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Marginal cost of road operation and maintenance

Swedish estimates based on data of 2004-2012

Jan-Erik Swärdh och Lina Jonsson

FINDING A BETTER WAY

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Abstract

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Denna studie är en del inom regeringsuppdraget SAMKOST där VTI har fått i uppdrag att utreda trafikens externa marginalkostnader. Författarna riktar ett stort tack till Mattias Haraldsson på Energimyndigheten som har granskat rapporten, till Christopher Creutzer som har varit behjälplig med databearbetningar, samt till Jan-Eric Nilsson och övriga seminariedeltagare vid VTI för värdefulla kommentarer.

Stockholm, november 2014

Jan-Erik Swärdh

Process för kvalitetsgranskning

Granskningsseminarium genomfört 2 juni 2014 där Mattias Haraldsson var lektör. Jan-Erik Swärdh har genomfört justeringar av slutligt rapportmanus xx november 2014. Forskningschef Mattias Viklund har därefter granskat och godkänt publikationen för publicering (datum). De slutsatser och rekommendationer som uttrycks är författarens/författarnas egna och speglar inte nödvändigtvis myndigheten VTI:s uppfattning.

Process for quality review

Review seminar was carried out on 2nd of July where Mattias Haraldsson reviewed and commented on the report. Jan-Erik Swärdh has made alterations to the final manuscript of the report xx of November 2014. The research director Mattias Viklund examined and approved the report for publication on (date). The conclusions and recommendations expressed are the author's/authors' and do not necessarily reflect VTI's opinion as an authority.

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Marginalkostnader för drift och underhåll på väg. Skattningar på svenska data från 2004-2012

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Sammanfattning

I den här studien skattas marginalkostnaden för drift och underhåll på det nationella svenska vägnätet. Studien bygger på VTI-notat 29-2011 där antalet observerade år har utökats till att omfatta 2004-2012.

Vägdata och trafikdata från nationella vägdatabasen (NVDB) har tillsammans med kostnadsdata från Trafikverkets (Vägverkets) bokföring utgjort vårt analyserade datamaterial. Observationerna är på driftområdesnivå.

Separata modeller har skattats för underhåll, vinterväghållning och övriga driftskostnader. Modellerna har skattats med paneldatametoden ”random effects”. En logaritmisk funktionsform har används vilket ger kostnadselasticiteter direkt från den skattade parametern. Tillsammans med mått på genomsnittliga kostnader kan marginalkostnaden beräknas.

Resultaten visar en skattad marginalkostnad på omkring 4 öre per lastbilskilometer för underhåll. Den skattade marginalkostnaden för vinterväghållning är nära noll per fordonskilometer och för övrig drift inte statistiskt skild från noll.

Jämfört med tidigare marginalkostnadsskattningar av drift och underhåll på nationella vägar ligger våra skattningar generellt lägre. En viktig anledning är att driftområden har slagits samman jämfört med tidsperioder som använts för tidigare studier.

Vi har testat andra modellspecifikationer för att analysera hur de skattade kostnadselasticiteterna förändras. Elasticiteten påverkas enbart marginellt om vi varierar exkluderade regioner med avseende på osäkerheten av kostnadsdatats bortfall. Däremot är skattad elasticitet i vissa fall känslig utifrån uppdelning på vägtyper men resultaten är inte robusta. Dessutom skulle en implementering av sådana uppdelningar bli svår eftersom vi inte på ett lätt sätt kan observera totala kostnader uppdelat på vägtyper.

Marginal cost of road operation and maintenance. Swedish estimates based on data of 2004-2012

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Summary

In this study, we estimated the marginal costs of road operation and maintenance by using the cost function approach on Swedish road network data from 2004 to 2012. The study continues the work published as VTI-notat 20-2011.

The data consists of traffic volume, costs, and road attributes for the Swedish national road network. The observations unit is road maintenance delivery units (MDU) where there were 109 such MDUs in Sweden in 2012.

Models have been estimated separately for: road maintenance, winter road operation, and other road operation. The data is given in panel format and the models are estimated with random effects. A logarithmic functional form has been used which implies that the estimated parameter can be interpreted as an elasticity. This elasticity together with the average cost yields the marginal cost.

The estimated results show that the marginal cost for road maintenance is some 0.04 SEK per heavy vehicle kilometer. For winter operation costs, on the other hand, the marginal cost is driven by all vehicles but is close to. For other road operation we cannot find a marginal cost that is statistically different from zero.

Compared to previous estimation of the marginal cost of road maintenance and operation, our estimates are somewhat lower. An important reason is that a number of MDUs have been merged since previous analyses.

We have tested other model specifications to briefly analyze how the estimated elasticity may change. The estimates are not sensitive to other region exclusions due to missing cost data, but are sometimes sensitive to road classification but in the latter case not robust across models. Also, implementation of such a result would be difficult as we cannot easily observe total cost classified into roads types.

1 Introduction

In this study, the marginal costs of road maintenance and road operation is estimated based on data of Swedish national roads. The study continues the long-run work at VTI of estimating such marginal costs (see e.g. Haraldsson, 2007; Jonsson and Haraldsson, 2009; Haraldsson, 2012). This analysis is a complement to another SAMKOST project, which are analyzing road reinvestment costs (Nilsson and Svensson, 2014).

Our present study extends the analysis of Haraldsson (2012) in two more important dimensions. First, we incorporate data of more years. More precisely we expand the data of Haraldsson (2012) to last until 2012 instead of 2009, i.e. three more years is added in our analysis. Second, we introduce more road attributes as explanatory variables than only length of the road network that was used in Haraldsson (2012). These attributes include number of bridges and tunnels, road buoyancy, and speed limits.

We follow the cost function approach and estimate the different costs separately as a function of traffic, road characteristics, winter condition variables, regional indicators, and yearly indicators. We use the random-effect panel-data estimator and assume a logarithmic functional form. The latter implies that the model coefficients are interpreted as elasticities. Based on the cost elasticity with respect to traffic and the average vehicle kilometer cost, we can calculate the marginal cost per vehicle kilometer.

1.1 Limitations

There are some data limitations that are important for our analysis. The most important one is the difficultness to allocate costs to the correct maintenance delivery unit. Fortunately, we can allocate the cost to the correct region and thus we can rely on the fractions of total costs per region which cannot be allocated to a maintenance delivery unit when we exclude data observations from the analysis. Also, we have to deal with multicollinearity problems when we estimate our models, mainly due to considerably high correlation between vehicle kilometers and road length. Thus we will specify our estimated model without using vehicle kilometers.

1.2 Disposition

In Section 2, we present the method including data sources and the empirical approach. Then the analysis follows in Section 3 including sensitivity analysis and a comparison with previously estimated marginal costs of road maintenance and road operation. The report is concluded in Section 4.

2 Method

To estimate the marginal costs of road maintenance and operation we use the cost function approach. This means that specific costs are explained by different cost driving attributes such as traffic, road characteristics and geographical region.

2.1 Data sources

The data used are road data, traffic data, and cost data, which originates from different sources. The observation unit is different “maintenance delivery units” (MDU) that the Swedish national road network is divided into. There were 109 such units in 2012, which means that the data are observed on a relatively aggregated level. Thus we have to watch out for problems with multicollinearity caused by high correlation between explanatory variables.

Compared to the analysis in Haraldsson (2012), there are fewer maintenance delivery units today because of reclassifications. We have adjusted data of all years to the current classification of MDU.

Finally, we also use data of snowfall, slippery roads and snow banks in our analysis. These data are provided by the Swedish Transport Administration and consist of region-level averaged number of days per year with such events. All municipalities within a region thus have the same observation of these variables.

2.1.1 Road data

The road data originates from a database of the Swedish national road network (NVDB). Based on this data we calculate the road length of each MDU.

Furthermore, we have a classification of different road types, from the biggest to the smallest: E-roads, highways, other primary roads, and other secondary roads. Also, we know the length of the roads with different speed limits. Both these information are used in the sensitivity analysis of our estimated models.

We have also access to other road characteristics in each maintenance delivery unit. These are, number of bridges and tunnels, road length with low buoyance, number of road resting places, and road length with cable barrier.

2.1.2 Traffic data

Traffic data is based on measurements on each road section of NVDB. The national roads in each maintenance delivery unit are divided into road sections. The number of vehicle passages is measured for each road section and reported separately for light vehicles and heavy vehicles. From these measurements the yearly traffic can be estimated. However, these measurements are not established each year so there is a calculated inflation based on road traffic forecast models. This method may imply data error of the traffic volume, especially on minor roads where the time lap between the traffic volume measurements is longer than for major roads.

In our study we use both the number of vehicle passages and vehicle kilometers as a measure for traffic flow. Vehicle passages are used in the cost function estimations while vehicle kilometers are used to calculate average costs. To calculate the vehicle kilometers we multiply the yearly traffic volume per road section with the length of the road section. Further aggregation is made by summing all vehicle kilometers in a given MDU.

2.1.3 Cost data

The cost data originates from the business system of the Swedish Transport Administration[1]. The cost data are separated with respect to road maintenance, winter road operation, and other road operation. The Swedish Transport Administration's definition of maintenance and operation is as follows, cited from Thomas (2004):

- *Maintenance* – services to preserve or restore the desired properties of the road system, and which result in effects and economic values that last for longer than one year. These measures can be planned in terms of both time and volume.

- *Operation* – services to keep the road system functioning, and which result in effects and economic values of a short-term and immediately active nature that last for less than one year. These services are in the nature of inspections, rapid rectifications of defects that arise suddenly, daily care, and the operation of road system equipment.

- *Winter road operation* – maintaining the passability and safety of the road system in accordance with established winter standards during the winter period

Examples of what is included in maintenance are repair of cracks and repair of potholes, while examples of what is included in operations are clean-up and road inspections.

We calculate maintenance as the sum of gravel road maintenance and paved road maintenance. In the same way we calculate operation as the sum of gravel road operation and paved road operation. Thereby we have three different cost classifications and three different cost functions to estimate.

2.2 Empirical approach

The models we estimate follow more or less the recommended approach in Haraldsson (2012). This means that we do not use a dynamic panel data formulation or squared terms of the traffic, and that we use the logarithmic approach:

$$\ln C_{it} = \alpha + \alpha_t + \beta_1 \ln Q_{it} + \sum_{k=1}^{n} \gamma_k \ln X_{it} + \sum_{l=1}^{m} \theta_l Z_{it} + \lambda R_i + \epsilon_{it}. \qquad (1)$$

C_{it} is the cost in maintenance delivery unit *i* in year *t* and Q_{it} is number of vehicle passages in maintenance delivery unit *i* in year *t*. *X* are other explanatory variables that can be transformed logarithmically, while *Z* are indicator variables or other variables that often take the value zero, and *R* is regional indicators. The error term, ϵ_{it}, includes the individual-specific effect. This effect is assumed to be uncorrelated with the explanatory variables as we estimate model (1) with a random-effect estimator.[2]

[1] On April 1st of 2010, the Swedish Transport Administration was established by (simplified) a fusion of the Road Administration and the Rail Administration.

[2] Other, less sensitive for assumptions, possible estimators are the fixed-effect estimator and the first-difference estimator. However, based on the relatively low variation of the variables over time for a given maintenance delivery unit we conclude that these estimators would be less appropriate than the random-effect estimator in our application.

Based on the brief discussion in Section 2.1.3, the hypotheses that we will empirically test are:

- Maintenance costs are driven by heavy vehicle traffic. This follows from technical knowledge about the relation between standard axle loadings and the wear and tear of roads, which states that maintenance costs are caused by heavy vehicles (see Haraldsson 2007, p. 39).
- Operation costs are driven by all vehicles as these costs are not associated with wear and tear of the roads.
- Winter operation costs are driven by all vehicles as these costs are not associated with wear and tear of the roads.

When we use a logarithmic functional form, an advantage is that the estimated parameter is the elasticity, which in this formulation is assumed to be constant. Then we easily can calculate the (constant) marginal cost (MC) by:

$$MC = \beta_1 \times AC, \tag{2}$$

where AC is the average cost. We calculate yearly average costs from our estimation data and averaged over the different years and MDUs. Also, we recalculated the average costs to take missing data into consideration. This missing data is presented in Table X. These average costs estimates given in the price level of 2012 are presented in Table 1.

Table 1 – Average costs in SEK per vehicle kilometer. 2012 year prices

Maintenance	Winter operation	Other road operation
0.180	0.065	0.012

Notes: Vehicle kilometer is based on all vehicles for operation but on heavy goods vehicles for maintenance.

2.2.1 Variable definitions

The different cost types are described in Section 2.1.3. These costs are all inflated by using the Consumer Price Index to prices of 2012. The variables are transformed logarithmically.

The number of vehicle passages and vehicle kilometers are described in Section 2.1.2. It is calculated separately for heavy vehicles and light vehicles, as well as for the different road classifications.

Compared to Haraldsson (2012), we have access to several more road characteristics and winter condition variables.

The road characteristics that we use are number of bridges and tunnels, road length with low buoyance, number of road resting places, and road length with cable barrier, observed on the maintenance delivery unit level. Only road buoyance of these variables is transformed logarithmically since the other three consists of a lot of zeroes.

The winter condition variables are number of days with: slippery roads, snowfall, and snow banks, yearly observed on the level of six Swedish regions. The status of the winter in Sweden may also influence the available resources for road maintenance as well as cause more or less road maintenance so we include these variables also in the maintenance cost model. Furthermore, we include the winter variables in the function for other operation costs as winter operation costs may influence the available resources for other road operation. During our observation period, the region Southeast is split with one part included in region South and the other part included in region East. However, these weather variables are based on the old regions and thus for the new region South calculated as the average between the old regions South and Southeast and for new region East calculated as the average between the old regions East and Southeast.

The traffic variable in the cost function would ideally be vehicle kilometers as this measure controls for the length of the road sections where the traffic passages is measured. However, using vehicle kilometers will generate high correlation between vehicle kilometers and road length leading to the problem of identifying separate effects of these explanatory variables. Thus, to identify the effect of traffic on costs we are instead using the number of vehicle passages. We can still calculate the marginal cost per vehicle kilometer by using equation (2) with the average cost expressed in vehicle kilometers.

Indicator variables for region and years are also used in all models. Region Mitt and year 2004 are the references.

2.2.2 Excluded observations

In Haraldsson (2012), there is an analysis of missing values with respect to MDUs for the years 2004-2009. The fraction of costs that cannot be specified to a specific maintenance delivery unit is presented in Table 3 of Haraldsson (2012). This table is reproduced as Table 2 here below. However, the region of the cost can be observed and based on these fractions some regions are excluded from the analysis. Regions with more than 40 percent costs not specified to a maintenance delivery unit seem to have been excluded.

In our study, we want to include balanced panels as long as possible. Thus we exclude the region for all years if we decide to exclude the regions. However, since we do not distinguish between paved and gravel roads and have more years in the data, we cannot use Haraldsson’s (2012) exclusions without consideration.

Region West for all cost types and region Mitt for maintenance are all excluded with almost all costs unspecified to a certain maintenance delivery unit in years 2004-2009. Therefore, we exclude these regions also in our analysis. It is more problematic to decide for region Mitt regarding maintenance and region Mitt and region Stockholm regarding other operation since these are treated differently in Haraldsson (2012) with respect to paved and gravel roads. Based on aggregated values of the cost missing values, we decide to exclude region Mitt in the maintenance cost analysis and include region Mitt and region Stockholm in the other operation cost analysis. We will present sensitivity analysis of these regions in Section 3.6.

The other regions have only small fractions of costs not specified to a certain maintenance delivery unit so we include these regions in the analysis. Finally, region Skåne for gravel roads maintenance have 33 percent of the costs not specified to a maintenance delivery unit in year 2004-2009 but only 8 percent of the costs for paved roads maintenance. Also, in the new region classification Skåne is unitized with parts of the region Southeast to the new region South. Region Southeast had only 8 percent for paved roads and 2 percent for gravel roads unspecified costs in analysis of Haraldsson (2012), and therefore we include the region South in our analysis.

We have also decided to exclude 8 MDUs because the calculated traffic flows showed yearly variation which is not likely to happen under the assumption of the same geographic size during all years. All these MDUs are merged compared to the MDU classification in Haraldsson (2012).

To sum up, in the main analysis of Section 3.2-3.4 we exclude regions for all years based on Table 3 in Haraldsson (2012). The sensitiveness of the region exclusions are tested in Section 3.6.

Table 2 – Percentage of costs that cannot be specified to a MDU

Region	Maintenance		Winter road operation	Other road operation	
	Paved	Gravel		Paved	Gravel
North	4	14	1	4	3
Mitt	85	22	2	49	8
Stockholm	86	100	35	41	31
West	98	98	100	100	100
Mälardalen	22	0	0	6	0
Southeast	8	2	3	28	18
Skåne	11	33	3	16	3

Notes: This Table is a reproduction of Table 3 of Haraldsson (2012).

3 Analysis

3.1 Descriptive statistics

In Table 2 we present minimum, mean, standard deviation and maximum values of our included variables.

Table 2 – Descriptive statistics

	Min	Mean	Std. dev.	Max
Maintenance costs	31.7	6630	7833	57600
Winter operation costs	1.34	16700	7647	61300
Other operation costs	5.27	3025	2396	15600
Vehicle kilometers*	9.64	499000	409000	2350000
Heavy vehicle kilometers*	0.14	54800	41900	208000
Road length, kilometers	123	965	379	2958
Road buoyance, kilometers	0	4.98	6.66	323
Tunnels and bridges	0	114	172	1136
Resting places	0	0.88	1.83	13
Cable barrier, kilometers	0	3.32	54.8	223
Slippery road, no of days	67.9	163	62.8	315
Snowfall, no of days	36.6	100	43.2	178
Snow banks, no of days	5.10	19.7	12.9	55.9
Region Mitt		0.215		
Region North		0.224		
Region Stockholm		0.103		
Region South		0.195		
Region West		0.119		
Region East		0.144		

Notes: For indicator variables only mean is presented since other measures are non-informative. Variables marked with * is defined in millions. The cost variables are in 1000-SEK and based on the sample that is used in that specific estimation.

Common for all variables is the large variation, which can be seen from that the standard deviation is large compared to the mean. This is especially obvious for maintenance costs and some of the other road characteristics. Here, also the logarithmic functional form has an important role to improve the model fit. Of the total vehicle kilometers heavy vehicles consist of about one tenth. The large variation in cost and vehicle kilometers is plausible considering the heterogeneity of the MDUs, which can be seen from the large variation in road length.

Furthermore, the mean cost is highest for winter operation and lowest for other road operation. In fact, almost two-thirds of the total maintenance and operation costs is due to winter operation. Here, new classification of maintenance cost may be the important reason. For example, in Haraldsson (2007) total road maintenance costs certainly including reinvestment costs are about 1.5 as high as the winter operation costs. Thus we have reasons to believe that reinvestment costs, all or some parts of them, are not included in our data.

3.2 Road maintenance

In Table 3, the estimated cost function for maintenance is presented. As described earlier, we hypothesize that heavy vehicle kilometers cause the wear and tear of roads. This has been tested in a model where both heavy vehicles and light vehicles are included as explanatory variables. The coefficient for heavy vehicles is positive and weakly significant while the coefficient for light vehicles is non-significant. Also, a model with heavy vehicles only leads to the highest rate of explanation. Thus we conclude that heavy vehicles only cause wear and tear of roads and the model presented in the table is based on such specification.

The vehicle-passages coefficient is positive but only weakly statistically significant with an elasticity of 0.19. Road length is as expected positive and significant. The other road characteristics are all non-significant and thus variation of these variables has no influence on maintenance costs. Furthermore, among the winter condition variables, slippery roads is negative and significant. The reason may be that more days with slippery roads during the winter take resources and thus may lead to less maintenance during the rest of the year.

There are region and time effects of the maintenance costs. Region East has significantly lower maintenance costs than region North. Most of the yearly indicators are non-significant, with 2010 as an outstanding observation. The maintenance costs of 2010 are more than twice as large as the maintenance costs in other years. This may be due to extra resources addressing maintenance in this particular year.

3.3 Winter road operation

In Table 4, the estimated cost function for winter road operation is presented. As described earlier, we hypothesize that traffic of all vehicles causes the winter road operation costs. This has been tested and no evidence speaks for using another measure of traffic than both light and heavy vehicles. Also, this model has the highest overall *R*-square compared to models with only heavy or light vehicles included.

The traffic-passages coefficient is positive and statistically significant with an elasticity of 0.15. Also, road length is positive and significant as expected. Among the other road characteristics, low road buoyance and the number of tunnels and bridges are both positive and significant. It seems plausible that more of both these characteristics compound the winter operation and thus increasing the costs.

The winter condition variables are all positive as expected, though the significance varies between them. The strongest effect on winter operation costs seems to be caused by slippery roads.

There are some regional effects that seem plausible when considering different weather conditions in Sweden. Region North likely have less winter operation costs than most regions since the temperature variation from below 0 degrees to above 0 degrees and vice versa are less common in the north. These temperature variations are one source for costly winter operation. Finally, there are small time effects of winter operation costs.

Table 3 – Estimated cost function for road maintenance

Passages – heavy vehicles	0.194* (0.140)
Road length	0.823*** (0.172)
Road buoyance	-0.019 (0.026)
Tunnels and bridges	0.001 (0.001)
Resting places	-0.041 (0.051)
Cable barrier	-0.084 (0.161)
Slippery road	-0.841*** (0.326)
Snowfall	0.018 (0.331)
Snow banks	-0.063 (0.152)
Region North	Reference
Region South	-0.353 (0.421)
Region East	-1.07*** (0.357)
Year 2005	0.108 (0.165)
Year 2006	0.134 (0.160)
Year 2007	-0.047 (0.175)
Year 2008	0.022 (0.177)
Year 2009	0.141 (0.177)
Year 2010	1.53*** (0.286)
Year 2011	-0.086 (0.217)
Year 2012	0.174 (0.237)
Overall *R*-square	0.450
No of observations	439

Notes: All non-indicator variables except Tunnels and bridges, Resting places, and Cable barrier are transformed logarithmically. Robust standard errors are given in parenthesis. ***, **, and * denote statistically significance from zero at the one, five, and ten percent level respectively. The estimations also include an intercept. Cable barrier is divided by 100 000. Region North is reference variable for paved road since region Mitt is excluded from the analysis. Passages and Road length are hypothesized to be non-negative and is therefore tested with a one-tail test.

Table 4 – Estimated cost function for winter road operation

Passages – all vehicles	0.151*** (0.062)
Road length	0.484*** (0.076)
Road buoyance	0.019* (0.012)
Tunnels and bridges	0.001** (0.000)
Resting places	-0.023 (0.015)
Cable barrier	0.032 (0.079)
Slippery road	0.269** (0.131)
Snowfall	0.220 (0.154)
Snow banks	0.131* (0.071)
Region North	-0.317*** (0.110)
Region Stockholm	-0.510*** (0.171)
Region South	0.029 (0.162)
Region East	-0.085 (0.122)
Year 2005	-0.105 (0.080)
Year 2006	-0.057 (0.075)
Year 2007	-0.056 (0.077)
Year 2008	-0.146 (0.083)
Year 2009	-0.005 (0.083)
Year 2010	-0.338** (0.142)
Year 2011	-0.102 (0.090)
Year 2012	-0.234** (0.107)
Overall R-square	0.337
No of observations	742

Notes: All non-indicator variables except Tunnels and bridges, Resting places, and Cable barrier are transformed logarithmically. Robust standard errors are given in parenthesis. ***, **, and * denote statistically significance from zero at the one, five, and ten percent level respectively. The estimations also include an intercept. Cable barrier is divided by 100 000. Passages and Road length are hypothesized to be non-negative and is therefore tested with a one-tail test.

3.4 Other road operation

In Table 5, the cost function for other road operation is presented. Also here, vehicle passages for all vehicles are presumed as the relevant traffic measure. This has been tested and we conclude that we have no evidence for using another measure of traffic. Also, the rate of explanation is highest for a model with vehicle passages for all vehicles.

The vehicle-passages coefficient is positive but non-significant at conventional significance level. Road length is, on the other hand, significantly positive as in all previous estimation.

Table 5 – Estimated cost function for other road operation

	Paved
Passages – all vehicles	0.073 (0.092)
Road length	0.301*** (0.112)
Road buoyance	-0.013 (0.015)
Tunnels and bridges	-0.000 (0.003)
Resting places	-0.006 (0.022)
Cable barrier	-0.249** (0.117)
Slippery road	0.326** (0.137)
Snowfall	-0.315* (0.165)
Snow banks	-0.067 (0.075)
Region North	0.476*** (0.147)
Region Stockholm	0.225 (0.226)
Region South	0.065 (0.201)
Region East	0.983*** (0.167)
Year 2005	-0.226*** (0.083)
Year 2006	-0.345*** (0.078)
Year 2007	-0.221*** (0.081)
Year 2008	-0.162* (0.088)
Year 2009	-0.147* (0.087)
Year 2010	-0.103 (0.150)
Year 2011	-0.403*** (0.098)
Year 2012	-0.029 (0.117)
Overall R-square	0.333
No of observations	703

Notes: All non-indicator variables except Tunnels and bridges, Resting places, and Cable barrier are transformed logarithmically. Robust standard errors are given in parenthesis. ***, **, and * denote statistically significance from zero at the one, five, and ten percent level respectively. The estimations also include an intercept. Cable barrier is divided by 100 000. Passages and Road length are hypothesized to be non-negative and is therefore tested with a one-tail test.

Among the road characteristics variables, there is an unexpected effect of lower operation costs when there are more roads with cable barriers. There is no clear reason for why this effect may occur.

More days with slippery roads lead to more operation costs while more days with snowfalls leads to less operation costs. Neither these effects have a clear reason.

Finally, there are regional and time effects also for the operation costs. The regional effects are considerably strong where both the regions North and East have much higher costs than the reference region Mitt. Regarding the time effects, it seems that the reference year has the highest operation costs.

3.5 Marginal cost estimates

In Table 6, we present the marginal cost estimates based on equation (2), i.e. the marginal costs are calculated from the average costs of Table 1 and our estimated cost elasticities.

Table 6 – Marginal costs in SEK per vehicle kilometer. 2012 years prices

	Cost elasticity	AC	MC
Road maintenance	0.194	0.180	0.035
Winter road operation	0.151	0.065	0.001
Other road operation	0.073 / 0	0.012	<0.001 / 0

Note: Vehicle kilometer is based on all vehicles for winter and other road operation but on heavy vehicles for maintenance.The cost elasticity for other road operation is not statistically significant and therefore we present two alternative of cost elastictities in the Table.

We can see that the marginal cost for road maintenance is some 0.04 SEK per heavy-vehicle kilometer. For operation, on the other hand, the marginal costs are as our hypothesis states driven by all vehicles. Here, the marginal cost is so close to zero to be consider almost negligible in a drivers perspective both for winter road operation and for other road operation.

How large is then the aggregated marginal costs for the whole country of Sweden? If we use the mean values of vehicle kilometers from Table 2 and multiply with the 109 maintenance delivery units, the aggregated marginal costs are 1.9 Billion SEK for road maintenance, 5 Billion SEK for winter operation, and 0.4 (or 0) Billion SEK for other road operation. Thus, the aggregated costs are not negligible, but bear in mind the statistical uncertainty of the estimates.

3.6 Comparison with previous studies and sensitivity analysis

Here we first analyze how our estimated results differ from previous Swedish studies of marginal cost for road operation and maintenance. However, since previously estimated marginal costs in some cases are relatively imprecisely estimated, there is a possibility that the magnitude of our estimates is different when new extended data is analyzed. Also, recall the different definitions of maintenance costs in this study where reinvestments costs are not included. We compare the cost elasticities instead of the marginal costs since the former are not sensitive to different price years and different estimates of the average costs.

In Table 6, results from three previous Swedish studies of marginal cost estimates are compared with the result in our study. We can see that our estimates are lower than Haraldsson (2012) in all cases. The largest differences appear for other road operation where our estimate is much lower than previous estimates. The reasons for lower road operation elasticity may be the estimation of paved and gravel roads together but also the fact that Haraldsson (2012) estimated the elasticity of gravel road operation without including road length as an explanatory variable.

Table 6 – Comparison with previous cost elasticity estimations.

	Haraldsson (2007)	Jonsson och Haraldsson (2009)	Haraldsson (2012)	Current study
Paved road maintenance	0.30	0.39	0.80	0.19
Gravel road maintenance	0.27		0.51	
Paved road operation	0.41	-	0.47	0.07
Gravel road operation	0.59	-	0.52	
Winter road operation	0.00	-	0.56	0.15
Years analyzed	1998-2002	2004-2007	2004-2009	2004-2012

Notes: Haraldsson (2007) are based on short-run elasticities for the sub samples.

Compared to marginal costs on the EU-level referred to latest EU handbook on external costs of infrastructure (Ricardo-AEA, 2014) our estimates are much lower, both for light and heavy vehicles. The comparison is not straight-forward though because the dominant part of the marginal cost for wear and tear of roads in SAMKOST is based on the analysis of reinvestment costs in Nilsson and Svensson (2014).

We have also tested to experiment with the excluded regions based on Table 2 and estimated the preferred model specification with including or excluding regions as described in Section 2.2.3. The results show that the significance of the estimated elasticities is unchanged and the magnitude of the estimated elasticities changes only slightly.

We have also tested to use separate road classes in our models with mixed results. Sometimes, the model is improved and the new variables have a clear interpretation but mostly the new variables are non-significant and separate effects are thus not identified. The reason may be that the relatively aggregated level of data and the missing value problems regarding the costs imply that fairly complicated model specification cannot accurately be estimated. An important problem to solve, however, for implementing models with road-type specific cost elasticities is that we need total costs per road type to calculate the average cost[3] and subsequently the marginal cost. Such cost classification is available neither in our data nor in the Annual Report of the Swedish Transport Administration.

[3] Or average cost per road class if the variables are separated in road classes.

Regarding the vehicle type that drives the different type of costs, our analysis supports the theory of heavy vehicle driving the costs of maintenance whereas the costs of winter operation and other operation are caused by all vehicles.

Finally, we have tested to estimate the cost elasticity of road maintenance for different time periods. To split the time period in two parts, that is 2004-2007 and 2008-2012, leads to interesting results. The cost elasticity of 2004-2007 is 0.33 and statistically significant, and for 2008-2012 the cost elasticity is about 0 and not statistically significant. This observation raises the difficult question of which time period to use for this kind of empirical analysis. It is not clear that more years of data necessary is better but there might be fluctuations over the year which will be considered if the time period is sufficiently long. If this result is a time trend or only a temporary fluctuation is something that future research has to answer.

4 Conclusions

In this study, we have estimated the marginal costs of road maintenance and operation by using the cost function approach on Swedish road network data from 2004 to 2012. The Swedish road network is categorized into maintenance delivery units (MDU), which is the observation level in our dataset.

Our estimated results show a marginal cost of some 0.04 SEK per heavy vehicle kilometer for road maintenance. For road operation, on the other hand, the marginal cost is close to zero on the vehicle-kilometer level for winter road operation and not different from zero for other road operation. Aggregated on the national level, on the other hand, the marginal costs sum up to 1.9 Billion SEK for road maintenance and 5 Billion SEK for winter operation.

As expected, most relevant for explaining maintenance and operation costs are road length. Other road characteristics, on the other hand, show mixed results.

We have compared our results with previous Swedish estimates of road maintenance and operation based on data of different time periods. Our estimates are lower in general which may have different explanations. One such important explanation is that the MDUs have changed during the time period and we have merged them for all observation years. The number of MDUs is 24 less in our analysis than in the data of 2004-2009 used in Haraldsson (2012).

Further empirical analysis shows that our estimated results are not sensitive to the excluded regions due to missing values of the costs. Different road classifications, on the other hand, sometimes cause changed results but mostly the parameters are difficult to identify. Also, implementation of such results would be difficult though, as we cannot easily observe total costs separated with respect to different road classifications.

For the future we can extend this analysis in several different ways. The data can be improved by incorporating more years but also by performing a more rigorous analysis of the missing values. Further, the estimated models can be improved, especially for road maintenance where a lagged dependent variable may be included as an explanatory variable. Such dynamic panel data models, however, require careful estimation procedure and one need to take endogeneity problems into account. Therefore, we have not been able to perform such time-consuming analysis within our study. Also, experience from Haraldsson (2012) shows that it is difficult to reach significant coefficients and that it is impractical, due to implementation reasons, to estimate the marginal costs both in the short run and in the long run, which will be a result of dynamic panel data estimation.

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