zero-values) we needed to shift the age of all sections upwards. This does not affect the regression results but would give a wrong picture for a separate descriptive analysis. Furthermore for practical reasons in the regression we finally constructed a categorical variable C_{past} for the motorway expenditures spent before 1980.

Table 2
Descriptive analysis of important variables for German motorways

Variable	Number of valid cases	Mean	Minimum	Maximum	Standard deviation
Renewal costs per km[1)] (DM million)	1830	1.73	0	29.34	2.79
Section length (km)	4138	4.48	0.031	23.03	3.44
Number of lanes	4134	2.2	1	4	0.43
Renewal costs before 1980 (DM million)	1243	0.99	0	18.76	2.37
Climate variable[2)]	4138	429	152	825	101.9
AADT[3)] passenger cars 1999	694	26395.9	1448	66488	130015.7
AADT[3)] trucks 1999	693	4521.7	339	13378	2391
AADT[3)] passenger cars 1990	594	21584.9	776	58731	11005.4
AADT[3)] trucks 1990	594	3572.8	146	9777	2006.4

[1)] Aggregated over a 20 years period (1980-1999). –[2)] Number of days with temperature changes from above to below zero from 1990 to 1999. –[3)] Annual average daily traffic volume.

Source: DIW Berlin.

Table 3
Correlation table for the motorway data Germany

		Costs per km (DM million)[1)]	Number of lanes	Costs before 1980 (DM million)	Climate variable[2)]	Age	AADT trucks[3)]	AADT passenger cars[3)]
Renewal costs per km (DM million)[1)]	Pearson Correlation	1	.175**	.160**	-.015	.206**	.195**	.002
	Significance (2-tailed)	.	.000	.000	.532	.000	.001	.979
	N	1830	1830	1201	1830	1829	279	279
Number of lanes	Pearson Correlation	.175**	1	.217**	-.081**	.429**	.478**	.631**
	Significance (2-tailed)	.000	.	.000	.000	.000	.000	.000
	N	1830	4134	1243	4134	4133	499	499
Renewal costs before 1980 (DM million)	Pearson Correlation	.160**	.217**	1	.055	.413**	.258**	.263**
	Significance (2-tailed)	.000	.000	.	.051	.000	.000	.000
	N	1201	1243	1243	1243	1243	201	201
Climate variable[2)]	Pearson Correlation	-.015	-.081**	.055	1	.051**	-.058	-.188**
	Significance (2-tailed)	.532	.000	.051	.	.001	.196	.000
	N	1830	4134	1243	4138	4137	499	499
Age	Pearson Correlation	.206**	.429**	.413**	.051**	1	.492**	.409**
	Significance (2-tailed)	.000	.000	.000	.001	.	.000	.000
	N	1829	4133	1243	4137	4137	499	499
AADT trucks[3)]	Pearson Correlation	.195**	.478**	.258**	-.058	.492**	1	.705**
	Significance (2-tailed)	.001	.000	.000	.196	.000	.	.000
	N	279	499	201	499	499	499	498
AADT passenger cars[3)]	Pearson Correlation	.002	.631**	.263**	-.188**	.409**	.705**	1
	Significance (2-tailed)	.979	.000	.000	.000	.000	.000	.
	N	279	499	201	499	499	498	499

[1)] Aggregated over 20 years (1980-1999). –[2)] Number of changes between temperatures below and above zero during the period 1990-1999. –[3)] AADT = Annual average daily traffic volume. Variable constructed as average over 10 years (1990-1999). **) Significant at 1 % level.

Source: DIW Berlin.

Table 3 shows the correlation table for the relevant variables. Generally, we can observe rather low correlations between the dependent and independent variables. As can also be seen the correlation of the dependent variable "cost per km" with the traffic variable "ADDT passenger cars" is not significant. However, there exists a significant but low correlation with the variable "AADT trucks". The highest correlation is with a value of 0.705 (at 1 % significance level) between the two traffic variables. This indicates multicollinearity problems if both variables enter the regression model. The rather low correlation coefficients should not be overinterpreted. It has to be borne in mind that the correlation table only indicates direct bivariate correlations but does not give any illustration of effects resulting from a combination of influence factors.

The figures 1 and 2 show the scatterplots of renewal costs and the traffic variables. From the visual inspection no obvious pattern can be detected. Both plots indicate a large variance and the need for logarithmic transformations as it was done for the translog approach (see section 4 on methodology). The scatterplots also confirm the result of the correlation analysis. Obviously, the observed spending pattern for renewal measures does not necessarily reflect the needs occurring from variations in traffic loads. This seems at least to be the result of the descriptive data analysis for German motorways and it is even true when aggregating the expenditures over a long time period, e.g. smoothing all cyclical effects and effects from delayed renewals due to budget reasons. Nevertheless, this preliminary finding might be a special one for the German situation. A general shortage of public money during the 90s has led to neglected maintenance and renewals and worsened road conditions (see for example Kunert and Link 1999). Therefore, the low correlation between renewal expenditures and traffic volume and the rather diffuse pattern of the scatterplots might illustrate this situation.

Figure 1
Scatterplot of renewal costs versus annual average traffic volume of trucks

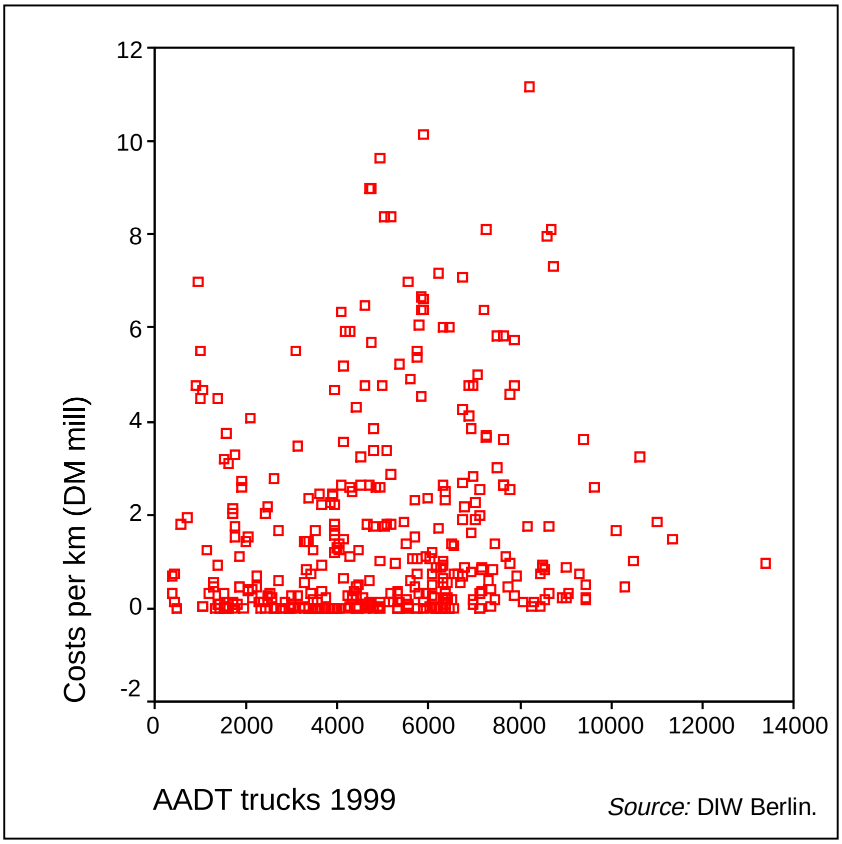
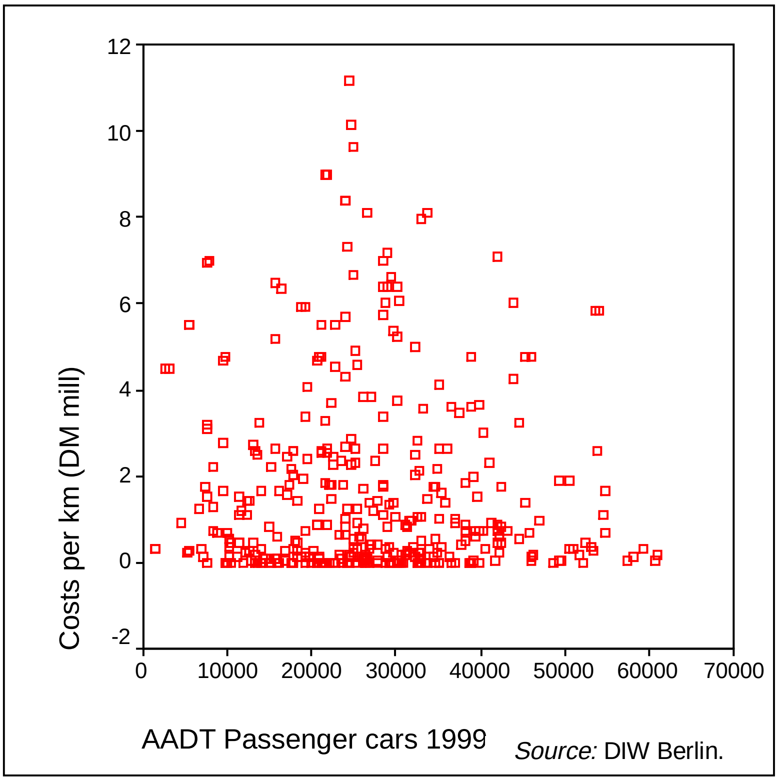


Figure 2
Scatterplot of renewal costs versus annual average traffic volume of passenger cars



4 The Model

In a first attempt a translog approach with two separate traffic variables "AADT trucks" and "ADDT passenger cars" including the respective multiplicative terms was estimated. This model failed due to serious problems of multicollinearity between the two traffic variables (some variables caused a variance inflation factor between 15 and 56). Translog-models which were estimated for one of the two traffic variables only (which included than only the second-order terms and multiplicative terms with other independent variables) achieved extremely poor R-squares. Therefore, the finally estimated model had the following form:

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

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.

The use of the ratio between the AADT-variable for tracks and passenger cars eases the problem that the dependent variable and the traffic variable refer not to the full same time period. However, with this approach some problems for deriving marginal costs for trucks and passenger cars occur (see chapter 6).

5 Estimation results

Table 4 shows the estimation results from the translog model given in (1). The model fit is with an R^2 of 21 % rather low. This however, is not surprising given the low correlation between the dependent and independent variables reported in chapter 3. Analysing the residuals from the estimated model reveals no model misspecification. Figures 3 and 4 show the p-p-plot and q-q-plot of the unstandardised residuals indicating that there are no signs of excess kurtosis or skewness. The Durbin-Watson test did not reveal any autocorrelation of first order (DW = 2.049). As can be seen from figure 5 no autocorrelation of higher order can be detected in the residuals. A slight problem seems to occur with respect to lag 4 but this reliefs for higher lags and cannot be considered to be serious. Both a chi-square test and a Kolmogorov-Smirnov Test cannot reject the normality assumption at a 5 % critical level. The graphical inspection does not indicate any heteroscedasticity.

As can be seen from table 4 the parameters of interest are significant at 5 % critical level or at least at 10 % level. An exception is the second-order term for the age variable. Furthermore, one of the district dummies is insignificant.[3] A model specification with the climate variable failed (wrong sign of the parameter). Obviously the allocation of climate data from 260 stations to motorway sections was too rough. The fact that the maximum distance between the climate stations and the motorway sections was 70 km underlines this explanation. A test for a Cobb-Douglas specification, i.e. a restriction of the translog model to the first order terms only, could not reject the translog approach. As already mentioned, trials with translog models containing both the AADT of trucks and the AADT of passenger cars as separate variables failed due to high multicollinearity. Translog models with only one of the two traffic variables yielded extremely low R^2-values (4 % and 6 % respectively).

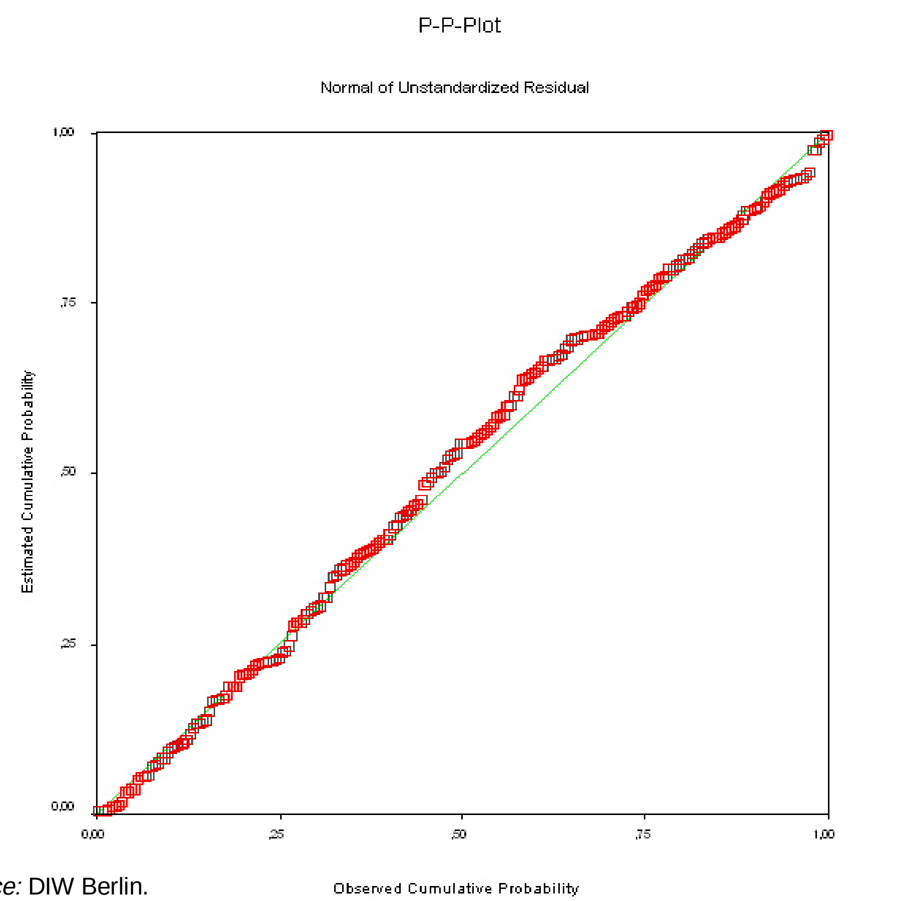
[3] This district dummy (α_2) refers to the federal state of Hamburg. Since only a few cases fall into this category the insignificant parameter is not surprising.

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

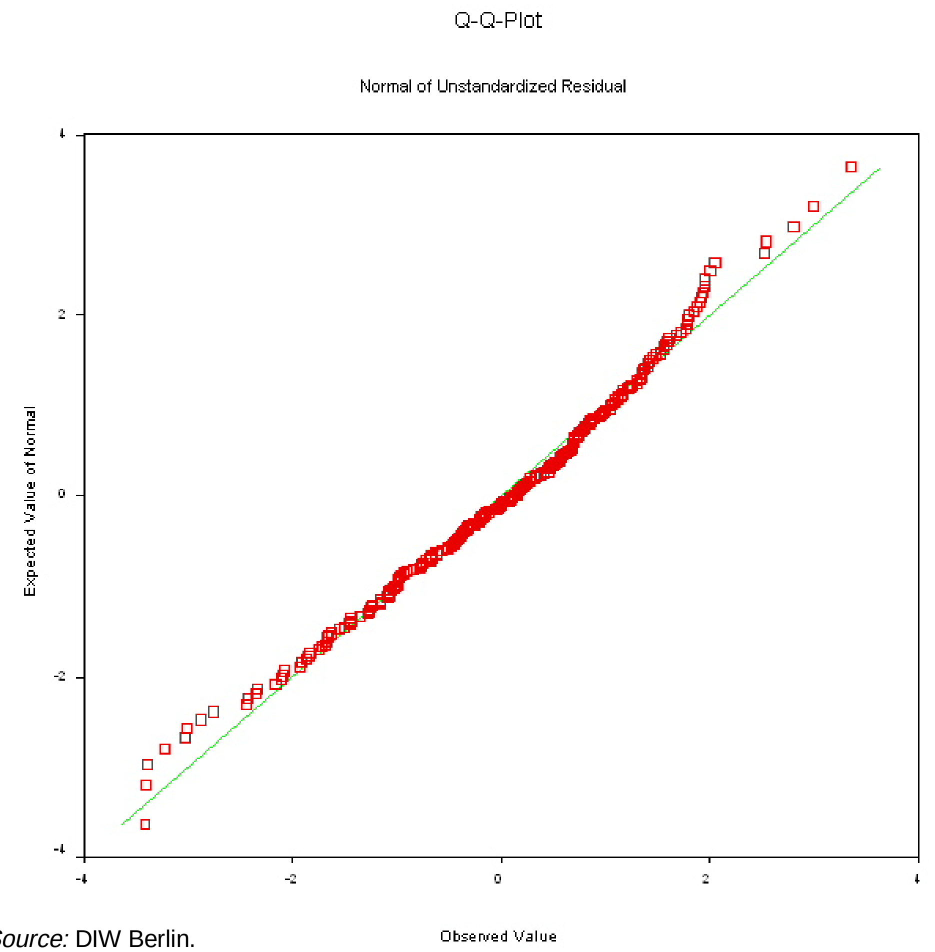
Source: DIW Berlin.

Figure 3
P-P-Plot of the standardised residuals



Source: DIW Berlin.

Figure 4
Q-Q-plot of the unstandardised residuals



Source: DIW Berlin.

6 Marginal costs

With the translog model from (1) it was only possible to derive marginal costs with respect to the ratio between the AADT of trucks and passenger cars. Let us denote this ratio with r. The derivative of the translog model with respect to r yields

$$\frac{\partial \ln C}{\partial \ln r} = \beta_2 + \beta_4 \ln r + \frac{1}{2}\beta_6 \ln age \qquad (2)$$

Transforming the logarithm of marginal costs finally gives

$$\frac{\partial C}{\partial r} = e^{\beta_2} \cdot r^{\beta_4} \cdot age^{1/2\beta_6} \qquad (3)$$

Figure 6 shows the shape of this marginal cost curve. For a proper interpretation one has to bear in mind that this is a marginal cost curve not with respect to traffic load of one of the two vehicle categories but with respect to the ratio between them. As can be seen the additional costs caused by an increase of r grow progressively. Starting at the minimum value of r in our data where the ratio between trucks and passenger cars is 0.03 we can see that the marginal costs of this traffic combination is almost zero. At a ratio of 0.04 the marginal cost is 0.2 € Cent and at the maximum value of our data, namely r = 0.44 the associated marginal cost is 2.7 € Cent. At an equal proportion between trucks and passenger cars the marginal cost would amount to 9 € Cent. Note, however, that we do not have such a value in our data set and the regression results are only valid for the data on which it was based.

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 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[4] 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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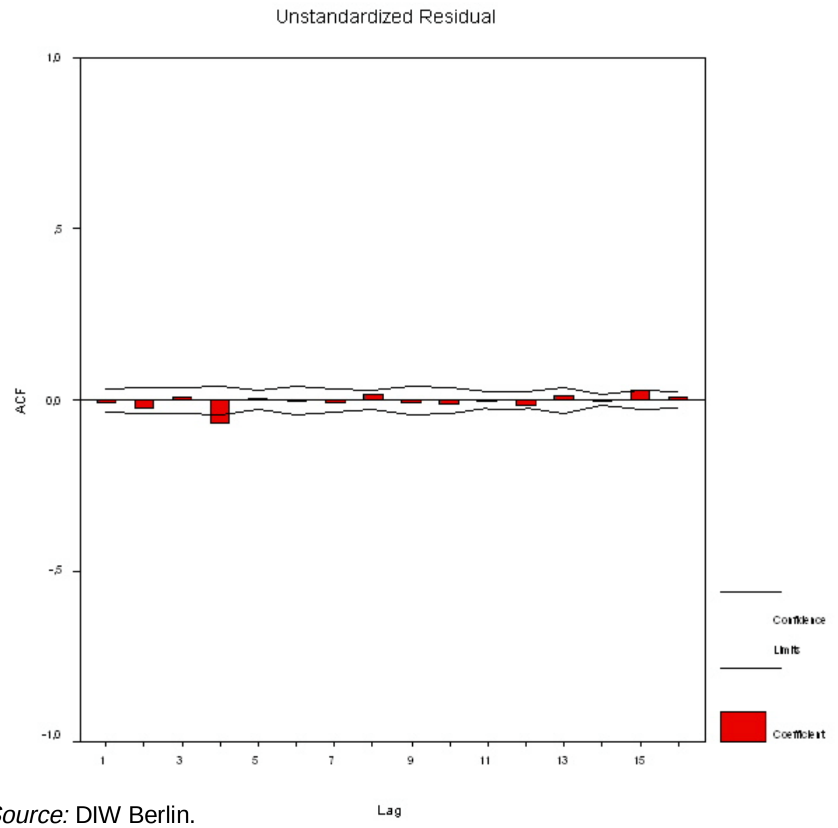
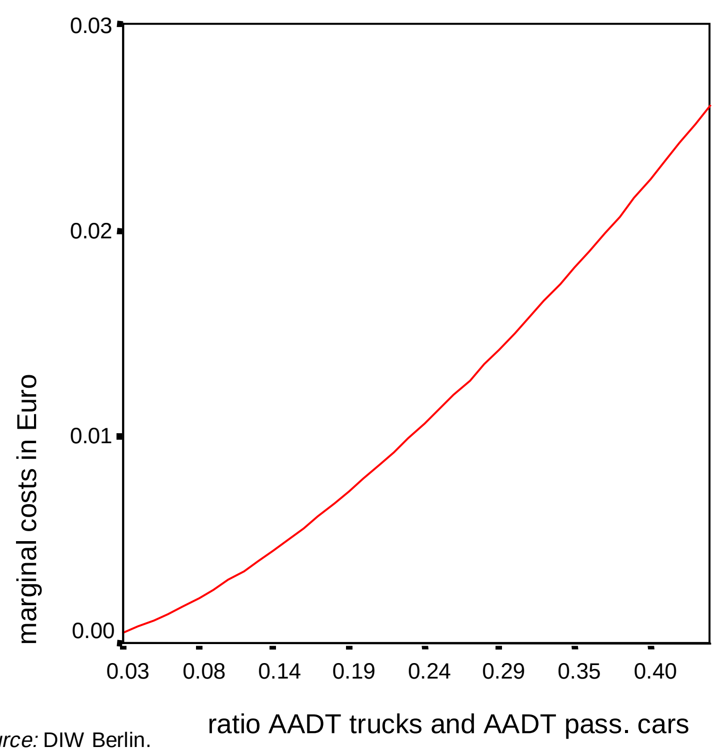
[4] The allowed range means that when fixing the AADT for passenger cars at a certain value and varying the AADT for trucks, the resulting ratio between the two has to lie between 0.03 and 0.44 (the minimum and maximum values for r in our sample).

Figure 5
Partial autocorrelation function of the unstandardised residuals



Source: DIW Berlin.

Figure 6
Marginal renewal costs of Germany motorways with respect to the ratio between the average annual daily traffic volume of trucks and passenger cars



Source: DIW Berlin.

7 Conclusions and generalisation

The cost function analysis for German motorways was the first attempt of that type to analyse the cost behaviour of motorway renewal costs. A considerable amount of time and labour had to be put on generating the necessary cross-sectional data base and the final data set cannot be characterised as a one which was actually required for such type of analysis. From the results presented in chapter 5 and 6 the following conclusions can be drawn:

From the methodological point of view it seems that the translog approach can provide sensible results for such type of analysis. However, the actually needed type of input data for traffic volume, namely a measure of axle loads, was not available. A translog model with two separate traffic measures (AADT trucks and AADT passenger cars) failed due to serious multicollinearity problems. Therefore, the only way was to use the ratio between the two. The implication of this is that no direct estimation of marginal costs for trucks and passenger cars was possible. Instead, the marginal costs with respect to the ratio was derived and by fixing the AADT passenger car variable at certain levels the development of marginal costs for trucks can be estimated.

A second methodological issue refers to the rather low R-square of the regression equation. This indicates that either important explanatory variables are missing (a hypothesis would be that introducing for example a climate variable and a variable for the type of construction would improve the model fit), or that the type of costs analysed are to a large extent rather related to spending behaviour of road authorities which is difficult to model.

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 which influence climate conditions have.

The case study has identified a non-linear shape of the marginal cost curve. The curve refers to the classical "u"-shape and within that shape to the increasing branch of the curve. This means that 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 Lindberg 2002 where a degressively increasing curve for marginal renewal costs of trucks is reported.

The illustrative values for marginal costs of trucks calculated by fixing the AADT variable for passenger cars at certain levels (sample minimum, mean and maximum) range from 0.07 € Cent to 2.7 € Cent. Compared to the results from the engineering approach (see Lindberg 2002) we can conclude that they are similar in their lower range but higher than the results from the engineering approach in the upper range.

Finally, it is obvious that improvements of the data situation are necessary for achieving better model fits with the translog approach. Moreover they are in particular necessary in order to derive directly marginal costs for types of vehicles.

The translog approach as it was estimated for renewal costs for German motorways is transferable to the analysis of other types of costs (especially maintenance and operation costs) as well as to other road types and other countries provided the necessary cross-sectional data is available. It is not recommended to transfer any quantitative output such as unit costs (costs per sqm of road surface) and the absolute level of marginal costs to other contexts (for example other road types) or other countries. A possible solution would be the transfer of the cost elasticity, e.g. the ratio between marginal and average costs.

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