Railway usage charges based on marginal maintenance costs

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The study reported here focused on finding a charging model for using regional railway lines. Due to geographical and technological characteristics, such lines are neglected and unused yet have great potential, especially for freight transport. The goal of the research was to calculate marginal maintenance costs of regional rail lines using an econometric cost function model. The econometric model was estimated using the least-squares method. The charges were calculated based on marginal costs and gross tonne kilometres (grt.km) and a comparison was made with the existing model for calculating charges. The grt.km calculation resulted in a charge lower than that calculated using the existing model, resulting in positive economic effects for carriers. The results of the proposed model are also in line with European transport policy objectives that strive to increase rail freight transport and redirect the flow of goods from road to rail, thus significantly lowering external costs.

Notation

a_j	parameters that have to be estimated
C	variable maintenance costs, which includes the costs of ordinary and major maintenance on railway infrastructure
$C_{vl,km}$	price per train-km based on full cost
C_{vp}	cost of supplement or deduction for the type of transport (depending on the type of train)
F_{vv}	coefficient of power vehicle categories (vv)
$MC_{grt,km,i}$	price per gross tonne kilometre (grt.km) at section i based on marginal costs
P_i	weighting of line category i
$Q_{grt,km}$	amount of grt.km on regional rail
$Q_{vl,km(vv,i)}$	number of train-km per individual line category (i) with the same power vehicle (vv)
U	usage charge
ε_i	error terms

1. Introduction

In Europe, infrastructure policy in the field of railway transport is directed by the European Union (EU), which releases guidelines for future transport development in EU Member States. European transport policies from 2001 (EC, 2001) and 2011 (European Commission, 2011) promote greater use of rail transport due to lower negative environmental impacts compared with road transport. European legislation (EC, 1991, 2012) provides for separate infrastructure management and transport services. Baumstark and Bonnafous (ECMT, 1998) argued that vertical separation is linked to the role of the state. However, Quinet (2001) stipulated that political decisions do not include the efficient use of railway infrastructure. Based on the adoption of four series of railway packages, the market

for railway services in the international environment has gradually started to open up. This has resulted in an increase in competitiveness due to the larger number of rail service providers. Given the scarcity of infrastructure and monopoly positions, a system of charging was gradually set up that is based on different approaches with the aim of increasing efficiency. For this purpose, numerous studies on the choice of charging system for the use of railway infrastructure were conducted (Andersson, 2008; ECMT, 2005; Nash, 2005). Van de Velde *et al.* (2012) found no evidence that vertical separation increases competition compared with a holding company model and, likewise, no proof that such increased competition would reduce costs.

Within the framework of existing legislation, EU Member States can determine their own infrastructure policy and charging systems, allowing efficient operation and optimum utilisation. However, efficiency is harder to achieve over the whole rail network as the demand for rail services is unevenly distributed. Moreover, the choice of transport mode also affects the quality of transport services.

In practice, different approaches, based on the cost of infrastructure and demand for rail services, are used. A marginal social cost (Li and Preston, 2015) charging approach accounts for additional costs to society caused by each transported kilometre on the railway infrastructure (ECMT, 2005). Marginal social costs are the sum of marginal private costs, which in fact are costs of infrastructure management, and marginal external costs (environmental costs, accident costs and so on). Marginal social costs can include the costs of increasing capacity utilisation, including increased delays to other operators and scarcity costs (Johnson and Nash, 2008). Scarcity and congestion

occur on the rail network when and where capacity utilisation is high (Nash and Matthews, 2003). Due to lack of competitiveness of the rail system compared with road, marginal external costs often do not apply to the charge for the basic railway infrastructure as this would lead to a further increase in costs, particularly on regional routes, which – due to the deteriorating economic situation – are still uncompetitive and thus unattractive to carriers.

In economic theory, various cost function alternatives for evaluating the cost of rail transport are in place. The transcendental logarithmic function (translog) developed by Christensen *et al.* (1973) was considered as a breakthrough in the field of assessing rail transport costs. Using this method, the theory of production and limits of the homogeneity of the production function were tested. Brown *et al.* (1979) used a transcendental function to calculate the marginal costs of rail transport. They found that the use of the neoclassical approach is appropriate when estimating costs. The neoclassical approach assumes that firms are technically efficient and they want to maximise profit. The transcendental logarithmic function has also been used to evaluate the marginal cost of infrastructure maintenance. Johansson and Nilsson (2004) estimated limit maintenance costs in Sweden and Finland and found that the transcendental specification and the link between maintenance costs and explanatory variables offer a good basis for understanding the costs of infrastructure maintenance.

When estimating the marginal costs of Austrian railways, Munduch *et al.* (2002) used a similar methodological approach. They found that the estimated marginal costs cover between 20% and 30% of average infrastructure maintenance costs. They further found that the length of the section and transported gross tonnes are the largest cost producers. At the same time, it is important to note that marginal costs are higher at secondary or local railway lines. When evaluating the marginal cost of rail infrastructure, Tervonen and Pekkarinen (2007) took into account the short-term variable costs. Traffic management costs and operating infrastructure costs are fixed in the short term. Tervonen and Pekkarinen also considered the total gross tonnes transported for both passenger and freight transport. When estimating marginal costs in a dynamic context, Andersson (2008) adopted a similar approach and noted that the ratio between marginal and average costs is very low, resulting in higher rail infrastructure co-financing by the state.

The research presented here focused on finding a charging model for the use of regional railway lines, which – due to geographical and technological characteristics – are neglected and unused yet have great potential, particularly for freight transport. Due to the low freight potential on certain regional routes, the offer of rail freight services is quite poor. At the same time, the quality of regional railway lines and low

demand for rail services do not attract rail carriers to offer their services on these routes. For these reasons, companies decide to use road transport, which is more flexible.

Based on preliminary findings mainly focused on the entire rail network, the aim of the present research was to estimate marginal costs of infrastructure maintenance for Slovenian regional railway lines. With this in mind, an econometric cost function model was developed that also includes the most important explanatory variables selected on the basis of previous research and expert judgement. The estimated marginal costs form the basis of calculating charges, which are currently based on train-km. However, calculation on the basis of full costs and train-km is not focused on the efficient use of infrastructure, because the share of empty wagons on regional routes is between 40 and 50% (SR, 2014). However, in the current model, this has no effect on determining the charge. The economic effects on railway transport service providers were estimated based on the calculated charges. The findings offer a choice of the most suitable charging model and facilitate infrastructure managers to increase efficiency in terms of the use of regional railway lines, which is currently 40–60% of line capacity, whereby more than 80% is represented by passenger traffic (SR, 2014). The latter, however, is exempt from charges in that it is a public service (GRS, 2012).

2. Methodology

Relevant data obtained from the company Slovenian Railways were first defined. This was followed by a definition of the cost function econometric model and calculation of the marginal costs and charges, which represent the cost for the rail carrier. Slovenia adopted full-cost pricing based on train-km. However, this has proven to be ineffective in improving regional rail freight transport. Therefore, the research hypothesis is: marginal cost pricing based on gross tonne kilometres (grt.km) is economically efficient.

2.1 Description of data

The analysis focuses on the regional railway lines in Slovenia, which are divided into 28 segments (SR, 2014). Due to indirect connections on the Slovenian railway network (Figure 1) and lack of data, one section of regional railway lines was excluded, which represents 1% of the total regional railway lines. Given this small percentage, this was not considered significant. Thus, in the model, 27 regional line sections in 2012 were analysed, meaning a total of 27 observations.

The research included only variable costs of short-term infrastructure maintenance (Link and Maibach, 1999). The explanatory variables of the cost function model were defined on the basis of Slovenian legislation in the field of rail transport (RoS, 2011) and relevant research conducted in other countries (Johansson and Nilsson, 2004; Munduch *et al.*, 2002). For each section of regional railway studied, information on the technical characteristics of the infrastructure and the statistics

Figure 1. Excluded section of regional rail lines

of Slovenian Railways were obtained. The dependent and explanatory variables are shown in Table 1. Variable maintenance costs include the costs of ordinary and major maintenance on railway infrastructure. To structure the cost function, variables such as the length of each section, the number of signals, the number of switches and the number of level crossings were taken into account. The quality of the track was determined on the basis of measurements of track geometry parameters taken at least once per year. Track geometric quality is based on track maintenance criteria of vertical alignment, lateral alignment, gauge and twist (UIC, 2005). Lower track geometry parameters mean a higher quality railway line, resulting in no need for additional maintenance that clearly would affect cost increases.

2.2 Cost function model

Maintenance costs are influenced by many different factors. Hence, when evaluating the cost function, multiple regression analysis in the form of a double logarithmic model was used. The model is based on neoclassical economic theory of the Cobb–Douglas production function, on the basis of which

Keeler (1974) formulated a cost function in the short term. A similar methodology was used in relevant studies on other countries (Johansson and Nilsson, 2004; Munduch *et al.*, 2002; Tervonen and Pekkarinen, 2007). The applied cost function has the form

$$\log C_i = a_0 + a_1 \log(km_i) + a_2 \log(grt_i) + a_3 \text{sig}_i + a_4 \text{swt}_i + a_5 \text{cross}_i + a_6 \text{tg}_i + a_7 \log(grt_i) \times \text{sig}_i + a_8 \log(grt_i) \times \text{swt}_i + a_9 \log(grt_i) \times \text{cross}_i + a_{10} \log(grt_i) \times \text{tg}_i + \varepsilon_i$$

in which km represents the track length, grt represents gross tonnes, sig is the number of signals, swt is the number of switches, cross is the number of level crossings and tg represents track geometric quality, which is based upon track maintenance criteria as mentioned earlier. The model was estimated using the least-squares method in the programme EViews 8.0.

The Ramsey reset test was performed to test the functional forms of the regression model. To confirm the assumptions of multiple regression (Greene, 2002; Gujarati and Porter, 2009), the premise for the analysis of multi-collinearity was assessed using the variance inflation factor, whereas for the homoscedastics the White test was performed. The presence of autocorrelation was checked using the Durbin–Watson test and the test of normality of errors was checked using histogram errors and the Jarque–Bera test.

2.3 Estimation of charges based on marginal cost

Using the existing model (SR, 2014), the usage charge was calculated using

$$U = \left(\sum_{i=1}^I \sum_{vv=1}^{vv} Q_{vl.km(vv,i)} \times F_{vv} \times P_i \times C_{vl.km} \times C_{vp} \right)$$

Using the model based on marginal costs, the charge was calculated using the equation

$$U = Q_{grt.km} \times MC_{grt.km,i} \times P_i$$

Table 1. Section data

Variable	Description	Mean	Median	Maximum	Minimum	Standard deviation
C	Variable maintenance costs	92 469.38	52 291.36	44 198.60	3345.34	91 444.14
km	Track length	21.52	16.00	73.00	2.00	17.34
grt	Gross tonnes	822 535.30	682 533.00	3 016 851.00	29 736.00	698 922.30
sig	Number of signals	16.33	14.00	47.00	0	12
swt	Number of switches	23.18	21.00	59.00	0	17.27
cross	Number of level crossings	24.15	14.00	77.00	0	22.84
tg	Track geometry	193.37	190.00	255.00	133.00	30.48

The marginal cost (MC) was calculated from the cost function using Equations 4–6, based on a similar methodology in reference studies (Johansson and Nilsson, 2004; Munduch *et al.*, 2002; Tervonen and Pekkarinen, 2007) where the most suitable unit of marginal costs was found to be grt.km.

$$4. \quad MC_i = \frac{\partial \hat{C}_i}{\partial \text{grt.km}_i} = \frac{\partial \hat{C}_i}{\partial \text{grt}_i} \times \frac{1}{\text{km}_i}$$

$$= \left(\frac{\partial \hat{C}_i}{\partial \text{grt}_i} \times \frac{\text{grt}_i}{\hat{C}_i} \right) \times \frac{\hat{C}_i}{\text{grt.km}_i}$$

whereby

$$5. \quad \left(\frac{\partial \hat{C}_i}{\partial \text{grt}_i} \times \frac{\text{grt}_i}{\hat{C}_i} \right) = a_2 + a_7 \text{sig}_i + a_8 \text{swt}_i$$

$$+ a_9 \text{cross}_i + a_{10} \text{tg}_i$$

and

$$6. \quad \hat{C}_i = \exp[\log(C_i) + 0.5(\text{standard error})^2]$$

$[(\partial \hat{C}_i / \partial \text{grt}_i) \times (\text{grt}_i / \hat{C}_i)]$ represents the elasticity depending on gross tonnes.

In rail freight transport, it is important to know the influence of the explanatory variables on the cost of infrastructure maintenance; such knowledge can also improve the efficiency of the railway infrastructure capacity use. From an infrastructure manager's viewpoint, elasticity is important in relation to the length of the rail line segment and the transported volume of goods. The length of the rail line segment affects decisions on expansion of the railway network and capacity increases, while

the volume transported affects better utilisation of trainsets and increases the volume of freight.

For the observed sections, the weighted marginal costs based on grt.km (Equation 7) were calculated using comparisons with research carried out in other countries.

$$7. \quad \overline{MC} = \sum \left(MC_i \times \frac{\text{grt.km}_i}{\sum \text{grt.km}_i} \right)$$

3. Results

3.1 Numerical results

The choice of the most appropriate model for estimating maintenance costs of the railway infrastructure was carried out on the basis of expert recommendations (Greene, 2002; Gujarati and Porter, 2009). The exclusion of individual explanatory variables was based on the value of the determination coefficient, *F*-statistics, *t*-statistics of individual variables and Schwarz and Akaike criteria. For comparisons among models, an adjusted *R*² for degrees of freedom according to the sample size and number of explanatory variables was used. Despite the small sample and the small number of explanatory variables, the adjusted determination coefficient was high, which indicates the suitability of the selected model. The final design of the cost function was

$$8. \quad \log C_i = a_0 + a_1 \log(\text{km}_i) + a_2 \log(\text{grt}_i)$$

$$+ a_3 \log(\text{grt}_i) \times \text{sig}_i + a_4 \log(\text{grt}_i) \times \text{swt}_i$$

$$+ a_5 \log(\text{grt}_i) \times \text{cross}_i + a_6 \log(\text{grt}_i) \times \text{tg}_i + \varepsilon_i$$

The estimated model parameters of the cost function and the test statistics are shown in Table 2.

Table 2. Estimated parameters

Coefficient		Standard error	t-statistic	Probability
<i>a</i> ₀	4.656 919	1.549 681	3.005 083	0.0070 ^a
log (km _{<i>i</i>})	0.939 195	0.166 929	5.626 305	0.0000 ^a
log(grt _{<i>i</i>})	0.238 966	0.109 124	2.189 862	0.0406 ^a
log(grt _{<i>i</i>}) × sig _{<i>i</i>}	0.001 761	0.000 905	1.945 803	0.0659 ^b
log(grt _{<i>i</i>}) × swt _{<i>i</i>}	−0.000 922	0.000 491	−1.876 512	0.0753 ^b
log(grt _{<i>i</i>}) × cross _{<i>i</i>}	−0.000 774	0.000 434	−1.783 029	0.0898 ^b
log(grt _{<i>i</i>}) × tg _{<i>i</i>}	0.000 321	0.000 263	1.218 787	0.2371
<i>R</i> ²	0.831 081		Mean dependent variable	11.014 530
Adjusted <i>R</i> ²	0.780 405		Standard deviation dependent variable	1.012 351
Standard error of regression	0.474 397		Akaike criterion	1.564 870
Sum squared residuals	4.501 054		Schwarz criterion	1.900 828
Log likelihood	−1.412 575		Hannan–Quinn criterion	1.664 768
<i>F</i> -statistic	16.399 990		Durbin–Watson statistic	1.889 569
Probability (<i>F</i> -statistic)	0.000 001			

^aSignificant at 5% characterising level

^bSignificant at 10% characterising level

Figure 2. Average costs

All estimated parameters except the parameter $\log(\text{grt}_i) \times \text{tg}_i$ were statistically significant at the 5% or 10% characterising level. The adjusted determination coefficient was 0.78, which indicates the high power of the variable cost model. The regression function of estimating costs was specified correctly, given that the Ramsey reset test showed an F -statistic of 0.66 (probability 0.4239). The problem of multi-colinearity between regressions was not detected because the values of the variance inflation factor were considerably lower than 10. The White test showed that heteroscedasticity between variances of conditional distributions was not present. The Durbin–Watson test indicated no positive or negative autocorrelation, as the value of the coefficient (1.8896) was in the range 1.743–2.257 at 1% statistical significance.

A histogram of the residuals showed a normal distribution. The Jarque–Bera test indicated a JB-statistic of 0.2362 and a probability of 88%. Moreover, the skewness and kurtosis coefficients were 0.13 and 3.37, respectively. The calculated coefficients indicate that the hypothesis should not be rejected and that the residuals were normally distributed.

Given the length of the segment, the cost elasticity was determined to be 0.94 whereas, in terms of gross tonnes, it was only 0.24. The findings show that by increasing transported gross weight by 1%, the variable costs of infrastructure maintenance increase by 0.24%. Similar results were found in relevant research in other countries (Johansson and Nilsson, 2004; Munduch *et al.*, 2002; Tervonen and Pekkarinen, 2007). Due to cost inelasticity, the average costs of railway infrastructure maintenance decrease (Figure 2) with each transported cargo. Lower than average marginal costs contribute to the economies of scale.

Railway infrastructure is a natural monopoly and as such is often ineffective, which is why subsidies are required. Theoretically, the best approach for charging fees is one that is based on marginal social costs (Nilsson, 1992) but, because

Table 3. Estimated marginal costs

Marginal costs: €			
Slovenia	Finland (Tervonen and Pekkarinen, 2007)	Austria (Munduch <i>et al.</i> , 2002)	Sweden (Johansson and Nilsson, 2004)
0.00188 ^a 0.00115 ^c	0.0018 ^b 0.0019 ^d	0.003 09 ^e	0.001 023 ^f

^aWeighted marginal cost for 2012

^bWeighted marginal cost from cross-section data for 1997

^cWeighted marginal cost (in prices of 2000)

^dWeighted marginal cost from cross-section data (in prices of 2000)

^eWeighted marginal cost from panel data in constant prices with respect to the base year 2000

^fWeighted marginal cost from cross-section data in Sweden (base year 2000)

of the deficit caused by railway infrastructure, various additional fees are used. Increased utilisation of the railway infrastructure would bring about greater efficiency, which is also the aim of development of the rail market.

From a scientific viewpoint, the results of the econometric analysis of maintenance costs are comparable with those in other reference studies. In line with the literature, the estimated variables were statistically significant. Deviations between the calculated marginal costs result from differences in labour costs between countries in 2012 (Eurostat, 2014), given that labour costs account for more than 60% of maintenance costs (SR, 2014). The biggest difference between the calculated marginal costs (Table 3) is between Slovenia and Austria, which are also most comparable in terms of the railway system. According to Eurostat, labour costs per hour are almost three times higher in Austria than in Slovenia.

Based on the estimated cost function, the marginal costs were calculated with the basis of calculating charges based on grt.km. The charge based on marginal costs is favourable for

Figure 3. Marginal costs

railway carriers and has a positive impact on their business. It also offers the possibility of increasing the supply of rail freight transport services.

3.2 Effects on existing model

Marginal infrastructure maintenance costs were calculated on the basis of Equations 4, 5 and 7. The marginal costs per segment were calculated to range between €0.0004 and €0.0204 per grt.km per year and the weighted marginal costs for all sections of regional lines to €0.001 888 per grt.km per year. As shown in Figure 3, the marginal costs decrease with grt.km, indicating that increasing the volume of cargo carried by rail would seem reasonable.

The current model is based on total maintenance and traffic management costs and is calculated on the basis of train-km. In 2012, the charge was €161 310 excluding VAT, taking into account that the coefficient category of towing vehicles was 1 and the rate of deduction was 0.72, given that, on average, trains weigh less than 1000 t. The power cars are divided into three categories (A, B and C) with appurtenant coefficients and the weight of the power cars is taken into account when calculating the usage charge. Since power cars in categories B and C are mostly used on regional tracks, the relevant coefficient was here taken to be 1. The price per train-km is €1.133 excluding VAT, with weighting categories for tracks summarised using the Network programme (SR, 2014).

When using the grt.km calculation and different prices for the sections, the charge was 9.79% lower than that calculated with the existing model. Positive economic effects from the proposed model are on the carrier's side, particularly in the sections where the most grt.km are moved. The function of

marginal cost is decreasing, which means that increasing grt.km results in increased positive economic impact on carriers. Increasing transported gross tonnes will not result in higher variable costs of maintaining infrastructure, as variable costs are inelastic with respect to transported gross tonnes.

Using the model based on grt.km also has a positive influence on empty wagons. The latter did not have a cost impact in the existing model since most freight trains on regional rail lines do not exceed 1000 t, which means a price deduction of 0.72. In the proposed model, however, empty wagons contribute to a greater gross tonne weight.

A change in the calculation model brings about positive direct and indirect effects. The hypothesis set in Section 2 can thus be confirmed. Based on calculations of the maximum economic benefit, the most appropriate model is the one based on grt.km. In the short term, revenues for infrastructure managers will be reduced. However, by increasing the gross tonnage of transported goods, operator revenues will increase. Due to inelasticity, the variable costs of maintaining infrastructure will not increase.

4. Conclusions

This research has shown that changing the current model for calculating usage charge would bring economic effects for both infrastructure managers and carriers. It should be noted that calculating the usage charge by the proposed method maximises economic benefits and reduces costs for the carriers.

The effects would be negative for infrastructure managers in the short run, since direct revenues from usage charges will be

reduced. By increasing transported gross tonnes of goods, revenues for operators will increase but, due to their inelasticity, the variable costs of infrastructure maintenance will not. With an increase in goods transported by rail there will also be wider positive economic effects due to reduced external costs in comparison with road transport.

The results of the proposed model are also in line with the objectives of European transport policies that strive to increase rail freight transport and redirect the flow of goods from road to rail, which results in significantly lower external costs. The objectives of European transport policies in the field of rail transport also include development of the internal rail market in Europe, where it is necessary to ensure a holistic approach to freight corridor management. Efficiency in the corridors, however, cannot be improved without effective links to the regional areas that, in terms of global integration, are neglected. Regional railway lines, nevertheless, represent a potential that remains untapped. In addition, regional areas in the field of railway transport and charging are poorly explored, with most studies focusing on the main railway lines. By establishing a system that will facilitate railway transport as part of the state, regional routes could be utilised more efficiently. To this end, in addition to economic criteria, organisational criteria also need to be taken into account because existing organisations are failing to support the satisfactory development of regional infrastructure.

Use of the proposed model can contribute to the sustainable development of transport systems, given that ongoing globalisation is increasing the flow of goods, with consequent negative impacts on the environment due to greater use of road transport. Furthermore, increased road transport has a negative impact on road infrastructure, with more than 50% of national roads in Slovenia already in very poor condition (SIA, 2015). Comprehensive solutions for regional rail transport are thus required.

Development of the rail market will require major changes that contribute to increasing rail's market share. Solving problems unilaterally is often not sufficient – comprehensive solutions are needed as systems are interdependent and cannot operate as effectively in isolation. Competitive railway systems and sustainable transport development can be achieved by including regional railway lines.

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