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Annex to Deliverable D 3

Marginal cost case studies for road and rail transport

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Abstract

To improve the efficiency of rail transport is an important objective of both the Swiss and the European transport policy. Track access and infrastructure charging are important instruments of such a policy. With respect to these instruments, Switzerland pursues a policy that follows closely the European approach of liberalization. In this paper, we provide a basis for a more marginal cost oriented railway infrastructure charging scheme. The objective is to estimate marginal costs of railway maintenance for Switzerland. The hypothesis is that marginal costs of railway maintenance are a function of different independent explanatory variables. Such explanatory variables are output measures like gross-ton-kilometers as well as technical and spatial features of the railway system. The methodology used to estimate marginal costs of railway maintenance refers to former European studies. We estimate cost functions using econometric methods and calculate marginal costs. A database covering 371 track sections from 2003 to 2005 (1113 observations) has been available for this study.

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1 Introduction

To improve the efficiency of rail transport is an important objective of both the Swiss and the European transport policy. Track access and infrastructure charging are important instruments of such a policy. With respect to these instruments, Switzerland pursues a policy that follows closely the European approach of liberalization.[1]

The Swiss railways reform introduced in 1999 the separation of infrastructure and transport sectors in terms of accounting and organisation. Access to the railway network was adapted to the EU-directive 91/440. There is open access for Swiss railway undertakings in freight traffic, for passenger traffic a concession for the conveyance of passengers is required. In freight traffic also foreign companies have open access to the Swiss railway system on the basis of reciprocity. As there are no discounts on quantity or other non-linear tariffs the reform increased competition substantially, especially in the market of transalpine freight traffic where several new railway companies entered the market.

According to Art. 9b para. 3 of the Swiss Railway Act (Eisenbahngesetz) the infrastructure manager has the basic right to charge the access. The charge has to be non-discriminatory and it can take into account different infrastructure costs (e.g. caused by topography), the environmental impact of vehicles as well as the characteristics of demand. The Swiss Federal Council determines the basic principles of charging and defines the rules of publication. These details are subject of the ‘Netzzugangsverordnung‘ (Swiss Order of Network Access). Basically, for regular and licensed passenger traffic the charge consists of the standardized marginal costs and a part of the revenues of traffic services (contribution margin). Today the train path price in Switzerland consists of several components.[2]

- “Minimum price”: Maintenance (0.0025 CHF/Gtkm[3]), train operation service (0.4 CHF/train- km), purchase of energy (0.0029 – 0.0062 CHF/Gtkm) and supplements for nodes (big nodes: 5 CHF, small nodes: 3 CHF).
- Contribution margin: Long-distance passenger traffic (4% share of revenue), regional passenger traffic (14% share of revenue), goods traffic (0.0052 CHF/Nettkm)[4]

We can conclude that train path prices in Switzerland correspond to some kind of calculated average costs respectively a “standardized level of marginal costs” (“Normgrenzkosten”). The equivalence to marginal costs is quite rudimental as there is no reflection of the specific costs of axle load, quality of rolling stock (‘track friendliness’) or speed. There are also no scarcity charges for congested lines, no peak load charges and the quality of a train path is not taken

[1] The European railway policy has been described in many places, see e.g. Commission of the European Communities (2001), White Paper: European Transport Policy for 2010: Time to Decide, COM (2001)370, Brussels.

[2] Due to subsidies (with the political aim of modal shift) the charges for freight traffic are temporarily reduced.

[3] Gtkm means gross-ton-kilometers.

[4] This is for the railway network of SBB (Schweizerische Bundesbahnen), on the one of BLS it is 0.0035 CHF/Gtkm.

into account. Overall, the infrastructure charging scheme offers only small incentives for a more efficient use of the railway system.

In this paper, we try to provide a basis for a more marginal cost oriented railway infrastructure charging scheme. The objective is to estimate marginal costs of railway maintenance for Switzerland. The hypothesis is that marginal costs of railway maintenance (as well as those for operation and renewal) are a function of different independent explanatory variables. Such explanatory variables are output measures like Gtkm or the number of trains or axles as well as technical and spatial features of the railway system.

The methodology used to estimate marginal costs of railway maintenance refers to former European studies, which focus on marginal costs and use micro-level data such as Johansson and Nilsson (2004), Tervonen and Idström (2004), Gaudry and Quinet (2003), Munduch et al. (2005), and Andersson (2006).

The outline is as follows. In section 2, we describe the collected data used for our econometric estimations. Section 3 summarises the model specification and presents the estimation results. In section 4 we derive results with respect to marginal costs while section 5 covers our conclusions.

2 Description of data

The first project step concerned the data base. To begin with, data availability was discussed with experts from SBB (Schweizerische Bundesbahnen), the national railway company of Switzerland. Responsible persons from SBB have assured their interest in the study and their willingness to provide the data needed. However, the discussion also showed that it would be a demanding task to generate a consistent data set because the data had to be taken from different sources. In collaboration with SBB we managed to provide a unique data set for Switzerland by merging three different data sources[5] into one data set.

The data used is based on the whole railway network of Switzerland including all main lines. This network can be divided in almost 500 sections. Most of these sections are maintained by SBB, some by other licensed railway companies. For every section a record of data was gathered for the years 2003, 2004 and 2005. This record contains:

- Infrastructure data
- Traffic data
- Cost data

The data set we got from SBB includes a vast amount of variables, especially for infrastructure and cost data. In the following sections we describe the different types of data.

[5] Data sources provided by SBB: DfA (Datenbank der festen Anlagen) for infrastructure data, PANDA for traffic data, and cost data.

2.1 Infrastructure data

The Swiss national rail network comprises approximately 4,900 kilometers of track, of which 56 percent is double track. The SBB defines a list of track sections (almost 500 sections in operation) that we will make use of. A track section is a part of the network, which varies in length from 0.39 to 81.6 kilometers. A section is not strictly homogeneous, that is between its endpoints, it can vary in terms of rail and sleeper types, ballast, curvature, slope etc. For this study, a vast amount of infrastructure data was available per section.

Not all of the track sections in the data base are possible to be used. Some defined track sections are maintained by other countries (16 sections in border areas, maintained by foreign railway companies as DB, ÖBB, FS and SNCF) others by other railway companies (58 sections). 36 track sections are marshalling yards where either no traffic data or no cost data are available. Finally, 18 track sections have to be dropped because they have been redefined in the period 2003 - 2005 or have only been in operation since 2005. This results in 371 observations (track sections) per year to analyze with complete information.

The infrastructure data was provided by SBB through their data system DfA (Datenbank der festen Anlagen). The DfA shows the current status of the network and contains all existing physical information about the railway network in Switzerland. The DfA was built up in recent years. Therefore, experts from SBB strongly recommend using the 2005 state of the DfA for all observations. As in our sample we did not include sections with new tracks constructed between 2003 and 2005 this recommendations makes sense and we follow it.

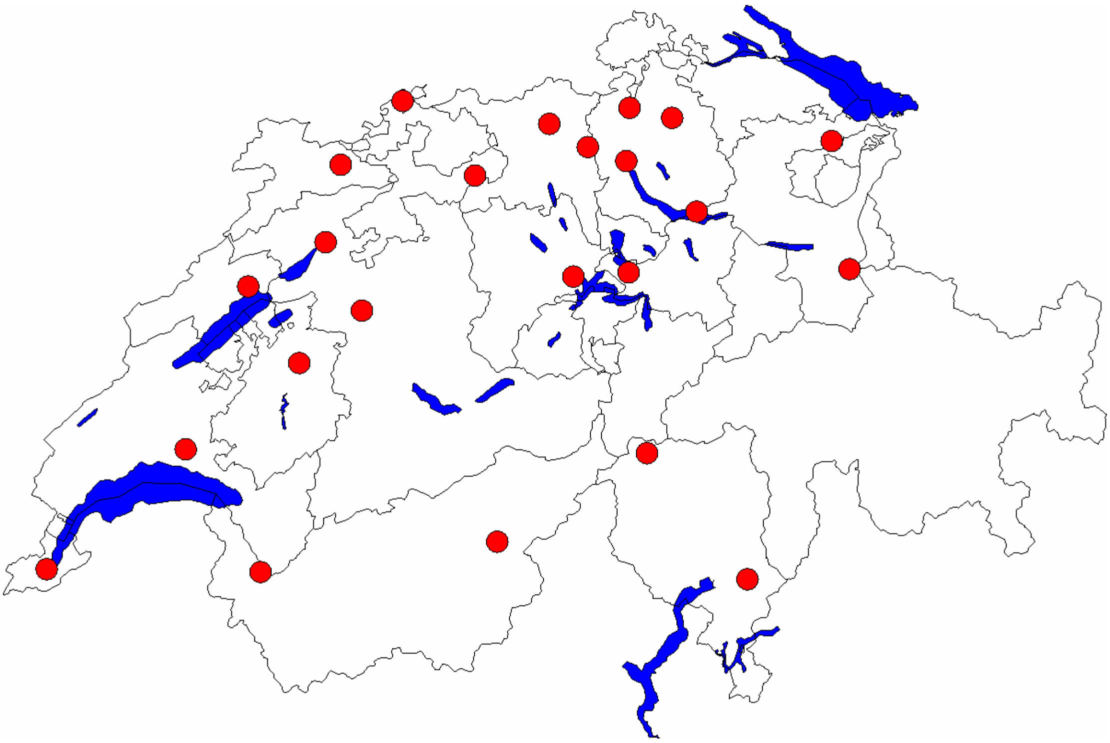
Table 1: Infrastructure data used (371 track sections, data for 2003, 2004 and 2005)

Variable	Measure	Observations	Mean	Standard deviation	Min	Max
Track length	m	1113	12510	12058	390	81310
Track distance	m	1113	7888	7268	390	40660
Switches	m	1113	1176	1284	0	9230
Bridges	m	1113	224	306	0	2754
Tunnels	m	1113	715	2.80	0	39820
Level crossings	No	1113	4	10	0	136
Radius 500	m	1113	2000	3315	0	38038
Slope 1	m	1113	2616	3859	0	26552
Slope 2	m	1113	1354	4658	0	61226
Noise / fire protection	m	1113	283	839	0	8710
Platform edge	m	1113	1415	1375	0	9572
Rails aged > 25	%	1113	0.20	0.26	0.00	1.00
Sleepers aged > 25	%	1113	0.15	0.22	0.00	0.99
Maximum speed	km	1113	114	25	40	200
Switches 1	No	1113	5	22	0	240
Switches 2	No	1113	27	49	0	422
Switches 3	No	1113	10	39	0	551
Shafts	No	1113	211	221	3	1589

Table 1 shows mean values for those infrastructure variables of the years 2003 - 2005 that will be used in the econometric estimation. The variables are all expected to affect maintenance and renewal costs. An analysis of correlation coefficients between variables shows that there are only little interdependencies. We assume to have no serious multicollinearity problems in the model estimation. However, we added dummy variables to the data to cover for different years and spatial differences, including dummy variables for different districts.

Figure 1 shows the locations of the **headquarters** of the 23 districts of SBB. The south of Switzerland is less densely populated than the rest of Switzerland; therefore, as can be seen in figure 1, the districts in the south are larger than in the rest of the country. The south-east of Switzerland is not run by the national railway company SBB, but by another railway company ("Rhätische Bahn").

Figure 1: Locations of the 23 districts (regions) of the SBB



Legend: The red dots show the locations of the headquarters of the 23 districts of SBB.

A special remark with respect to **train stations**: Larger train stations such as Zurich, Geneva or Berne and stations which are railway junctions such as Brig are listed as sections. Since the railway infrastructure is very complex in large stations we take these sections into consideration as ordinary sections. However, for estimation purposes we will define a dummy variable for sections which include only stations. An additional variable – the platform edge in meters – takes into account that small stations are included in other sections.

2.2 Traffic data

Traffic data were provided by SBB through their traffic data system PANDA. The system gives average daily data on number of trains, axle load and gross-tons per track, as well as yearly data on train kilometers, axle load kilometers and gross-ton-kilometers per track for the main lines. Analogous to the infrastructure data, table 2 gives the key values for traffic variables of the years 2003 - 2005. Table 2 contains gross ton-kilometers (Gtkm) and train kilometers (train km) per section.

Table 2: Traffic data used (371 track sections, data for 2003, 2004 and 2005)

Variable	Measure	Obs.	Mean	Std. Dev.	Min	Max
Total train km - 2003	km	1113	365'613	390'720	3'308	2'522'007
Total train km - 2004	km	1113	387'726	423'480	4'306	2'794'162
Total train km - 2005	km	1113	398'461	419'415	3'646	2'654'653
Total train km - 2003-05	km	1113	383'934	411'691	3'308	2'794'162
Total axle km - 2003	km	1113	13'155'267	19'282'200	87'826	170'417'983
Total axle km - 2004	km	1113	14'457'683	21'956'408	68'258	190'837'933
Total axle km - 2005	km	1113	14'406'014	20'912'474	74'523	182'182'425
Total axle km - 2003-05	km	1113	14'006'321	20'754'971	68'258	190'837'933
Total Gtkm - 2003	1000 km	1113	160'768	231'871	1'037	2'040'742
Total Gtkm-km - 2004	1000 km	1113	175'613	259'938	833	2'236'565
Total Gtkm - 2005	1000 km	1113	176'275	248'260	952	2'118'660
Total Gtkm - 2003-05	1000 km	1113	170'885	247'062	833	2'236'565

2.3 Cost data

SBB provided us with very detailed cost data per section for which SBB is responsible for maintenance. The cost data contain information such as costs on:

- Operation maintenance (e.g. cleaning, snow and ice removal)
- Track maintenance
- Forestry
- Engineering
- Signal tower maintenance
- Wire maintenance
- Electronic installation

Moreover, within these different cost categories SBB separates between short-run maintenance costs (“Contracting A”) that arise yearly and long-run costs which arise periodically and have the characteristics of renewal costs (“Contracting B”). Due to the fact that the excellent data base is only available since 2003, the estimation of renewal costs is based on a relatively short time period of three years. Therefore, we do not estimate renewal costs by themselves but in combination with maintenance costs. Similar to Andersson (2006), we observe that renewal costs per track section can vary significantly between years.

According to cost experts of SBB there are three reasonable cost categories to estimate:

- **Model type 1:** Yearly arising maintenance costs that consider all expenditures for "Contracting A" (main model)
- **Model type 2:** Yearly arising maintenance costs only for operation and track maintenance
- **Model type 3:** Maintenance and renewal costs (all expenditures for "Contracting A" and "Contracting B"

The descriptive statistics of the cost variables used in the three model structures are shown in table 3. Cost data are available in Swiss Francs (CHF), so the econometric analysis was performed with the original data. The main results concerning marginal and average costs are presented in EUR for better comparison.

Table 3: Cost data used, in CHF (371 track sections, data for 2003, 2004 and 2005)

Variable	Obs.	Mean	Std.Dev.	Min	Max
Maintenance costs (Contracting A) - 2003	1'113	568'497	593'025	17'929	5'193'119
Maintenance costs (Contracting A) - 2004	1'113	540'233	547'118	20'759	5'027'611
Maintenance costs (Contracting A) - 2005	1'113	535'171	539'829	15'345	4'619'208
Maintenance costs (Contracting A) -2003-05	1'113	547'967	560'930	15'345	5'193'119
Only operation and track maintenance costs - 2003	1'113	270'494	289'139	3'724	2'225'127
Only operation and track maintenance costs - 2004	1'113	260'968	267'076	3'449	1'810'884
Only operation and track maintenance costs - 2005	1'113	249'532	256'071	3'344	1'959'106
Only operation and track maintenance costs - 2003-2005	1'113	260'331	271'368	3'344	2'225'128
Maintenance and renewal costs (Contracting A+B) - 2003	1'113	837'428	867'668	17'929	7'489'656
Maintenance and renewal costs (Contracting A+B) - 2004	1'113	850'194	943'387	20'759	8'361'440
Maintenance and renewal costs (Contracting A+B) - 2005	1'113	917'129	990'163	15'345	7'876'671
Maintenance and renewal costs (Contracting A+B) - 2003-2005	1'113	868'250	936'176	15'345	8'361'440

3 Model specification and estimation results

3.1 General model specification

In this section we present the model selected to estimate marginal costs of infrastructure maintenance. We refer to former empirical work such as Johansson and Nilsson (2004), Tervonen and Idström (2004), Munduch et al. (2005) and Andersson (2006).

An important aspect of former empirical work is the application of a pooled ordinary least squares technique. Pooled OLS treats all observations as a cross section sample assuming that there is no systematic variation over the three years. But in order to control for a time effect we introduce dummy variables for different years.[6] Our general model specification is:

$$C_{it} = \alpha + x_{it}\beta + \varepsilon_{it}$$

While *i* indicates track section and *t* time period, C_{it} denotes the costs, and x_{it} the vector of explanatory variables. The letters α and β are the coefficients to estimate, while ε_{it} is the error term of each section in time *t*. Each model contains a specified dependent cost variable, and a number of explanatory variables (infrastructure variables and a traffic variable) that measure the output from the track section.

Our next step concerns the functional form of the cost function. Most common functional forms in literature are linear, log-linear and Translog specifications. While Johansson and Nilsson (2004) as well as Tervonen and Idström (2004) used a Translog specification, Munduch et al. (2005) and Andersson (2006) applied a classical log-linear specification. In order to compare our results to most recent empirical work we are using a log-linear specification as well.[7]

3.2 Detailed model specification

The detailed specification of the model depends on the expectation about cost drivers. Railway experts assume that maintenance costs are more likely to be driven by gross tons than by other variables. In accordance with Johansson and Nilsson we split the variable gross-ton-kilometers into two separate variables: gross tons per track kilometer and track length. This separation isolates the costs driven by gross tons from traffic length effects.

For the other explanatory variables we rely on two sources:

6 Applying dummy variables for different years, we correct for the time effect. Regarding to the time dimension the model is similar to a fixed-effects model.

7 A good presentation of a log-linear specification is given by Munduch et al. (2005).

- First, we screened former empirical work to find appropriate variables. Other studies included variables such as tunnel meters, bridge metres, switch meters, curvature, slopes, the age of rails and sleepers etc.
- Second, we made use of our large set of variables in infrastructure. We checked for different variables such as level crossings, noise/fire protection, retaining walls, different signals, switches, shafts etc.

Not all examined variables entered the final estimations. The variables which were applied in the final estimations are shown in table 3.

Table 4: Information per track section, explanatory variables

Name of variable	Description
Track length	Distance of tracks
Gross tons	Number of gross tons (logarithm)
Switches	Length of switches in meters (logarithm)
Bridges	Length of bridges in meters (logarithm)
Tunnels	Tunnel meters (as percentage of track length)
Level crossings	Number of level crossings
Radius 500	Bends with radius < 500 in meters (as percentage of track length)
Slope 1	Slopes of 10‰ to 20‰ in meters (as percentage of track length)
Slope 2	Slopes steeper than 20‰ in meters (as percentage of track length)
Noise / fire protection	Noise / fire protection in meters (as percentage of track length)
Platform edge	platform edge in meters (as percentage of track length)
Rails_age_25	Rails older than 25 years (as percentage of track length)
Sleepers_age_25	Sleepers older than 25 years (as percentage of track length)
Maximum speed	Maximum speed per track (logarithm)
Switches 1	Number of mechanic switch machines, type 1
Switches 2	Number of mechanic switch machines, type 2
Switches 3	Number of electro-mechanic switch machines
Shafts	Number of shafts
D_station	Dummy for stations (1 for station, 0 for other sections)
D_03	Dummy for the year 2003 (1 for 2003, 0 for other years)
D_04	Dummy for the year 2004 (1 for 2004, 0 for other years)
Dummies per region	Different dummies for 23 districts

3.3 Estimation results

The estimation results of the three model types are presented in table 5. The estimations are carried out with *Intercooled STATA 9.1*. In order to avoid inefficient estimations due to heteroskedasticity, we apply a robust estimator. For each model two estimations were calculated, one with regional dummies and one without regional dummies. As mentioned in chapter 2, the estimations have been run over 1113 observations, which are 371 observations per year for three years.

Generally, the explanation power of all three models is relatively high. Adjusted R^2-values are between 0.61 and 0.84. Similarly to the experience of Andersson (2006) for Sweden we do not face any serious problems adding renewal costs to maintenance costs (model type 3). We find the smallest explanatory power in model type 2. Adding more variables or replacing variables such as gross tons by the number of trains – as suggested by Andersson (2006) – does not lead to a higher adjusted R^2-value.

The inclusion of regional dummies (districts) has a relatively small effect on the explanatory power of the estimated models. We consider this as a sign that the districts use comparable technologies for track maintenance. An important finding is that the algebraic signs of the variables included do not change between the different model types.

Taking a closer look at our main model type 1 (estimations (1) and (2)) we see that most coefficients (not the regional dummies) are significant at the 1 percent level and mostly have expected signs.

- Not surprisingly, the estimations (1) and (2) show highly significant and positive values for track length, gross tons, switch meters, bridge meters, level crossings, curvature, platform edge meters, steep slopes, noise/fire protection, and for the station dummy variable. Additional infrastructure variables such as the number of switches and shafts are also highly significant (mostly significant at the 5% level).
- At first glance, the negative sign for tunnel meters is irritating (significant at the 5% level). However, the natural protection of tunnels from snow and rain might reduce wear and tear and therefore the amount of maintenance costs.
- Quite surprising is the negative sign for maximum speed (which however is narrowly not significant at the 10% level). We assume that a maximum speed can be achieved on the track sections with less curvature and less slope. A simple correlation analysis confirms this assumption: the maximum speed per track is negatively correlated with curvature (-0.52) and with steep slopes (-0.36).
- As already mentioned, the inclusion of regional dummies has little impact on the explanatory power of the model. However, it has interesting effects for two variables: estimating the regional dummies leads to a significant negative variable for tunnel meters, while moderate slopes become insignificant.
- Finally, the dummy variable for 2003 is significant at 5% level. Therefore, costs were significantly higher in 2003 than in the following years.

Looking at the results of model type 2 which are given by estimations (3) and (4) we see that the explanatory power of the model is clearly less high than for model type 1. Using other model specifications does not improve the explanatory power of the model significantly. Compared to the results of model type 1 the most interesting changes in variables are to be found in curvature. Curvature seems to be less important for operation and track maintenance costs.

Considering the results of model type 3 we find good values for the adjusted R^2. The explanatory power of the model is almost as good as for model type 1. Analogous to the results of model type 1, the estimations (5) and (6) show highly significant and positive values for track length, gross tons, switch meters, bridge meters, level crossings, curvature, platform edge meters, steep slopes, noise/fire protection, and for the station dummy variable. In contrast to the results of model type 1 we find negative values for the dummy variable for the years 2003 and 2004, respectively. The dummy variable for 2004 is significant at the 5% level. Combined with the results of the estimations (5) and (6) this observation leads to the conclusion that in 2005 more money was spent for renewal, while in 2003 more money was spent for maintenance.

In summary, the most reliable model type is model type 1. We find here the highest values for the adjusted R^2. Less explanatory power can be found for model type 2 estimations. This result is invariant when we change the model specification (additional or other explanatory variables). Finally, the results of model type 3 estimations are quite good. However, a longer time span than three years would be preferable for analysing renewal costs.

Table 5: Estimations results

Model	Model type 1		Model type 2		Model type 3	
Dependent variable	All maintenance costs (Contracting A)		Only operation and track maintenance costs		Maintenance and renewal costs (Contracting A+B)	
Estimations	(1)	(2)	(3)	(4)	(5)	(6)
Observations	1113	1113	1113	1113	1113	1113
Explanatory variables						
Constant	8.078*** (16.43)	8.158*** (16.26)	4.666*** (7.77)	4.695*** (7.17)	7.243*** (11.98)	7.055*** (11.61)
Track length	0.605*** (23.10)	0.632*** (23.09)	0.586*** (14.63)	0.622*** (13.69)	0.638*** (20.67)	0.682*** (20.85)
Gross tons	0.200*** (9.14)	0.195*** (8.62)	0.285*** (5.64)	0.270*** (5.91)	0.265*** (9.73)	0.267*** (9.66)
Switches	0.034*** (8.98)	0.034*** (8.79)	0.047*** (7.11)	0.046*** (7.34)	0.038*** (7.56)	0.035*** (7.00)
Bridges	0.039*** (5.46)	0.036*** (4.68)	0.048*** (4.50)	0.045*** (4.40)	0.048*** (5.38)	0.045*** (4.48)
Tunnels	-0.032 (-0.99)	-0.074** (-2.03)	-0.146* (-1.78)	-0.192** (-2.43)	0.048 (0.85)	-0.002 (-0.04)
Level crossings	0.007*** (3.60)	0.008*** (3.50)	0.007*** (3.14)	0.007*** (3.00)	0.009*** (4.15)	0.010*** (4.48)
Radius 500	0.334*** (3.80)	0.325*** (3.48)	0.345 (0.75)	0.350 (1.31)	0.489*** (4.35)	0.476*** (4.01)
Slope 1	0.097* (1.81)	0.072 (1.33)	0.235** (1.97)	0.250** (2.05)	0.100 (1.49)	0.063 (0.91)
Slope 2	0.248*** (3.09)	0.231*** (2.76)	0.379*** (3.42)	0.260* (1.79)	0.212** (2.19)	0.215** (2.10)
Noise / fire protection	-0.443** (-2.28)	-0.426** (-1.98)	-0.275 (-0.77)	-0.188 (-0.49)	-0.831*** (-3.09)	-0.635** (-2.03)
Platform edge	0.458*** (4.91)	0.531*** (5.51)	0.548*** (4.09)	0.631*** (4.29)	0.434*** (4.57)	0.512*** (5.37)
Rails_age_25	0.178 (1.15)	0.225 (1.41)	0.426 (1.36)	0.404 (1.19)	0.056 (0.25)	0.197 (0.88)
Sleepers_age_25	-0.017 (-0.14)	-0.095 (-0.76)	-0.272 (-0.97)	-0.299 (-1.02)	0.099 (0.55)	-0.036 (-0.20)
Maximum speed	-0.123 (-1.57)	-0.134 (-1.58)	0.121 (0.84)	0.111 (0.63)	-0.096 (-0.95)	-0.089 (-0.83)
Switch machines 1	0.001** (2.54)	0.002*** (3.40)	0.003*** (3.10)	0.002** (2.51)	0.001 (1.02)	0.002** (2.53)
Switch machines 2	0.002*** (5.22)	0.002*** (4.97)	0.003*** (5.76)	0.003*** (4.91)	0.003*** (4.65)	0.002*** (4.52)
Switch machines 3	0.001*** (4.30)	0.001*** (2.97)	0.002*** (4.32)	0.001*** (3.39)	0.001** (2.24)	0.001 (1.38)
Shafts	0.000*** (3.89)	0.000*** (3.19)	0.000** (2.04)	0.000*** (3.30)	0.000** (2.47)	0.000* (1.77)
D_train station	0.290*** (6.25)	0.329*** (7.08)	0.286* (1.86)	0.320** (2.31)	0.243*** (4.36)	0.308*** (5.62)
D_03	0.068** (2.32)	0.067** (2.37)	0.033 (0.49)	0.031 (0.48)	-0.056 (-1.54)	-0.056 (-1.58)
D_04	0.011 (0.41)	0.011 (0.42)	0.047 (1.26)	0.047 (1.32)	-0.081** (-2.20)	-0.081** (-2.26)

Regional dummies (Districts)						
Giubiasco	---	0.157 (1.60)	---	0.125 (0.83)	---	0.147 (1.20)
Brugg	---	0.010 (0.10)	---	0.132 (0.88)	---	-0.035 (-0.29)
Biel	---	0.103 (0.96)	---	0.402*** (2.59)	---	0.199 (1.63)
Bern	---	-0.013 (-0.13)	---	0.390*** (2.63)	---	-0.056 (-0.48)
Brig	---	-0.059 (-0.34)	---	0.083 (0.39)	---	-0.211 (-1.06)
Basel	---	0.083 (0.95)	---	-0.182 (-1.29)	---	0.115 (1.12)
Bülach	---	0.068 (0.72)	---	0.167 (1.15)	---	0.122 (1.07)
Delémont	---	0.130 (1.25)	---	0.071 (0.41)	---	0.217* (1.68)
Fribourg	---	-0.003 (-0.02)	---	0.022 (0.14)	---	0.070 (0.54)
Arth-Goldau	---	-0.136 (-1.38)	---	-0.471 (-1.09)	---	-0.076 (-0.63)
Genf	---	0.156 (1.05)	---	0.341* (1.80)	---	0.184 (1.04)
Lausanne	---	0.157 (1.48)	---	0.383** (2.51)	---	0.227* (1.86)
Luzern	---	-0.089 (-0.92)	---	0.078 (0.52)	---	-0.120 (-0.97)
Neuenburg	---	0.033 (0.32)	---	0.114 (0.72)	---	0.082 (0.71)
Olten	---	-0.064 (-0.69)	---	0.204 (1.39)	---	-0.169 (-1.55)
Spreitenbach	---	0.233** (2.11)	---	0.449** (2.57)	---	0.212 (1.57)
Rapperswil	---	-0.051 (-0.58)	---	0.038 (0.27)	---	0.038 (0.35)
Sargans	---	-0.118 (-1.15)	---	0.064 (0.43)	---	-0.117 (-0.95)
St.Gallen	---	0.014 (0.15)	---	0.046 (0.31)	---	0.048 (0.42)
St.Maurice	---	0.123 (1.23)	---	0.086 (0.51)	---	0.098 (0.79)
Winterthur	---	0.043 (0.45)	---	0.011 (0.07)	---	0.172 (1.49)
Zürich	---	0.239** (2.28)	---	0.437*** (2.75)	---	0.356*** (2.81)
Adjusted R^2	0.832	0.840	0.609	0.630	0.776	0.787
SE	0.39	0.38	0.77	0.75	0.49	0.48

Remarks: ***/**/* denote significance at the 1-/5-/10-percent-level. One regional dummy (the dummy for the district Ascona) has been dropped; otherwise the model would have been over specified. T-values are given in parentheses. The sign --- indicates that the variable has not been included in the model estimated.

4 Marginal costs

According to Johansson and Nilsson (2004) estimated elasticities can be used to derive estimates of marginal costs for each track unit.[8] Since we are interested in the cost effects of an additional gross-ton-kilometer (Gtkm) per section, we calculate marginal costs (MC) with respect to Gtkm. The formula is given by:

$$MC = \frac{\partial C}{\partial Gtkm} = \frac{\partial C}{\partial Gton}\frac{1}{km}$$

We assume that conditional to the specific data base the distance represents a constant in track marginal costs. For track *i*, this leads to

$$MC_i = \frac{\partial \hat{C}_i}{\partial Gtkm_i} = \frac{\partial \hat{C}_i}{\partial Gton_i}\frac{1}{km_i} = \left(\frac{\partial \hat{C}_i}{\partial Gton_i}\frac{Gton_i}{\hat{C}_i}\right)\frac{\hat{C}_i}{Gtkm_i}$$

$\hat{C}_i$ denotes the fitted value of C_i and is calculated by $\hat{C}_i = \exp(\hat{\alpha} + \hat{\beta}x_{it} + 0.5\hat{\sigma}^2)$ .The expression in parenthesis represents the elasticity of the maintenance costs with respect to gross-tons.

To calculate the average marginal cost, we weight the marginal costs per section, using the number of gross-ton-kilometers on each section unit as a weight. Table 6 shows the marginal costs (MC) and the average costs (AC) for the whole network for our six estimated models. Average costs are computed by using the fitted values divided per Gtkm.

The marginal maintenance costs with respect to Gtkm for our main model type 1 are 0.00045 and 0.00043 EUR respectively. Generally the value is lower when we include regional dummies. Average maintenance costs per Gtkm are approximately 0.002 EUR per Gtkm. The cost recovery for model type 1 is approximately 20% of total maintenance costs. This confirms that pricing at marginal costs does not recover total costs, but is motivated by efficiency thoughts. Similar results have been found for Sweden (Andersson, 2006).

The lowest values for marginal and average costs are clearly found for model type 2 where only operation maintenance and track maintenance costs have been considered. The highest cost data are provided by model type 3 where renewal and maintenance costs have been included. In model types 2 and 3 the cost recovery lies between 26 and 29%.

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8 For a good explanation see also Munduch et al. (2005).

Table 6: Marginal costs and average costs per Gtkm, in EUR

Model type	Model type 1		Model type 2		Model type 3	
Estimation	(1)	(2)	(3)	(4)	(5)	(6)
Marginal costs (MC)	0.00045	0.00043	0.00038	0.00034	0.00097	0.00095
Average costs (AC)	0.00222	0.00220	0.00133	0.00125	0.00364	0.00357
Cost recovery	20.0%	19.5%	28.5%	27.0%	26.5%	26.7%

An international comparison shows that our results for marginal costs are in line with the estimations in other countries. According to the Austrian study of Munduch et al. (2005) the marginal costs in Austria are 0.00058 EUR for all lines and slightly lower for main lines (0.00050 EUR). The marginal costs for Sweden, found by Andersson (2006), are approximately between 0.00030 and 0.00040 EUR, which corresponds to our results of model type 1.

To verify our results, we used an alternative model specification, which was applied by Munduch et al. (2005). The specification includes variables which have a direct impact on the coefficient of gross tons. The application of this specification for Switzerland leads to slightly higher marginal costs (see the estimation results in the appendix).

5 Conclusions

The good data base provided by the national railway company of Switzerland, SBB, gave us the chance to estimate marginal costs for Switzerland. The number of track sections and the availability of data for the time span 2003 - 2005 led to a reasonable number of observations, at least for yearly arising maintenance costs. Our results confirm the findings of national studies for Sweden, Austria and Finland and may serve to implement a marginal cost oriented charge per gross-ton-kilometer for yearly arising maintenance costs.

Looking at renewal costs, additional years for estimation are needed in order to get reliable results. Our estimations suggest that marginal renewal costs are approximately of the same size as marginal maintenance costs and therefore significantly raise infrastructure charges that are based on marginal costs. But this is only a provisional result which has to be confirmed by using data of a broader time span. There is an ongoing improvement of the SBB data base, such that in further research we should be able to extend the data base over more years.

What do the above results signify for Swiss track infrastructure charges? Our estimates show that mean marginal maintenance costs are about 0.00045 EUR (0.00068 CHF respectively) per Gtkm. If renewal costs are additionally included, mean marginal costs would be around

0.00097 EUR (0.00146 CHF respectively) per Gtkm. This is significantly lower than today's maintenance charge in Switzerland of 0.0025 CHF/Gtkm.

Furthermore, our results show that mean average maintenance costs are 0.0022 EUR/Gtkm (0.0033 CHF/Gtkm) which is around five times higher than mean marginal costs. As expected, marginal cost pricing would imply drastically lower charges compared to charges based average costs. Today's maintenance charge in Switzerland lies in between mean marginal costs and mean average costs.

It has to be added that in Switzerland maintenance charges for freight traffic are temporarily reduced, due to subsidies (with the political aim of modal shift). For combined traffic maintenance charges add up to 0.0010 CHF/Gtkm (0.00067 EUR/Gtkm). This is still more than estimated mean marginal maintenance costs, but less than estimated mean marginal maintenance and renewal costs together.

The estimated mean marginal costs can be spatially differentiated according to different criteria, e.g. alpine regions, flat or urban areas. Our estimates show no significant differences of marginal maintenance costs per Gtkm between flat areas and alpine regions.[9] But for Swiss urban areas marginal maintenance costs are estimated up to 0.00085 EUR/Gtkm which is almost twice as much as mean marginal maintenance costs. This gives a first estimate for spatially differentiated infrastructure charges.

6 Appendix: Model with alternative specification

In this appendix we present the results of an alternative model specification following the approach of Munduch et al. (2005). Table 7 shows the corresponding estimation results. In this specification we use different explanatory variables which partly are a multiplication of a certain infrastructure variable e.g. such as slope metres with gross tons.

The hypothesis behind this specification is that the effect of topography (slopes, tunnels) or densitiy of railway stations (platform edge) on marginal maintenance costs also depends on how the track is used e.g. the number and the weight of trains (gross tons) per year. In this case, some of the explanatory power given to slope, tunnel or platform edge metres in the model specification used before (see table 5) is actually due to the number of gross tons.

By recalculating the marginal maintenance costs with respect to Gtkm we can figure out whether this alternative model specification has an impact on marginal and average costs. Comparing the results of table 7 with estimation (2) in table 5 we find that applying the Mun-

[9] If the calculation is done on the basis of train km instead of Gtkm marginal maintenance costs are significantly higher in alpine regions than in flat areas by a factor of 1.43, because average train weight is higher in alpine regions.

duch et al. specification for Switzerland leads to only slightly higher marginal maintenance costs. Therefore, we can conclude that in the case of Switzerland the model specification in the main report reflects almost fully the marginal maintenance costs of an additional gross ton.

Table 7: Estimations results (including variables with a direct impact on gross tons)

Dependent variable	All maintenance costs (Contracting A)
Observations	1113
Explanatory variables	
Constant	7.639*** (26.19)
Track length	0.702*** (32.52)
Gross tons	0.196*** (11.27)
Radius 500	0.751*** (7.36)
Switches	0.048*** (10.35)
Platform edge * Gross tons	0.049*** (6.61)
Slope 2 * Gross tons Tunnels	0.034*** (5.49)
Tunnels * Gross tons	-0.012*** (-4.39)
Adjusted R^2	0.771
SE	0.45
Marginal costs (MC)	0.000435
Average costs (AC)	0.00217
Cost recovery	20.1%

Remarks: ***/**/* denote significance at the 1-/5-/10-percent-level. T-values are given in parentheses.

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