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Annex A3

Deliverable 10: Infrastructure Cost Case Studies

An Economic Analysis of Track Maintenance Costs

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Authors:
Per Johansson and Jan-Eric Nilsson

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Deliverable 10: Infrastructure Cost Case Studies, Annex A3: An Economic Analysis of Track Maintenance Costs

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An Economic Analysis of Track Maintenance Costs

Per Johansson
IFAU - Office of Labour Market Policy Evaluation
751 20 Uppsala, SWEDEN

Jan-Eric Nilsson
VTI - Road and Transport Research Institute,
Box 760
781 27 BORLÄNGE, SWEDEN

June 29, 2001

Abstract

The costs for maintaining different track units are analyzed using Swedish and Finnish railway data for the years 1994−1996 and 1997−1999, respectively. To derive insights on the logic of spending on track maintenance, the analysis is based on few a priori assumptions about underlying structures. We provide indications of scale economies in track maintenance with respect to traffic load and calculate a policy-relevant derivative value, i.e. the marginal cost of track use.

1 Introduction

Under the pressure of huge losses and poor performance, countries all over the world are busy restructuring their railway industries, each in its own way (cf. Kopicki & Thompson 1995 for a set of illustrative cases). The increased use of market forces is common to all reforms. In Europe, vertical separation of previously nationalized monopolies is at the core of the reforms. One (private or public) agent is made responsible for the infrastructure while independent (private and/or public) firms operate trains.

Establishing an institutional framework that enhances the ability of formerly strongly regulated utilities to generate a social surplus is no trivial task. Laffont & Tirole (2000) eloquently demonstrate how this can be done in the telecommunications industry. For the following reasons we believe the need to create such a framework to be equally large in a vertically separated railway industry

(a) Roads are used close to capacity across the European continent during large parts of the day. To provide an alternative means of transport when vehicles clog down road capacity, the vast track-and-structure assets that have been built over the years must be efficiently used.

(b) Governments keep providing large subsidies to their railways across the continent. It must be ascertained that these funds are put to the best possible use.

(c) Competition in a vertically separated railway industry generates regulatory problems that never surfaced when the industry was run as a nationalized and vertically integrated monopoly. Several of these regulatory problems are different from those in other businesses.

A new directive regarding infrastructure charges and track capacity allocation has recently been adopted by the European Union (Official Journal 2001), representing one cornerstone of such a framework. Marginal cost pricing in order to enhance the efficient use of track infrastructure is at the core of the new policy. One component of marginal costs is the wear-and-tear of rolling stock on the infrastructure. The purpose of the present paper is to present a methodologically rigorous estimation of these costs.

The background for our work is Sweden's early start of the process of vertical unbundling. In 1988, a central government agency (*Banverket* or BV) was made responsible for the infrastructure while the incumbent operated all railway services. Since then, private operators have also started businesses and in June, 2000, more than 20 firms were in operation; cf. Kopicki & Thompson (1995, ch. 5) and van de Velde (1999, ch. 3) for more institutional details.

An obvious implication of the new industrial structure is that all costs related to infrastructure are accounted for separately from train operation costs. In addition, the bulk of track maintenance costs are booked on a disaggregate level, at least in some countries. The Swedish railway network (about 13 000 km), for instance, is split up into some 260 track units. Not only information about spending on maintenance but also about traffic, length, number of switches, bridges and tunnels, the quality of tracks, etc. is available at the track unit level. This set of detailed micro-econometric information differs from the aggregated time series data that has previously been used to analyze the cost structure of the consolidated railway industry. Similar data is also available from the more recent restructuring in Finland. Therefore, we have access to two unique databases for establishing possible regularities in the pattern of railway infrastructure maintenance costs.

Based on data over the years 1994 – 1996 and 1997 – 1999 from the Swedish and Finnish data sets, we have regressed track maintenance costs against information about fixed installations, track length and utilization. We find evidence that variations in the number of trains using the infrastructure have a small impact on maintenance activities. We also calculate the marginal costs of track use and show that these are low. Unavailable data (Sweden) and a short time series (Finland) make it impossible to estimate the marginal costs related to reinvestment.

The paper is organized in the following way. Section 2 reviews the structure of the Swedish and Finnish data sets, providing a background to the empirical modelling described in Section 3. Section 4 presents results from the estimation and associated tests. The insights that the material provides about railway maintenance are summarized in Section 5 and Section 6 concludes.

2 The Data

To understand the structure of the micro-data available for analysis, consider the stylized description of a railway network and its components, the track units, outlined by Figure 1. In principle, a track unit is homogenous with respect to traffic and technical qualities. The single-track line between stations A and B is used by a certain number of trains and should therefore comprise one track unit. Between station B and a switch called C, the line is double tracked, while it is single tracked between C and D; these two parts of the line should be registered as separate track units. Since the traffic load differs, sections D-F, F-G and F-H should also comprise separate units. Major marshalling yards, such as E, are accounted for separately as are some major stations such as D. The Swedish (presented in subsection 2.1) and Finnish (subsection 2.2) data sets are organized along these lines.

2.1 The Swedish Data

BV's system for registering technical data makes it feasible to see how many switches, bridges, tunnels and other technical installations there are on each separate track unit. In addition, a track quality index comprising eight classes,

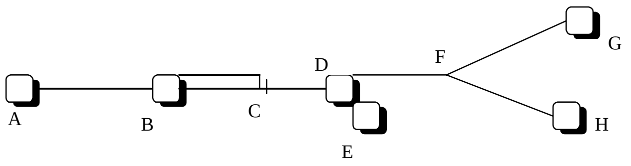

Figure 1: Sketch of a railway network and its track units.

each representing the (average) standard level of sleepers, fastenings and rails is assigned to each track unit. For instance, index no. 8 - the best tracks - is given to track sections with the predominantly heaviest (per meter) whole welded rails on concrete sleepers. An administrative distinction is also made between track units that are part of a main or secondary line and those that are not. 20 maintenance districts - each responsible for a set of track units corresponding to a certain number of track kilometers (km) - are responsible for recording the data.

While common costs could, in principle, be distributed over the track units using different keys, results reported here only refer to track-specific costs. Our presumption is thus that neither the agency's main or regional offices, nor the common costs of its districts, vary with the traffic load; common costs affect average, but not marginal, costs. Thus, the records account for about 1.6 out of the total spending of 2.3 billion SEK in 1994 (70 percent; Johansson & Nilsson 1998). BV's records do not include information about spending on re-investments.

Traffic operated over the Swedish railway network is measured as gross ton km over each track unit, i.e. the number of km that trains of a certain weight - also including the weight of loco and cars - have traversed on each track unit. Since track length is used as a separate explanatory variable in the estimation, the number of gross ton km is divided by track length to obtain a gross weight statistic. It should also be noted that line length is the physical length of a track section where track length is larger than, or equal to, line length due to the number of meeting stations and the extent of double tracking.

There are 264, 258 and 250 observations of costs per track unit in the complete material for the years 1994, 1995 and 1996. Due to problems with missing data, the final data set comprises 169, 176 and 175 observations, respectively; cf. Table 1. The main reason for this data loss is that information about traffic load is not available for stations and marshalling yards; Johansson & Nilsson (1998) present the database in more detail.

Table 1: The Swedish data set for 1994 ($n = 169$) , 1995 ($n = 176$) and 1996 ($n = 175$). Mean and standard deviation per track unit. 1995 price level. 1 SEK was 0.13 USD in 1995.

Variable		Mean			St.dev.		
		1994	1995	1996	1994	1995	1996
Maintenance costs (m SEK)	C	5.88	5.55	5.18	5.91	4.93	4.14
Track length, km	Y	66.68	66.32	66.23	48.09	45.78	46.17
No. of switches	z_1	30.84	31.74	30.50	27.60	27.21	27.16
No. of bridges	z_2	15.46	15.49	15.89	12.68	12.70	13.18
No. of tunnels	z_3	0.48	0.47	0.58	1.44	1.40	1.85
Track quality index (1,...,8)	z_4	5.18	5.41	5.65	1.91	1.88	1.80
Secondary lines	I	0.33	0.33	0.34	0.47	0.47	0.47
Gross ton (the natural logarithm)	u	14.92	14.79	14.78	1.80	1.67	1.68

2.2 The Finnish Data

The structure of the Finnish material is similar, but not identical, to that from Sweden. It comprises information for the 1997−1999 period with 93 observations for both 1997 and 1998 and 92 observations for 1999.[1] Each observation relates to a track unit. Costs that are common for the organization have also been allocated to the track unit level. In contrast to Sweden, the Finns provide information about spending on re-investments, such as track renewal.

¿From Table 2 it can be seen that the Finnish data set is less detailed than the Swedish one. Thus, there is no information available about the number of bridges and tunnels. The average speed allowed on a track unit is used as a proxy for quality, the logic being that higher speed is allowed on track units with better quality. Information about which district is responsible for maintaining a track unit is not reported. Rather than the administrative categorization of tracks into primary and secondary lines, the Finnish material makes a distinction between lines that are, respectively are not, electrified.

3 Empirical Modelling

The Translog cost function of Berndt and Christensen (1972) is chosen as a flexible specification of the cost structure. Let i be an index for track unit, j

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[1] We are grateful to the Finnish Rail Administration for making these data available to us.

Table 2: The Finnish data set for 1997 ($n = 93$) , 1998 ($n = 93$) and 1999 ($n = 92$). Mean and standard deviation per track unit. 1995 price level. 1 FMK was 0.21 USD in 1995.

Variable		Mean			St.dev.		
		1997	1998	1999	1997	1998	1999
Maintenance costs (m FMK)	C	3.30	3.06	2.95	2.04	2.01	1.80
Re-investment costs (m FMK)	R	11.01	11.82	9.82	21.66	24.29	18.57
Track length, km	Y	80.63	80.62	81.22	45.18	45.21	45.01
Number of switches	z_1	45.01	45.00	45.47	31.86	31.88	31.68
Non-Electrified	I	0.57	0.57	0.52	0.50	0.50	0.50
Average speed	z_5	41.09	41.09	41.55	22.76	22.76	22.56
Gross ton (the natural logarithm)	u	14.60	14.59	14.75	1.83	1.76	1.32

an index for district and t a time index. C_{ijt} is the maintenance cost, P_{kt} the marginal price for factor k, Y_{ijt} the track length, U_{ijt} the utilization level (gross weight) and $\mathbf{z}_{ijt}$ a vector of track-technical variables (the number of switches, number of tunnels etc.). Then, the Translog specification is

$$\begin{aligned}\ln C_{ijt} &= \alpha + \beta_y y_{ijt} + \beta_u u_{ijt} + \beta_{yy} y_{it}^2 + \beta_{uu} u_{ijt}^2 + \beta_{yu} y_{ijt} u_{ijt} + \sum_{k=1}^{K} \beta_k p_{kt} + \\ &\quad \sum_{k=1}^{K} \gamma_{ky} y_{ijt} p_{kt} + \sum_{k=1}^{K} \gamma_{ku} u_{ijt} p_{kt} + \frac{1}{2}[\sum_{h=1}^{K} \sum_{k=1}^{K} \gamma_{kh} p_{kt} p_{ht}] + \mathbf{z}_{ijt} \boldsymbol{\beta}_z + \varepsilon_{ijt} \\ &= \mathbf{x}_{ijt}' \boldsymbol{\beta} + \varepsilon_{ijt}, \qquad (1)\end{aligned}$$

where $y_{ijt} = \ln Y_{ijt}, u_{ijt} = \ln U_{ijt}, p_{kt} = \ln P_{kt}, k = 1, ..., K$ and $\{\varepsilon_{ijt}\}$ are assumed to be independently and identically distributed error terms.

This function includes marginal prices. While it is possible to calculate average prices for factor inputs and use these averages as proxies for marginal prices, some factor inputs are never used for some track units. The marginal price for these would therefore be infinite. An alternative approach would be to calculate the average prices each year and use these averages in the estimation. Our first priority in the paper is, however, to estimate elasticities and derive (marginal) costs for track use from these estimates. Knowledge of marginal prices is then of limited relevance if the marginal prices are the same for each track unit within each year. Since both Sweden and Finland are fairly small countries with factor prices that are harmonized at large, (marginal) prices are assumed to be equal across track units.[2]

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[2] To see that no marginal prices are needed, let $\eta_{ijt}^u = \partial \ln C_{ijt} / \partial u_{ijt}$ be the elasticity of

The data section suggested that there are two different ways of classifying a track unit in Sweden; main and secondary lines. In order to understand whether this distinction has something to say about differences in maintenance techniques, the parameters for track length and utilization level are estimated separately for the respective type of railway lines. In Finland, where this classification is not used, the information about whether the line is electrified or not is used as a proxy. We can then test for whether the track length and utilization level parameters are the same for these two classes of railway lines. Furthermore, we also test for whether our data should be pooled over the three years i.e. whether we can set the restriction that $\boldsymbol{\beta}_z$, β_{yy}, β_{uu} and β_{yu} are constant over the three years. For the Swedish data, we allow for constant district dummies $\alpha_j, j = 1, ..., 20$. Altogether, this gives us

$$\begin{aligned}\ln C_{ijt} \quad = \quad & \alpha + \alpha_t + \alpha_j + \beta^*_{yt} y_{ijt} + \beta^*_{ut} u_{ijt} + \beta_{yyt} y^2_{ijt} + \beta_{\mathrm{u}\, ut} u^2_{ijt} + \beta_{yut} y_{ijt} u_{ijt} + \\ & \beta_{It} I_{ijt} + \beta^{*y}_{It} I_{ijt} y_{ij} + \beta^{*u}_{It} I_{ijt} u_{ijt} + \beta^I_{yyt} I_{ijt} y^2_{ijt} + \beta^I_{\mathrm{u}\, ut} I_{ijt} u^2_{ijt} + \\ & \beta^I_{yut} I_{ijt} y_{ijt} u_{ijt} + \boldsymbol{\beta}'_{zt} \mathbf{z}_{ijt} + \varepsilon_{ijt}, \qquad (3)\end{aligned}$$

where $I_{ij} = 1$ if track unit i of district j is located on a secondary/non-electrified line and zero otherwise.

3.1 The Swedish data

Our data set indicates that the average - over the three years - cost for maintaining tracks is 3.8 (3.6) and 6.4 (5.4) million (m) SEK for the secondary and main lines, respectively, with the standard deviation in parenthesis. Our sample of 520 observations consists of 167 secondary and 353 main track units. From estimating the full model (equation 3) it is possible, using a conventional $F-$test, to test for whether a restricted model - where time constant parameters as well as the parameters for secondary and main tracks are the same over the three-year period (39 restrictions) - provides a better description of the data than the full

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track wear. The marginal cost for track wear is then $MC^u_{ijt} = \partial C_{ijt} / \partial U_{ijt} = \eta^u_{ijt} (C_{ijt}/U_{ijt})$. From equation 1, we can see that $\eta^u_{ijt} = \beta_u + 2\beta_{uu} u_{ijt} + \beta_{yu} y_{ijt} + \sum_{k=1}^K \gamma_{ku} p_{kt}$. With marginal prices that are constant for each track unit within each year, equation 1 equals

$$\begin{aligned}\ln C_{ijt} \quad = \quad & \alpha + \alpha_t + \beta^*_{yt} y_{ijt} + \beta^*_{ut} u_{ijt} + \\ & \beta_{yy} y^2_{ijt} + \beta_{uu} u^2_{ijt} + \beta_{yu} y_{ijt} u_{ijt} + \mathbf{z}_{ijt} \boldsymbol{\beta}_z + \varepsilon_{ijt}, \qquad (2)\end{aligned}$$

where $\alpha_t = \sum_{k=1}^K \beta_k p_{kt} + \frac{1}{2} [\sum_{h=1}^K \sum_{k=1}^K \gamma_{kh} p_{kt} p_{ht}]$, $\beta^*_{yt} = \beta_y + \sum_{k=1}^K \gamma_{ky} p_{kt}$ and $\beta^*_{ut} = \beta_u + \sum_{k=1}^K \gamma_{ku} p_{kt}$. From equation 2, we have $\eta^{u*}_{ijt} = \beta^*_{ut} + 2\beta_{uu} u_{ijt} + \beta_{yu} y_{ijt}$ and since $\beta^*_{ut} = \beta_u + \sum_{k=1}^K \gamma_{ku} p_{kt}$, it is obvious that $\eta^{u*}_{ijt} = \eta^u_{ijt}$.

model. We get $F = 1.154$ (P-value $= 0.25$) and hence, these restrictions cannot be rejected;

(i) there is no statistically significant difference in coefficients between the years;

(ii) although average costs differ, we cannot detect any difference in the *structure* of how the two types of railway lines are maintained once we control for traffic, track length, etc.

The final model used for analyzing the Swedish data is therefore

$$\begin{aligned}\ln C_{ijt} &= \alpha + \alpha_t + \alpha_j + \beta_y^* y_{ijt} + \beta_u^* u_{ijt} + \\ &\quad \beta_{yy} y_{ijt}^2 + \beta_{uu} u_{ijt}^2 + \beta_{yu} y_{ijt} u_{ijt} + \beta_I I_{ijt} + \boldsymbol{\beta}_z' \mathbf{z}_{ijt} + \varepsilon_{jt}. \qquad (4)\end{aligned}$$

3.2 The Finnish data

The mean and (standard deviations) - calculated as an average over the three years - are 2.5 (1.6) and 4.0 (2.2) m FMK, for the non-electrified and electrified track units, respectively. In our sample of 278 track units, 154 are non-electrified and 124 electrified. Estimating the full model (i.e. equation 3) it is possible, again using the $F-$test, to test for whether a restricted model (now with 35 restrictions) is better than the full model. We get $F = 0.538$ (P-value $= 0.985$) and - in the same way as for the Swedish material - we cannot reject the restrictions. The final model used for analysing the Finnish data is

$$\ln C_{it} = \alpha + \alpha_t + \beta_y^* y_{it} + \beta_u^* u_{it} + \beta_{yy} y_{it}^2 + \beta_{uu} u_{it}^2 + \beta_{yu} y_{it} u_{it} + \boldsymbol{\beta}_z' \mathbf{z}_{jt} + \varepsilon_t. \qquad (5)$$

For comparison, this model formulation is also used when estimating the Swedish data (cf. columns 4 and 5 in Table 3 below).

4 Results

The results of the estimation will first be reported separately for Sweden and Finland (sub-sections 4.1 and 4.2). Thereafter, we summarize our estimates of the marginal costs of track wear in sub-section 4.3.

4.1 The Swedish railways

The parameter estimates from our two models (equations 4 and 5) are given in Table 3. Comparing columns 2 and 4, we can see that when the number of bridges, tunnels and the district factor are eliminated, there is little difference between those of our parameter estimates of that are of main interest. Hence, it will be possible to compare the results from the two data sets, despite the lack of some variables in the Finnish data set.

Considering that we use cross-section data, the fit of both models is excellent with $R^2 = 77$ and 74 percent, respectively. Analyzing the residuals from the estimated model 4 reveals no large model misspecification. As can be seen from Figure 2, there are no signs of excess kurtosis, skewness and a Kolmogorov - Smirnov (KS) test cannot reject (p-value = 0.06) normality. We have one outlier in the Swedish material but the results do not change if this observation is removed. Moreover, the graphical examination of the residuals does not indicate any heteroscedasticity.

We can note that the signs of the parameters of interest are as expected, except for two insignificant parameters for our tunnel factor.[3] The parameters of main interest, track length (y) and utilization (u), are all significant except the second-order term for track length.[4]

The two parameters for the number of bridges are insignificant, and only levels two (at 10 percent level of significance) and five reveal a higher cost than for the track units with no tunnels. It is also noteworthy that the parameter representing the different cost structure for main and secondary lines (β_I) is insignificant - despite the large difference in mean level established above - when conditioning on the covariates. Not only is the same technology used across the network, as demonstrated above; when we control for traffic and the other explanatory parameters, the differences in costs for maintaining different classes of tracks vanish. Moreover, there is no significant shift $-$ measured by the intercepts α_{95} and $\alpha_{96}-$ in the costs over the three years under study.

Figures 3 and 4 plot the elasticity of costs relative to line length[5] and utilization (i.e. $\eta^y_{ijt} = \partial \ln C_{ijt}/dy_{ijt}$ and $\eta^u_{ijt} = \partial \ln C_{ijt}/du_{ijt}$) against gross ton km, $Gtkm = UY^l$, where Y^l is line length[6]; each data point is simply $\eta^{u*}_{ijt} = \beta^*_{ut} + 2\beta_{uu}u_{ijt} + \beta_{yu}y_{ijt}$ and correspondingly for line length. The elasticity of

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[3] We include the number of tunnels as a factor in seven levels (with no tunnels as the base level); there are 23, 27, 17, 5, 5 and 11 track units with 1, 2, 3, 5 and 6 and more tunnels, respectively.

[4] Significance or insignificance results in the following refer to the 5 per cent level at least.

[5] Since the estimate $\widehat{\beta}_{yy}$ is insignificant, we set $\beta_{yy} = 0$ when calculating η^y_{ijt}.

[6] Line length, (Y^l), differs from track length (Y) for track units with double tracks; Y$\geq Y^l$.

Table 3: Parameter estimates from the two estimated models for the Swedish data. The first model (equation 4) also includes 19 district dummies not reported here. We note, however, that three of these dummies are significantly lower than that of the benchmark district. The interpretation is that - after controlling for our explanatory variables - costs are lower in these three districts. This points to a way of using the model for comparison of productivity across *Banverket's* organizational units.

	Equation 4		Equation 5	
Variables/Coefficients	Est.	t-value	Est.	t-value
α	-6.749	-3.924	-6.828	-4.210
α_{95}	-0.005	-0.093	0.000	0.003
α_{96}	0.013	0.241	0.005	0.292
I/β_I	0.026	0.342	0.004	0.048
y/β_y^*	2.338	5.943	2.023	5.589
u/β_u^*	0.986	5.051	1.037	5.692
yu/β_{yu}	-0.104	-5.868	-0.096	-5.665
y^2/β_{yy}	-0.010	-0.294	0.023	0.786
u^2/β_{uu}	-0.014	-2.288	-0.017	-2.995
Bridge	0.005	0.708		
Bridge^2	0.000	-0.459		
Switches	0.011	3.601	0.010	3.462
Switches^2/100	-0.006	-1.184	-0.005	-1.169
INDX	0.210	2.290	0.269	3.022
INDX^2	-0.028	-3.145	-0.033	-3.773
Tunnel (factor in seven levels)				
1	-0.070	-0.604		
2	0.206	1.782		
3	-0.062	-0.461		
4	0.256	1.078		
5	0.626	2.423		
6	0.057	0.331		
R^2	0.767		0.736	

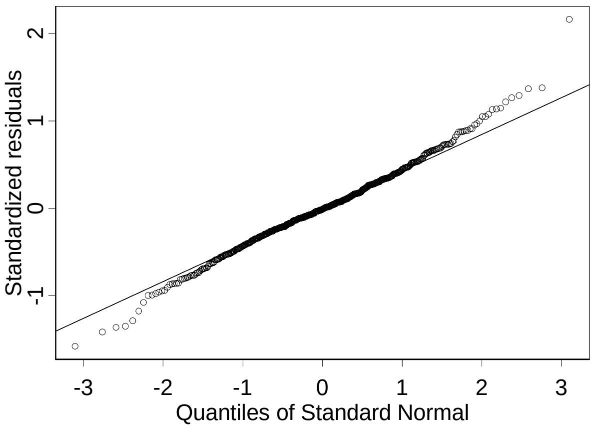

Figure 2: Q-Q plot of standardized residual. Swedish data.

costs relative to utilization (η^u) falls when traffic loads increase and remain basically constant after the first two billion gross ton km. Our point observations of elasticity therefore provide the image that the costs for maintaining tracks have the familiar u-shape, at least the falling part of the u. The same pattern prevails for η^y.

The mean values of these elasticities are summarised in Table 4. The overall mean of cost elasticity with respect to track length (η^y) is 0.80 while separate estimates for main and secondary lines are 0.71 and 0.97, respectively. Calculated standard deviations are, however, so large that we cannot safely claim mean elasticities to be below one. However, for the main lines it is fair to say that increasing track length - adding more double-track sections - would reduce the average maintenance costs. Our single most important observation is that the mean η^u is 0.17, meaning that the average costs for maintaining railway infrastructure decrease with the traffic load. In subsection 4.3, this value will be used to calculate marginal costs.

One key to understanding why elasticities at the two classes of lines differ is most probably that main lines include track sections that are entirely or partly double tracked, while secondary lines are typically single-tracked with fewer meeting stations. Since maintenance activities on main tracks can more often be undertaken with one of the tracks closed off from traffic for a relatively convenient period of time, the physically identical measures may require workers to get off the line more frequently on secondary lines; each job thus takes more

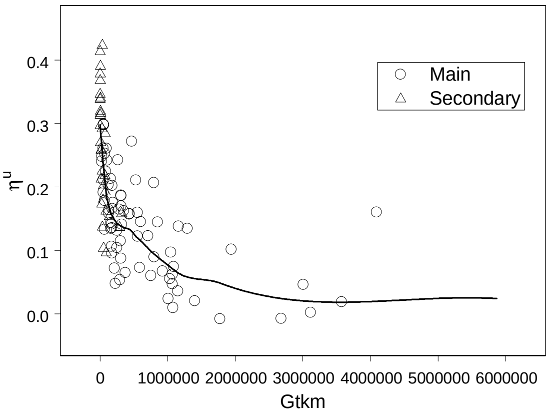

Figure 3: The elasticty of utilization on cost against (thousand) gross ton km. One mark represent**s** 5 data points. The line is calculated using a loess smooth.

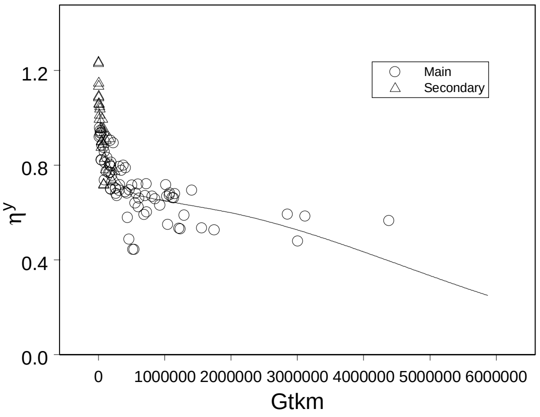

Figure 4: The elasticty of track length against (thousand) gross ton km. One mark represent**s** 5 data points. The line is calculated using a loess smooth.

Table 4: Mean elasticities of track length and utilization, subdivided into main and secondary lines. Standard deviations are calculated using the delta method (cf. Greene, 1993, ch. 7)

	All	Main	Secondary
mean η^y	0.796	0.713	0.972
standard deviation	0.235	0.231	0.244
mean η^u	0.169	0.139	0.233
standard deviation	0.035	0.037	0.034

time. As we have noted, our data indicates that the technologies are similar per se, both since β_I is not significant and since we could not reject the hypothesis of identical coefficients in the F-test above.

While traffic and track length seem to be the most important determinants of track maintenance costs, Table 3 shows that the number of switches and the quality index also have a significant impact on costs. The cost elasticity with respect to an increase in the number of switches is 0.705, and based on the total number of switches and total maintenance costs, it can be deduced that an additional switch would increase the maintenance costs by about SEK 14 000. The mean cost elasticity with respect to the quality index is 0.245. Considering the current average track standard and average maintenance costs, and assuming that the index variable is measured on - at least - a ratio scale, an investment to improve the average track quality of an average track unit with one index unit would reduce maintenance costs by about SEK 280 000.

4.2 The Finnish railways

The parameter estimates for two different analyses are included in Table 5. The fit of the first model, which only includes maintenance costs, is once more excellent with $R^2 = 83$ percent. Figure 5 indicates no large misspecification and from graphically examining the residuals, we do not find any evidence of heteroscedasticity.[7]

The track length coefficients β^*_y and β^*_{yy}, are significantly different from zero, but the corresponding coefficients for traffic load β^*_u and $\beta^*_{\mathrm{u}u}$ are not. Still, the β^*_u coefficient has the expected sign and is significant at the 10 percent level in a one-tail test. Spending on maintenance does obviously not respond to variations in

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[7] The Kolmogorov - Smirnov (KS) test (KS = 0.05) cannot reject (p-value = 0.5) normality.

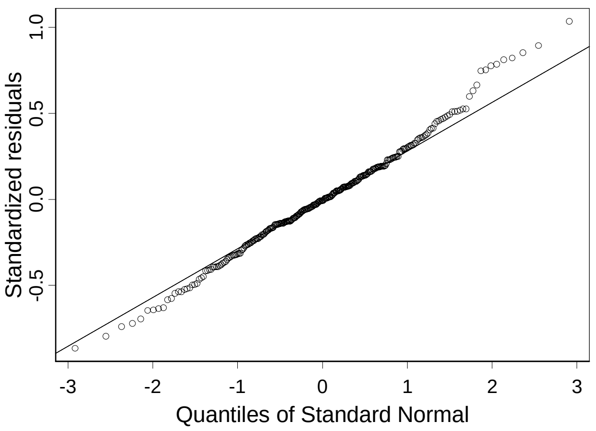

Figure 5: Q-Q plot of standardized residual. Finnish data set.

traffic load in the same way as in the Swedish data.[8] The parameter estimates for the quality proxy (Speed) are significant and display the same pattern as INDX for the Swedish data and the parameters for number of switches are both highly significant, indicating an increasing cost at a decreasing rate; the magnitude of that impact is, however, small. Moreover, Finland has a significantly negative time trend for costs, indicating cost-savings of ten percent or more between 1997 and 1998 or 1999, respectively.

The elasticity of costs relative to track length[9] (i.e. $\eta_{it}^{y} = \partial \ln C_{it}/dy_{it}$) is plotted against *Gtkm* in Figure 6. The sharp decline in elasticity for low values of *Gtkm* is driven by the non-electrified lines while elasticities fall slowly with the traffic load on electrified lines. The similar structures of Figures 6 and 4 indicate that non-electrified lines are tantamount to what was referred to as secondary lines in the Swedish material. These are the lines where it has not been deemed worthwhile to invest in electrification because of a low traffic flow.

The mean values of the respective elasticities have been calculated and are summarized in Table 6. The overall mean η^{y} is 0.63 which is lower than in the Swedish model. Because of large standard deviations, we cannot conclude (statistically) that the means are below one. Although the η^{u} are estimated with

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[8] A test for a restricted Cobb-Douglas specification still indicates that the Translog specification cannot be rejected. $F = 3.429$ and with three degrees of freedom, the Translog specification can be rejected at 1.8 percent risk.

[9] Since the estimate $\widehat{\beta}_{yu}$ is insignificant, we set $\beta_{yu} = 0$ when calculating η_{it}^{y}.

Table 5: Parameter estimates (using $n = 298$ observations) from the Finnish data set from the final model and the parameter when adding the re-investment cost.

	Maintenance Cost		With Reinvestments	
Variables/Coefficients	Est.	t-value	Est.	t-value
α	8.780	6.645	10.764	2.967
α_{98}	-0.104	-2.145	-0.036	-0.269
α_{99}	-0.139	-2.830	-0.051	-0.381
I/β_I	-0.318	-4.936	-0.550	-3.102
y/β_y^*	1.504	3.462	1.408	1.179
u/β_u^*	0.167	1.501	-0.326	-1.065
yu/β_{yu}	0.001	0.071	-0.018	-0.341
y^2/β_{yy}	-0.104	-2.766	-0.078	-0.754
u^2/β_{uu}	-0.006	-1.519	0.026	2.234
Switches	0.010	4.460	0.012	1.889
Switches^2/100	-0.003	-2.264	-0.001	-0.379
SPEED	0.013	3.298	0.005	0.478
SPEED^2/100	-0.013	-3.287	0.009	0.809
R^2	0.827		0.498	

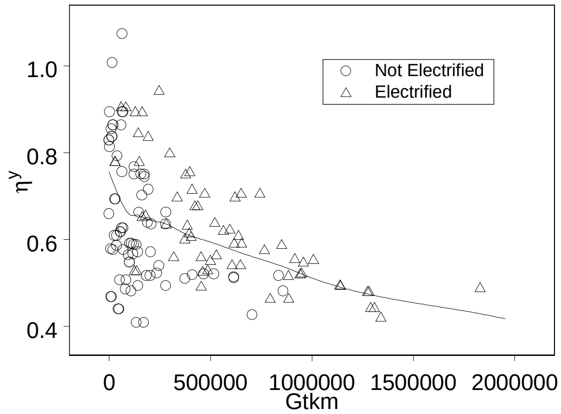

Figure 6: The elasticty of track length on cost against (thousands) gross ton km. One mark represents 2 data points. The line is calculated using a loess smooth.

Table 6: Mean elasticities of track length and utilization, subdivided into main and secondary lines. Standard deviations are calculated using the delta method (cf. Greene, 1993, ch. 7)

		Electrified	
	All	yes	no
mean η^y	0.635	0.626	0.642
standard deviation	0.286	0.285	0.287
mean η^u	0.167	0.167	0.167
standard deviation	0.111	0.111	0.111

low precision, it is clear that they are below unity with similar implications as in the Swedish material. In particular, the magnitude of the respective elasticities is very similar.

So far, the analysis only includes costs for current maintenance. But it is obvious that spending for reinvestment purposes is relevant in our context. The costs for maintaining tracks increase with time and sooner or later, the annual maintenance cost will be high enough to warrant a renewal of the facility; rather than spending increasing sums of money on current maintenance, it is cheaper to replace tracks-and-sleepers on a longer section of the line, change switches, etc., thus saving money in the future. The timing of the track renewal is related to the traffic load; the more traffic over a track unit, the more frequent is the renewal frequency. This is the logic for also including renewal costs in any comprehensive analysis of infrastructure spending.

The Finnish, but not the Swedish, material includes information about this type of spending. However, we only have observations from three specific years rather than the long periods of time that would be required to get an understanding of the cost structure. With sufficiently long observation periods and stable external factors, including traffic load, reinvestment could be expected to be more frequent on track units with more traffic than on those with less.

The last two columns of Table 5 provide coefficient estimates when spending on renewal has been added to current maintenance. A first observation is that the explanatory power of the model falls to $R^2 = 50$ percent. Only two variables are now significant with the electrification dummy and the squared utilization capturing most of the effect on the cost. We abstain from drawing any further conclusions from this three-year dataset.

4.3 Marginal cost

The estimated elasticities can be used to derive estimates of marginal costs for each single track unit, i.e. of the wear and tear inflicted on tracks by allowing for an additional train of some certain weight to pass over a track unit. To this end, we must start by including a distance component in the traffic activity measure. While elasticity is measured relative to an increase in gross ton per track unit, the preferred marginal cost measure is due to an increase in *Gtkm*. The measure of marginal cost (MC) per *Gtkm* is then

$$Mc = \frac{\partial C}{\partial Gtkm} = \frac{\partial \ln C}{\partial \ln Gtkm} \frac{C}{Gtkm} = \frac{\partial \ln C}{\partial \ln U} \frac{C}{Gtkm} = \eta_u \frac{C}{Gtkm}.$$

Thus, we assume that, at the margin, the cost is unaffected by line length Y^l, hence MC is the marginal cost of increasing the utilization for a given line length. Estimates of the marginal cost are given by substitution of the estimates and the inclusion of fitted costs, i.e.

$$MC_{ijt} = \widehat{\eta}^u_{ijt} \frac{\widehat{C}_{ijt}}{Gtkm_{ijt}}$$

where $\widehat{C}_{ijt} = \exp(\widehat{\alpha} + \widehat{\alpha}_t + \widehat{\alpha}_j + \widehat{\beta}^*_y y_{ijt} + \widehat{\beta}^*_u u_{ijt} + \widehat{\beta}_{yy} y^2_{ijt} + \widehat{\beta}_{uu} u^2_{ijt} + \widehat{\beta}_{yu} y_{ijt} u_{ijt} + \widehat{\beta}_I I_{ijt} + \widehat{\boldsymbol{\beta}}'_z \mathbf{z}_{ijt} + 0.5\widehat{\sigma}^2)$ and $\widehat{\sigma}^2$ is an estimate of the variance. Scatter plots of the logarithm of the marginal costs against *Gtkm* are given in Figures 7 and 8 for the Swedish and Finnish data, respectively. It confirms the previous observation that higher traffic volumes imply lower average and marginal maintenance costs. Marginal costs for the wear and tear of adding trains to electrified tracks in Finland seem to remain approximately constant when the number of trains increases.

Because of the detailed system for recording track use, it would be technically feasible to charge a different price for using each separate track unit, as implied by the above figures. In view of the efficiency objective, this is also principally correct. Trains would then need to pay a different amount per gross ton km for using each different track unit, and the actual payment for each specific train would depend on its particular weight.

To provide a more comprehensive statistic, there is, however, also reason to calculate the 'average marginal cost', both for the network as a whole and for the main and secondary lines separately. For this purpose, we choose to weight together our respective marginal costs, using the track activity on each track unit as our weight, i.e. $weight_{ijt} = Gtkm_{ijt} / \sum_{ij} Gtkm_{ijt}$. This weighting scheme generates the same level of revenue as if a separate charge is levied for each track unit. The estimated marginal costs are show in Table 7, both for the network as a

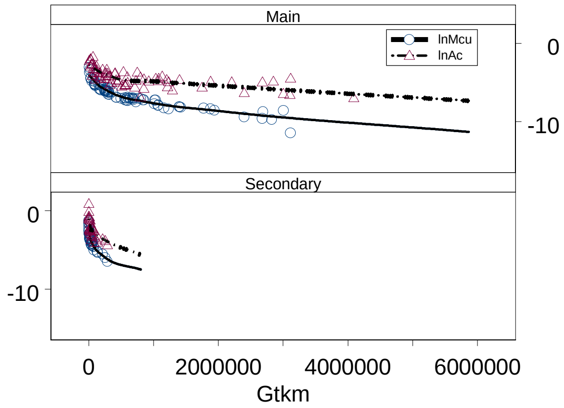

Figure 7: Logarithm of average and marginal costs (1000 SEK, in 1995 prices) per thousand gross ton km. The lines are estimated using a loess smoother. One mark represents 5 data points.

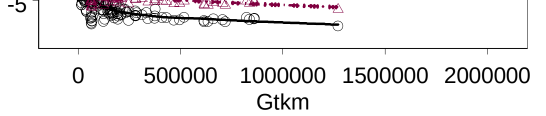

Figure 8: Logarithm of average (Ac) and marginal costs (Mc) (1000 FMK, in 1995 prices) against (thousands) *Gtkm*. The lines are estimated using a loess smoother. One mark represents 2 data points.

whole and separated for main/electrified and secondary/non-electrified lines. We can see that all estimated marginal costs are higher in Finland than in Sweden.

The estimate from the Swedish data implies that a 1300 gross ton freight train, moving some 800 km between its points of departure and arrival and being charged (on average) 0.0012 SEK per gross ton km would have to pay about SEK 1200 for the whole trip. Using the estimate from the Finnish data, a similar transport would be charged about SEK 2300. In line with our observation, that track maintenance is a decreasing cost activity and with this marginal cost price, no more than 17 percent of the annual maintenance cost would be recovered for the three years in Finland. Since we have only included 70 percent of the annual spending on track maintenance in Sweden, no more than 12 percent of the total costs would be recovered.

Table 7: Estimates of marginal cost in ore (1 SKR = 100 ore) and pfennig (1 FIM= 100 fpennig). 1 SEK is FMK 1.42 in 2000.

	Sweden		Finland	
	1995	2000	1995	2000 (in SEK)
ALL	0.117	0.120	0.147	0.225
Main/electrified	0.082	0.084	0.111	0.170
Secondary/non-electrified	0.909	0.930	0.248	0.380

A final word about the basis for our observations - i.e. the underlying maintenance policies of the respective agencies - is warranted. Our results provide an impression of how costs are affected by different variables, in particular traffic. The basic result is that maintenance activities are not very responsive to variations in traffic. There is still some causal relationship between traffic and maintenance, however. One reason might be that agencies have a policy of fixing problems when these pop up. A positive relation between traffic and costs then simply indicates that more must be done, the more extensive is the traffic since more traffic will wear down the infrastructure more quickly. Another, or rather a complementary, policy could be that tracks are to be held in reasonable shape, irrespective of if problems actually occur. This policy could, in turn, be based on traffic loads, which would then explain the positive relationship. We do, however, not know which explanation is most reasonable for describing our results.

5 Taking stock

What is the logic of the results found above, i.e. what do we learn about the structure of track maintenance costs? A first observation is of technical nature; the Translog specification of the functional relationship between costs and explanatory variables seems to provide a good basis for understanding the pattern of spending on track maintenance. But although costs do not vary linearly with variations in traffic and track length, non-linearities are not very strong.

A second observation is that the explanatory power of our model is high; information about traffic levels, track length, number of switches and quality provides a good intuition for understanding the levels of spending on track maintenance. When information about these variables is available, the classification of tracks to one administrative class or another does not seem to add to our understanding of maintenance patterns.

Third, similarities between the two countries are considerable but not complete. In particular, the impact of traffic levels on costs is less distinct in Finland than in Sweden. The mean elasticity of costs relative to traffic is, however, estimated to be strikingly similar. Is it then logically consistent that marginal costs for track use are almost 90 per cent higher in Finland than in Sweden? The answer must be affirmative. Each country has its own features of the network. The two countries here, for instance, differ with respect to track gauge and winter conditions in Finland are generally harsher than in Sweden. In particular, Finnish but not Swedish observations also include costs that are common for the organization. The way in which these common costs have been allocated across track units may, per se, have an effect on our estimates. While the pattern of spending - the logic of allocating resources for the purpose of maintaining tracks - seems to be common, it is not anomalous to observe unit or marginal costs for doing the job that vary across countries.

Can we generalize the results to other countries, for instance to countries with more traffic and possibly a higher density of traffic on each track unit? The intuition from Figures 7 and 8 indicates that this may be feasible. Both figures show that marginal costs remain approximately constant when the traffic load has passed some threshold value. It would still be heroic to generalize from studying two countries only, in particular since both are located in the same climate zone and since their traffic loads are smaller than in many continental countries.

It is important to point to the vulnerability of the marginal cost estimates derived. Marginal costs constitute a derivative of our basic analytical result, the elasticity estimate. But in contrast to elasticity, marginal costs are scale dependent; a marginal cost in one country cannot be immediately compared to that in another, while elasticity can.

Finally, if we would like to infer production technology parameters from the estimations above, organizations must be assumed to be cost minimizing. In view of the fact that agencies of both countries are funded through the public budget, this may not be an innocuous assumption. Our theoretical understanding, and even more so the empirical results relative to the possible problems of X-inefficiencies in public organizations, are incomplete, however. After all, budget-funded agencies also have reason to keep track of their costs; the lower the cost for a certain activity, the more activities and the higher technical standard can - ceteris paribus - be afforded. Moreover, a public agency hires its staff on the open market which means that there is a flow of technical experts between the public and private sectors; this would at least ascertain that the agency gets access to reasonably modern insights about how to behave in order to reduce costs. In a study of the efficiency on Belgian railroads, the author concludes that "(t)he implications of inefficiencies for factor use are found to be substantial, although the associated costs are quite small." (De Borger 1993. p 443.) A comparison of the technical efficiency of the former British Airports Authority before and after privatization concludes that no substantial changes can be established (Parker 1999). The possibility that officials are able to make clever decisions in order to minimize costs and select appropriate factor mixes without having access to statistics cannot be dismissed.

6 Concluding comments

In a review of the cost structure of the railway industry, Kessides and Willig (1995) establish that the industry as an aggregate displays scale economies: An equi-proportionate change in the levels of all services provided in the firms' complete network would require a less than proportionate change in the level of costs within relevant ranges of traffic production. This means that activities can be described by way of a long-run average cost curve that declines as the quantity of the firms' output of a given collection of services increases. While we may hypothesize that possible scale, scope and density economies have a natural basis in the huge and lumpy investments in track-and-structures, and less in the costs for operating the system, previously available data has not lent itself to understand these aspects.

The present paper demonstrates that the costs for maintaining tracks constitute a complementary reason for the industry's cost reduction with usage, at least for the levels of track use reported here; the cost elasticity for marginal variations in traffic levels is far below one. One policy implication is that if traffic is priced at marginal costs for track wear, revenue from these charges would be inadequate for recovering the total costs for the maintenance of the railway infrastructure.[10]

We have also discussed the necessity of making reinvestment costs part of the charging structure. Lack of data (Sweden) and a short time-series (Finland) have not made it feasible to draw any conclusions about the appropriate size of the marginal cost with respect to renewal spending. Policy makers would therefore have to rely on engineering data and rules of thumb to come up with a number, much in the same way as the corresponding cost is estimated for roads.

Like all empirical, non-experimental analyses, the data sets that have been analyzed reflect the way in which activities have been handled in historic time. With hindsight, this may be flawed policies, for instance since decision makers had incomplete information when allocating resources or in view of external budget constraints that are seen to be inappropriate. Spending in one year may also reflect the accumulated consequences of traffic loads over previous years. With the data at hand, we have poor possibilities of controlling for any of these circumstances. The strength of the analysis, on the other hand, is that we base the results on very few assumptions and simply look at the evidence at hand.

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[10] Another component of the marginal cost is scarce track capacity. Nilsson (2000) suggests a way of also charging for this cost. Charging for congestion costs would make up for at least parts of the deficit from charging wear and tear.

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