CATRIN -- Cost Allocation of TRansport INfrastructure cost

SIXTH FRAMEWORK PROGRAMME
PRIORITY 1.6.2
Sustainable Surface Transport

CATRIN

Cost Allocation of TRansport INfrastructure cost

D8 – Rail Cost Allocation for Europe

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Authors:
Phill Wheat, Andrew Smith and Chris Nash (ITS) with contribution from partners

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CATRIN Partner Organisations

VTI; University of Gdansk, ITS Leeds, DIW, Ecoplan, Manchester Metropolitan University, TUV Vienna University of Technology, EIT University of Las Palmas; Swedish Maritime Administration, University of Turku/Centre for Maritime Studies

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Project summary

CATRIN is a Research project to support the European Transport Policy, specifically to assist in the Implementation of Transport pricing. CATRIN will increase the probability that new progressive pricing principles can be implemented which facilitate a move towards sustainable transport. CATRIN is both intermodal and interdisciplinary, emphasizes the need of new Member states, understands that different organisational forms require different recommendations, that recommendations need to be given in short and long-term perspective and that they have to be thoroughly discussed with infrastructure managers.

CATRIN will clarify the current position on allocation of infrastructure cost in all modes of transport. Pricing principles will be dealt with under the knowledge that they varies with the organisational structure of a sector. CATRIN will establish the micro-aspects of cost recover above marginal costs, including the results of applying a club approach and the implication of who bears the costs for cost recovery under alternative allocation rules, using game theoretic analytical tools.

CATRIN will develop the understanding of policy need of new Member states and can give tailored recommendations. In a modal focus, with real world cases, CATRIN will develop proxies to marginal costs and test some of the allocation approaches. Based on engineering studies CATRIN will analyse the possibility to defining more differentiated pricing rules for vehicle/locomotive categories. Partners with strong engineering knowledge are included and CATRIN will blend the economic principles of pricing with engineering knowledge. CATRIN will outline the possibilities for a European Road Damage test that will give new evidences on the fourth-power-rule. CATRIN will develop financing alternatives for icebreaking and will explore cost allocation in the aviation sector. Finally, CATRIN will strongly address the implementation potential and constraints experienced by infrastructure managers

1 Executive Summary

1.1 Background

This deliverable reports on the work undertaken in Work Package 5 on rail cost allocation. This is one of four modal work packages in CATRIN; the others being air transport, water transport and road transport.

The work package objectives are:

- To increase the understanding of the marginal infrastructure cost in the rail sector and examine the cost structure in the Case Studies based on D2.
- As part of this process, to develop new methods as well as new data sets.
- To conclude on the most important vehicle characteristics that influence rail damage and to estimate the magnitude of their influence based on existing knowledge.
- To better integrate econometric and engineering research in this area.
- To examine methods for the allocation of capacity costs to services/types of traffic

This research builds on the research undertaken in the GRACE project. A review of this and other research was undertaken in Deliverable 1 (Link et al, 2008) of the CATRIN project. The review identified several outstanding research issues that related to both methodological inconsistencies across studies and some findings which did not seem plausible. All in all this limited the strength of recommendations drawn from this research.

For this Work Package we have undertaken case studies for countries which include the countries that previously have undertaken research in this area (Great Britain, Sweden, Switzerland and France), as well as for new countries. This allows us to revisit the previous research in a coordinated fashion as well as gain wider insight into the issues by expanding the number of countries considered.

1.2 Overview of research undertaken

We have built on the research in GRACE but also introduced new methodological coordination and innovations. The key research that has been undertaken within the Work Package is:

- New econometric case studies for Great Britain, Austria, Sweden, Switzerland and France and an econometric study pooling data from Great Britain, Austria, Belgium, Netherlands, Ireland and the US. These are aimed at developing better understanding of infrastructure wear and tear marginal costs. All studies have adopted similar methodologies and ex post analysis of the results to make them as comparable as possible. New data sets have been used (Great Britain and pooled international case studies) while data sets for other studies have been refined.
- An engineering case study examining the relative damage of different vehicle types. This provides useful information on the likely variation of marginal costs with vehicles and is a level of detail that is not feasible in econometric analysis.
- Examination of the ways to integrate the recommendations econometric and engineering research. In particular how can the strengths of each approach be best exploited and combined to yield robust results?

- Three case studies examining methods of allocating capacity costs to individual services. Two case studies are for Great Britain, one on determining avoidable cost, a long run concept, and the other on determining the opportunity cost of individual pathing slots, a short run concept. The link and node based charging system adopted in Italy is also reviewed.

1.3 Key findings from the wear and tear marginal cost research

The infrastructure wear and tear marginal cost research undertaken in CATRIN has applied new methods and provided new evidence on marginal costs for the case study countries. We have undertaken research which represents a clear step forward from that undertaken in the GRACE project. In particular we find:

- By decomposing marginal cost into average cost and the usage elasticity we can see the reasons for the large variation in marginal costs across countries and within countries. Average cost differs considerably between and within countries driven by differences in infrastructure quality and traffic density. In contrast usage elasticities do differ by traffic density but in a much more predictable manner;
- Unlike what we found in GRACE, usage elasticities seem to be increasing with traffic density, all other things equal. This has been found through adopting the more flexible Box-Cox models. Thus marginal costs do not necessarily fall indefinitely with traffic density;
- The engineering case study has demonstrated clear differences in the damage per gross tonne-km for different vehicle types for the track sections considered. We have also had more success in incorporating passenger and freight measures into our econometrics. However for both these innovations it is difficult to generalise much from the specific results given that these results will be affected by the network maintenance policy, exact traffic composition and track characteristics. Further development of these methods is desirable;
- In drawing conclusions from and comparisons across models we have controlled for infrastructure variables which has aided our understanding of the underlying cost variation; and
- We have provided new evidence on renewal marginal costs for Switzerland and Great Britain.
- We have developed clear recommendations on the range of elasticities to be applied in specific circumstances. Thus we now have a better understanding of why usage elastciities differ between countries;

In CATRIN we have introduced several methodological innovations over and above what was implemented in the GRACE project. These include the

- Wide use of the flexible Box-Cox model;
- Analysis of the composition of costs in each country to aid comparison of results across countries;
- Harmonisation of method;
- Use of simulation to plot marginal cost and usage elasticities with traffic density and infrastructure quality holding all other things equal;
- The use of engineering research to supplement econometric research

1.4 Generalisation

1.4.1 Method

The methodological innovations have resulted in us knowing more about marginal cost and its variation both within and across countries. This allows us to easily generalise our findings and issue strong recommendations. A key finding of our research is that even when evaluated at country specific mean network measure, marginal costs vary considerably between countries. Also marginal costs vary considerably within countries. These differences are driven by many factors such as infrastructure quality and traffic density. As such it is difficult to generalise our results on marginal cost. Instead we note the relationship:

Marginal cost = (Average cost) x (Usage elasticity)

Inspection of the underlying data of the first component of marginal cost, average cost, reveals that average cost is very variable both between and within case study countries. This is intuitive as we would expect average cost to be impacted strongly by the infrastructure quality and traffic density differences across countries.

However we estimate much less variation in the usage elasticities across countries and within countries. It is important to note that we have utilised sophisticated econometic models which potentially allow the usage elasticity variation to be considerable, however we do not find this in our modelling. Thus the models have found less variation in usage elasticities (relative to marginal costs) across countries as opposed to the model structure imposing such a finding.

As such we advocate recommending estimates of usage elasticities rather than specific marginal costs. These can then be multiplied by country specific average cost estimates to yield estimates of marginal cost. We do still find some variation in usage elasticities within countries, but there is a more systematic pattern which allows us to make recommendations for usage elasticities based on traffic density of the network.

Our research has clearly demonstrated that marginal costs differ considerably by traffic density and infrastructure quality. This supports charging different routes, each with different traffic density and infrastructure quality characteristics, within countries different marginal costs. This will be more cost reflective although there is the obvious trade-off between cost reflectiveness and complexity. Our proposed generalisation approach allows for this flexibility. This can be undertaken by the country simply providing average cost by route and choosing a suitable elasticity for each route from our research.

To summarise, we recommend generalisation as follows:

1. Country provides average cost either at the network wide level or for specific routes which have discernable traffic density and infrastructure quality characteristics;
2. The country should choose an appropriate usage elasticity for the network as a whole or for specific routes by reference to the traffic density the infrastructure in question;
3. For the network as a whole or for each specific route, the average cost and chosen usage elasticity should be multiplied together to give estimates of marginal cost.

Our recommendations on the values of usage elasticities are presented in section 1.2.2. There maybe instances where a country has available some specific analysis to inform the precise level of the elasticities in their country. In this case and providing that the analysis is robust, it may be better to use these country specific estimates. However, we consider that the estimates in 7.2.2 are generally robust and so there maybe cause for concern should any country specific estimates differ substantially from those presented in 1.2.2.

Before our recommended values are presented it should be noted that it is important that the definition of average cost covers the cost elements to which the recommended usage elasticites apply to. In particular for maintenance only cost average cost should include the following elements:

- Permanent way costs
- Signalling and telecoms costs
- Electrification and plant costs

Network wide overheads should be excluded. For renewals, our recommended elasticities are less precise given the limited number of studies available for consideration. However we recommend that the average cost for maintenance and renewal includes all the elements of maintenance cost described above and also includes as many elements of renewal costs except for network wide overheads[1].

1.4.2 Recommended usage elasticities

Table 1.1 outlines our recommended usage elasticities for maintenance costs. The elasticities are given by different traffic densities. We do not provide elasticities that vary with infrastructure quality since these differences tend to be relatively minor for the reasonable tonnage density levels considered in Table 1.1.

Table 1.1 Recommended usage elasticities by traffic density

Traffic density classification	**Low**	**Medium**	**High**
Traffic density range (tonne-km / track-km per annum)	**< 3,000,000**	**3,000,000-10,000,000**	**> 10,000,000**
Recommended Usage Elasticty	0.2	0.3	0.45

These values have been determined through comparison of the results of the six maintenance cost studies undertaken in CATRIN. We have made substantial progress in making the results comparable across countries and as such we have reasonable confidence that our recommended values are robust given the information available. There is still uncertainty associated with each recommend value and as such actual values maybe slightly different from those above (especially for the high traffic density value). What is important is that the usage elasticity is increasing with traffic density.

Whether a country adopts these recommended values depends on the amount of other information available. For instance if a robust study for the specific country has been undertaken, then it maybe best to take forward the elasticities from this as the basis for charging. In this case the recommended values presented in Table 1.1 should be seen as benchmark values. Should the results from country specific studies differ considerably from those in Table 1.1 then this should prompt further analysis/interrogation of the country

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[1] The reason for excluding network wide overheads is that these can not be non-arbitrarily allocated to track sections or zones. Since this data was not used to estimate our models and thus the resulting elasticities, these should not be included in either maintenance or renewal costs.

specific study to understand why the country in question differs from the benchmark values. Care should also be taken that the usage elasticities from any country specific studies are comparable with those in Table 1.1 in terms of the elements of costs considered in the study vis-à-vis those considered in the CATRIN study (see section 1.2.1).

We do not provide elasticities by passenger and freight traffic since we have no clear evidence that passenger traffic is more or less damaging per gross tonne-km than freight traffic. The engineering study found that passenger did slightly more damage than freight and this was supported by the econometric studies, however there was little consensus in relative magnitudes of the marginal cost for the two traffic types with some of the econometric results looking unrealistic. Further the engineering research indicated that freight could feasibly be more damaging than passenger traffic depending on the exact vehicle mix. We also note that any difference in the usage elasticity for each traffic type depends not just on differences in relative damage but also the share of total traffic of each traffic type.

For renewals costs we have a limited number of studies which can help in determining this usage elasticity. Further we are unable to give specific values for the usage elasticity by different traffic density (and infrastructure quality combinations).

As such we recommend that if countries want to charge for maintenance costs and renewals, they compute separate marginal costs for maintenance and renewal component. For the maintenance component, a country would use the usage elasticities in Table 1.1 multiplied by the appropriate average cost to come up with measures of marginal cost for the whole network or for specific routes within the network. For the renewal component we recommend that the country compute a network wide renewal marginal cost calculated as renewal average cost multiplied by an elasticity of 0.35. However there is a large degree of uncertainty for this estimate, partly because of the small number of supporting studies that have looked at renewal costs but also because of the disparate range of their results. As such this should be seen as a starting value which maybe improved upon should any country specific evidence be available.

1.4.3 Differentiating charges by vehicle type

The engineering research clearly demonstrated that there are large differences between the damage on the infrastructure for some vehicle types even per gross tonne-km. Therefore costs would be better reflected by differentiating the charges by vehicle type. This could be undertaken in a number of ways. One way is to come up with a charge per vehicle-km for every vehicle using the network. The advantage is that there are clear incentives to operators to run less damaging vehicles and demand such vehicles from operators. However, this would require a lot of work since a bespoke engineering study would be needed to determine the relative damages of the specific vehicles on the track.

If this approach was desired, the results econometric from CATRIN could be used to determine the actual amount of cost variable with traffic possibly differentiated by routes[2], while a bespoke engineering model could then allocate this variable cost to vehicles. Thus the econometric results from CATRIN can be used but bespoke engineering models have to be developed separately.

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[2] Computed as an appropriate usage elasticity from section 7.2.2 multiplied by the relevant total cost

A less resource intensive and complex method of differentiating charges is to adopt a bonus/minus system where the most damaging vehicles pay a higher charge per gross tonne-km and the least damaging vehicles pay a lower charge. All other vehicles pay a medium charge per gross tonne-km. This is likely to be less resource intensive as the engineering models only needs to identify the group of vehicles that are most and least damaging, rather than the exact relative damage of each vehicle.

1.5 Further infrastructure wear and tear marginal cost research issues

In this deliverable we have made a large step forward in our understanding of how marginal costs vary across and within countries. Part of the success has been that we have undertaken a coordinated approach in statistical method, understanding the data and post processing of the model results. A further success factor has been the involvement of engineering experience and research in the project. This has helped us to evaluate the results of the econometrics and provide new evidence on the relative differences in damage of different vehicle types.

We consider that the outstanding research issues for the econometric models are:

1. The need to incorporate panel data techniques into models which use the Box-Cox functional form. This is potentially very important as the Box-Cox model seems to explain the data better than the equivalent double-log model, however we are currently unable to use panel data techniques to control for unobserved heterogeneity in these models;
2. Both pooling and country specific modelling approaches should be taken forward within future research. There are both relative advantages and disadvantages of each approach and both yield interesting insights into the differences in marginal costs across countries;
3. The pooling approach can be best developed through:
    a. Incorporation of more infrastructure variables;
    b. Incorporation of more years of data;
    c. Further harmonisation of data definitions (particularly cost definitions)
4. To continue to develop further measures of usage elasticities and marginal cost which better harmonise for the actual quality of the infrastructure. This could involve specification of actual levels of each infrastructure quality variable for each study which is comparable with the levels used in all other studies, as opposed to defining them relative to sample reference points as adopted in this project. This is an onerous task but with suitable engineering advice may be achievable. Harmonising the infrastructure quality variables available for use in each study would obviously help this process.
5. Even when we control for infrastructure quality, we still find that track sections with low tonnage density have very high estimates of marginal cost. This could be because the models do not predict the marginal cost levels very precisely for these extreme observations, however this should be investigated further. In particular it would be useful to compute confidence intervals/prediction intervals for these observations/predictions.
6. Need to better model renewals costs. In particular longer panel datasets need to be collected to allow analysts to ‘smooth out’ lumpy renewals and possibly adopt dynamic modelling techniques. Andersson (2006) has attempted incorporation of dynamics into models with some success, however was limited by the length of his

panel. Further the further use of survival analysis should be considered. However both techniques require a long time series of data.

7. The quality and comparability of data across countries is critical for making valid comparisons and recommendations. Great effort has been taken to control for as many factors as possible in this research however we suspect that datasets are still not totally consistent between countries. This is partly because datasets are generally collected for purposes other than for econometric analysis. It would be better if the EC could urge member states to be more forthcoming with respect to data collection for future research purposes. There is a need to understand the composition of costs better and in particular eliminate any arbiter allocation of costs to observations as this can distort estimated results.

We consider that the primary outstanding research issue for the engineering analysis is to find ways to be able to better generalise the results of specific case studies. In CATRIN we only undertook case studies for two track sections in Sweden and it is not clear how transferable the results are to other track sections both within and outside Sweden. Therefore there is clearly the need to undertake more case studies across various countries.

To undertake a case study requires detailed information on traffic composition and characteristics as well as infrastructure characteristic data. They also take a long time to numerically compute and the results can be sensitive to fairly subtle differences in traffic and infrastructure composition. As such once a reasonably large number of case studies have been undertaken we could undertake statistical analysis on the outputs, relating damage to a simple set of variables describing traffic and infrastructure characteristics. This may provide a suitably simply means of generalisation of the engineering results.

1.6 Recommendations on allocation of capacity costs

Wherever capacity is scarce, there is a strong argument for charging reservation fees to reflect the opportunity cost of slots, in terms of net revenue, unpriced user benefits and net external benefits. Ideally this would represent the net benefit of the second best use of the slot, which can only be known when all possible uses have been examined and the optimum determined. This is hardly practical as a way of setting tariffs when future demand for slots may come from unknown new entrants. More practical is setting a tariff according to the opportunity cost of the slot to the existing dominant operator. This is particularly the case when, as is the case on almost all routes in Britain, the dominant operator is a franchised passenger operator, with long term franchise and access agreements and for which detailed information on costs and demand is available to the franchising authority and the regulator. In other circumstances calculation of the charge will be more rough and ready, but – as long as care is taken not to set the charge so high as to lead to capacity being left unused – introduction of such a charge, reflecting the opportunity cost of taking slots away from the dominant operator, is likely to have a socially beneficial effect on timetable planning and the use of scarce capacity. An example derived from Britain illustrates how a relatively simple pattern of peak and off peak charges per slot may be derived, whilst Italian practice illustrates how a weighting may be applied to reflect the fact that trains travelling at a speed different from the optimal for the route in question consume more capacity than a single train of the dominant type.

However, such charges do not directly reflect the cost of the capacity provided under long term framework agreements which entitle the operator, or their customer, to a certain amount of capacity in the long run. In this case the long run avoidable cost of the capacity in question should be reflected in a fixed charge to the customer concerned. Where open access competition exists, such a fixed charge might be problematic in terms of affecting the terms of competition between the incumbent and new entrants. But in the case of a monopoly franchise there is no such complication. Such a charge would be particularly relevant where a regional authority is responsible for franchising passenger services, whilst the national government subsidises infrastructure in general. Without such a charge, the regional authority has no reason to consider the costs of providing capacity when setting out its long term plans for the services in question.

Both the above developments in track access charging would increase the revenue of the infrastructure manager, reducing the burden on national taxpayers and easing the financial problems that infrastructure managers have when funding from the state is inadequate for its needs.

On most routes throughout Europe it is possible to identify a dominant operator and type of service, and to estimate the opportunity cost of slots as the cost of taking a slot from that operator, although the regulatory authority will not always have as good data as in Britain, where it has access to detailed traffic, revenue and cost data. In the absence of such data, continued consideration should be given to the role of auctioning slots as a way of revealing their value to train operators. Similarly many countries use long term framework agreements on infrastructure access, as provided for under Directive 200/14, and such an approach makes good sense where operators are investing in assets or the development of services and want reassurance that they will be able to reap the rewards of their investment. Such agreements are particularly relevant where services are franchised for a period of a number of years, as is the case not just in Britain but also for subsidised services in Sweden, and increasingly in Germany, Netherlands and Denmark. We believe it important that franchising authorities should be faced not just with the short run marginal cost of the services they actually operate but also the fixed cost of the capacity they require long term under the franchise agreement. Thus we recommend the use of two part tariffs, with the fixed charge based on avoidable costs, in such cases.

2 Introduction

This deliverable reports on the work undertaken in Work Package 5 on rail cost allocation. This is one of four modal work packages in CATRIN; the others being air transport, water transport and road transport.

The work package objectives are:

- To increase the understanding of the marginal infrastructure cost in the rail sector and examine the cost structure in the Case Studies based on D2.
- As part of this process, to develop new methods as well as new data sets.
- To conclude on the most important vehicle characteristics that influence rail damage and to estimate the magnitude of their influence based on existing knowledge.
- To better integrate econometric and engineering research in this area.
- To examine methods for the allocation of capacity costs to services/types of traffic

The remainder of this deliverable is organised as follows. Section 3 reviews existing best practice in estimating marginal infrastructure wear and tear costs. This draws heavily on the review in Deliverable 1, but in addition we present a new review of the engineering methodology which is subsequently applied in the engineering case study. Section 4 summarises the new evidence from the econometric case studies, while section 5 summarises the engineering case study. Section 6 reviews methods of allocation of capacity costs to different services and finally Section 7 sets out the recommendations from the research. The full set of individual case studies is included in the Annex.

3 Existing Best Practice

3.1 Overview

Existing best practice in measuring rail infrastructure marginal wear and tear cost has been reviewed in Deliverable 1 of the project[3]. Previous studies in rail infrastructure costs can be categorised into top-down and bottom-up studies. Top-down studies consider elements of total cost and use statistical or judgemental techniques to determine what elements or proportions of elements are variable with traffic. Bottom-up approaches utilise established engineering relationships to model directly the extra damage caused by more traffic and then apply unit costs of remedial work to determine the marginal cost.

Prior to the CATRIN research, there have been a number of detailed top-down econometric studies from both the academic and consultancy sectors in recent years attempting to quantify the marginal wear and tear cost of rail traffic covering a wide range of European railways. They find that average marginal costs differ considerably across countries ranging from 0.15 to 1.78 € per thousand gross tonne-km (TGTKM) for maintenance only cost and 0.79 to 4.99 € per TGTKM for maintenance and renewals. However there is more accord between the estimates of the proportion of costs variable with traffic across studies. This measure, also corresponding to the elasticity of cost with respect to traffic (herein called the usage elasticity) ranges from 0.07 to 0.26 for maintenance costs and 0.27 to 0.30 for maintenance and renewals costs[4,5].

The review identified several outstanding research issues from the econometric studies to date. While the studies have provided fairly consistent estimates of the overall elasticity of maintenance costs with respect to traffic a number of outstanding issues were identified:

- Why do estimates of usage elasticity differ so much between countries?
- Why do estimates of marginal costs differ so much (and even more so than for the elasticity estimates) between countries?
- Do usage elasticity and marginal cost fall indefinitely with traffic levels or is that result purely due to limitations in model specification and data availability?
- Usage and elasticity and marginal cost estimates need to be obtained as a function of vehicle characteristics and type of traffic;
- More systematic account needs to be taken of infrastructure characteristics, capability and condition measures;
- Further studies on renewals costs should be carried out.

The review considered the bottom-up engineering models proposed and/or used in Great Britain and Sweden. In particular it showed how engineering relationships can be used to

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[3] Link, H., Stuhlemmer, A. (DIW Berlin), Haraldsson, M. (VTI), Abrantes, P., Wheat, P., Iwnicki, S., Nash, C., Smith, A., CATRIN (Cost Allocation of TRansport INfrastructure cost), Deliverable D 1, Cost allocation Practices in the European Transport Sector. Funded by Sixth Framework Programme. VTI, Stockholm, March 2008

[4] These are scaled usage elasticities which adjust the raw usage elasticities to reflect differing proportions of total maintenance (and renewal if applicable) costs used in different studies. See page 45 in Link et al (2008) for more details.

[5] Part of the reason for the narrower range of usage elasticity estimates for maintenance and renewal cost is because of the very small number of studies.

allocate costs to specific vehicle types since the engineering models are sensitive to different vehicle characteristics.

The disadvantage of the engineering approach is that it models elements of work in a piece meal fashion and may miss important linkages within the system. As such it may under estimate marginal cost. It also relies on the availability of robust measures of unit costs for remedial work. Finally the engineering models themselves may rely on judgement which limits their applicability. Ultimately undertaking robust engineering bottom-up modelling of the railway system is a time and resource consuming task.

This contrasts to the econometric approach which uses realised cost data. As such it ‘lets the data speak’. However the econometric approach to date has been unable to disaggregate marginal cost between vehicles to any large degree. Also the econometric approach is not insusceptible to the influence of researcher judgement or the quality and consistency of the underlying data.

With the advantages and disadvantages of each approach in mind, we consider that there are two ways of developing the previous research in this area. First the results of either approach can be used to validate the results of the other. This addresses the concern that both approaches are not insusceptible to judgement or problems with data quality. Second the two approaches could be combined so that the econometric approach is used to determine what amount of cost is variable with traffic with the engineering models then allocating this cost to different vehicles depending on the damage characteristics of each.

In the remainder of this section we provide further details of engineering modelling approaches; in particular focusing on vehicle simulation models coupled with asset life models which constitute the methodology for the engineering case study within this Work Package.

3.2 Vehicle simulation and asset degradation modelling

3.2.1 Track deterioration

A number of modelling techniques have been developed in recent years and several powerful computer simulation packages are now available which allow accurate prediction of the levels of track damage caused by running individual vehicles on specific routes, and how these influence the rate of wear and other forms of damage to the various components making up the track. In assessing this degradation two key modes of maintenance activity are usually considered: (1) rail damage which is caused by the action of the wheel on the rail, and includes wear and fatigue of the rail surface; and (2) track settlement which is caused by the load of vehicle passages and results in uneven settlement of the track in the ballast. Rail damage is usually corrected by grinding (mainly using large automated grinding vehicles) and track settlement has to be corrected periodically by tamping, again usually using large dedicated vehicles.

The influence of the behaviour of specific vehicles, in term of rail damage, can be assessed using a method based on the ‘Tgamma’ number which is the product of the tangential or creep forces and the slippage or creepage in the contact patch between wheel and rail. This index is then used to interpret whether the vehicle is damaging the track due to wear, rolling contact fatigue (RCF) or more commonly, a combination of both.

The vehicle damage in terms of track settlement has been studied by many researchers and particularly the Technical University of Munich analysed the ballast settlement under controlled laboratory condition and developed from this work equation to calculate the settlement rate. The following equation has been derived prediction of the mean ballast settlement:

$$S_{med} = 1.89\, p \ln\Delta N + 5.15\, p^{1.21} \ln N$$

Where:

N = number of axle passes
ΔN = number of axle passes<10000
p = ballast pressure
S_{med} = mean ballast settlement

3.2.2 Vehicle modelling

The engineering analysis of railway track degradation described above requires the following input data:

- Track characteristics
- Vehicle characteristics
- Traffic details

The track quality data and topographic route information are the input data to calculate the time response of a vehicle. Vehicle models are constructed using a dynamic analysis package (in this work the Vampire package has been used) and include details of masses, geometries, suspension components, number of axle and axle load. The damage for each type of vehicle is then grouped, considering the actual traffic scenario, to establish the weighting of predicted maintenance work required for freight and passenger vehicles separately.

3.2.3 Combination of damage mechanisms

The relation between track damage and cost is difficult to establish by engineering methods as it depends not only on the track condition and vehicle behaviour but on the decisions regarding maintenance and renewal. If historical information on maintenance costs is available and can be separately categorised into the different modes of deterioration then this can be used to allocate a weighting to the results from the engineering analysis.

There is a tool used by Network Rail in the UK called T-SPA which is a Track Strategic Planning Application. It is a decision support tool designed to provide an analysis of a broad range of renewal and maintenance options based on the predicted damage, linking in particular the volumes and cost of the work to the condition and performance outputs that would be obtained. The costs estimated are based on UK historical data and therefore UK costs and intervention rules. The primary objective of T-SPA is to support the development of robust long term plans, the quality of which is critical to the future funding of the railway infrastructure. TSPA has also been included in a new decision support tool known as VTISM (Vehicle Track Interaction Strategic Model). In the future TSPA or VTISM could be used to provide the overall cost framework within which the engineering analysis provides the specific vehicle contributions.

Unfortunately we did not have permission to use this for our study. However we would be keen to utilise this model as it may allow us to estimate marginal costs in addition to relative damages from the engineering model. However, even in the absence of TSPA we can make important statements on the relative damages of the different vehicles relating these back to the characteristics of such vehicles.

4 Econometric evidence on marginal infrastructure wear and tear costs

4.1 Introduction

In this section we will summarise the results of the econometric case studies undertaken under Work Package 5. A full write up of each case study is provided in Annexes 1A-1F. We draw out useful results on usage elasticities and marginal costs and discuss how these vary with traffic.

The section is structured as follows. Section 4.2 describes the methodology adopted by the case studies. Section 4.3 gives an overview of each case study and section 4.4 compares the costs considered in each country. Section 4.5 reports on new evidence on usage elasticities and section 4.6 reports on new evidence on marginal costs.

New econometric case studies have been undertaken in five countries:

- Sweden
- Switzerland
- Austria
- Great Britain
- France

A further case study was undertaken which pooled data over six infrastructure managers, namely Network Rail (Great Britain), OBB (Austria), Prorail (Netherlands), Amtrak (US), Irish Rail (Ireland) and Infrabel (Belgium). As described below, the purpose of this study, inter alia, was to consider the impact of estimating elasticities and marginal costs from a pooled, international sample of countries, as compared with analysing each country individually. However, it was not possible, owing to confidentiality agreements, to pool the individual datasets used in the CATRIN project. The sample used for this element of the analysis is thus based on a dataset generated as part of a separate project (see Annex 1F), but which includes two of the countries involved in the CATRIN project (Great Britain and Austria).

4.2 Methodology

Within the CATRIN research we have applied a consistent and coordinated approach to the econometric case studies. This includes following common methodology and analysing the results of the models in a similar way. In this sub-section we discuss the econometric method used in all studies; while sub-sections 4.5 and 4.6 describe, as a preamble to the actual results, how we coordinated analysing the results of the models.

The econometric studies have estimated variable cost functions and then derived marginal costs from the results. To illustrate the method, consider a variable cost function which has double log functional form and two traffic types A (passenger) and B (freight):

$$\ln(C_i) = \alpha + \beta_1 \ln(Q_{Ai}) + \beta_{11} \ln(Q_{Ai})^2 ... + \beta_2 \ln(Q_{Bi}) + \beta_{21} \ln(Q_{Bi})^2 + \gamma \ln(I_i) \qquad (1)$$

Where

- C_i is the maintenance and, if applicable, renewal cost per annum for section or zone i;
- Q_i is outputs for section or zone i ; here in terms of traffic with vehicles of different types (A and B). In the above formulation a squared term is also included; and
- I_i is a vector of fixed input levels for section or zone i – these include the infrastructure variables (e.g. track length and track quality).

Given that we succeed in the estimation of the function in (1) the marginal cost can be derived as the product of the average cost (AC) and the cost elasticity ε. In the example above we included the square of the traffic variable Q_A which means that the elasticity with respect to traffic type A is non-constant if β_{11} is non-zero.

$$\varepsilon_A = \frac{dC}{C}\frac{Q_A}{dQ_A} = \frac{d\ln C}{d\ln Q_A} = \beta_1 + 2\beta_{11}\ln(Q_A) \qquad (2)$$

In the remainder of this report we refer to this elasticity as the usage elasticity with respect to traffic A. The average cost is simply the cost C divided by the relevant output variable Q. However, the average cost will depend on the traffic volume Q. Therefore the marginal cost will usually depend on the traffic volume.

$$MC = \varepsilon AC = \varepsilon\frac{C}{Q_A} = \left[\beta_1 + 2\beta_{11}\ln(Q_A)\right]\frac{C}{Q_A} \qquad (3)$$

Two additional observations should be highlighted.

- First, while the theoretical specification above includes different outputs in terms of different vehicle types, the reality is more problematic. This is because in reality, the correlation between different outputs is so strong that the econometric model has difficulty in distinguishing between the effect from different vehicle types. This issue has been re-examined in the CATRIN econometric studies
- Secondly, input prices are often assumed to be constant between sections or areas and thus are not included in the studies.

In addition to the double log functional form, case studies have considered using the Box-Cox functional form. This is given by replacing the log (ln) transformation of variables by the Box-Cox transformation given by:

$$w^{(\lambda)} = \frac{w^{\lambda} - 1}{\lambda} \qquad (4)$$

where w is the variable to be transformed and λ is a parameter to be estimated. This transformation is flexible since it nests both the log transformation ($\lambda \to 0$) and the linear transformation ($\lambda = 1$). This means that there is a natural statistical test of the appropriateness of the double log functional form. As with the double log model, both usage elasticities and marginal costs can be derived from this model post estimation. However, even in models with no second order terms for traffic (that is, ignoring the squared terms in equation (1)), the Box-Cox models allow usage elasticities to vary with traffic levels since:

$$\varepsilon_A = \frac{dC}{C}\frac{Q_A}{dQ_A} = \frac{d\ln C}{d\ln Q_A} = \hat{\beta}_1 (Q_A{}^{\hat{\lambda}})/(C^{\hat{\lambda}}) \qquad (5)$$

This functional form nests several functions as special cases. It lets the data determine the appropriate functional form without (necessarily) having to rely on second order approximations as with the Translog function which requires more parameters to be estimated. Thus the Box-Cox is potentially very flexible while still relatively parsimonious which has the benefit of fitting the data well and yielding relatively precise parameter estimates.

As with the double log models, marginal costs are computed as the product of the estimated elasticity and fitted average cost.

Before proceeding further, it is useful to clarify the terminology used for different functional forms in the subsequent discussion. In particular we define:

- Double log functional form to be any functional form where the dependent and the explanatory variables are in logarithms. This may include first order terms and second order terms (including interaction terms) in explanatory variables;
- Cobb Douglas functional form is a special case of the double log functional form as it only includes first order terms;
- Translog functional form is also a special case of the double log functional form as it includes all first and second order terms (including interactions);
- Box-Cox functional form. This is not nested within the double log functional form (some specifications of the double log are nested within the Box-Cox). In this functional form, the dependent variable and a selection of explanatory variables are transformed by the Box-Cox transformation.

4.3 Overview of studies

Table 4.1 summaries the characteristics of each of the case studies. In the table, the term “zone” relates to some geographical area or region within a country at which maintenance cost data can sensibly be analysed. Zones comprises a number of track sections, and thus track section data is more disaggregated than zonal data. The studies have utilised both new and existing data sets.

Where existing data sets have been used, the emphasis was to undertake a coordinated and robust re-examination of the data. This included the use of Box-Cox models and where possible inclusion of separate passenger and freight traffic variables. Coordination of the case studies was via specification of which models were to be estimated and then what outputs are needed from each study in order to better compare the results. Where new datasets were available, these were first cleaned and then a similar coordinated methodological approach was applied to data analysis.

The scope of each study is described below and the results, including the comparison framework, are discussed in section 4.2.4 and 4.2.5.

Table 4.1 Characteristics of the econometric case studies

	Cost data		**Type of Data**			
Country	**Maintenance**	**Renewal**	**Track Section**	**Zonal**	**Time**	**New Data Set?**
Sweden	✓		✓		1999-2002	
Switzerland	✓	✓	✓		2003-2007	
Austria	✓		✓		1998-2000	
Great Britain	✓	✓		✓	2005	✓(M+R)
France	✓		✓		1999	
Pooled International	✓			✓	Various	✓

	Number of traffic types avaliable			**Preferred Model**		
Country	**Single Measure**	**Pass and Freight**	**Further disaggregation possible**	**Double log with Constant Elasticity**	**Double log with variable elasticity**	**Box-Cox (variable elasticity)**
Sweden	✓	✓				✓
Switzerland	✓	✓				✓
Austria	✓					✓
Great Britain	✓	✓		✓(M+R)	✓(M only)	
France	✓	✓	✓			✓
Pooled International	✓				✓	

Sweden (Annex 1A)

For Sweden, the same dataset as that used in GRACE was used. However new functional forms were applied to the data and the issue of disaggregating traffic measures into passenger and freight was revisited, following poor results in the GRACE project. In addition, various sensitivities are applied to the data in line with our approach to achieve greater comparability between country case studies.

The available data set consists of some 185 track sections with traffic (freight and/or passenger) that we observe over the years 1999 - 2002. A track section is a part of the network, normally a link between two nodes or stations that varies in length and design. Each track section observation has information on annual maintenance costs , traffic volumes (gross tonnes) for freight and passenger trains as well as a range of infrastructure characteristics, inter alia track length, track section length-to-distance ratio, length of switches, average rail age, number of joints (joints) and average quality class. Maintenance costs are derived from Banverket’s financial system and cover all maintenance activities. Both corrective and preventive maintenance is included, but winter maintenance (snow clearing and de-icing) is not included. Major renewals are also excluded, but it does include minor replacements considered as spot-maintenance. Infrastructure characteristics are taken from the track information system at Banverket and traffic volumes from various Swedish train operating companies.

The original data set has been split into two parts. One part comprises track sections with mixed traffic, and the other comprises track sections dedicated to freight trains only. The reason for this derives from the underlying idea behind the marginal cost calculation and differentiation. Track sections without any passenger traffic are significantly different from those with mixed traffic from an engineering point of view. Each part of the data set is analysed separately given their different engineering characteristics. Analysis of the mixed line data proceeds through estimation of both double log and Box-Cox models. Box-Cox models are found to be preferred following the rejection of the double log restrictions. However concerns are raised as to the sensitivity of the Box-Cox model when interaction terms are introduced between traffic and infrastructure variables. For freight only lines a double log model is used.

Switzerland (Annex 1B)

The data used is based on the whole railway network of Switzerland including all main lines. This network can be divided into 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 to 2007. 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. The Swiss national rail network comprises approximately 4,900 kilometres of track, of which 56 percent is double track. Not all of the track sections in the data base can be used for various reasons including ownership and remapping over the period. This results in 366 observations (track sections) per year to analyze with complete information.

Traffic data includes average daily data on number of trains, axle load and gross-tons per track, as well as yearly data on train kilometres, axle load kilometres and gross-tonne-kilometres per track for the main lines. Importantly this is available for passenger and freight traffic separately. The analysis focused on the use of gross-tonne-kilometres and train kilometres as main cost drivers. Infrastructure variables includes track length, switches, bridges and tunnels, radius and slope, noise and fire protection, rail age and sleepers age as well as maximum line speed.

The modelling considered both double-log and Box-Cox models and found the Box-Cox model was preferred and in addition a small set of interaction terms were also found to be advantageous.

Austria (Annex 1C)

The study had access to a three years cross-sectional data set at the level of track sections which was also used in an earlier Austrian study[6] (see Munduch et al. 2002). It contains for each of the years 1998, 1999 and 2000 observations for 220 track sections of the ÖBB network. For each track section, the costs of maintenance and renewals, the gross-tonne kilometres, train-kilometres as well as loaded and empty wagon-axle kilometres is reported. Data was not available for passenger and freight traffic separately. Data on infrastructure characteristics (track length, track class, length of single and double track tunnels, bridges, gradients etc.) and on infrastructure condition (age of tracks) was available. The cost data were deflated at 2000 prices[7] and are expressed in Euro. The original dataset was corrected by excluding implausible observations (such as share variables of more than 100%), coding errors and incomplete observations across the three years for some of the sections. The dataset finally used for this case study contains 211 sections, e.g. 633 observations.

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[6] The delivery of a new dataset by ÖBB covering the years 2005-2007 was delayed until October 2008 and was therefore too late for this case study.

[7] We have used the construction price index as deflator (1.11 and 1.06 for 1998 and 1999 respectively).

The study estimates both double log and Box-Cox models and the Box-Cox model was found to be preferred. This is because the Box-Cox model has better fit and the nested double log model can be rejected.

While this study does not consider new data, this data has been analysed in a coordinated fashion with regards to the other case studies and passenger and freight traffic distinction has been re-examined.

France (Annex 1D)

The data available for France is a cross section from 1999 for maintenance costs. There are approximately 1500 track sections in the data set, although this dataset had to be reduced to under 1000 (exactly 928) to remove track sections with zero observations for some traffic types. In this sample, 95% of maintenance costs are recorded at track section level, but no renewal costs.

Traffic data is available for four categories: freight, Paris regional & suburban, passenger regional and passenger intercity. While data is available for both tonne-km and train-km it was decided to utilise the tonne-km data as this had performed well in past studies and aids correspondence with other studies. There is also a raft of infrastructure data available for the study and this includes “State variable” (Switches per segment, length in meters, power type and type of traffic control) and “Quality variables” (age of rail, age of sleepers, maximum line speed, share of concrete sleepers).

Both the double log and Box-Cox functional forms were tested and the sensitivity of the functions to the inclusion and exclusion of state and quality variables was examined.

In addition to the study on maintenance costs, a further study examining the variability of operations costs (train pathing and day-to-day signalling operations) has been undertaken. This was at a regional level and is reported in detail in Annex 1Diii. We do not report the results in this main body, given that there are no comparable studies.

Great Britain (Annex 1E)

This study is a direct update of the study undertaken by Wheat and Smith for the GRACE project and reported in Wheat and Smith (2008). Here this is updated from considering maintenance expenditure only to considering maintenance and renewal expenditure. In addition, various sensitivities are applied to the data in line with our approach to achieve greater comparability between country case studies. Cross section data from Network Rail for 51 Maintenance Delivery Units (MDUs) for 2005/06 is used. 67% of total maintenance expenditure is available at the MDU level. The remaining expenditure (33% of the total maintenance budget) includes maintenance of electrification and plant equipment and other expenditure and can not be allocated to individual MDUs. The cost categories allocated to MDU consist of signalling and telecoms (15% of total maintenance), Permanent way (34% of total maintenance) and General MDU expenditures. In addition we have available track renewal data which comprises renewal expenditure related to the Permanent Way.

Traffic data is available at three levels of disaggregation; from total traffic at the highest level to intercity passenger traffic, other passenger and freight traffic at the most granular level.

Information on the infrastructure includes data on length by track type, maximum line speed and axle load, signalling equipment, rail age and length of electrification. Of these variables length of track, proportion of track length with maximum axle load greater than 25 tonnes, with maximum line speed greater than 100 mph, with continuous welded rail (CWR) or proportion with rail age above 30 years and a labour price index, were included in the final model.

Both the double log and Box-Cox functional forms were tested although the final model was relatively simplistic, being a double-log constant elasticity model. This reflects the difficulty in doing analysis of renewals costs with a cross section of data.

Pooled International Study (Annex 1F)

To date econometric infrastructure wear and tear marginal cost studies have been conducted through analysis of cost, traffic and infrastructure data on a country-by-country basis (see Deliverable 1 (Link et al, 2008) for a survey). However, each study utilises data with subtly different definitions and the datasets tend to contain a different mix of infrastructure variables. Also the statistical methods applied and specification used in each study differ from case study to case study. This presents a challenge for making recommendations from the results of such studies, since it is not clear whether differences in results between studies are genuine differences between countries or are simply artefacts of the data and method differences.

As noted earlier, one of the main aims of this work package of the CATRIN project has been to achieve greater comparability between studies by imposing commonality across case studies as far as possible (for example, common functional form). However an alternative approach to the problem is to pool data across several counties and analyse this data through one statistical model.

The study utilises a bespoke dataset on six countries (five of which are in the European Union) for which data collection has been undertaken over a number years in cooperation with infrastructure managers. The data was initially used as part of the 2008 Periodic Review of Network Rail undertaken by the Office for Rail Regulation (ORR) in Great Britain (Smith, Wheat and Nixon, 2008)[8]. For that study, the primary use of the data was to assess the efficiency of Network Rail and other infrastructure managers. However the dataset is also suitable for measuring marginal costs.

It should be noted that the pooled sample used in this paper is not a pooling of all of the data for the individual CATRIN case studies (Sweden, Switzerland, France, Great Britain and Austria). Such an approach would have been highly desirable, but was not possible due to confidentiality agreements / understanding between the individual CATRIN partners and the data providers. However, the sample used in this paper includes data for two of the countries covered by the CATRIN case study (Great Britain and Austria) and so comparisons can be made for those countries. The other countries covered in this study are the US (Amtrak), Belgium (Infrabel), Ireland (Irish Rail) and The Netherlands (ProRail).

The cost data used in this analysis covers the maintenance elements of Permanent Way, Signalling and Telecoms and Electrification and Plant. The traffic data is the aggregate tonne-

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[8] As part of the CATRIN project data for Austria was added to the sample used in the ORR study.

km measure (the sum of passenger and freight gross tonne-km) and infrastructure data on track length and proportion of track length electrified is available. The total number of observations for analysis over the 6 countries is 96 (an unbalanced panel).

The data is analysed using panel data techniques and a double-log functional form. The pooled international study found that estimates of the usage elasticity and marginal costs which are comparable to previous studies. However, the model seems quite imprecise (in the sense of overall fit and variance of parameter estimates), which perhaps is the biggest limitation of using a pooled model in this case, where the sample size was relatively small, and the panel was quite unbalanced. However, in principle, if it had been possible to pool all of the data from the CATRIN partners, then the sample size would have been much larger. The study also examined and produced some useful results concerning the impact of using datasets based on different levels of aggregation (i.e. zonal versus track section data). As such we conclude that this approach should be developed in tandem with the country specific studies in future.

4.4 Costs considered in each study

Before the results of the studies are described it is useful to consider what elements of maintenance (and renewal costs if applicable) are considered in each study. This will be important when comparing the results of studies because different elements of cost will have different variation with traffic.

A broad description of the cost elements considered in each study is given in the study’s respective Annex. Given the abundance of case studies that have looked at maintenance only costs, there is a strong need to compare the results against each other in a robust manner. To do this we review the components of each study’s cost measure. We define four categories of maintenance cost:

- Permanent way maintenance – maintenance of the rails, sleepers and ballast;
- Signalling and telecoms maintenance – maintenance of signalling and any line side telecommunications
- Electrification and plant maintenance – maintenance of contact electrification apparatus, plant (such as pumping stations, signal power supplies and point machines) and distribution equipment (such as cables and transformers)
- Other maintenance – that can be reasonably allocated to track section level including inspections and maintenance of noise protection and environmental management

Table 4.2 shows which categories are considered in each study and the resulting proportion of total maintenance cost considered in each study[9]. Most studies have considered the whole of maintenance cost while the study in Great Britain, and to a lesser extent the Pooled International study, have examined a more restrictive definition.

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[9] Where we define 100% to be if all four elements of cost are considered in the analysis. That is, the proportion of cost considered is relative to the sum of all four elements of maintenance defined above.

Table 4.2 Cost considered in each country[10]

	Maintenance category				**Proportion of total maintenance cost considered in the study**
Country	**Permanent Way**	**Signalling and Telecoms**	**Electrification and plant**	**Other**	
Sweden	✓	✓	✓	✓	100%
Switzerland (All of Contracting A)	✓	✓	✓	✓	100%
Austria	✓	✓	✓	✓	100%
Great Britain	✓			(Part)	67%
France	✓	✓	✓	✓	100%
Pooled International	✓	✓	✓	(Part)	90%

Renewal costs are considered in Switzerland and in Great Britain only. In Great Britain this relates to track renewal only (renewal of rails, sleepers and ballast). The definition in Switzerland is broader as it covers all line side work.

4.4.1 The cost base and valid comparisons across studies

The difference in the cost considered between studies raises the question as to whether it is valid to compare the results between studies. In this deliverable we consider two results from the studies; usage elasticities and marginal costs. In this sub-section we discuss any adjustments necessary to each of these results to make valid comparisons across studies due solely to differences in the cost base for each study. Sections 4.5.1 and 4.6.1 consider other issues that are necessary to consider for comparing usage elasticities and marginal costs respectively across studies.

Marginal Costs

For the maintenance only studies, it is not considered that any adjustment needs to be made to the marginal costs for each study, due to differences in the cost base, in order to make valid comparisons across studies. This is because we believe that for the British and Pooled International case studies (i.e. those studies that include less than 100% of maintenance costs) it is reasonable to assume that all the excluded cost is not subject to usage related damage. In particular all studies consider permanent way costs which will have the most usage related damage associated with it. Also the excluded costs are simply overheads (Britain and Pooled International), signalling and telecoms (Britain only) and electrification[11] and plant (Britain only). All of these cost elements are likely to have minimal usage related variability. Thus, apart from sampling error, the marginal costs derived from a model which considered 100% of cost should be the same as those derived from the (available) restricted set of costs.

The case of comparing the marginal costs from the two maintenance and renewal studies is more problematic. For the Great British renewal cost study, it is no longer the case that we would expect the excluded cost not to have any usage related damage. In particular, cost elements such as renewal of electrification equipment are excluded from the cost base which would be expected to have some usage related damage. However without undertaking econometric analysis of this cost category, it is difficult to specify any quantitative adjustment

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[10] Where we define 100% to be if all four elements of cost are considered in the analysis. That is, the proportion of cost considered is relative to the sum of all four elements of maintenance defined above.

[11] While renewal of electrification equipment is likely to have some variability with respect to usage, maintenance of electrification equipment is likely to have a low variability with usage (for example see Booz Allen Hamilton (2005))

for the marginal costs. Any adjustment would be upward for Britain, since it only includes track renewals.

Usage elasticities

For the maintenance only models there is a need to scale the estimated usage elasticity by the proportion of costs considered in the study. In the discussion of marginal cost adjustments, we assumed that any excluded cost is not subject to usage related damage. Put another way, this assumes that the excluded costs are not variable with traffic. As such, all other things equal, the usage elasticity will fall as more of the excluded costs are subsequently considered. More formally, the elasticity is equal to the ratio of marginal cost to average cost. As we include more of the originally excluded costs into the cost base marginal cost will (by assumption) stay constant, but average cost will fall. In particular the relationship between average cost under the restricted cost base (AC^{R}) and average cost under the 100% of the cost base (AC^{F}) is given by

$$\mathrm{AC}^{\mathrm{F}} = \mathrm{AC}^{\mathrm{R}} / \mathrm{p} \qquad (6)$$

Where p is the proportion of cost considered in the study. This in turn implies:

$$\varepsilon^{\mathrm{F}} = \frac{\mathrm{MC}}{\mathrm{AC}^{\mathrm{F}}} = \frac{\mathrm{MC}}{\mathrm{AC}^{\mathrm{R}} / \mathrm{p}} = \varepsilon^{\mathrm{R}} \cdot \mathrm{p} \qquad (7)$$

When we consider maintenance and renewal costs it is no longer possible to assume that the excluded cost elements will not be variable with traffic. All we can say is that the actual elasticity will lie between that estimated directly from the model and that given in equation (7) above[12].

4.5 Results: Usage elasticities

4.5.1 Comparison framework

As described in section 4.2, the usage elasticity shows the proportionate change in cost in response to a proportionate change in an output. Alternatively the usage elasticity can be thought of as the proportion of costs that are found to be variable with traffic. In this sub-section we present the results from each case study regarding estimated usage elasticities.

A key aim of this project is to compare the usage elasticities across countries and discover how these change with traffic density and infrastructure quality. As such it is first necessary to consider the appropriate way to compare such results. Two questions arise from this task.

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[12] The upper bound (ε^{R}) assumes that all remaining cost is variable at the same proportion as the cost elements considered. The lower bound (ε^{F}) assumes that all the remaining cost is not variable with usage. Obviously it could be the case that the remaining cost is more variable than that considered and so ε^{R} is not the upper bound, but given the cost composition we consider this to be unlikely.

First, what summary measure is most appropriate for comparing usage elasticities across countries? Second, how can we compare the variation in usage elasticities within individual countries (with respect to traffic density and infrastructure quality) across the different countries included in this project? The latter is not straight forward becuas ethe relationship between the usage elasticity and traffic is complicated by the fact that other variables (such as infrastructure quality and other characteristics) also change with usage.

When deciding on the appropriate summary measure there are several possible candidates. We discuss each in turn below.

Whole sample averages

A simple summary measure of the usage elasticity for an individual country is to take an average of those estimated for each observation of the model. The average could be a simple mean of all observations or an average weighted by gross tonne-km. The latter assigns more weight to those observations with more traffic and can be thought of as an average elasticity from a random sample from all the gross tonne-kms on the network. These measures have been reported in studies to date (for example those in GRACE).

The measures may have relevance when we need to know likely cost recovery ratios in individual countries. However they are of limited use when comparing results across countries, with a view of forming recommendations on what value of the usage elasticity is appropriate in certain circumstances, for the following reasons. First, the measures utilise the entire sample in their computation and thus are impacted by the tails of the distribution, which are likely to be imprecisely estimated by the model. This problem is more acute in the weighted average measure, which weights the observations in one tail much higher than in the other. Therefore, these measures (and in particular the weighted average measure) are likely to be affected by the degree of skewness in the distribution of usage elasticities and this maybe a reason for suspecting a priori that these measures would not be the same across countries. Second, in computing average elasticity measures there is no attempt to adjust for systematic infrastructure quality and traffic density differences across countries.

An alternative measure is the median usage elasticity. This is less susceptible to the skewness of the distribution and the inaccuracies of the estimates in the tails. However it still suffers from the short coming that there is no attempt to adjust for differences in the average values of traffic density and infrastructure quality between countries.

Evaluating the usage elasticity at the sample mean of variables

A second set of measures are those that evaluate the model at some point average of the variables in the model. Such measures include the usage elasticity evaluated at the sample mean of all variables. This measure does not use the tails of the distribution of estimated usage elasticities and so is not as susceptible to the skewness of the distribution and the inaccuracies of the estimates in the tails. However it still suffers from the short coming that there is no attempt to adjust for differences in the average values of traffic density and infrastructure quality between countries. A further disadvantage is that the computed set of mean variables may not exist (or even roughly exist) in the dataset (for instance because certain variables being strongly negatively correlated with each other) which raises questions of the usefulness of this measure. However these measures are a good starting point for comparison nether the less.

Evaluating the usage elasticity at the same levels of variables across all studies

Finally the usage elasticity for each study can be evaluated at a specific traffic density and at a specific infrastructure quality. This has the advantage of comparing like-with-like and should provide very comparable measures. In practice we have been able to specify precise traffic densities to evaluate the usage elasticity from each model, but it is too onerous to determine common infrastructure quality levels given the multitude of different infrastructure quality variables used from study to study. Instead we have had to fix these at the sample mean infrastructure quality within each country. This should control for traffic density effects and to some extent infrastructure quality effects.

Overall judgement

Given that different measures have advantages and disadvantages we report all of them. However for comparison purposes we prefer the measures which evaluate the models at specific traffic density and infrastructure quality levels. In addition, as discussed in section 4.4.1 above, all comparisons across studies should be undertaken using scaled usage elasticities as computed using equation (7).

Given that there are five case studies that have considered maintenance cost and only two case studies which have considered maintenance and renewals costs we reserve the rigorous comparative analysis for the maintenance cost studies and present only limited comparisons for the maintenance and renewal case studies. As noted above, it is also less likely to be reasonable to scale (combined) maintenance and renewal elasticities. This is because more elements of renewal cost are likely to have variation with usage compared with maintenance cost (for which permanent way has the most variation).

The remainder of this sub section is structured as follows. First we discuss the results for maintenance only cost covering results for all traffic first (4.5.2) and then results for passenger and freight traffic separately (4.5.3). We then discuss our results for maintenance and renewal costs (4.5.4).

4.5.2 Maintenance only cost: Total Usage Elasticities

The Total Usage Elasticity is termed to describe the proportionate impact on costs from a proportionate increase in all traffic types. For models which consider more than one traffic measure, it is given by the sum of the usage elasticities for each traffic measure. All the case studies outlined in 4.3 have considered maintenance only cost for at least a single tonnage measure. As such all studies are used for this comparison.

Table 4.3 shows the various (scaled) summary measures for the total usage elasticities for each case study. We choose to evaluate the total usage elasticity at both 3,650,000 and

12,775,000 tonne-km per track-km because these provide the approximate lower and upper bound of the average tonnage densities across countries.

Table 4.3 Summary measures for the total usage elasticity from each study – maintenance only cost, scaled where appropriate[13]

<table>
<tr><th rowspan="2">Study</th><th rowspan="2">Preferred functional form</th><th rowspan="2">Mean Tonnage density (Tonne-km / Track-km)</th><th colspan="3">Whole Sample Averages</th></tr>
<tr><th>Unweighted Mean</th><th>Weighted Mean</th><th>Median of sample</th></tr>
<tr><td>France</td><td>Box-Cox</td><td>7,300,000</td><td>0.35</td><td>0.39</td><td>0.32</td></tr>
<tr><td>Sweden</td><td>Box-Cox</td><td>7,650,000</td><td>0.23</td><td>0.25</td><td>0.23</td></tr>
<tr><td>Switzerland</td><td>Box-Cox</td><td>13,100,000</td><td>0.23</td><td>0.22</td><td>0.22</td></tr>
<tr><td>Austria</td><td>Box-Cox</td><td>10,600,000</td><td>0.40</td><td>0.55</td><td>0.37</td></tr>
<tr><td>Great Britain</td><td>Double-log</td><td>4,810,000</td><td>0.27</td><td>0.25</td><td>0.24</td></tr>
<tr><td>Pooled International</td><td>Double-log</td><td>8,135,000</td><td>0.33</td><td>0.23</td><td>0.29</td></tr>
<tr><th>Study</th><th>Evaluated at sample mean of data</th><th colspan="2">Evaluated at average infrastructure quality and 3,650,000 tonne-km per track-km</th><th colspan="2">Evaluated at average infrastructure quality and 12,775,000 tonne-km per track-km</th></tr>
<tr><td>France</td><td>0.40</td><td colspan="2">0.28</td><td colspan="2">0.53</td></tr>
<tr><td>Sweden</td><td>0.25</td><td colspan="2">0.22</td><td colspan="2">0.25</td></tr>
<tr><td>Switzerland</td><td>0.22</td><td colspan="2">0.19</td><td colspan="2">0.22</td></tr>
<tr><td>Austria</td><td>0.35</td><td colspan="2">0.29</td><td colspan="2">0.36</td></tr>
<tr><td>Great Britain</td><td>0.08</td><td colspan="2">0.06</td><td colspan="2">1.00</td></tr>
<tr><td>Pooled International</td><td>0.28</td><td colspan="2">0.38</td><td colspan="2">0.18</td></tr>
</table>

There is a wide variety of difference between each of the summary point measures even within the same country. This is to be expected given the wide distribution of usage elasticities estimated within each study. This is an artefact of the flexible model form adopted.

Remarkably, the vast majority of estimates are between 0.2 and 0.35. For those results that are outside this range, there exists plausible explanations as to why this is so:

- The reason for some low and high results for Great Britain is because of the U-shaped elasticity curve found for that study (see Figure 4.2). Thus when the model is evaluated at the sample mean and reported at the median it gives very low results while when the model is evaluated at relatively high tonnage densities, the model estimates very large usage elasticities.
- For the pooled international study we find a falling usage elasticity with traffic density which explains the high (low) estimate in Table 4.3 at low (high) relative to sample mean tonnage density. As discussed in more detail below, we prefer the more flexible Box-Cox functional form for explaining variation in usage elasticities with traffic density. In any case the measures for the pooled international model are not far outside the 0.2-0.35 range.
- For the Austrian study there exists some observations that have very high estimated usage elasticities. These observations have very high tonnage densities but also have

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[13] For Great Britain and the Pooled International case study results

infrastructure characteristics that, when combined together, result in the very high usage elasticities. This explains the high unweighted and particularly high weighted usage elasticities. When evaluated at the sample mean, median and at the two specific tonnage densities, the estimates are much more inline with the results from other studies. As such, we believe that the core results from the Austrian study are consistent with those from the others and would highlight this as a clear example of how misleading whole sample averages can be when comparing the general findings of studies.

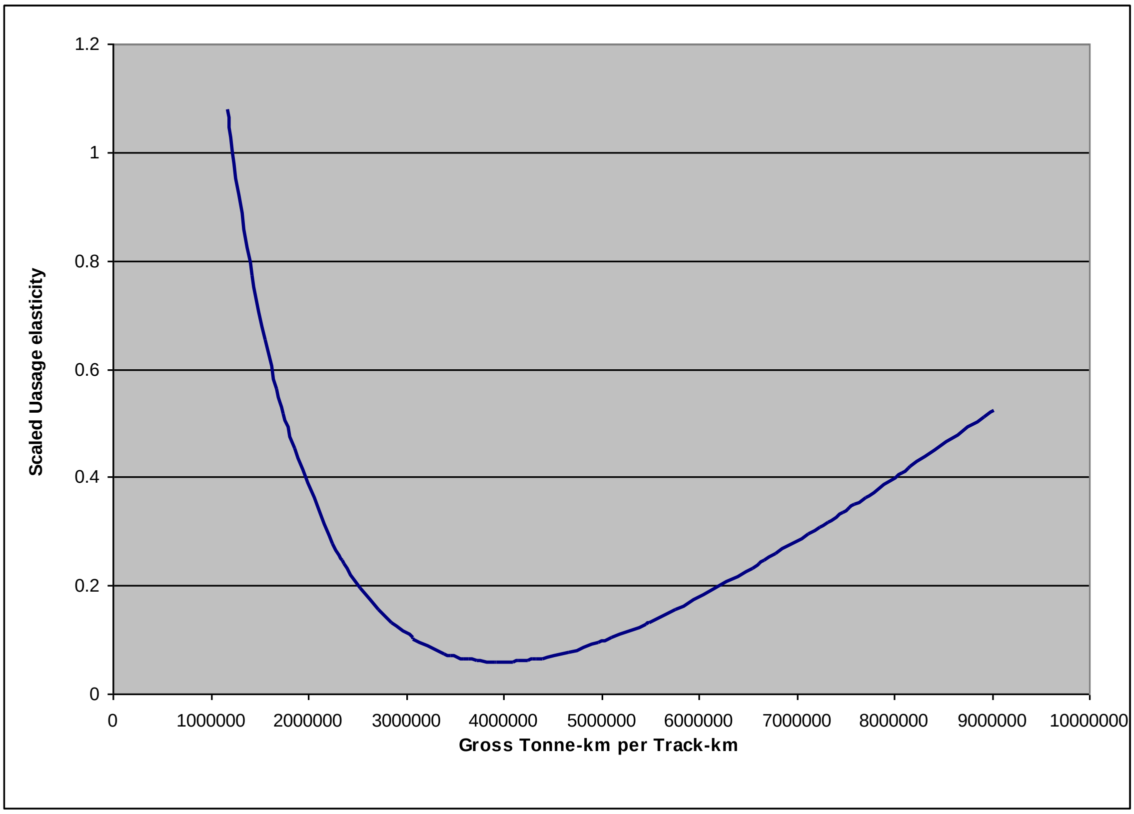
- The French study estimates a very steep increase in the usage elasticity with traffic density. As such the French study is consistent with the other studies at low to medium tonnage densities and hence the unweighted mean, median and low tonnage evaluation measures are within the 0.2-0.35 range but the weighted mean and high tonnage evaluation are outside.

Even with the slight inconsistency of the French study, we conclude that the ‘average’ total usage elasticity is between 0.2-0.35 with a large degree of confidence. We have more confidence in this finding than the range reported in GRACE, given the number of alternative metrics that we have considered in making this judgement.

Turning to how the elasticity estimates vary with traffic, we first note that all the studies that utilised Box-Cox functional forms reported increasing elasticities with traffic density. The study for Great Britain and the Pooled International study found falling then increasing and strictly decreasing changes in usage elasticities with traffic density respectively. We have decided to only consider the Box-Cox models when determining how the elasticity varies with traffic for the following reasons:

- All studies that have adopted the Box-Cox model reject the nested double-log model;
- For the British study, a Box-Cox model was estimated and the nested double log model could not be rejected. However this is likely to be a symptom of the limited number of data points available for estimation (53);
- For the Pooled International study it was not possible to estimate a Box-Cox model in tandem with implementing panel techniques which were essential for this study;
- For the Pooled International and British study the models did not allow for interactions between the usage elasticity and infrastructure variables which limits their flexibility;
- The finding of a falling usage elasticity implies, all other things equal, very aggressive marginal cost falls with tonnage-density that seems incompatible with engineering theory.

Figure 4.2 Variation of the total elasticity for the British case study – maintenance cost only



As noted in 4.5.1 to compare variation in usage elasticities with both tonnage density and infrastructure quality, it is necessary to plot or tabulate them for different values of tonnage density and infrastructure quality holding all other things equal. To do this we hold all non-quality related infrastructure characteristics at the sample mean (within each country).

First, we discuss how the elasticity varies with traffic density across the Box-Cox models. Figure 4.3 shows a plot of the usage elasticity against traffic density for France, Sweden and Switzerland. Here infrastructure quality is fixed at the average level in the country.[14]

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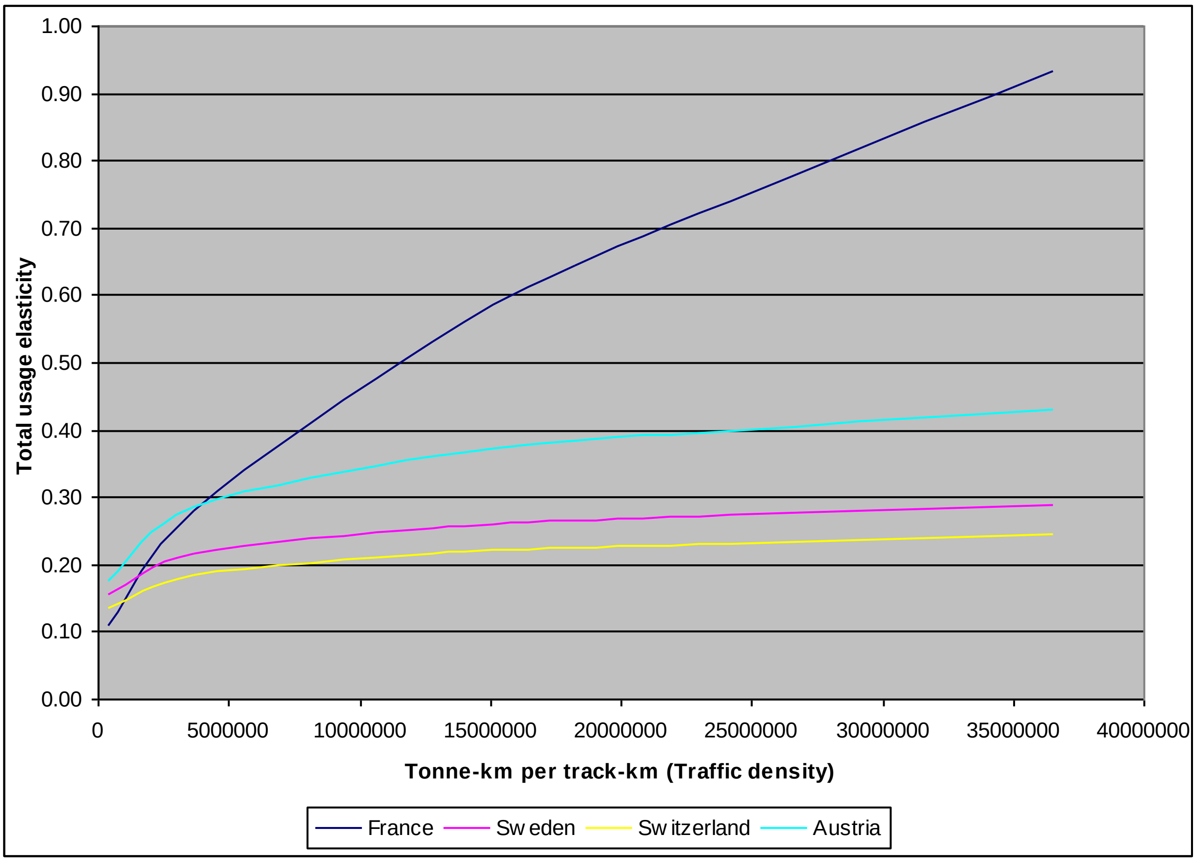
[14] We have already discussed in 4.5.1 that this assumption is not ideal for making like-with-like comparisons, but is the best that can be achieved. However it is better than not controlling for infrastructure quality.

Figure 4.3 Total usage elasticity against traffic density for Box-Cox models (average infrastructure quality)

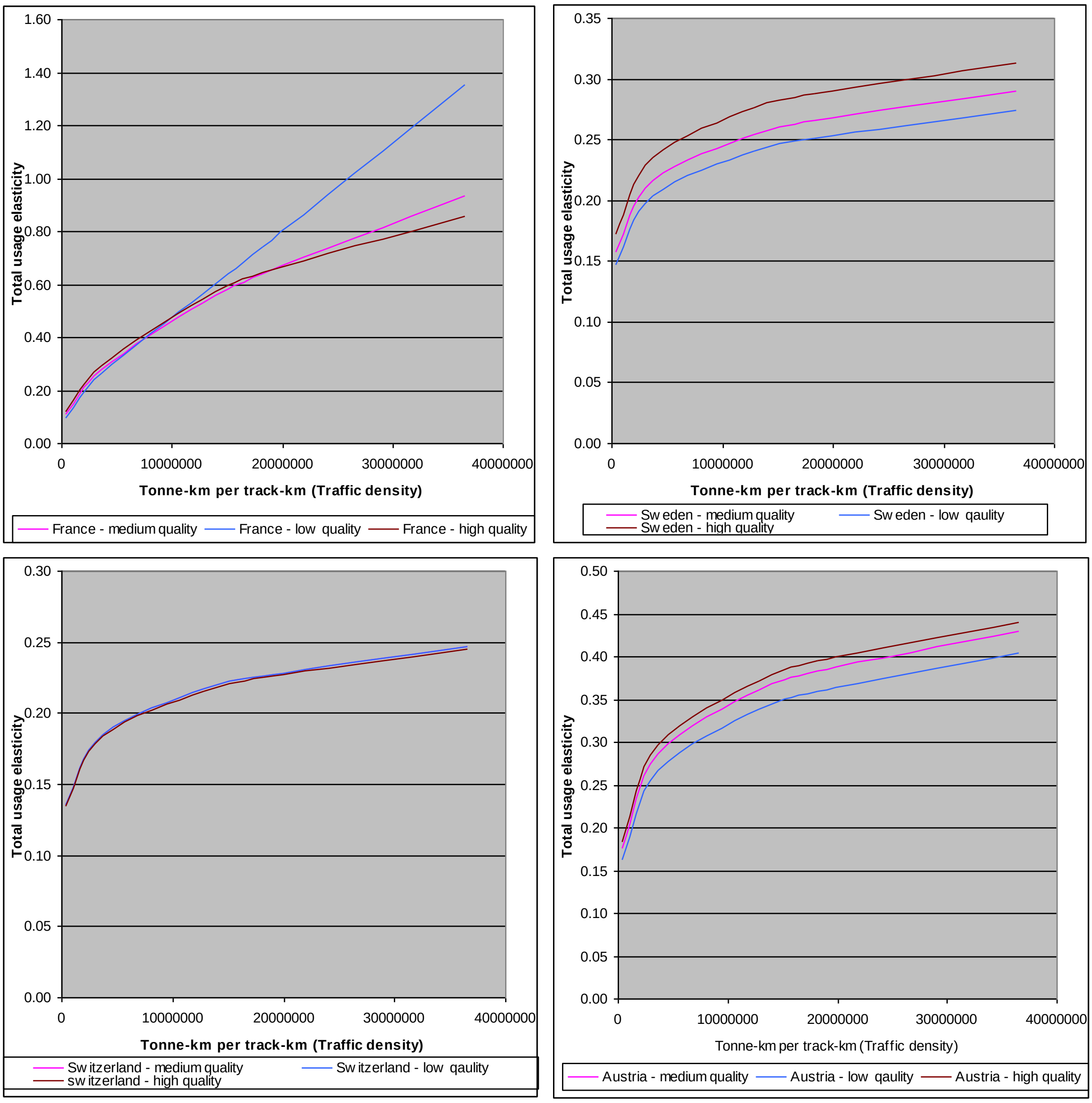


Second, we need to consider how the usage elasticity varies with infrastructure quality. This is motivated by our finding that marginal costs are very dependent on infrastructure quality (see sub-section 4.6.2) and so a natural question is whether this translates into variation in the usage elasticity.

Figure 4.4 shows plots for each of the three countries at different levels of infrastructure quality. Overall it does not appear that infrastructure quality has a big impact on the usage elasticity, except perhaps at high tonnage density levels. In any case, there is no consensus between countries to reach any conclusion on which way infrastructure quality affects the usage elasticity.

Overall we have confidence that the average total usage elasticity is between 0.2-0.35 and have found that this is increasing with traffic density. However we have found little evidence that it differs with infrastructure quality.

Figure 4.4 Total usage elasticity against traffic density for Box-Cox models at different infrastructure quality levels



4.5.3 Maintenance only cost: Passenger and Freight Usage Elasticities

Previously in the GRACE project, there was limited success in separating traffic into passenger and freight. Where passenger and freight data was available, inclusion of it led to implausible estimates of the usage elasticities especially for freight. For the CATRIN project we have revisited this issue with much more success. This success has been found through adopting a range of methodological alternatives and we have had particular success in distinguishing between passenger and freight traffic using Box-Cox models.

The studies in Sweden, Switzerland, Great Britain and France had data on traffic disaggregated by passenger and freight (and in the case of France further disaggregation was possible for passenger). Unfortunately once analysed, it was determined that the data for Great Britain could not yield any sensible information about this disaggregation and so is not considered here. For the three other countries, the usage elasticity (whole sample weighted by tonne-km) for each traffic type is shown in Table 4.4.

Table 4.4 Usage elasticities for passenger and freight traffic using Box-Cox models, measured as whole sample average weighted by tonne-km

	Usage elasticities		Ratio of Passenger to Freight
Country	Passenger	Freight	
Sweden	0.199	0.058	3.431
Switzerland (Maintenance)	0.127	0.049	2.605
France	0.273	0.114	2.395

For all countries the passenger usage elasticity was found to be over two times that of the freight usage elasticity. It should be noted that *a priori*, even if marginal costs are believed to be the same for passenger and freight (per gross tonne-km), we would not expect the elasticities to be the same. This is because the usage elasticity value depends on the relative traffic mix between passenger and freight. All other things equal there should be a higher elasticity for passenger relative to freight as the ratio of passenger to freight tonne-km increases. As such we reserve the discussion as to whether passenger or freight traffic do more damage to the infrastructure to sub-section 4.6 when we examine marginal cost estimates.

What is perhaps more important is that all three studies find that usage elasticities are increasing for both passenger and freight traffic when all other variables are set at the sample mean[15]. Thus the pattern found for the total usage elasticities is replicated for the individual passenger and freight elasticities. In addition the sum of the passenger and freight usage elasticities are in line with those estimated from models using only one traffic measure. Both of these consistencies with the single tonnage models represent step forwards relative to the finds from GRACE. For example Wheat and Smith (2008) found for Britain that the sum of the passenger and freight usage elasticities were substantially lower than for the comparable elasticity from a single traffic measure model. Thus we conclude that adopting the Box-Cox functional form has helped yield more sensible results on passenger and freight.

4.5.4 Maintenance and renewal costs

Two studies, Switzerland and Great Britain, have examined the sum of maintenance and renewal. The estimates for the usage elasticities derived from these models are 0.28 from the Swiss model and 0.49 from the British model.

The British study looked at only 67% of maintenance costs, the main element being permanent way maintenance and also only track renewals, which accounts for approximately 30% of renewals expenditure. Given that these two categories are likely to be the most variable with traffic, it is no surprise that the estimated elasticity for Great Britain is so high relative to that for Switzerland which examined all maintenance and renewal that could be allocated to track sections.

As discussed in section 4.4.1, it is not reasonable to scale the usage elasticity for Great Britain since it is likely that other elements of renewal costs are variable with traffic. For example

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[15] The exception to this is the French study which finds the freight elasticity increasing and then decreasing as usage increases.

Booz Allen Hamilton (2005) estimates for Great Britain that AC electrification equipment is 35% variable with traffic. However we can provide a lower and upper bound for the usage elasticity. The upper bound is given by the unscaled usage elasticity (0.49) and implicitly assumes that all excluded expenditure (both maintenance and renewal) has the same proportional variation with traffic. This is very unlikely given the evidence from section 4.5.2 and from Booz Allen Hamilton (2005). The lower bound is given by assuming that none of the excluded cost is variable with traffic. This bound is approximately 0.21, taking into account that renewals expenditure is roughly double that of maintenance in the studied year. This too is unlikely given that some of the renewals cost is believed to be variable with traffic. The middle of this range is 0.35.

With the above in mind, it seems reasonable to suggest that the studies actually point towards the usage elasticity being between 0.28 and 0.35. However there is obviously a great deal of uncertainty associated with these estimates given that only two studies have considered renewals. This is clearly an area for further research using a variety of methods as discussed in Section 7.

4.6 Results: Marginal costs

4.6.1 Comparison framework

As we did for the usage elasticities, we want to compare variation in marginal costs across countries and within countries. We therefore need to construct summary measures of the ‘average’ marginal costs for countries and determine variation in marginal costs with traffic density and infrastructure quality. Further, this task is more important than for the usage elasticities because we find a great deal of variation in marginal costs within countries and this is greater than the variation in usage elasticities. This is primarily because average costs vary considerably with traffic density and infrastructure quality. Since marginal cost is the product of the usage elasticity and average cost, then it too varies considerably with the same characteristics.

We compute the same menu of summary measures for marginal cost for each study as we did for the usage elasticity comparison. The advantages and disadvantages of each measure are the same as those given in 4.5.1, so we present all the measures (for maintenance only cost at least).

It should be noted that the weighted average measure has a potentially useful property that it represents the uniform charge that could be levied on all track sections (per gross tonne-km) and recover exactly the same charging revenue as charging each track section at the unique level estimated in the model, assuming no change in usage from introduction of either charging scheme. As such this measure is potentially very useful for individual countries in deciding on a suitable single charge for their network. However it has still has limited usefulness in comparing marginal costs across countries because of differences in the distribution in marginal costs.

Likewise we plot marginal costs against tonnage density for different levels of infrastructure quality for each country as we did for the usage elasticities.

We use PPP exchange rates to convert local currencies into (French) Euro[16]. Using PPP adjusted exchange rates has two main advantages. First they control for the differences in average wage levels across countries. While average wages are for all industries as opposed to railway wages, in the absence of specific evidence to the contrary they do provide a better control than using an unadjusted exchange rate. Second PPP exchange rates are much less volatile over time, which aids comparison across studies. It is important to emphasis that PPP exchange rates are used to compare marginal cost results across studies. Caution should be taken in literal interpretation of the results such as in circumstances of reporting the marginal costs for one particular country.

4.6.2 Maintenance only cost: marginal cost for all traffic

Table 4.5 gives the summary marginal cost estimates for each study. The table shows that different measures can, in some cases, give radically different marginal cost and this shows the importance of comparing a range of measures.

Table 4.5 Summary measures for maintenance only marginal cost, € per thousand gross tonne-km

Study	**Preferred functional form**	**Mean Tonnage density (Tonne-km / Track-km)**	**Whole Sample Averages**		
			Unweighted Mean	**Weighted Mean**	**Median of sample**
France	Box-Cox	7,300,000	2.70	1.39	1.80
Sweden	Box-Cox	7,650,000	11.52	0.46	0.86
Switzerland	Box-Cox	13,100,000	0.84	0.32	0.50
Austria	Box-Cox	10,600,000	2.60	1.20	1.50
Great Britain	Double-log	4,810,000	2.51	1.73	1.56
Pooled International	Double-log	8,135,000	4.36	2.17	2.53

Study	**Evaluated at sample mean of data**	**Evaluated at average infrastructure quality and 3,650,000 tonne-km per track-km**	**Evaluated at average infrastructure quality and 12,775,000 tonne-km per track-km**
France	2.01	2.25	2.00
Sweden	0.54	0.52	0.24
Switzerland	0.39	0.92	0.39
Austria	0.88	1.46	0.79
Great Britain	1.07	3.16	1.78
Pooled International	3.55	5.98	1.18

The whole sample weighted mean has commonly been reported by the existing literature. The range from the CATRIN studies is 0.32€ per thousand gross tone-km (€TGTKM) to 2.17€TGTKM. This range has a greater maximum and a greater minimum than that found in GRACE, but overall is comparable. This finding is to be expected because this measure

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[16] The PPP exchange rates used between local currency and French € were as follows: Sweden 10.178 (2001); Switzerland 1.887 (2005); Great Britain 0.703 (2005), United States (Pooled International) 1.084 (2005). The year was chosen to be in the middle of the sample period for each country's dataset.

utilises the whole sample and since many countries in CATRIN were also considered in GRACE we would expect our models to give similar answers.

Further we find that we have more balance in the distribution of this measures from the five studies compared to GRACE where there were several studies with very low weighted average marginal costs and only one country (Great Britain) with high marginal costs. This is due to the addition of the Pooled International and French case studies that both have high average and marginal costs.

The whole sample unweighted mean can give radically different estimates than other measures from study to study. This maybe because all studies estimate very high marginal costs for very low tonnage density sections. Depending on the number of these sections they could have a large impact on the result of this measure.

There is reasonable consensus between studies using the median marginal cost or evaluated at the sample mean. For Great Britain, the marginal cost evaluated at the sample mean is substantially lower than at the median or any of the whole sample averages. This is due to the U-shaped marginal cost function estimated.

Perhaps most useful for comparison purposes are the two marginal costs evaluated at average infrastructure quality and at the same tonnage levels. This is because these measures hold traffic density constant across studies and attempt to control for differences in infrastructure quality (be it only relative to the means in each study – which will be different from study to study). We still find some differences in estimates between studies. This is partly due to the different shapes of the marginal cost curves estimated. In particular the marginal cost curves from the Box-Cox models decay relatively slowly with traffic density, while the marginal cost curve for Britain is U-shaped and decays very quickly for the international model. A further explanation is our approach to controlling for infrastructure quality is limited and variations in average infrastructure quality may explain the differences.

Figure 4.5 plots the marginal cost for all studies holding infrastructure characteristics and quality at sample mean levels. All studies find that marginal cost is falling with traffic, with the exception of the curve for Great Britain which finds falling and then increasing marginal cost. Even when holding infrastructure quality at average levels there are still big variations in marginal cost across countries (see discussion above). It is perhaps also surprising that we still find very high marginal costs for low trafficked sections even after controlling for quality difference. However this could be because the model does not predict these costs very well, since the low trafficked sections are far the sample mean and tend to have poor quality infrastructure rather than average, which means the model can not be expected to predict the cost of these sections with average infrastructure quality very well.

Figure 4.5 Plot of marginal cost for all studies holding infrastructure characteristics and quality at sample mean levels[17]

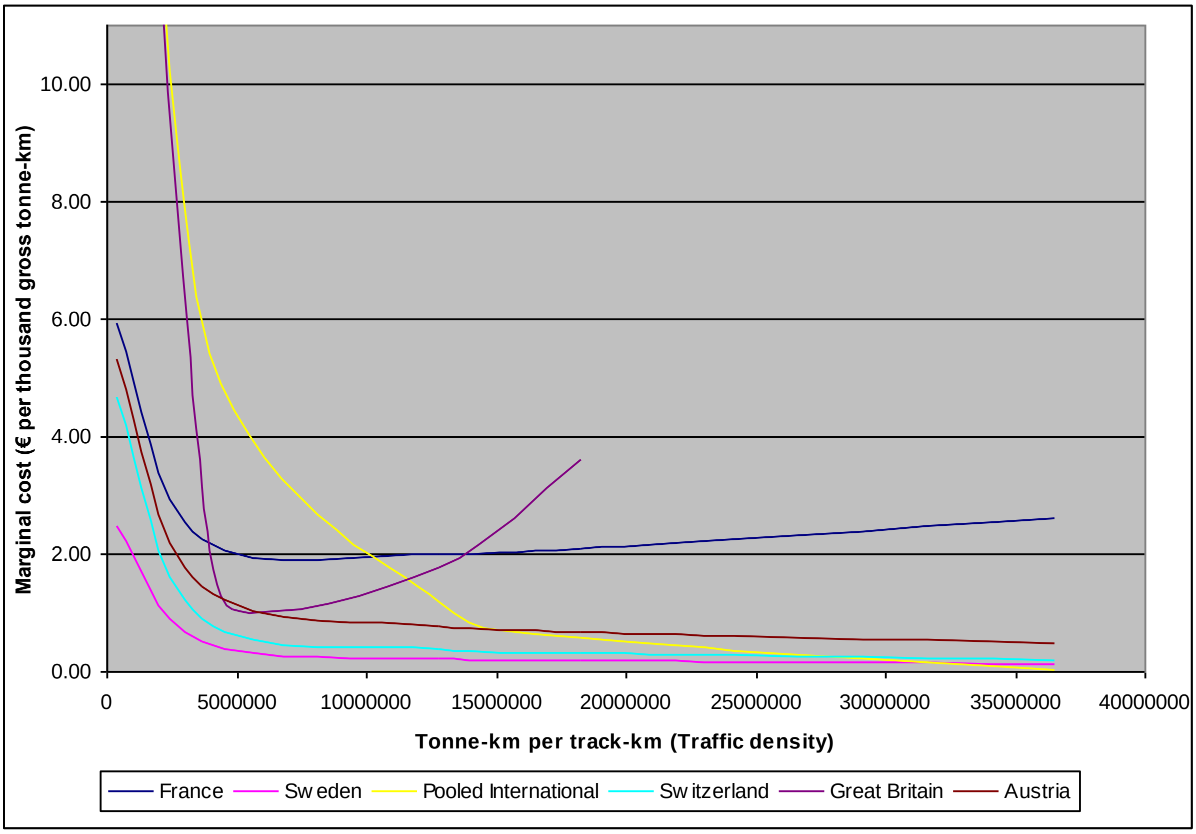

Figure 4.6 plots the marginal cost for all studies for different level of infrastructure quality. With the exception of Switzerland that only had two infrastructure quality variables which had little impact on the model, all studies find that marginal cost increases the lower the quality of the infrastructure, all other things equal. This is intuitive for maintenance cost because better quality infrastructure can be thought of as having had greater capital investment and so requires less ongoing maintenance, all other things equal.

In this sub section we have reported various measures of ‘average’ marginal cost for each study and discussed how these vary with traffic density and infrastructure quality. While we can explain differences in the resulting marginal costs we do note that there is more consensus in usage elasticities than marginal costs and as discussed in section 7 it is the usage elasticity that we propose for generalisation purposes.

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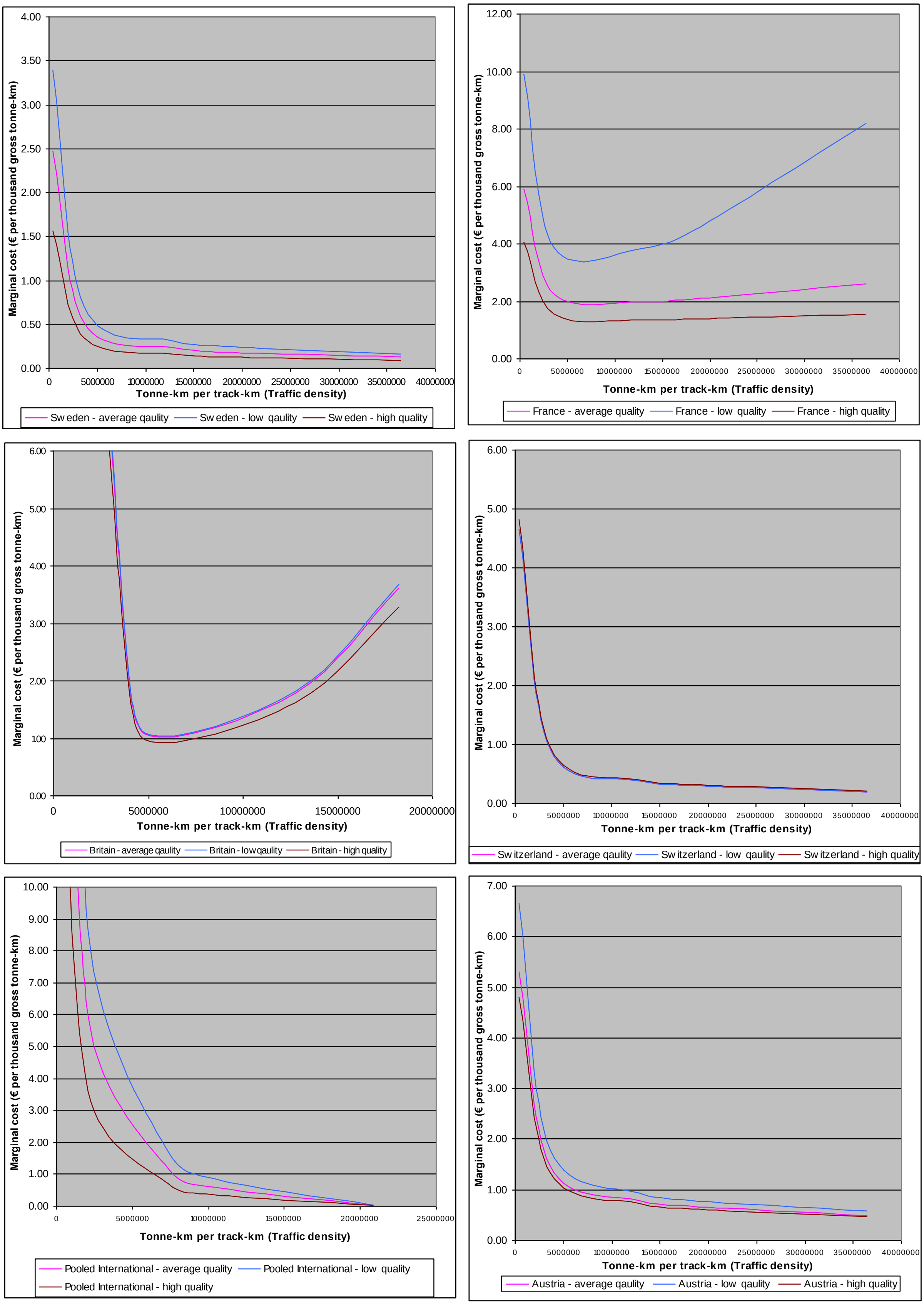
[17] The MC for GB are plotted for a narrower range of tonnage densities. This is due to the unreliability of estimates at the low and high extremes. This results from the use of aggregated zonal data.

Figure 4.6 Plots of marginal cost against traffic density for different levels of infrastructure quality for all studies holding infrastructure characteristics at sample mean levels



4.6.3 Maintenance cost only: Marginal cost for passenger and freight

Table 4.6 shows the marginal cost estimates (whole sample average weighted by tonne-km) for the three studies that considered passenger and freight as separate traffic variables. All studies find that passenger marginal costs are greater than freight although the relative difference ranging from one and a half times to over seven and a half times. Marginal costs are falling with traffic density, as found for total traffic.

Section 5 reports on an engineering study looking at the relative damages of passenger traffic and freight traffic. This found that some vehicles did do substantially more damage than other even per gross tonne-km although on aggregate passenger traffic did only slightly more damage per gross tonne-km than freight traffic. The engineering study was simply a case study on two track sections in Sweden and so caution must be taken in to wide generalisation of the results. However the engineering study does indicate that the econometric estimates of passenger traffic being of up to seven and a half fold greater marginal cost than freight traffic maybe too dramatic. Indeed the engineering models seem to be showing that the exact traffic and track mix is important and certain mixes could result in freight traffic being more damaging than passenger.

Table 4.6 Marginal cost estimates by passenger and freight traffic using the whole sample average weighted by tonne-km measure, Euro per thousand gross tonne-km

	Marginal Cost			
Country	**Passenger**	**Freight**	**Total (for comparison)**	**Ratio of Passenger to Freight**
Sweden	1.058	0.140	0.461	7.559
Switzerland (Maintenance)	0.265	0.184	0.321	1.438
France	2.103	0.692	1.390	3.036

4.6.4 Maintenance and renewal cost

The estimates using the whole sample weighted average measure for the studies that considered maintenance and renewal costs were 0.71 and 8.12 Euro per thousand gross tonne-km for the Swiss and British case study respectively. This is a very big difference and reflects both differences in the estimated usage elasticities and differences in average costs. Our view is that the British estimate seems high partly because we believe the estimate for the usage elasticity is high (even though we can explain some reasons for the elasticity being so high, that is, the restricted cost base, even net of this effect, it still seems high).

It is difficult to draw too many conclusions from the above given the small number of studies undertaken. What is clear is that there is more consensus between usage elasticities than between marginal costs.

4.7 Context of CATRIN results vis-à-vis existing literature

Throughout this section we have offered comments as to how our results compare with those found in GRACE. However we have not shown exact comparisons between these new results and the results from the existing literature. This has been deliberate. What has become clear is that it is very difficult to compare the results from study to study without being clear about what is exactly being reported from each. We have closely coordinated the CATRIN case studies so that we can compare the results; for previous studies we do not have this ability. Therefore we would strongly caution about making direct comparisons with the existing literature reported in CATRIN Deliverable 1 (which drew heavily on the studies from GRACE) and summarised in section 3 of this Deliverable[18].

We do note that the countries reported in Deliverable 1 have all subsequently been taken forward as CATRIN case study countries with the work undertaken by the same authors. As such this new work can be viewed as superseding that reported in Deliverable 1. The only exception is the study reported for Finland, which found a usage elasticity for maintenance cost lower than the range reported in this Deliverable. Unfortunately we can offer no more comment except that we have more certainty in our results as they have been coordinated rigorously to yield like-for-like comparisons.

The work in CATRIN sought to build on the work done in GRACE and explicitly aimed to enable better comparisons between studies, which we noted was a problem in GRACE. Thus whilst we don’t compare CATRIN studies with those of GRACE directly, what we do see is a clearer story coming out of CATRIN than GRACE in terms of what we know about MC and elasticities and how they vary with tonnage and infrastructure quality, and we can now give clear much clearer generalisation advice to other countries

4.8 Summary

In this section we have presented new econometric evidence on marginal costs. The research in CATRIN has yielded new insights in the level and variation of marginal costs across and within countries. We find marginal costs decrease with traffic density and the higher the quality of the infrastructure. However even after accounting for these factors there is still a lot of variation between countries which makes direct generalisation difficult.

We have also presented evidence on usage elasticities regarding their level and variation of marginal costs across and within countries. We find that for maintenance only cost average total usage elasticties range from 0.2-0.35 and for maintenance and renewal, while we have less evidence, these seem to be between 0.28 and 0.35. We also find that the usage elasticity is increasing with traffic density, while find no evidence that the usage elasticity is systematically affected by infrastructure quality. Given this consensus across studies we take the usage elasticity forward as the preferred candidate for generalisation.

We find that marginal costs for passenger traffic are greater than for freight although there is little consensus on the precise ratio of the two. However we note that from the perspective of generalisation, the relative size of the usage elasticities for the two traffic types will be determined partly by the traffic mix and so direct generalisation from our estimates is difficult. We present our full findings on how to generalise our results in Section 7.

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[18] We would also caveat that some of the “proportion of cost considered” were approximate for some countries. Following the work in Work Package 5, these proportions have been refined and those presented in Table 4.2 in this deliverable should be taken as definitive.

5 Engineering evidence on marginal infrastructure wear and tear costs

The engineering modelling approach outlined in Section 3.2 has been applied to two track sections in Sweden. Here we review this study and discuss the implications for the relationship between econometric and engineering modelling.

5.1 Description of Track Sections

The first case study is based on the Ostkustbanan route from Stockholm to Uppsala. The traffic scenario over this track route is dominated by passenger traffic that is composed by both high speed and commuter train. Freight traffic makes up a relatively small proportion of the traffic at just over 6%.

A detailed breakdown of traffic is shown in Table 5.1.

Table 5.5 Description of composition of vehicle traffic for track section 430

Vehicle type	Vehicles per year	Sum of axle load [tonne]	Tonnage [tonne]	Aggregate tonnage [%]	Speed [km/h]
Freight Loco	1024	78.0	79852	0.5	80
Freight Wagon T.	5375	23.3	125014	0.8	80
Freight Wagon L.	9981	90.0	898332	5.4	80
High speed Loco	3969	73.0	289710	1.8	200
High speed Coach	7937	51.0	404800	2.5	200
Passenger Loco	59529	78.0	4643297	28.1	130
Passenger Coach	216290	46.5	10057501	61.0	130

The second track section considered, called Track section 111, is a dedicated freight route known as Malmbanan running from Luleå, to Narvik in Norway. Traffic here is clearly dominated by freight vehicles most of which consist of vehicles with so called three piece freight bogies. These are known to have a very high unsprung mass (the mass of the wheels and axle and any part of the vehicle not separated from this by suspension).

A detailed breakdown of traffic is shown in Table 5.2.

Table 5.2 Description of composition of vehicle traffic for track section 111

Vehicle type	Vehicles per year	Sum of axle load [tonne]	Tonnage [tonne]	Aggregate tonnage [%]	Speed [km/h]
Freight Loco	13791	190	2620319	11.0	60-70
Passenger Loco	2170	78	169260	0.7	110
Passenger Coach	13068	46.5	607662	2.5	110
Freight Wagon L.	161356	100	16135646	67.6	60
Freight Wagon T.	197213	22	4338696	18.2	70

5.2 Results

5.2.1 Results by vehicle type

Vehicle models were prepared and run on the supplied track data. For each track section this produced relative measures between the different vehicle types for two damage types: track settlement and rail wear damage. The results for track settlement for each vehicle are shown as a percentage distribution in Figure 5.1 for track section 430 and in Figure 5.2 for track section 111. These relative factors are per gross tonne and so they can be viewed as relative damage of each vehicle per gross tonne-km.

For track section 430, the high speed locomotive results in the highest damage and the tare freight wagon is lowest. The ratio of damages is approximately 12.5:17 or put another way a high speed loco per gross tonne-km does approximately 35% more settlement damage per gross tonne-km.

For track section 111, the freight locomotive results in the highest damage while the passenger coach results in the least damage per gross tonne-km. the ratio of damages is 22:18, or alternatively a freight loco does 30% more damage per gross tonne-km than a passenger coach.

Figure 5.1 Track settlement damage per GTkm by vehicle for track section 430

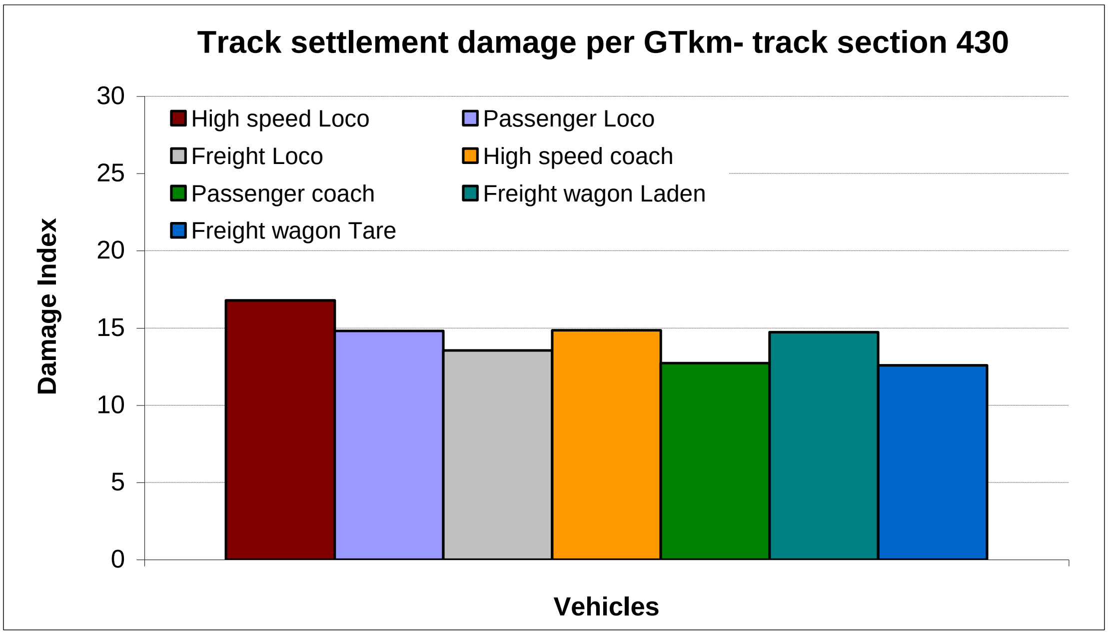
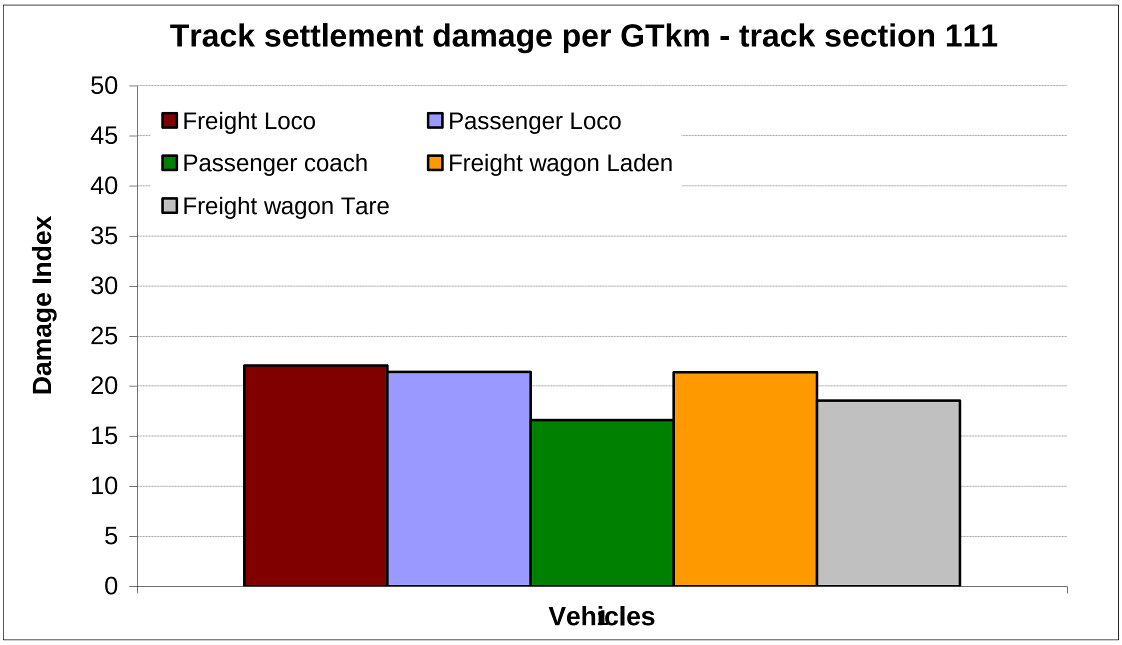


Figure 5.2 Track settlement damage per GTkm by vehicle for track section 111



The results for rail wear damage are given in Figures 5.3 and 5.4 for track section 430 and 111 respectively. These show a wider variation of relative damages by vehicle, with a high speed locomotive doing approximately double the damage than a Freight wagon Laden for track section 430 and passenger locomotive does nearly triple the damage of a freight loco in the case of track section 111.

Figure 5.3 Rail damage per GTkm by vehicle for track section 430

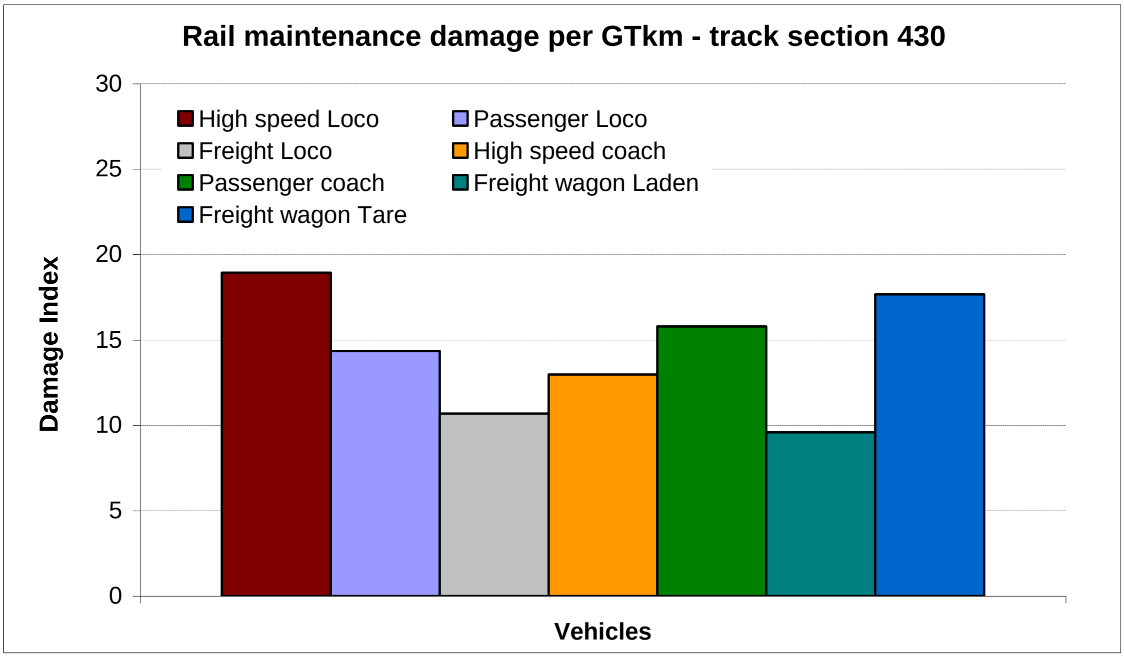
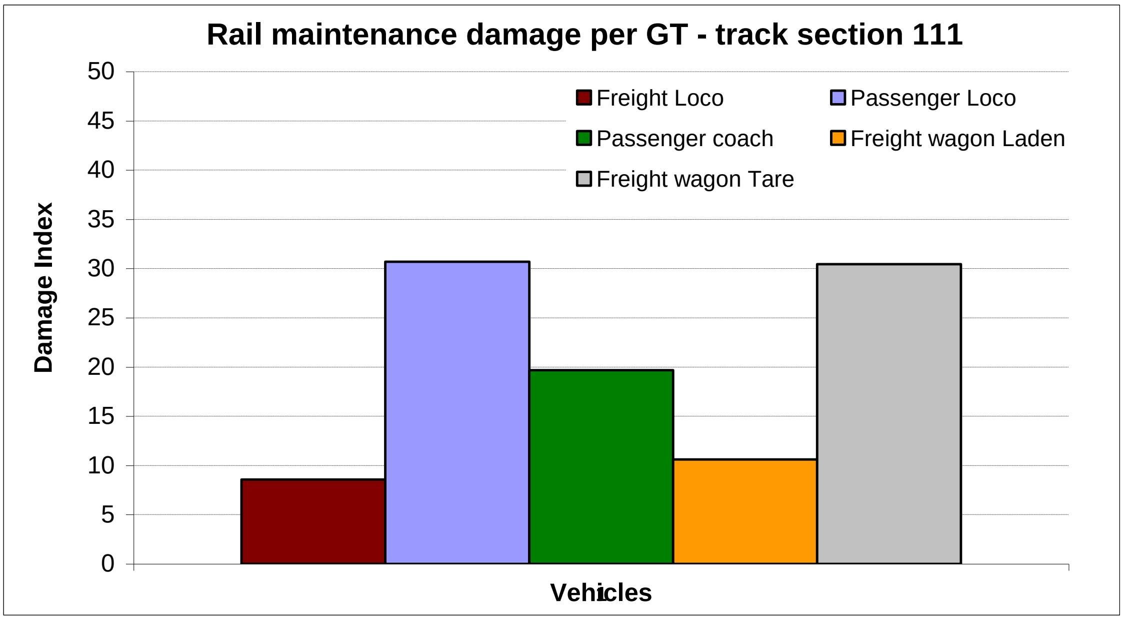


Figure 5.4 Rail damage per GTkm by vehicle for track section 111



The above results show, especially for rail wear damage, the damage caused by different vehicles can be considerably different even when measured per gross tonne-km. This supports using the engineering models to allocate variable cost (perhaps derived from econometric models) to different vehicles.

5.2.2 Results for passenger and freight

The engineering modelling in the case study have clearly shown the difference that subtle characteristics of vehicles can have on resulting infrastructure damage. However the study also considered the relative damage of the aggregated passenger and freight vehicles each track section.

The findings of this part of the study have direct relevance to the specification of econometric models. While it is infeasible for econometric models to incorporate traffic by vehicle type, some studies, and indeed some studies in CATRIN, have sought to disaggregate traffic into passenger and freight. However if following aggregation of all the different vehicle types, the engineering study finds little evidence of differences in damage of passenger and freight traffic per gross tonne-km, then this provides support for only having total gross tonne-km in the econometric model.

Table 5.3 shows the split between passenger and freight traffic for both damage types. This shows that per gross tonne-km freight does more track settlement damage than passenger, but the reverse is true for rail damage.

Table 5.3 Split between passenger and freight traffic for both damage types

	Track settlement		**Rail damage**	
	Passenger	**Freight**	**Passenger**	**Freight**
Track Section 430	47%	53%	57%	42%
Track Section 111	46%	54%	61%	39%

Thus to determine which traffic type does more damage, the importance of each damage type has to be determined. We do this by examining the proportionate split between maintenance work aimed at rectifying track settlement damage versus maintenance work aimed at rectifying rail damage. For track section 111, this split is given in Table 5.4. We then compute a weighted average of the two damage types for passenger and freight, by using the cost shares of each maintenance activity as weights[19].

Table 5.4 Split of maintenance cost between the two damage types for track section 111

	Total Maintenance	**Track Settlement Maintenance**	**Rail Maintenance**
Cost (SEK)	30,855,962	6,603,176	24,252,786
Proportion Split	100%	21.4%	78.6%

The result of taking this weighted average is that the ratio between passenger and freight is 57.8%:42.2%. Thus the outcome of the modelling for track section 111 is that passenger trains do slightly more damage per gross tonne-km relative to freight. The finding that the passenger does more damage than freight is inline with the findings from the Swedish econometrics although the econometric finding was a substantially larger difference than that found for the engineering.

Overall, however there are reasons to suspect that the relative damage of passenger and freight trains could be either more or less depending on the maintenance policy adopted between countries and the precise mix of passenger and freight vehicles using the network. Therefore there maybe benefit from trying to incorporate passenger and freight traffic separately into econometric models, however it is still concerning that the estimated relative differences between the econometric models and the engineering models are so great. As such judgement should be applied and it may be best for some datasets, where the econometric estimates of passenger and freight marginal costs look unrealistic to only include the single tonnage variable in the econometric model. Engineering models to distribute the estimated variable cost to individual vehicles.

The study also compared the results to those obtained by using the data on vehicle characteristics and the equated gross tonne-km formula used by the British Office for Rail Regulation for charging vehicles in Britain. For some vehicles there were big differences between these two engineering approaches but for others the differences were minor. However, at least for the specific track sections, the detailed modelling undertaken in the case study is likely to be more representative of the true damage done by each vehicle. However the exercise does highlight how case study specific the results of engineering models can be.

Regarding implications for econometric analysis, while the engineering modelling has found substantial differences in damage between some vehicles overall it did not find dramatic differences between passenger and freight traffic. However these results are likely to be sensitive to the network maintenance policy, track section and exact vehicle mix. Therefore there maybe benefit from trying to incorporate passenger and freight traffic separately into econometric models

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[19] Note however that the validity of using this weighting structure requires that the elasticity of each of the two groups of cost with traffic is the same. This ensures that the both damages are proportional to remedial maintenance cost by the same proportionality constant.

However it is still concerning that the estimated relative differences emerging from the Swedish econometric model and the engineering models are so great. As such judgement should be applied and where the econometric estimates of passenger and freight marginal costs look unrealistic, it maybe better to only include the single tonnage variable in the econometric model. This may yield a better estimate of what cost is variable with traffic and then engineering models could be used to distribute this cost to specific vehicles. It is at the specific vehicle level where there are big differences in damage rather than at the passenger versus freight level. We discuss this in more detail in Section 7.

5.3 Summary and implications

In this section we have reported the results from the engineering case study which examined the relative damages of different vehicle for two track sections in Sweden. Overall it was found that even per gross tonne-km there are, for some vehicles, considerable variation in damages. However when the results were suitably average to the passenger and freight traffic level there was only a small difference in damage between the two groups per gross tonne-km. This case studies is the first time that engineering analysis has been used along side econometric studies on infrastructure wear and tear marginal cost research. As such it should be seen as a start on a longer research programme. In particular the present study is limited by only looking at two track sections which makes generalisation of its findings difficult. We return to this in Section 7.

The case study demonstrates that cost reflectiveness could be improved by adoption of vehicle specific gross tonne-km charges. However to adopt such a system would require bespoke engineering research for the specific vehicles and tracks in a network. A more workable model maybe a bonus / malus system were by the least / most damaging vehicles would be penalised, incentivising operators to adopted more track friendly vehicles.

6 Allocation of Capacity Costs

6.1 Introduction

So far this deliverable has been solely concerned with the measurement of short run marginal social cost rather than the costs of providing capacity. There are two reasons why providing appropriate incentives to train operators and other funding bodies may require capacity to be charged for. The first concerns giving appropriate incentives for the short run timetable planning process. When there is a shortage of capacity, train operators will fail to take into account the opportunity cost of the slots they demand when planning timetables. Moreover if they are only charged for the wear and tear they actually cause, then they will not be charged for reserving slots they do not use, even if by doing so they prevent other operators from using them. Various solutions to this have been proposed, including auctioning slots or levying reservation charges to reflect this opportunity cost. Work in the GRACE project proposed a method for finding this opportunity cost, but it was very cumbersome and only one or two examples could be run. As part of the work of this project, the software has been greatly improved to allow it to run much faster, and a complete time-of-day profile has been produced for the opportunity cost of slots between Leeds and London as an illustration of the method. This is considered in the next section. An important part of a scarcity charging system will be to charge different trains according to the amount of capacity they take up. An examination of existing track access charging systems showed the most sophisticated approach to doing this at present to be built in to the Italian track access charging regime, and that is considered in the following section.

However there is a second reason why it may be desired to charge the costs of providing capacity and that is more concerned with long run planning. Train operators very often have framework agreements with infrastructure managers which give them long term rights to certain amounts of capacity. On the basis of such rights they determine their long run investment plans. Where services are subject to franchise agreements, the franchising authority will be undertaking a similar long run planning process. If operators and franchising authorities are only asked to pay the short run marginal costs of the slots they use, they will have no incentive to take into account the long run cost of providing capacity to meet their needs. Thus there is an argument for charging a fixed charge as part of a long run track access agreement to reflect the cost of providing the capacity promised to the operator under that agreement. Such fixed charges may be problematic where there is on track completion as in freight if they are seen as discriminating between operators, but for franchised services they do not discriminate provided that all bidders face the same set of fixed charges. If the fixed charge is based on a simple allocation of costs according to a rule such as their share of train kilometres, then the charge will give wrong incentives by under or overcharging relative to costs. Thus the charge needs to be based on the costs the infrastructure manager would avoid if the services of the operator in question did not exist. Then, if this charge exceeds the value the operator or funding body places on the services, they have an incentive to replan them to use less capacity. Research on establishing this for the different sectors of British Rail formed part of the sector management approach of the 1980s, and further work on this issue has recently been undertaken as part of the determination of the fixed charges for the different passenger franchises in Britain. The last main section of this chapter examines this approach to the allocation of capacity costs.

6.2 Estimating the opportunity cost of slots

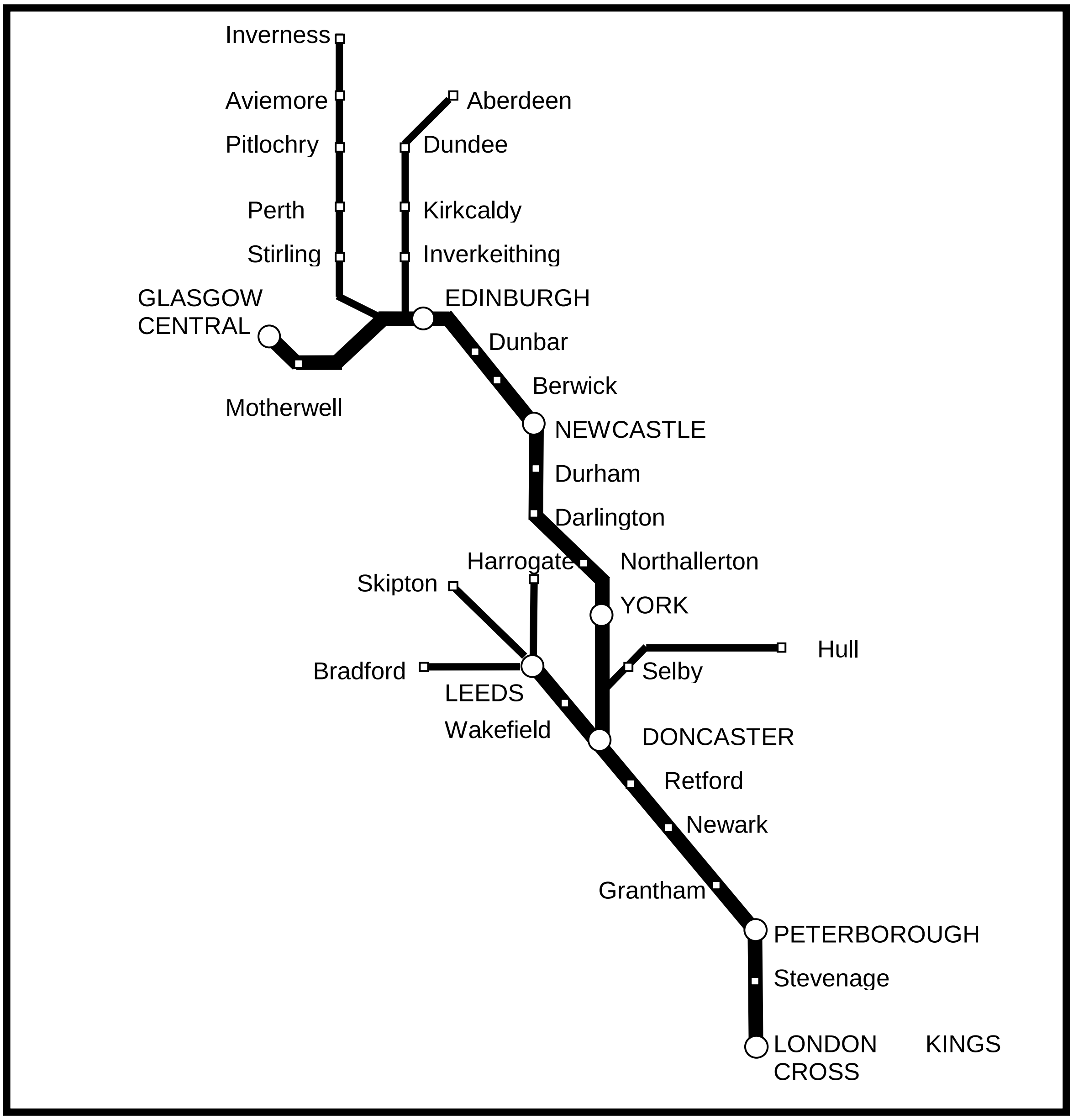
This case study concerns the stretch of the East Coast Main Line from London to Doncaster. The East Coast Main Line forms the principal trunk route from London to Leeds, York, Newcastle and Edinburgh; many trains continue to Glasgow. It is heavily used, particularly between London and Doncaster, which is where the main lines to Leeds, Hull and an important route to Scunthorpe and Grimsby branch off. There is a shortage of capacity over the Peterborough-Doncaster stretch of the route, which is mainly double track with occasional passing loops. Several new open access operators are bidding for slots to operate over this section, whilst expanding freight operations are also seeking additional slots. There are also shortages of capacity south of Peterborough where long distance trains conflict with London commuter trains at junctions, on a double track section over a viaduct and at the London terminal.

Most passenger services over this route are provided by National Express East Coast under a franchise agreement. For the franchised passenger operator, the impact of changing track access charges is neutralized by the fact that, under the franchise agreement, it is simply passed through to the government as a change in subsidy or premium paid. Where capacity charges may play an important part is in reflecting the opportunity cost of the passenger franchise not using these paths. Currently, other operators only pay the variable part of the infrastructure charge and have no incentive to economize in their use of capacity, for instance by changing speeds, time of day or route. Thus, the approach we investigate in this paper is construction of a tariff based on the opportunity cost of the slot to the franchisee. If the open access or freight operator requires capacity that would deprive the franchisee of more than one slot (for instance, because their trains are slower than those of the franchisee), then they would be charged for the appropriate number of slots. Since the franchisee is known and is required to make data available to the regulator, this approach to charging should be feasible. Of course, if there are several other operators competing for the slot and they all have higher values than the franchisee, then this will understate the true opportunity cost of the slot. However, basing charges on the identity of unknown possible new entrants appears difficult, at least until they start operating and data becomes available.

The opportunity cost of a slot for this type of service can be estimated as the sum of:

- the additional amount of traffic attracted to rail by the presence of this train multiplied by the price it pays
- the consumers' surplus to rail users as a result of the additional quality and capacity provided by the train (including reduced crowding on other services)
- the savings of external costs to road users and the public at large from the train attracting passengers from road.
- less the train operating, infrastructure and external cost savings from failing to run this train.

Figure 6.1: East Coast Mainline route



As the opportunity cost of paths over this section of track will be the value of the paths in the highest value use, this will obviously vary by time of day. So, to develop a tariff for scarce capacity, we should really examine a whole range of uses of paths for a variety of times of day. Earlier work (Johnson and Nash, 2008) was constrained to looking at a handful of services due to the prohibitively large run times involved. Recent developments in the software implementation of the PRAISE model using MATLAB now means the model runs much faster. This allows us to estimate the value of paths throughout the day. We do this by separately removing sixteen individual southbound services from Leeds to London to the franchisee and an additional four services from Hull to London. The improved PRAISE model also facilitates the accurate implementation of the impact of overcrowding on the network.

The value of the passenger slots will be estimated using the PRAISE model. The PRAISE (Privatized Rail Services) model was developed at the Institute for Transport Studies, University of Leeds to look at the potential for open access competition following the privatization of rail services (Whelan *et al*, 1997; Preston *et al*, 1999). More recently, the model has been re-written and developed to be capable of assessing demand and costs for small networks of stations incorporating the services of any number of operators, each with a variety of different ticket types.

PRAISE forecasts demand for individual services and ticket type, taking account of fares, journey times, desired departure times and overcrowding, so it is very useful for looking at issues concerning capacity, detailed timetabling and fares and ticket restrictions, as well as competition between different operators. In this case, it will forecast the extent to which changes in the timetable will lead to changes in rail passenger traffic, taking account of the precise times of the trains affected, the possibility of passengers taking other trains in the timetable or ceasing to use rail at all, and the changes in the fares and levels of crowding passengers face on the different options.

There are four stages to the calibration of the demand model. The first involves the estimation of the generalized cost of travel for each return service and ticket combination. The second involves calibrating ticket specific constants to ensure that the base market shares can be replicated. The third involves setting the sensitivity of the model to replicate known elasticities of demand. The fourth stage iterates to adjust for overcrowding on trains. An upper level of the model scales overall changes in rail demand following service level changes based on generalized journey time elasticities as estimated in the standard British rail demand forecasting model.

The cost model employs a cost accounting approach incorporating costs that are related to operating hours, costs that are related to train kilometers and fixed costs. Costs can be varied by operator and rolling stock type based on figures from the Rail Industry Monitor (TAS, 2004) and can be combined with estimates of revenue to generate forecasts of operator profitability.

PRAISE yields results for changes in consumer surplus, operating profits, modal switch values and vehicle kilometers, which can be used in conjunction with external cost valuations to undertake an appraisal. These external costs comprise those imposed by rail itself, and those imposed by other modes of transport whose volumes are changes by the change in rail frequencies. For external costs and benefits of other modes of transport, we use values from the study of Sansom *et al* (2001). To apply these values, we need to know how much traffic transfers to or from road and the types of road and time of day in question.

The change in rail passenger trips can be used to calculate the modal shift between rail, car, coach and not travel or new journeys. An integral part of these calculations are the application of diversion factors to the change in passenger trips.

Using diversion factors based on Train Operating Company Figures from 1998, this information is used to calculate a number of the impacts outlined in the appraisal framework.

We looked at the effect of removal of eleven passenger trains throughout the day. The results are presented in Table 6.1.

Table 6.1: Changes in passenger kms, franchisee profits and opportunity cost based on the removal of franchisee operated services throughout the day (£).

Service removed (time leaving Leeds southbound)	Change in Train passenger kms	Change in Franchisee profits £	Opportunity cost of slot (£)	Comments
505	-6456	-953	1829	
605	-9227	-823	2361	
700	-5150	432	310	
805	-15044	-756	3363	First to accept Business Savers
905	-14470	852	3550	First to accept Saver tickets
1005	-12383	-296	1495	
1205	-2548	1810	-1738	
1405	-1196	1131	-1977	
1505	-2231	1880	-1492	
1605	-1933	1620	-1440	
1705	-562	1483	-1529	

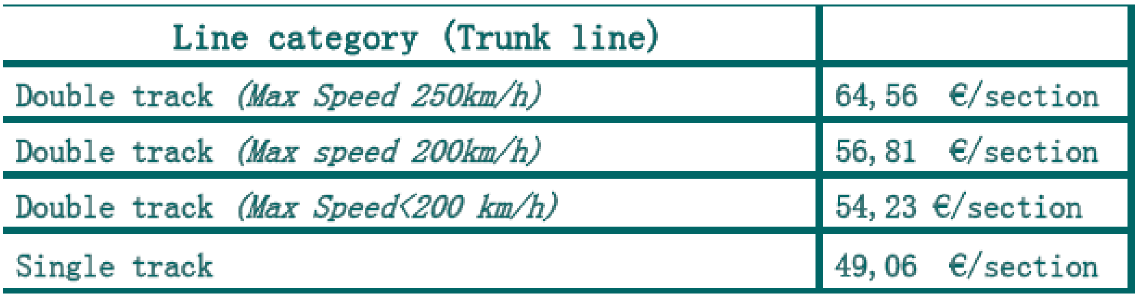
The removal of individual services reduces patronage, increasing adjustment costs and making existing services more overcrowded, leading to a reduction in consumer surplus, and reduces train operating costs.

It will be seen that the opportunity cost of slot varies as would be expected from around -£1400 during the daytime inter peak period to £1500 in the shoulders of the peak and £3500 in the peak. This could readily form the basis of a tariff of reservation charges by time of day. A more serious issue is that the revenue to the train operator substantially understates the social benefits of the services. Assuming this is also the case for the bidders for the paths, for capacity charges to have the correct incentive effects, subsidies would need to be given to operators to reflect these external benefits.

6.3 Charging according to capacity consumed

The structure of the charge for the use of rail infrastructure in Italy is composed of a fixed and a variable part, differentiated according to their application on a trunk line (main line) or a secondary line.

The fixed part of the charge is differentiated according to the quality of the line, i.e. the number of tracks, the average speed allowed and the general equipment of the infrastructure. This part, of which the table below shows the amount by each cost item, is independent from the traffic intensity and the capacity of the line.



Line category (Trunk line)	
Double track *(Max Speed 250km/h)*	64,56 €/section
Double track *(Max speed 200km/h)*	56,81 €/section
Double track *(Max Speed<200 km/h)*	54,23 €/section
Single track	49,06 €/section

Nodes	51,65 €/node
Secondary lines	46,48 €
Little used lines	0,00

The variable part addresses the capacity of the line and depends on a set of parameters reflecting wear and tear, traffic density and inefficient use of capacity (through the speed of the train).

There are two types of capacity charge.

Firstly a charge per kilometre on the trunk line sections, differentiated by:

1. Speed relative to the optimal for the type of section and time of day
2. Traffic density, each section is allocated to a category varying by time of day.

Speeds vary between 40 km p.h. for day time use of a metropolitan line and 170 km p.h. for day time use of a 250 km p.h. line. A speed difference of up to 20% leads to no surcharge; 20-50% a 30% surcharge; 50-100% a 200% surcharge and above that the surcharge is 400%.

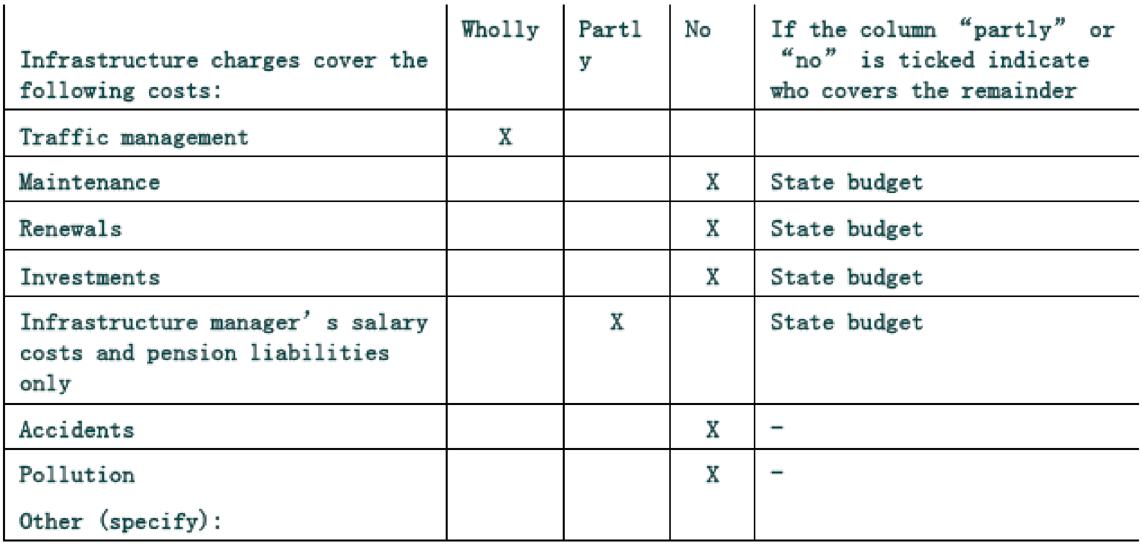
Traffic densities are grouped into 3 categories; below 50% of capacity, 50-75% and above 75%. There is a 70% reduction for the first category and a 50% surcharge for the last.

Secondly, there is a charge per minute for time spent in key nodal sections.

These charges are differentiated by time of day, with a 20% discount for night time and 30% surcharge in the morning peak. For the five main stations (Torino, Milano, Firenze, Roma, Napoli), the charges are multiplied by 4.

Furthermore, the variable part of the charge also include parameters for taking into account wear and tear, with particular reference to electric wires damages (through the use of pantographs) and tracks.

It is important to stress that the costs allocated according to these criteria, are not estimated congestion, scarcity and wear and tear costs, but rather they are traffic management plus salary costs. Maintenance costs and renewal are funded by State budget, as shown in the table below, and therefore not paid directly by the rail operators.



Infrastructure charges cover the following costs:	Wholly	Partly	No	If the column "partly" or "no" is ticked indicate who covers the remainder
Traffic management	X			
Maintenance			X	State budget
Renewals			X	State budget
Investments			X	State budget
Infrastructure manager's salary costs and pension liabilities only		X		State budget
Accidents			X	-
Pollution			X	-
Other (specify):				

Summing up, the RFI approach for supporting the efficient use of rail infrastructure arises from the combination of three main parameters, determining the order of magnitude of the variable part of the rail charge:

a) density (a proxy of the congestion);
b) speed (measured as the difference between the speed of the train in question and the speed deemed optimal for the route in question)
c) wear and tear.

Scarcity is addressed through the imposition of higher charges to the extent that the route is more congested and the average speed of the train higher than the optimal speed of the line (distinguished by night time – 22.00-6.00; semi-peak hour – 9.00-22-00; and peak hour – 6.00-9.00).

A similar approach is assumed for supporting the efficient use of the most congested nodes, charging higher the time (in minutes) spent in congested nodes and in particular when the train is using the node during the peak hour.

6.4 Avoidable cost of capacity

The term avoidable cost refers to the cost saving from discontinuing provision of a service or set of services, given assumptions about what other services will still be running. The avoidable cost approach is not relevant to the determination of appropriate charges to incentivise train operating companies to plan time tables which make the best use of existing capacity. That is the role of short run marginal social cost pricing. Rather avoidable costing is appropriate to long term planning, for instance where train operators enter into long term framework agreements with infrastructure managers which guarantee them a certain amount of capacity, although not particular slots. This may be associated with long term franchises. In such circumstances, appropriate incentives for the long term planning of and investment in train operations will be given by charging the train operator the avoidable cost of the capacity reserved for it, preferably as a fixed charge over the life of the agreement.

We consider there to be the following stages in determining avoidable cost:

1. Define service groups - these should relate to the organisational structure of the railway system. For example, in the British study the service groups were individual train operating companies;
2. Define the cost base to apply the analysis to – this should be broad enough to capture any future renewals savings from discontinuing provision of some infrastructure and of a sufficiently long time horizon since cost savings will be differ from year to year (for example because of lumpy renewals)
3. Determination of what metrics drive each element of cost;
4. Determination of the proportion of each cost category that is variable with each metric;
5. Determination of how each metric changes with the removal of each service group;
6. Compute the difference in net present value terms of the cost saving from removing the service relative to the base scenario

By metric we mean a measure which determines the level of a cost category. For example signalling renewal costs will be partly determined by the number of signalling units on a particular section of the network, since there are obviously less signalling units to renew should some be removed following removal of a service group.

The above modelling approach has many stages, some of which require analysis at very detailed geographic levels, could involve many separate models and these could possibly rely heavily on judgement. To an extent the business planning models developed by infrastructure managers should be able to inform these stages. These include the Infrastructure Cost Model developed by Network Rail which relates asset and traffic databases to profiles of future costs through application of maintenance and renewal policy rules.

As part of the 2005 Structures of Costs and Charges Review, the Office of Rail Regulation commissioned AEA Technology to undertake a study on avoidable cost for the Great British rail network. They specified that they wanted the service groups to be the franchised train operating companies (TOCs) that comprise the core passenger network in Great Britain. ORR was interested in whether the pre-existing formula to allocate fixed charges between TOCs could be reformed to be more cost reflective.

The study identified the following metrics as drivers of each cost element:

- Route-km
- Track-km
- Equated track-km – a measure of track-km standardised to reflect differences in infrastructure characteristics and traffic characteristics
- Signalling Equivalent Units (SEUs) – a measure of the number of signalling elements present weighted by complexity
- Train-km
- Electrified track-km
- Electrified train-km

This choice of metrics was motivated both from the perspective of being true cost drivers but also, from a practical perspective, their availability for the study.

For each cost element a proportion variability with respect to each metric was identified. The sum of the variability proportions across all metrics for each cost category was not necessarily equal to 100% since there was allowance for a degree of non variable costs for some expenditure elements.

An example is track maintenance which is assumed 100% variable with equated track-km. Track renewal was broken down into two parts: switches and crossing (S&C) renewal (assumed 100% variable with S&C track-km) and plain line renewal (assumed 100% variable with plain line track-km. For other elements of cost, there was little evidence produced to support the allocation of proportions to metrics and so this relied heavily on judgement. However this is not a limitation of the methodology, but rather the limited scope of this specific study.

Following allocating metrics to each cost category, it was then necessary to determine how each metric changed following removal of each TOC. For some metrics this could be done precisely. For example, for train-km, electrified train-km and tonne-km, this was determined with reference to a traffic database. However for other metrics determination utilised simple statistical models or judgement. For example the quantity of switches and crossings (S&C) was modelled through a statistical analysis of S&C density against the average number of running lines and train density. There are many other possible variables (such as measures of traffic mix) which could improve such modelling. The change in SEUs was also determined by an estimated statistical relationship. The equated plain line track km, equated train-km, equated train-km, track km, electrified track km were determined by professional judgement.

It was found that approximately 70% of total costs can be allocated to TOCs via the avoidable cost principle. For charging purposes it would be necessary to reduce this charge for each TOC by the amount of variable access charges that the TOC is expected to pay in a given year. The remaining 30% of cost not allocated to specific train operators could either be paid directly to the infrastructure manager via a lump sum subsidy or recovered from operators using some kind of Ramsey rule. If the latter approach is adopted there should be clear distinction between what elements of the charge are variable (short run marginal cost) access charges, which are the remaining avoidable cost charge and which are the contribution to the remainder. This is to avoid blurring of the otherwise clear information to funders.

This case study has demonstrated a method of allocating a substantial proportion of the fixed costs of rail infrastructure to individual train in a transparent and efficient way. These costs are the long run avoidable costs which would be saved if the services of this operator did not exist. It is not appropriate to add these costs to the charges for actual train km run, as this would give incentives to make less than optimal use of the existing infrastructure. Rather these costs, over and above those covered by short run marginal cost pricing, are best levied as a fixed charge, set when a long run framework agreement assuring the operator a certain amount of capacity is agreed, and modified when that framework agreement is renegotiated. The result is to provide valuable information to influence the long run planning of and investment in the train service, by the train operator or – in the case of subsidised services – the funding authority.

We have shown from examination of a British case study that the approach is feasible, although as currently applied it rests heavily on many assumptions and professional judgement. There is therefore a need for more research to examine the relationship between the train service provided and the assets required, and the cost implications of changes in those assets.

6.5 Summary

In this chapter we have presented evidence on appropriate ways of charging for rail infrastructure capacity. Firstly we have shown that it is possible to calculate the opportunity cost of taking slots away from the dominant operator to reallocate them to other operators, in terms of lost net revenue, user benefits and external benefits. Moreover in the case study we examined this opportunity cost followed a reasonably systematic pattern by time of day, with high values in the peak, moderate values in the shoulder of the peak and low values off peak, which could readily be turned into a set of reservation charges by time of day. Of course, operators who consume more than one slot because their train runs at a different speed to the dominant speed on the route in question should pay accordingly. We go on to show how this issue is dealt with in the current Italian structure of charges, in that there is a surcharge for trains which differ substantially from the most efficient speed for the route in question, with a bigger surcharge the more the speed disparity.

Reservation charges for individual slots are an appropriate way of reflecting the opportunity costs of particular slots to train operators when they are planning their timetable. But they do not reflect the longer term cost of providing capacity in order to satisfy the right to capacity granted in long term framework agreements between train operators and infrastructure managers and required to fulfil long term franchise conditions. Giving appropriate incentives for the long term planning of and investment in rail services requires the avoidable cost of this capacity to be reflected in a fixed charge to the train operator. The methodology for calculating such avoidable costs is demonstrated in the final section of this chapter, which shows it is a complex task but in principle feasible. Further research on estimating the relationships between services run assets required and the costs of maintaining and renewing them is needed.

On most routes throughout Europe it is possible to identify a dominant operator and type of service, and to estimate the opportunity cost of slots as the cost of taking a slot from that operator, although the regulatory authority will not always have as good data as in Britain, where it has access to detailed traffic, revenue and cost data. In the absence of such data, continued consideration should be given to the role of auctioning slots as a way of revealing their value to the train operator. Similarly many countries use long term framework agreements on infrastructure access, as provided for under Directive 200/14, and such an approach makes good sense where operators are investing in assets or the development of services and want reassurance that they will be able to reap the rewards of their investment. Such agreements are particularly relevant where services are franchised for a period of a number of years, as is the case not just in Britain but also for subsidised services in Sweden, and increasingly in Germany, Netherlands and Denmark. We believe it important that franchising authorities should be faced not just with the short run marginal cost of the services they actually operate but also the fixed cost of the capacity they require long term under the franchise agreement. Thus we recommend the use of two part tariffs, with the fixed charge based on avoidable costs, in such cases.

7 Recommendations

7.1 Introduction

In this section we draw recommendations from the research that we has been undertaken with Work Package 5. Overall we consider three themes of recommendations. First what have we learnt about infrastructure wear and tear marginal cost and how can our results be applied to countries who have not undertaken dedicated marginal cost studies but wish to determine marginal cost for their networks? Second, what recommendations on methodological best practice on how to undertake infrastructure wear and tear marginal cost studies can be made? Related to this is what are the outstanding research issues associated with undertaking infrastructure wear and tear marginal cost studies? Thirdly, what are the recommendations from our study of allocating capacity costs to services?

Section 7.2 presents recommendations for how our results can be applied to countries that have not undertaken dedicated marginal cost studies but wish to determine marginal cost for their networks. Within this section we present a series of elasticity estimates that can be used by countries to compute marginal costs at different geographical disaggregations. Section 7.3 presents our methodological best practice recommendations and Section 7.4 outlines the further research issues. Finally Section 7.5 outlines recommendations and future research needs on allocating capacity costs to services.

7.2 Generalising the wear and tear marginal cost research

The infrastructure wear and tear marginal cost research undertaken in CATRIN has applied new methods and provided new evidence on marginal costs for the case study countries. In this section we outline how these results can be best applied to countries who wish to determine marginal costs in their network but who have not undertaken a country specific marginal cost case study.

7.2.1 Generalisation framework

A key finding of our research is that even when evaluated at country specific mean network measure, marginal costs vary considerably between countries. Also marginal costs vary considerably within countries. These differences are driven by many factors such as infrastructure quality and traffic density. As such it is difficult to generalise our results on marginal cost. Instead we note the relationship:

Marginal cost = (Average cost) x (Usage elasticity)

Inspection of the underlying data of the first component of marginal cost, average cost, reveals that average cost is very variable both between and within case study countries. This is intuitive as we would expect average cost to be impacted strongly by the infrastructure quality and traffic density differences across countries.

However we estimate much less variation in the usage elasticities across countries and within countries. It is important to note that we have utilised sophisticated econometric models which potentially allow the usage elasticity variation to be considerable, however we do not find this in our modelling. Thus the models have found less variation in usage elasticities (relative to marginal costs) across countries as opposed to the model structure imposing such a finding.

As such we advocate recommending estimates of usage elasticities rather than specific marginal costs. These can then be multiplied by country specific average cost estimates to yield estimates of marginal cost. We do still find some variation in usage elasticities within countries, but there is a more systematic pattern which allows us to make recommendations for usage elasticities based on traffic density of the network.

Our research has clearly demonstrated that marginal costs differ considerably by traffic density and infrastructure quality. This supports charging different routes, each with different traffic density and infrastructure quality characteristics, within countries different marginal costs. This will be more cost reflective although there is the obvious trade-off between cost reflectiveness and complexity. Our proposed generalisation approach allows for this flexibility. This can be undertaken by the country simply providing average cost by route and choosing a suitable elasticity for each route from our research.

To summarise, we recommend generalisation as follows:

1. Country provides average cost either at the network wide level or for specific routes which have discernable traffic density and infrastructure quality characteristics;
2. The country should choose an appropriate usage elasticity for the network as a whole or for specific routes by reference to the traffic density the infrastructure in question;
3. For the network as a whole or for each specific route, the average cost and chosen usage elasticity should be multiplied together to give estimates of marginal cost.

Our recommendations on the values of usage elasticities are presented in section 7.2.2. There maybe instances where a country has available some specific analysis to inform the precise level of the elasticities in their country. In this case and providing that the analysis is robust, it may be better to use these country specific estimates. However, we consider that the estimates in 7.2.2 are generally robust and so there maybe cause for concern should any country specific estimates differ substantially from those presented in 7.2.2.

Before our recommended values are presented it should be noted that it is important that the definition of average cost covers the cost elements to which the recommended usage elasticites apply to. In particular for maintenance only cost average cost should include the following elements:

- Permanent way costs
- Signalling and telecoms costs
- Electrification and plant costs

Network wide overheads should be excluded. For renewals, our recommended elasticities are less precise given the limited number of studies available for consideration. However we recommend that the average cost for maintenance and renewal includes all the elements of maintenance cost described above and also includes as many elements of renewal costs except for network wide overheads[20].

7.2.2 Recommended usage elasticities

Table 7.1 outlines our recommended usage elasticities for maintenance costs. The elasticities are given by different traffic densities. We do not provide elasticities that vary with infrastructure quality since these differences tend to be relatively minor for the reasonable tonnage density levels considered in Table 7.1.

Table 7.1 Recommended usage elasticities by traffic density

Traffic density classification **Traffic density range (tonne-km / track-km per annum)**	**Low** **< 3,000,000**	**Medium** **3,000,000-10,000,000**	**High** **> 10,000,000**
Recommended Usage Elasticty	0.2	0.3	0.45

These values have been determined through comparison of the results of the six maintenance cost studies undertaken in CATRIN. We have made substantial progress in making the results comparable across countries and as such we have reasonable confidence that our recommended values are robust given the information available. There is still uncertainty associated with each recommend value and as such actual values maybe slightly different from those above (especially for the high traffic density value). What is important is that the usage elasticity is increasing with traffic density.

Whether a country adopts these recommended values depends on the amount of other information available. For instance if a robust study for the specific country has been undertaken, then it maybe best to take forward the elasticities from this as the basis for charging. In this case the recommended values presented in Table 7.1 should be seen as benchmark values. Should the results from country specific studies differ considerably from those in Table 7.1 then this should prompt further analysis/interrogation of the country specific study to understand why the country in question differs from the benchmark values. Care should also be taken that the usage elasticities from any country specific studies are comparable with those in Table 7.1 in terms of the elements of costs considered in the study vis-à-vis those considered in the CATRIN study (see section 7.2.1).

We do not provide elasticities by passenger and freight traffic since we have no clear evidence that passenger traffic is more or less damaging per gross tonne-km than freight traffic. The engineering study found that passenger did slightly more damage than freight and this was supported by the econometric studies, however there was little consensus in relative magnitudes of the marginal cost for the two traffic types with some of the econometric results looking unrealistic. Further the engineering research indicated that freight could feasibly be more damaging than passenger traffic depending on the exact vehicle mix. We also note that any difference in the usage elasticity for each traffic type depends not just on differences in relative damage but also the share of total traffic of each traffic type.

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[20] The reason for excluding network wide overheads is that these can not be non-arbitrarily allocated to track sections or zones. Since this data was not used to estimate our models and thus the resulting elasticities, these should not be included in either maintenance or renewal costs.

For renewals costs we have a limited number of studies which can help in determining this usage elasticity. Further we are unable to give specific values for the usage elasticity by different traffic density (and infrastructure quality combinations).

As such we recommend that if countries want to charge for maintenance costs and renewals, they compute separate marginal costs for maintenance and renewal component. For the maintenance component, a country would use the usage elasticities in Table 7.1 multiplied by the appropriate average cost to come up with measures of marginal cost for the whole network or for specific routes within the network. For the renewal component we recommend that the country compute a network wide renewal marginal cost calculated as renewal average cost multiplied by an elasticity of 0.35. However there is a large degree of uncertainty for this estimate, partly because of the small number of supporting studies that have looked at renewal costs but also because of the disparate range of their results. As such this should be seen as a starting value which maybe improved upon should any country specific evidence be available.

The value of 0.35 was determined by noting that models that have considered renewal costs they considered both maintenance and renewal costs together. The range of maintenance and renewal elasticities determined in section 4.5.4 was 0.28. For medium traffic density, the recommended maintenance usage elasticity is 0.3. Given that 0.3 is to the lower part of the range for the combined maintenance and renewal elasticity, 0.35 for the renewal component seems reasonable. To reiterate, we obviously have less confidence in this recommendation than those for maintenance only cost but this reflects the limited number of studies undertaken which consider renewals.

7.2.3 Differentiating charges by vehicle type

The engineering research clearly demonstrated that there are large differences between the damage on the infrastructure for some vehicle types even per gross tonne-km. Therefore costs would be better reflected by differentiating the charges by vehicle type. This could be undertaken in a number of ways. One way is to come up with a charge per vehicle-km for every vehicle using the network. The advantage is that there are clear incentives to operators to run less damaging vehicles and demand such vehicles from operators. However, this would require a lot of work since a bespoke engineering study would be needed to determine the relative damages of the specific vehicles on the track.

If this approach was desired, the results econometric from CATRIN could be used to determine the actual amount of cost variable with traffic possibly differentiated by routes[21], while a bespoke engineering model could then allocate this variable cost to vehicles. Thus the econometric results from CATRIN can be used but bespoke engineering models have to be developed separately.

A less resource intensive and complex method of differentiating charges is to adopt a bonus/minus system where the most damaging vehicles pay a higher charge per gross tonne-km and the least damaging vehicles pay a lower charge. All other vehicles pay a medium charge per gross tonne-km. This is likely to be less resource intensive as the engineering models only needs to identify the group of vehicles that are most and least damaging, rather than the exact relative damage of each vehicle.

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[21] Computed as an appropriate usage elasticity from section 7.2.2 multiplied by the relevant total cost

7.3 Recommendations on methodological best practice

In CATRIN we have introduced several methodological innovations over and above what was implemented in the GRACE project. These include the:

- Wide use of the flexible Box-Cox model;
- Analysis of the composition of costs in each country to aid comparison of results across countries;
- Harmonisation of method;
- Use of simulation to plot marginal cost and usage elasticities with traffic density and infrastructure quality holding all other things equal;
- The use of engineering research to supplement econometric research

These innovations increase the flexibility of the models to explain costs or facilitate better comparisons across models and thus lead to more generalisable results. In doing this we have been able to address the outstanding research issues identified in CATRIN Deliverable 1. In particular we have:

- Developed clear recommendations on the range of elasticities to be applied in specific circumstances. Thus we now have a better understanding of why usage elastciities differ between countries;
- By decomposing marginal cost into average cost and the usage elasticity we can see the reasons for the large variation in marginal costs across countries and within countries. Average cost differs considerably between and within countries driven by differences in infrastructure quality and traffic density. Usage elasticities do differ by these factors but in a much more predictable manner;
- Unlike what we found in GRACE, usage elasticities seem to be increasing with traffic density, all other things equal. This has been found when adopting the more flexible Box-Cox models. Thus marginal costs do not necessarily fall indefinitely with traffic density;
- The engineering case study has demonstrated clear differences in the damage per gross tonne-km for different vehicle types for the track sections considered. We have also had more success in incorporating passenger and freight measures into our econometrics. Although for both these innovations it is difficult to generalise much from the specific results given that these results will be affected by the network maintenance policy, exact traffic composition and track characteristics;
- In drawing conclusions from and comparisons across models we have controlled for infrastructure variables which has aided our understanding of the underlying cost variation; and
- We have provided new evidence on renewal marginal costs for Switzerland and Great Britain.

As a result of this we are able to make a number of recommendations on methodological best practice. For econometric studies:

1. Functional form – We note that our use of the Box-Cox functional form has resulted in consensus that the usage elasticity is generally rising with traffic density. We consider this to be a sensible result. We also note that the Box-Cox model nests a double log model and this was rejected in the majority of studies. Thus there are compelling reasons to continue to consider the use of Box-Cox models in this research. However

we do note that we are at present not able to adopt panel data techniques (in particular random effects) when using this functional form using commonly available software. This is a draw back of our implementation of the Box-Cox functional form and one that should caution about rejecting a double-log model. As such until such issues are resolved, both functional forms should be taken forward;

2. To understand variation in both usage elasticities and marginal costs practitioners should calculate marginal costs and elasticities holding traffic and infrastructure quality at defined levels. This also aids comparisons between models;
3. To compare results across models it is necessary to understand the composition of cost variables used in each study. Ideally each study would have the same definition of cost. However if this is not possible, scaling the resulting elasticities by the proportion of cost considered in each study is a useful ex post normalisation provided the assumption that none of the excluded cost is variable with traffic is reasonable. This is likely to be more reasonable for maintenance cost than renewal.
4. Regarding a summary measure of marginal cost, computing marginal cost as an average of the estimated values for all observations weighted by tonne-km is useful for the individual country as this average marginal cost if charged to all tonne-km raises the same revenue, all other things equal, as charging each track section or zone its estimated marginal cost. However importing a value of such a measure from one country to another is dangerous as this measure can vary substaintially across countries;
5. Regarding a summary measure of the usage elasticity, if the purpose of the comparison is to compare results across studies and then possibly to form recommendations on generalisable usage elasticities, we do not recommend using an average of all observations weighted by tonne-km. This is because this measure weights heavily the observations with high tonnage density which are estimated least precisely and depending on the number of these observations, may have a large impact on the result. Instead we recommend comparing usage elasticities computed at the sample mean of all variables or the median usage elasticity and comparing usage elasticities evaluated at specific traffic density and infrastructure quality combinations. This gives a much richer set of comparisons than simply one statistic.

The engineering study has found strong differences in damage between different vehicle types even per gross tonne-km. The emerging engineering best practice is the primariliy the need to consider both the infrastructure characteristics and quality in the modelling as well as the vehicle characteristics It would clearly be beneficial to encourage a charging regime which favoured less damaging vehicles and this would in turn drive vehicle design in a more track friendly direction.

7.4 Further infrastructure wear and tear marginal cost research issues

In this deliverable we have made a large step forward in our understanding of how marginal costs vary across and within countries. Part of the success has been that we have undertaken a coordinated approach in statistical method, understanding the data and post processing of the model results. A further success factor has been the involvement of engineering experience and research in the project. This has helped us to evaluate the results of the econometrics and provide new evidence on the relative differences in damage of different vehicle types.

We consider that the outstanding research issues for the econometric models are:

1. The need to incorporate panel data techniques into models which use the Box-Cox functional form. This is potentially very important as the Box-Cox model seems to explain the data better than the equivalent double-log model, however we are currently unable to use panel data techniques to control for unobserved heterogeneity in these models;
2. Both pooling and country specific modelling approaches should be taken forward within future research. There are both relative advantages and disadvantages of each approach and both yield interesting insights into the differences in marginal costs across countries;
3. The pooling approach can be best developed through:
    a. Incorporation of more infrastructure variables;
    b. Incorporation of more years of data;
    c. Further harmonisation of data definitions (particularly cost definitions)
4. To continue to develop further measures of usage elasticities and marginal cost which better harmonise for the actual quality of the infrastructure. This could involve specification of actual levels of each infrastructure quality variable for each study which is comparable with the levels used in all other studies, as opposed to defining them relative to sample reference points as adopted in this project. This is an onerous task but with suitable engineering advice may be achievable. Harmonising the infrastructure quality variables available for use in each study would obviously help this process.
5. Even when we control for infrastructure quality, we still find that track sections with low tonnage density have very high estimates of marginal cost. This could be because the models do not predict the marginal cost levels very precisely for these extreme observations, however this should be investigated further. In particular it would be useful to compute confidence intervals/prediction intervals for these observations/predictions.
6. Need to better model renewals costs. In particular longer panel datasets need to be collected to allow analysts to ‘smooth out’ lumpy renewals and possibly adopt dynamic modelling techniques. Andersson (2006) has attempted incorporation of dynamics into models with some success, however was limited by the length of his panel. Further the further use of survival analysis should be considered. However both techniques require a long time series of data.
7. The quality and comparability of data across countries is critical for making valid comparisons and recommendations. Great effort has been taken to control for as many factors as possible in this research however we suspect that datasets are still not totally consistent between countries. This is partly because datasets are generally collected for purposes other than for econometric analysis. It would be better if the EC could urge member states to be more forthcoming with respect to data collection for future research purposes. There is a need to understand the composition of costs better and in particular eliminate any arbiter allocation of costs to observations as this can distort estimated results.

We consider that the primary outstanding research issue for the engineering analysis is to find ways to be able to better generalise the results of specific case studies. In CATRIN we only undertook case studies for two track sections in Sweden and it is not clear how transferable the results are to other track sections both within and outside Sweden. Therefore there is clearly the need to undertake more case studies across various countries.

To undertake a case study requires detailed information on traffic composition and characteristics as well as infrastructure characteristic data. They also take a long time to numerically compute and the results can be sensitive to fairly subtle differences in traffic and infrastructure composition. As such once a reasonably large number of case studies have been undertaken we could undertake statistical analysis on the outputs, relating damage to a simple set of variables describing traffic and infrastructure characteristics. This may provide a suitably simply means of generalisation of the engineering results.

7.5 Recommendations on allocation of capacity costs

Wherever capacity is scarce, there is a strong argument for charging reservation fees to reflect the opportunity cost of slots, in terms of net revenue, unpriced user benefits and net external benefits. Ideally this would represent the net benefit of the second best use of the slot, which can only be known when all possible uses have been examined and the optimum determined. This is hardly practical as a way of setting tariffs when future demand for slots may come from unknown new entrants. More practical is setting a tariff according to the opportunity cost of the slot to the existing dominant operator. This is particularly the case when, as is the case on almost all routes in Britain, the dominant operator is a franchised passenger operator, with long term franchise and access agreements and for which detailed information on costs and demand is available to the franchising authority and the regulator. In other circumstances calculation of the charge will be more rough and ready, but – as long as care is taken not to set the charge so high as to lead to capacity being left unused – introduction of such a charge, reflecting the opportunity cost of taking slots away from the dominant operator, is likely to have a socially beneficial effect on timetable planning and the use of scarce capacity. An example derived from Britain illustrates how a relatively simple pattern of peak and off peak charges per slot may be derived, whilst Italian practice illustrates how a weighting may be applied to reflect the fact that trains travelling at a speed different from the optimal for the route in question consume more capacity than a single train of the dominant type.

However, such charges do not directly reflect the cost of the capacity provided under long term framework agreements which entitle the operator, or their customer, to a certain amount of capacity in the long run. In this case the long run avoidable cost of the capacity in question should be reflected in a fixed charge to the customer concerned. Where open access competition exists, such a fixed charge might be problematic in terms of affecting the terms of competition between the incumbent and new entrants. But in the case of a monopoly franchise there is no such complication. Such a charge would be particularly relevant where a regional authority is responsible for franchising passenger services, whilst the national government subsidises infrastructure in general. Without such a charge, the regional authority has no reason to consider the costs of providing capacity when setting out its long term plans for the services in question.

Both the above developments in track access charging would increase the revenue of the infrastructure manager, reducing the burden on national taxpayers and easing the financial problems that infrastructure managers have when funding from the state is inadequate for its needs.

On most routes throughout Europe it is possible to identify a dominant operator and type of service, and to estimate the opportunity cost of slots as the cost of taking a slot from that operator, although the regulatory authority will not always have as good data as in Britain, where it has access to detailed traffic, revenue and cost data. In the absence of such data, continued consideration should be given to the role of auctioning slots as a way of revealing their value to train operators. Similarly many countries use long term framework agreements on infrastructure access, as provided for under Directive 200/14, and such an approach makes good sense where operators are investing in assets or the development of services and want reassurance that they will be able to reap the rewards of their investment. Such agreements are particularly relevant where services are franchised for a period of a number of years, as is the case not just in Britain but also for subsidised services in Sweden, and increasingly in Germany, Netherlands and Denmark. We believe it important that franchising authorities should be faced not just with the short run marginal cost of the services they actually operate but also the fixed cost of the capacity they require long term under the franchise agreement. Thus we recommend the use of two part tariffs, with the fixed charge based on avoidable costs, in such cases.

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Annexes

SIXTH FRAMEWORK PROGRAMME
PRIORITY 1.6.2
Sustainable Surface Transport

CATRIN

Cost Allocation of TRansport INfrastructure cost

D8 – Rail Cost Allocation for Europe

Annex 1A – Marginal Cost of Railway Infrastructure Wear and Tear for Freight and Passenger Trains in Sweden

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Mats Andersson (VTI)

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Project summary

CATRIN is a Research project to support the European Transport Policy, specifically to assist in the Implementation of Transport pricing. CATRIN will increase the probability that new progressive pricing principles can be implemented which facilitate a move towards sustainable transport. CATRIN is both intermodal and interdisciplinary, emphasize the need of new Member states, understands that different organisational forms require different recommendations, that recommendations need to be given in short and long-term perspective and that they have to be thoroughly discussed with infrastructure managers.

CATRIN will clarify the current position on allocation of infrastructure cost in all modes of transport. Pricing principles will be dealt with under the knowledge that they varies with the organisational structure of a sector. CATRIN will establish the micro-aspects of cost recover above marginal costs, including the results of applying a club approach and the implication of who bears the costs for cost recovery under alternative allocation rules, using game theoretic analytical tools.

CATRIN will develop the understanding of policy need of new Member states and can give tailored recommendations. In a modal focus, with real world cases, CATRIN will develop proxies to marginal costs and test some of the allocation approaches. Based on engineering studies CATRIN will analyse the possibility to defining more differentiated pricing rules for vehicle/locomotive categories. Partners with strong engineering knowledge are included and CATRIN will blend the economic principles of pricing with engineering knowledge. CATRIN will outline the possibilities for a European Road Damage test that will give new evidences on the fourth-power-rule. CATRIN will develop financing alternatives for icebreaking and will explore cost allocation in the aviation sector. Finally, CATRIN will strongly address the implementation potential and constraints experienced by infrastructure managers.

Marginal cost of railway infrastructure wear and tear for freight and passenger trains in Sweden

Mats Andersson

VTI

Box 760

781 27 Borlänge

Sweden

Tel.: + 46 243 44 68 66; Fax: +46 243 736 71

E-mail address: mats.andersson@vti.se

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Abstract

We analyse maintenance cost data for Swedish railway infrastructure in relation to traffic volumes and other characteristics, and separate the cost impact from passenger and freight trains. Lines with mixed passenger and freight traffic, and dedicated freight lines are analysed separately using both log-linear and Box-Cox regression models. We find that for mixed lines, the Box-Cox specification is preferred, while a log-linear model is chosen in the case of dedicated freight lines. The cost elasticity with respect to output is found to be higher for passenger trains than for freight trains. From a marginal cost pricing perspective, freight trains are currently paying too much, while passenger trains should be charged more. An adjusted pricing scheme based on these results would still lead to higher revenues than today if total demand is unaffected.

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1 Introduction

There has been increasing European attention to the issue of marginal costs of railway infrastructure wear and tear in the last decade. European rail infrastructure administrations have great interest in these marginal cost estimates as they are an important corner-stone of the European transport pricing policy (European Parliament, 2001). The EU-project CATRIN (Cost Allocation of TRansport INfrastructure cost) supports the European Transport Policy, specifically to assist in the implementation of transport pricing for all modes of transport. Following the paper by Johansson and Nilsson (2004) on railway infrastructure maintenance costs, there is now research ongoing in several European countries (Lindberg, 2006).

The general approach is to do regression analysis on maintenance costs and control for infrastructure characteristics and traffic volumes. The majority of recent studies use an aggregate measure of output of the track, which is expressed in total gross tonnes of traffic consisting of both passenger and freight trains. Furthermore, log-linear models are dominating the research.

The Swedish Rail Administration (Banverket) is responsible for railway access charges in Sweden. The current charge for infrastructure wear and tear is SEK 0.0029 per gross tonne kilometre as a flat rate for all users (Banverket, 2008).[1] To increase efficiency in current pricing schemes, introducing differentiated track access charges has been discussed, based on wear and tear from different vehicle types. The hypothesis is that freight and passenger trains deteriorate the infrastructure differently, inducing different levels of cost and therefore should be priced accordingly. The reason for this position is that freight and passenger trains generate different forces on the railway track through differences in speeds, axle loads, suspensions etcetera as well as require different track quality levels. This issue has also received some attention in Sweden in a report on differentiated access charges by track engineers at the Royal Institute of Technology (KTH) and Banverket (Öberg et al., 2007).

Whether this standpoint can be supported by empirical, econometric work is yet to be revealed, but some preliminary work by Gaudry and Quinet (2003) indicates that there might be substantial differences in wear and tear, not only between freight and passenger trains, but

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[1] The exchange rate between Swedish Kronor (SEK) and Euro is 10.18 (PPP estimate from year 2001).

also within the group of passenger trains. Furthermore, they advocate in favour of the Box-Cox model as an alternative to previously used log-linear models. To be able to analyse the question of differentiation, the aggregate measure of traffic volume has to be abandoned in favour of a model where the different traffic categories are used as outputs.

In this paper, we analyse a four-year data set on Swedish railway maintenance costs in order to contribute to the analysis on differentiated marginal costs. The purpose is threefold. First, we are interested in separating gross tonnes for freight and passenger trains in order to see if cost elasticities and marginal costs are different for the two traffic categories. Second, the choice between logarithmic and Box-Cox transformation of the data will be analysed. Third, lines with a mixed passenger and freight traffic pattern will be separated from lines dedicated to freight traffic only to see if there are systematic differences in freight marginal costs between these track types.

The paper is structured as follows. A short overview of recent work is given in section 2 followed by a description of the data in section 3. Model specifications and results from the econometric analyses with marginal cost calculations are given in section 4 and 5 respectively. In section 6, we discuss our results and draw conclusions.

2 Literature review

The issue of estimating cost functions for railway organisations has a long history and can be found as early as the 1960’s (Borts, 1960). The focus of the early research was to check for inefficiencies in the U.S. railroad industry and to regulate monopoly prices in the presence of economies of scale (Keeler, 1974).

Recent European studies have a different perspective as they are looking at the cost structure in vertically separated rail infrastructure organisations to derive short run marginal costs. These studies have grown out of a sequel of research projects on transport infrastructure pricing funded by the European Commission, such as Pricing European Transport Systems (PETS) (Nash and Sansom, 2001), UNIfication of accounts and marginal costs for Transport Efficiency (UNITE) (Nash, 2003) and Generalisation of Research on Accounts and Cost Estimation (GRACE) (Nash et al., 2008).

The study that initiated most of the current work is Johansson and Nilsson (2004) who estimate rail infrastructure maintenance cost functions on data from Sweden and Finland from the mid 1990's. They apply a reduced form of the Translog specification suggested by Christensen et al. (1973) using total gross tonnes as output of the track, controlling for infrastructure characteristics, but excluding factor prices. The analysis builds on the assumption that costs are minimised for a given level of output. Cost elasticities and marginal costs are given as main results.

Railway infrastructure maintenance cost functions have since then been estimated in Austria (Munduch et al., 2002), Norway (Daljord, 2003), Finland (Tervonen and Idström, 2004), Switzerland (Marti and Neuenschwander, 2006), Sweden (Andersson, 2006, 2007a and 2008) and the UK (Wheat and Smith, 2008). All of these studies use log-linear model specifications and also an aggregate measure of output, i.e. total gross tonnes. Pooling annual data for several years is done in all cases, except for Andersson (2007a and 2008) who uses panel data techniques.

Considering the variation between the individual studies, the results have been reasonably similar in terms of cost elasticities with respect to output, when controlling for the cost base included (Wheat, 2007). There is evidence for the maintenance cost elasticity with respect to output of gross tonnes to be in the range of 0.2 - 0.3, i.e. a 10 percent change in output gives rise to a 2 - 3 percent change in maintenance costs. Marginal costs on the other hand vary between countries and are more difficult to compare.

The only alternative econometric approaches so far to the one suggested by Johansson and Nilsson (2004) are found in Gaudry and Quinet (2003) and Andersson (2007b). Gaudry and Quinet (2003) use a very large data set for French railways in 1999, and explore a variety of unrestricted generalised Box-Cox models to allocate maintenance costs to different traffic classes. They reject the Translog specification as being too restrictive on their data set, which indicates that a logarithmic transformation of the data is not as efficient as using a Box-Cox transformation. Andersson (2007b) uses survival analysis on rail renewal data to derive marginal costs.

3 The data

The available data set consists of some 185 track sections with traffic (freight and/or passenger) that we observe over the years 1999 - 2002. A track section is a part of the network, normally a link between two nodes or stations that varies in length and design. Each track section observation has information on annual maintenance costs (*ccm_tot*)[2], traffic volumes expressed as gross tonnes for freight (*fgt*) and passenger trains (*pgt*) as well as a range of infrastructure characteristics. These are track length (*bis_tsl*), track section length-to-distance ratio (*ld_ratio*), length of switches (*swit_tl*), average rail age (*rail_age*), average switch age (*swit_age*), number of joints (*joints*), average rail weight (*rlwgh*) and average quality class (*qc_ave*). Maintenance costs are derived from Banverket's financial system and cover all maintenance activities. Both corrective and preventive maintenance is included, but winter maintenance (snow clearing and de-icing) is excluded. Major renewals are also excluded, but it might include minor replacements considered as spot-maintenance. A description of the cost data is given in Appendix 1. Infrastructure characteristics are taken from the track information system at Banverket and traffic volumes from various Swedish train operating companies.

We have split the original data set into two parts. One part is tracks with mixed traffic and the other is tracks dedicated to freight trains only. The reason for this is the underlying idea behind the marginal cost calculation and differentiation. Tracks without any passenger traffic are significantly different from tracks with mixed traffic from an engineering point of view. This has to do with the alignment and design of the track to deal with different train types running at different speeds with different loads. A dedicated freight line can be aligned to minimise deterioration and cost from a freight train, while the alignment for a mixed line has to be a compromise between the needs for both freight and passenger trains. In a mixed situation, freight trains will normally run at lower speeds and weights than passenger trains leading to freight trains "hanging" on the inner rail in curves, while passenger trains will "push" towards the outer rail. The super-elevation (cant) of the track is therefore non-optimal for both. Introducing a marginal change in passenger traffic (running the first passenger train) on a dedicated freight line would therefore not give rise to a marginal change in costs, but rather a leap in costs to adjust the alignment to the mixed situation as well as covering the

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[2] Costs are expressed in Swedish kronor (SEK) and 2002 price level.

costs from the passenger train. Our position is that dedicated lines are better off to be analysed separately and these results will be presented alongside results of mixed lines.

The mixed line data set covers 648 observations, i.e. around 160 track sections over four years, and our dedicated freight line data set contains 101 observations (around 25 track sections).

Table 1. Descriptive statistics

Variable	**No. Obs.**	**MEAN**	**ST. DEV.**	**MIN.**	**MAX.**	+/-
Mixed lines						
ccm_tot	648	7,650,672.00	7,775,205.00	130,530.00	80,852,300.00	n.a.
fgt	648	5,349,595.00	8,007,622.00	6,426.95	85,571,500.00	+
pgt	648	3,096,828.00	5,116,585.00	74.72	46,913,700.00	+
bis_tsl	648	74,589.15	55,515.31	3,719.00	261,561.00	+
ld_ratio	648	1.92	1.50	1.00	11.01	-
swit_tl	648	1,855.96	1,785.92	58.03	14,404.70	+
rail_age	648	17.21	9.59	2.00	60.66	+
swit_age	648	17.63	8.64	1.00	45.25	+
joints	648	168.74	134.29	1.00	799.00	+
rlwgh	648	50.87	4.60	39.77	60.00	-
qc_ave	648	2.06	1.05	0.00	4.59	+
cost/track metre	648	115.49	84.05	5.89	667.47	n.a.
cost/gross tonne	648	2.92	5.99	0.01	73.27	n.a.
cost/gross tonne km	648	0.07	0.09	0.001	0.63	n.a.
Dedicated freight lines						
ccm_tot	101	3,027,278.00	3,636,412.00	54,394.60	24,491,800.00	n.a.
fgt	101	1,027,368.00	1,841,278.00	6,426.95	9,500,550.00	+
pgt	101	n.a.	n.a.	n.a.	n.a.	n.a.
bis_tsl	101	48,984.92	40,238.06	8,878.00	170,162.00	+
ld_ratio	101	1.16	0.34	1.01	2.81	-
swit_tl	101	609.09	411.23	66.46	1,694.19	+
rail_age	101	28.05	23.38	1.00	98.00	+
swit_age	101	26.41	12.22	5.00	67.66	+
joints	101	69.61	60.57	0.00	266.00	+
rlwgh	101	44.79	4.90	32.00	60.00	-
qc_ave	101	3.54	0.64	1.44	4.94	+
cost/track metre	101	63.70	76.92	1.23	656.72	n.a.
cost/gross tonne	101	7.89	11.03	0.18	88.26	n.a.
cost/gross tonne km	101	0.30	0.59	0.004	5.10	n.a.

A descriptive summary of the data sets is given in table 1 and there are some differences between the two data sets worth pointing out:

- Average annual spending on maintenance is close to 2.5 times higher on mixed lines.
- Average freight traffic density is 5 times higher on mixed lines.
- Track length is 1.5 times higher on mixed lines.
- There are 3 times more switches on mixed lines.
- Both switches and rails on dedicated freight lines are on average more than 10 years older than on mixed lines.

- Average track quality is much lower on dedicated freight lines.
- Maintenance costs per gross tonne are almost 3 times higher on dedicated freight lines.
- Maintenance costs per track metre are 2 times higher on mixed lines.

The +/- column indicates our a priori expectation about the relationship between each variable and maintenance costs. Hence, higher values of freight and passenger gross tonnes, track section length, switches, rail and switch age, joints and quality class[3] are expected to increase maintenance costs, other things equal. A higher length-to-distance ratio means easier access to the track and would lead to more efficient work schedules and reduced costs. Higher rail weight resists wear and tear and lead to less maintenance.

4 The econometric approach

We have pointed out above that knowledge of marginal costs is essential to European railway administrations. Among the available methods to estimate the marginal costs, we will use an econometric approach, i.e. an application of statistical methods to economic data. To estimate a cost function, we build on the duality between production and costs under the assumption that costs are minimised for a given level of output and input of factor prices.

We can describe the relationship between maintenance costs (C), a vector of outputs ($\mathbf{q}$) and a vector of factor prices ($\mathbf{p}$) as

$$C = f(\mathbf{q}, \mathbf{p})$$

For our analyses, we have reasons to believe that the spatial variation in factor prices, i.e. labour, energy and capital costs over the Swedish rail network is negligible. This idea was first suggested by Johansson and Nilsson (2004) with the argument that the Swedish labour market agreements are heavily regulated at a national level. Another reason is that the majority of the track work during these years is done in-house by the Production Division of Banverket. We will therefore exclude the factor price vector **p** in our estimated cost functions and proceed with the assumption of equal factor prices over the network.

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[3] Quality class ranges from 0 (high quality) to 5 (low quality) and can vary over a track section. This is important to note for interpreting results later in the paper.

However, output in terms of traffic volumes is not the only factor that can influence the variation in costs over a rail network. As output varies over the network, so do the technical characteristics of the track, climate and managerial skills, which need to be controlled for. Thus, we will assume that there is a relationship between costs for infrastructure maintenance (C), and the level of output ($\mathbf{q}$) given other characteristics of the infrastructure ($\mathbf{x}$) and dummy variables ($\mathbf{z}$);

$$C = f(\mathbf{q}, \mathbf{x}, \mathbf{z}).$$

A **log-linear regression model** in form of this relationship is given in expression (1), where i denote observations, t time, k, m and n are the number of output, infrastructure and dummy variables respectively in the model. α, β_k, δ_m and γ_n are parameters to be estimated. ε is the error term assumed NID (0, σ).

$$\ln C_{it} = \ln\alpha + \ln q_{kit}\beta_k + \ln x_{mit}\delta_m + z_{nit}\gamma_n + \varepsilon_{it} \tag{1}$$

The cost elasticity in the log-linear model is the derivative of the cost function with respect to the variable of interest. If the model does not include higher-order or interaction terms, the k elasticities for our output variables are expressed in general form as

$$\frac{\partial \ln C}{\partial \ln q_k} = \hat{\beta}_k = \hat{\phi}_k^{LL}. \tag{2}$$

These elasticities are constant over the range of output we analyse, but including higher order terms or interactions will lead to non-constant elasticities. Exact elasticity expressions will be given under the detailed specifications in the following chapter.

The log-linear model above imposes a restriction on our model as it assumes that the most efficient transformation of our data is logarithmic. An alternative to the logarithmic transformation is the **Box-Cox regression model**, making use of the formula for variable transformation by Box and Cox (Greene, 2003).

$$w^{(\lambda)} = \frac{w^{\lambda} - 1}{\lambda} \tag{3}$$

For λ to be defined for all values, w must be strictly positive. The direct benefit of using the Box-Cox transformation is that it includes the log transformation as a special case. Hence, if our data are log normal, the transformation parameter λ will be insignificant from zero. If not, the log transformation in model (1) will not be an efficient way of treating our data.

The econometric specification in general form, using a common transformation parameter for both the left and right hand side is given in (4)

$$C_{it}^{(\lambda)} = \alpha + q_{kit}^{(\lambda)}\beta_k + x_{mit}^{(\lambda)}\delta_m + z_{nit}\gamma_n + \varepsilon_{it} \,. \tag{4}$$

Output (q) and infrastructure (x) variables are transformed, while the constant, variables with genuine zeros and dummy variables (z) are left un-transformed. The elasticity in the Box-Cox model (4) also includes the estimated transformation parameter λ (Econometric Software, Inc., 2002) and the general expression is

$$\frac{\partial \ln C_{it}}{\partial \ln q_{kit}} = \hat{\beta}_k \left(\frac{q_{kit}}{C_{it}} \right)^{\lambda} = \hat{\phi}_{kit}^{B-C} \,. \tag{5}$$

Hence, the elasticity in a Box-Cox model will be non-constant and vary with output and cost level. For a derivation of the elasticity, see Appendix 2.

5 Econometric specifications and results

In this section, we present the econometric specifications and results, including elasticities and marginal costs calculations. We start by looking at a model for mixed lines followed by a dedicated freight line model. All estimations are done in *Stata 9* (StataCorp, 2005).

5.1 Mixed lines

As the Box-Cox model includes the log-linear model as a special case, we have initially estimated a Box-Cox regression model on all track sections with mixed traffic (648 observations). The model includes output of both freight (*fgt*) and passenger (*pgt*) gross tonnes per annum. Apart from that, we control for length-distance ratio (*ld_ratio*), track section length (*bis_tsl*), switches (*swit_tl*), rail age (*rail_age*) and switch age (*swit_age*). These are all transformed variables. Non-transformed variables are joints (*joints*), average quality class (*qc_ave*) and dummy variables for 3 *years*, 15 *track districts* and *stations*. The model specification is given below (6) and the estimated model in table 2 (dummy variables excluded).

$$\begin{aligned}C_{it}^{(\lambda)} &= \alpha + \beta_1 fgt_{it}^{(\lambda)} + \beta_2 pgt_{it}^{(\lambda)} + \beta_3 ld\_ratio_{it}^{(\lambda)} + \beta_4 bis\_tsl_{it}^{(\lambda)} + \\ &\beta_5 swit\_tl_{it}^{(\lambda)} + \beta_6 rail\_age_{it}^{(\lambda)} + \beta_7 swit\_age_{it}^{(\lambda)} + \beta_8 qc\_ave_{it} + \\ &\beta_9 joints_{it} + \sum_{n=1}^{3} \gamma_n year_{it} + \sum_{m=1}^{15} \eta_m district_{it} + \omega_1 station_{it} + \varepsilon_{it}\end{aligned} \tag{6}$$

Table 2. Box-Cox regression model estimates – Mixed lines

```
Box-Cox Regression                                Number of obs   =        648
                                                  LR chi2(28)     =    1095.67
Log likelihood = -10326.475                       Prob > chi2     =      0.000

------------------------------------------------------------------------------
     ccm_tot |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     /lambda |   .1694008   .0209993     8.07   0.000     .1282429    .2105587
------------------------------------------------------------------------------

Estimates of scale-variant parameters
-------------------------------------------------------------
             |      Coef.  chi2(df)  P>chi2(df)    df of chi2
-------------+-----------------------------------------------
Notrans      |
      qc_ave |   1.237109    10.875    0.001            1
      joints |   .0081398     7.742    0.005            1
       _cons |  -10.45406
-------------+-----------------------------------------------
Trans        |
         fgt |    .059676    14.466   0.000             1
         pgt |   .2235988    94.018   0.000             1
    ld_ratio |  -4.468812    32.894   0.000             1
     bis_tsl |   1.400582   178.966   0.000             1
     swit_tl |   .8810679    36.992   0.000             1
    rail_age |   .8363738     8.817   0.003             1
    swit_age |   1.970124    30.454   0.000             1
-------------+-----------------------------------------------
      /sigma |   5.301378
-------------------------------------------------------------

   Test         Restricted     LR statistic      P-Value
    H0:       log likelihood       chi2       Prob > chi2
---------------------------------------------------------
lambda = -1     -11465.836      2278.72           0.000
lambda =  0     -10360.243        67.54           0.000
lambda =  1     -10807.235       961.52           0.000
```

All coefficients are significant at the 1 percent level (except some of the track district dummy variables). Our a priori expectations of the signs of these variables are given in table 1, section 3 and all estimated coefficients fulfil expectations. There are positive relationships between maintenance costs and output levels, track section length, switches, rail and switch age, joints, quality class and station areas. Conversely, costs are negatively related to the length-distance ratio. These findings are in line with what has previously been found in Andersson (2006).

The estimate of λ, the transformation parameter, is 0.17 and significantly different from zero at the 1 percent level. Hence, we reject the logarithmic transformation of our dependent and transformed independent variables.

Table 3 summarises the estimated Box-Cox elasticities, evaluated at the sample means for output and maintenance costs using expression (5). Standard errors are adjusted using a cluster indicator for track sections, i.e. independence is assumed between track sections, but not within. A challenging result is that the mean cost elasticity with respect to passenger traffic volumes is more than three times higher than the equivalent elasticity for freight. The confidence intervals are not overlapping, indicating a significant difference at the 5 percent level. In other words, passenger trains seem to drive maintenance costs more than freight trains, which is not in accordance with conventional wisdom among track engineers. Ceteris paribus, a freight train is considered to do more damage to the track than a passenger train (Öberg et al., 2007).

Table 3. Cost elasticities – Box-Cox

Elasticity	**Observations**	**Mean**	**Std. Error***	**[95% Conf. Interval]**	
Freight	648	0.052264	0.001134	0.050026	0.054503
Passenger	648	0.179364	0.003643	0.172443	0.186285

* Cluster adjusted

Figures 1 and 2 contain plots of elasticities from the Box-Cox model. We find increasing elasticities with output, but at a decreasing rate (figures 1 and 2). This shape has also been found in previous work by Andersson (2007a) on Swedish railway maintenance costs and by Link (2006) on German motorway renewal costs.

The estimated elasticities from specification (6) give us reason to reconsider our model and also consider interaction variables, variables that will capture the joint effect from two variables. Introducing interaction variables though, has no significant impact on the results in table 2 and 3.

Figure 1. Cost elasticity w r t freight volumes – Box-Cox

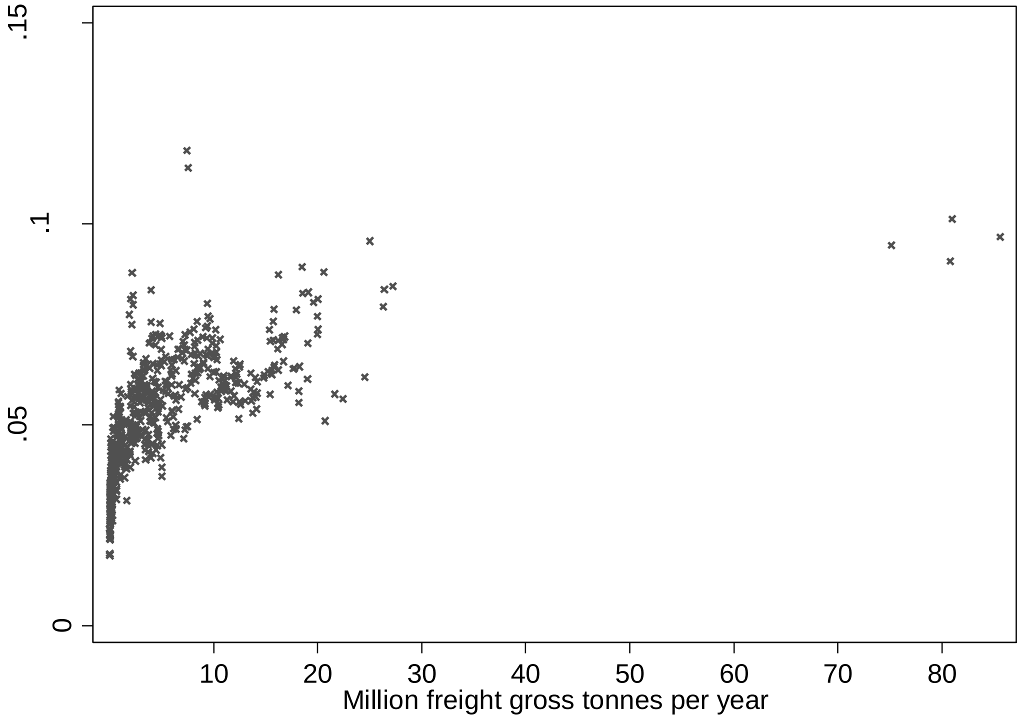
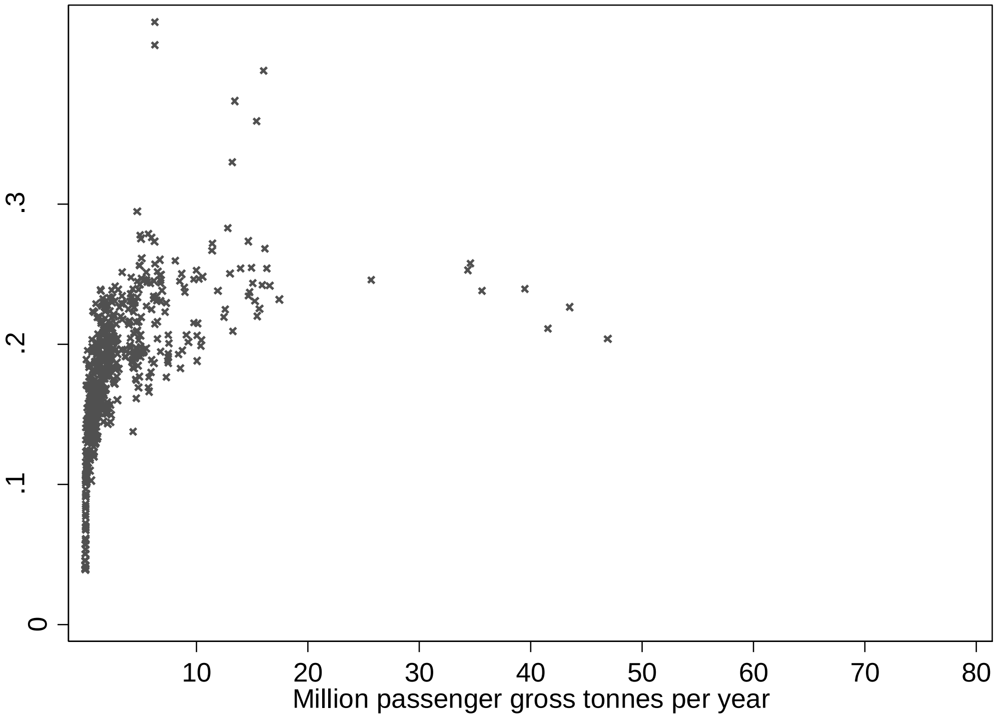


Figure 2. Cost elasticity w r t passenger volumes – Box-Cox



5.2 Dedicated freight lines

In line with the analysis of mixed lines, we have initially estimated a Box-Cox model, but the likelihood ratio test has not rejected the transformation parameter λ being zero. We therefore specify a log-linear model for dedicated freight lines. This model is built on 101 observations and some of the variables used for mixed lines are excluded. Switches, age variables, quality class and joints have proven insignificant, but we use rail weight (*lnrlwgh*) as a quality proxy instead. We also include a squared term for output to capture a non-linear relationship. The final model specification is given in (7).

$$\begin{aligned}&\ln C_{it} = \alpha + \beta_1 \ln fgt_{it} + \beta_2 (\ln fgt)^2_{it} + \beta_3 \ln ld\_ratio_{it} + \\ &\beta_4 \ln bis\_tsl_{it} + \beta_1 \ln rlwgh_{it} + \beta_2 (\ln rlwgh)^2_{it} + \sum_{n=1}^{3} \gamma_n year_{it} + \varepsilon_{it}\end{aligned} \tag{7}$$

The estimated model is given in table 4 (dummy variables excluded). The signs of the coefficients are in line with our a priori expectations except for length-to-distance ratio, which is now positive. This indicates that costs increase rather than decrease with more meeting points and double tracks.

Table 4. Log-linear regression model estimates – Dedicated freight lines

```
Linear regression                                      Number of obs =     101
                                                       F(  9,    91) =   52.26
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.8112
                                                       Root MSE      =  .56534

------------------------------------------------------------------------------
             |               Robust
        lncm |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       lnfgt |   1.919855   .6047601     3.17   0.002       .718573    3.121136
      lnfgt2 |  -.0580122   .0237509    -2.44   0.017     -.1051905    -.010834
     lnldrat |    1.07993   .1948566     5.54   0.000      .6928717    1.466989
       lntsl |   .7595336   .0851649     8.92   0.000      .5903641    .9287031
     lnrlwgh |   41.21475   19.12571     2.15   0.034      3.223882    79.20561
    lnrlwgh2 |  -5.527185   2.539759    -2.18   0.032      -10.5721   -.4822659
       _cons |  -85.22377   34.40323    -2.48   0.015     -153.5616   -16.88598
```

Table 5 summarises the estimated cost elasticity, evaluated at the output mean using expression (8).

$$\frac{\partial \ln C}{\partial \ln fgt} = \hat{\beta}_{\ln fgt} + 2 \cdot \hat{\beta}_{(\ln fgt)^2} \cdot mean(\ln fgt) = \hat{\phi}^{LL} . \tag{8}$$

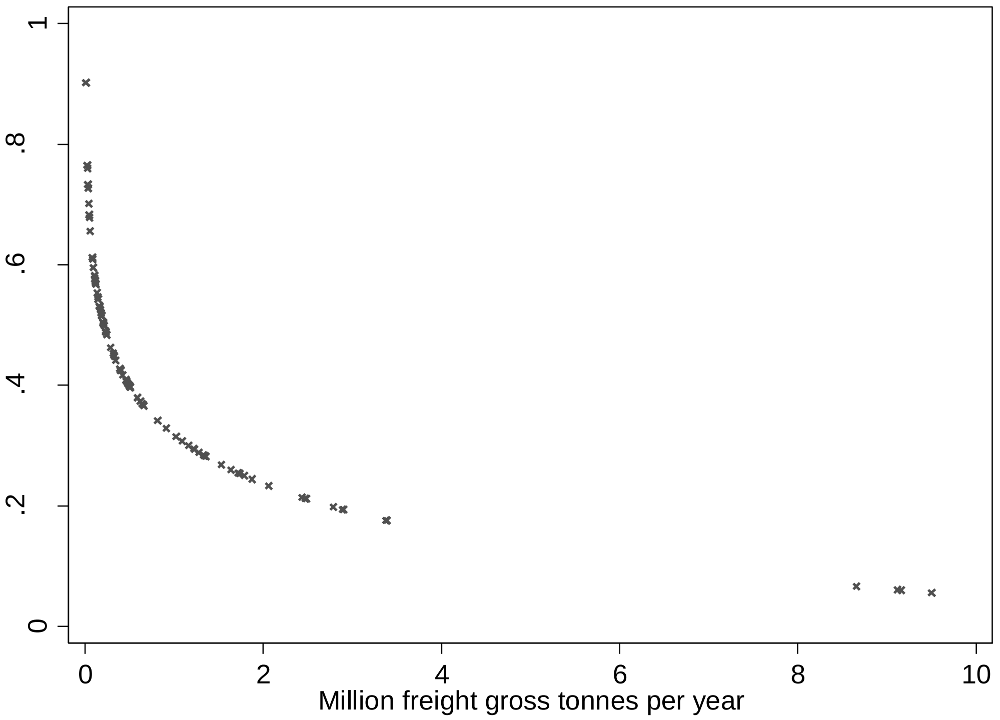
Table 5. Cost elasticity – Dedicated freight lines

Elasticity	**Observations**	**Mean**	**Std. Error***	**[95% Conf. Interval]**	
Freight	101	0.435141	0.036208	0.361194	0.509088

* Cluster adjusted

The estimate is substantially higher than the freight elasticity in the Box-Cox model. Figure 3 gives a plot of the elasticity function and it is downward sloping as opposed to upward for the mixed line elasticities.

Figure 3. Cost elasticity w r t freight volumes – Dedicated freight lines



5.3 Average and marginal cost estimates

The elasticities derived in sections 5.1 and 5.2 are important inputs in the calculation of marginal costs. The cost elasticities of output are expressed per gross tonne (q), but from a pricing perspective, we also prefer the marginal cost to be distance related and expressed in terms of gross tonne kilometres (q^{gtk}). Following Johansson and Nilsson (2004), for output k we express the marginal maintenance cost (9) as

$$MC_k = \frac{\partial C}{\partial q_k^{gtk}} = \frac{\partial \ln C}{\partial \ln q_k^{gtk}} \cdot \frac{C}{q_k^{gtk}} = \frac{\partial \ln C}{\partial \ln q_k} \cdot \frac{C}{q_k^{gtk}} = \phi_{it} \cdot \frac{C}{q_k^{gtk}} . \tag{9}$$

Marginal cost is the product of the cost elasticity ϕ and average cost. By this, we assume that the cost is unaffected by line length at the margin. Estimates of track section marginal costs can be derived by using the output (k) specific elasticity estimates and predicted costs as in (10)

$$MC_{kit}^{j} = \hat{\phi}_{kit}^{j} \cdot \frac{\hat{C}_{it}^{j}}{q_{kit}^{gtk}} , \tag{10}$$

where j indicates mixed or dedicated lines. The calculated marginal costs from (10) are observation specific. In order to adjust for the variation of marginal costs over track sections, we can calculate a weighted average marginal cost. We use the output of each traffic category as a track section weight in relation to total output per category. Estimates of marginal costs from track sections with high traffic levels are given a higher weight than marginal costs from track sections with less traffic.

$$WMC_k^j = \sum_{kit} \left[MC_{kit}^{j} \cdot \frac{q_{kit}^{km}}{\sum_{kit} q_{kit}^{km}} \right] \tag{11}$$

This allows the infrastructure manager to use a unit rate for wear-and-tear over the network, and still be revenue neutral to using track section specific marginal costs.

Table 6. Average costs

Average cost	Observations	Mean	Std. Error*	[95% Conf. Interval]	
Mixed freight	648	0.682289	0.269658	0.150024	1.214554
Mixed passenger	648	5.609661	2.011954	1.638362	9.580960
Dedicated freight	101	0.224562	0.035756	0.151540	0.297585

* Cluster adjusted

The predicted average maintenance cost (AC) is given in table 6. AC is defined as predicted maintenance cost divided by the output specific gross tonne kilometres. The average maintenance cost per gross tonne km for mixed lines is approximately SEK 0.68 for freight and SEK 5.60 for passenger, while for dedicated lines it is SEK 0.22.

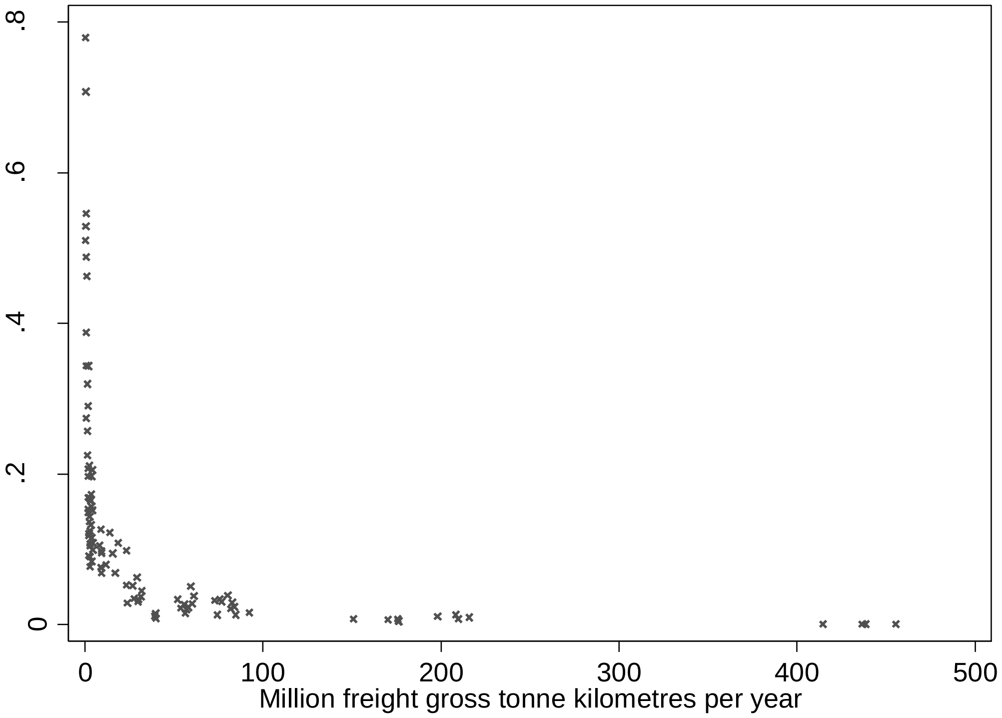
The estimated marginal costs are given in table 7. Mean marginal cost for dedicated lines is SEK 0.126. An output-weighted mean estimate is SEK 0.0168. The marginal cost for freight trains in the Box-Cox model (6) is SEK 0.021 and SEK 0.0014 as a weighted estimate. For passenger trains, the equivalent estimates are SEK 0.296 and SEK 0.0108. We observe some high marginal costs in all three cases for low volume track sections, which drive up the mean values. The marginal costs for dedicated freight lines are plotted in figure 4 and for mixed lines in figures 5-6[4].

Table 7. Marginal costs

Marginal cost	**Observations**	**Mean**	**Std. Error***	**[95% Conf. Interval]**	
Mixed freight	648	0.020780	0.007640	0.005701	0.035860
Mixed freight**	648	0.001425	0.000089	0.001249	0.001600
Mixed passenger	648	0.296449	0.088197	0.122362	0.470536
Mixed passenger**	648	0.010771	0.000714	0.009362	0.012180
Dedicated freight	101	0.126460	0.028038	0.069200	0.183720
Dedicated freight**	101	0.016804	0.002476	0.011747	0.021860

* Cluster adjusted; ** Weighted estimate

Figure 4. Marginal costs - Dedicated freight lines



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[4] We restrict the plot to marginal costs below 1 SEK/Gross tonne kilometre.

Figure 5. Marginal costs - Freight trains - Mixed lines

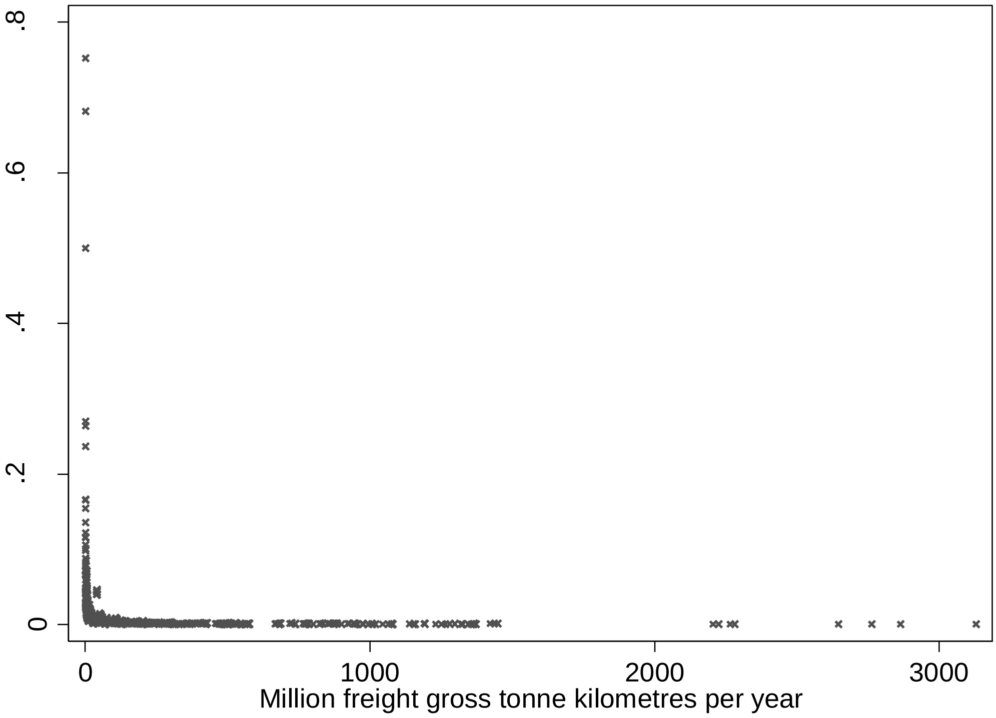
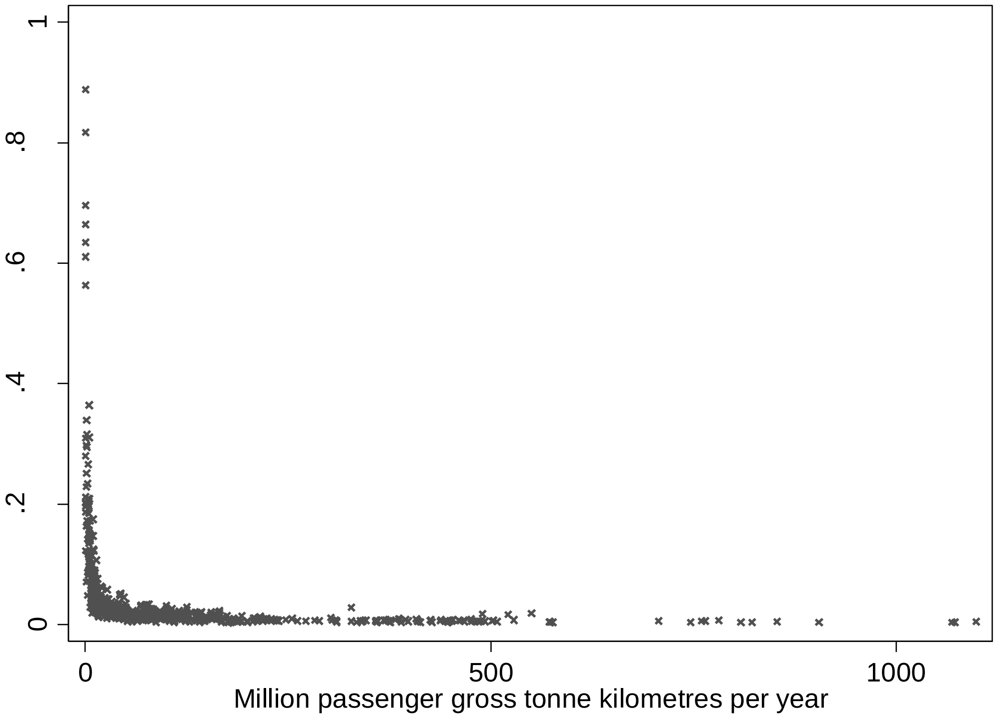


Figure 6. Marginal costs - Passenger trains - Mixed lines



6 Discussion and conclusions

There has been increasing European attention to the issue of marginal costs of railway infrastructure wear and tear in the last decade. The EU-project CATRIN (Cost Allocation of TRansport INfrastructure cost) supports the European Transport Policy, specifically to assist in the implementation of transport pricing for all modes of transport. In this paper, we have analysed maintenance cost data for Swedish railway infrastructure in relation to traffic volumes and other characteristics, and separated the cost impact from passenger and freight trains. Furthermore, we have analysed the choice between logarithmic and Box-Cox regression models and finally checked for differences between railway lines with a mixed passenger and freight traffic pattern and lines dedicated to freight traffic only.

The analysis shows that a Box-Cox regression model is preferred for lines with mixed traffic, but the log-linear model is not rejected for dedicated freight lines.

We observe that most coefficients follow our a priori expectations in terms of cost drivers. One feature though is that the sign of the coefficient for length-distance ratio variable goes from negative (mixed lines) to positive (dedicated freight lines). This seems a little confusing at first glance as a higher ratio indicates higher track time availability. There is a probable explanation though. The dedicated freight lines have fairly low traffic levels, which mean that there is no direct benefit in having multiple tracks with regards to available track time. Hence, track time for maintenance is no scarcity on low-volume lines, but on heavily utilised tracks and adding more tracks to a low-volume line will generate costs. Adding more tracks to a high-volume track on the other hand will reduce maintenance costs as track availability is increased with lower costs as a bonus (less time is spent establishing, re-establishing and waiting during a maintenance activity).

The most challenging result is the ratio between the passenger and freight elasticities in the mixed line case. A suggested explanation to the high passenger elasticity is to look at track management behaviour and rules. Passenger trains operate at higher speeds and require a high-quality track with tougher intervention levels compared to freight trains. This implies more frequent maintenance activities on a mixed line than on a line dedicated to freight only. Management documents at Banverket corroborate this view. Inspection class is a function of speed and gross tonnes (Banverket, 2000). Tamping levels are a function of comfort classes, which are based on quality classes. Higher speeds generate lower tolerance levels in these quality classes (Banverket, 1997). The cost elasticity is then not solely based on physical wear and tear, but on a combination of wear and tear, and ride comfort. Maintenance policies and actions are highly passenger train service orientated in Sweden and this is reflected in the cost structure.

Still, it can be a matter of omitted variable bias, a common problem in regression analysis. Previous work by Andersson (2007a and 2008) has used fixed effect (FE) estimation on the same data set, using an aggregate output of freight and passenger train volumes. FE estimation solves the omitted variable bias problem if track specific characteristics are time-invariant (Wooldridge, 2002). We are not aware of any FE applications in a Box-Cox framework, but this would be one way of extending this research. Another extension is along the line of acquiring more data, inter alia speeds and axle loads, which are currently not available to us. These variables are used in the deterioration models by Öberg et al. (2007), which allocate freight and passenger train damage to the track.

There is also a difference between the elasticity found for freight trains on dedicated lines and what has previously been found. A 10 percent change in freight traffic on a dedicated line would change maintenance costs by 4.4 percent. The magnitude of the elasticities in previous models (Andersson, 2006, 2007a and 2008), where an aggregate measure of traffic is used, i.e. a total of freight and passenger trains, have been in the range of 0.2 - 0.3. An explanation can be that we have a track that is set up more in line with its usage and costs can therefore be more related to the traffic than when we look at the entire network and use an aggregate output measure. Furthermore, elasticities are falling with output as opposed to the increasing shape found in the mixed line case. The dedicated freight lines differ from mixed lines in terms of tonnage levels and maintenance strategies, and it is therefore difficult to expect identical relationships for both mixed and dedicated lines. The low volumes subsequently lead to higher weighted marginal costs on dedicated freight lines.

The freight elasticity in the model for mixed lines is well below, while the passenger elasticity is more in line with, previous estimates. Marginal costs though differ from what we have previously considered as relevant (Andersson, 2007a and 2008), namely SEK 0.006 – 0.007 per gross tonne kilometre using total gross tonnes as output and panel data estimators. Freight marginal costs are much below this level and also lower than what is currently charged for wear and tear. Conversely, passenger marginal costs are almost twice of what is previously found and four times the current charge.

A change in the pricing scheme in the direction of the results presented in this paper would lead to more revenues, even if all freight related gross tonnes (70 percent of total tonnage) face a lower wear and tear charge. The joint effect would still give a revenue increase of some 50 percent, with passenger trains paying a much larger share than today. This assumes that total demand for passenger services is unaffected by the price increase.

Most econometric models on railway infrastructure costs have used the data available in the specific case. Within the CATRIN project, we have discussed the potential of using engineering knowledge to enrich our econometric specifications. One important factor identified from this process has been to include some vehicle characteristics, which normally are not collected by railway authorities. Due to lack of information, we have not been able to move towards these suggestions, but they have been highlighted in our work with Banverket as areas where future data collection should aim.

A final observation is that Box-Cox models have introduced some new and interesting possibilities regarding differentiation when analysing Swedish railway infrastructure cost data, but also some issues that we need to attend in future research to improve elasticity and marginal cost estimates. Utilising an efficient variable transformation in conjunction with the information available in panel data is a key for future work.

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8 Appendix 1 Categorisation of Swedish Railway Infrastructure Costs

As a part of CATRIN, the categorisation of different activities related to renewing, maintaining and operating the infrastructure has been discussed. Differences in these categories have been a source of discussion related to why results from econometric studies vary between countries.

This text aims at briefly describing how Swedish railway infrastructure activities are categorised and form different cost categories.

8.1 Funding and coding

The Swedish Rail Administration (Banverket) receives an annual grant from the government. This grant consists of a number of areas to be financed. Specific details about the conditions under which this grant can be used are given in a government instruction to Banverket together with the grant for an upcoming budget year. For 2007, the area of *Track Management* was assigned Million SEK 12 670, with 7 150 to Investments, 4 000 to Operation, Maintenance and Traffic Management and 1 520 to Mortgages and Interests. Banverket sets up an internal financial code system to distribute the grant to activities, c.f. to separate renewals from upgrades and new constructions as they all fall under the Investment category.

There are also a number of activity codes linked to the financial codes and any activity code beginning with the letter *B* is related to the area of Track management. Subgroups are given, to cover for the specification in the grant as well as for internal reporting.

Track access charges are reported as revenue, which can be used on the track. This means that what is actually spent on the track each year is access charges plus government grants.

In general, Banverket follow the European standard SS-EN 13306 Maintenance Terminology in their definitions of maintenance and associated activities.

8.2 Infrastructure operation (Övrig anläggningsskötsel)

This group consists of activities undertaken without affecting functional or technical condition of a unit.

The two categories are winter services (B0707) and other track specific costs for operation and maintenance (B0706), where the former is dominating. Other costs are specifically described as “not being related to a given quality to be performed”. Among these are service of various detection systems and cleaning of station areas.

8.3 Maintenance (Underhåll)

Maintenance is divided into corrective and preventive maintenance, where preventive maintenance can be either condition-based or predetermined.

Corrective maintenance is immediate maintenance (B0801) after observed or reported faults, urgent actions after inspection (B0802) or damages (B0803) that occur after sudden and unexpected incidents.

Preventive maintenance is *condition control*, which consists of safety (B0804) and maintenance (B0805) inspections, and other inspections (B0806); *condition-based maintenance*, which is minor replacements (B0809), tamping (B0810), vegetation control (B0813), rail grinding (B0815), ditching and draining (B0818), painting (B0819), neutralisation (B0822), rail and sleeper adjustments (B0823), overhauls and repairs (B0825) and other condition-based maintenance (B0827). *Predetermined maintenance* (B0826) is interval based according to specific rules and standards.

8.4 Renewals (Utbyten)

Renewals are handled slightly different as mentioned above. The activity codes are common with upgrades and new constructions, but after receiving the grant, an internal budget separates renewals from other construction activities. The internal accounts is therefore easily scanned for renewal costs, but it is impossible (without viewing every single invoice) to see the type of renewal undertaken. The activity codes in this case leave no information but in which phase of the project, the costs are accrued.

Because of this, renewals can be anything from minor replacements (even if this also exists as a maintenance activity) to major rail replacements. The distinction becomes a financial issue rather than a clear cut categorisation of activities. Still, despite the grey zone between maintenance and renewal, the impression from contacts with Banverket is that renewal costs are derived from more large scale activities than minor replacements.

9 Appendix 2 Derivation of the cost elasticity in a Box-Cox model

Consider the following general relationship

$$\frac{y^{\theta}-1}{\theta}=\beta\left(\frac{x^{\lambda}-1}{\lambda}\right) \tag{A2.1}$$

We are looking for the elasticity $\frac{\partial \ln y}{\partial \ln x}$, which according to the chain-rule is

$$\frac{\partial \ln y}{\partial x}\cdot\frac{\partial x}{\partial \ln x}=\frac{\partial \ln y}{\partial x}\cdot\left(\frac{\partial \ln x}{\partial x}\right)^{-1}=\frac{\partial \ln y}{\partial x}\cdot\left(\frac{1}{x}\right)^{-1}=\frac{\partial \ln y}{\partial x}\cdot x \tag{A2.2}$$

Find $\frac{\partial \ln y}{\partial x}$ by first re-writing (1).

$$\begin{aligned}
&\frac{y^{\theta}-1}{\theta}=\beta\left(\frac{x^{\lambda}-1}{\lambda}\right)\Leftrightarrow\\
&y^{\theta}=\beta\theta\left(\frac{x^{\lambda}-1}{\lambda}\right)+1\Leftrightarrow\\
&\theta\ln y=\ln\left(\beta\theta\left(\frac{x^{\lambda}-1}{\lambda}\right)+1\right)\Leftrightarrow\\
&\ln y=\frac{1}{\theta}\ln\left(\beta\theta\left(\frac{x^{\lambda}-1}{\lambda}\right)+1\right)=\frac{1}{\theta}\ln\left(\beta\theta\left(\frac{x^{\lambda}}{\lambda}\right)-\frac{\beta\theta}{\lambda}+1\right)
\end{aligned} \tag{A2.3}$$

Now, take the derivative of ln y with respect to x,

$$\frac{\partial \ln y}{\partial x}=\beta\theta x^{\lambda-1}\cdot\frac{1}{\theta}\cdot\frac{1}{\beta\theta\left(\frac{x^{\lambda}-1}{\lambda}\right)+1}=\beta x^{\lambda-1}\cdot\frac{1}{\beta\theta\left(\frac{x^{\lambda}-1}{\lambda}\right)+1}= \tag{A2.4}$$

We want $\frac{\partial \ln y}{\partial x}.\frac{\partial x}{\partial \ln x}$ which is,

$$\beta x^{\lambda-1} \cdot \frac{1}{\beta\theta\left(\frac{x^{\lambda}-1}{\lambda}\right)+1} \cdot x = \beta x^{\lambda} \cdot \frac{1}{\beta\theta\left(\frac{x^{\lambda}-1}{\lambda}\right)+1} \tag{A2.5}$$

From (A2.3), we can see that the second factor in (A2.5) is $\frac{1}{y^{\theta}}$, which gives the elasticity as

$$\frac{\partial \ln y}{\partial x} \cdot \frac{\partial x}{\partial \ln x} = \frac{\beta x^{\lambda}}{y^{\theta}} \tag{A2.6}$$

or when $\theta = \lambda$,

$$\frac{\partial \ln y}{\partial x} \cdot \frac{\partial x}{\partial \ln x} = \beta\left(\frac{x}{y}\right)^{\lambda} \tag{A2.7}$$

SIXTH FRAMEWORK PROGRAMME
PRIORITY 1.6.2
Sustainable Surface Transport

CATRIN
Cost Allocation of TRansport INfrastructure cost

D8 – Rail Cost Allocation for Europe

Annex 1B – Track maintenance and renewal costs in Switzerland

Final Version
February 2009

Authors:
Michael Marti, René Neuenschwander and Philipp Walker (Ecoplan)

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VTI; University of Gdansk, ITS Leeds, DIW, Ecoplan, Manchester Metropolitan University, TUV Vienna University of Technology, EIT University of Las Palmas; Swedish Maritime Administration, University of Turku/Centre for Maritime Studies

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Project summary

CATRIN is a Research project to support the European Transport Policy, specifically to assist in the Implementation of Transport pricing. CATRIN will increase the probability that new progressive pricing principles can be implemented which facilitate a move towards sustainable transport. CATRIN is both intermodal and interdisciplinary, emphasize the need of new Member states, understands that different organisational forms require different recommendations, that recommendations need to be given in short and long-term perspective and that they have to be thoroughly discussed with infrastructure managers.

CATRIN will clarify the current position on allocation of infrastructure cost in all modes of transport. Pricing principles will be dealt with under the knowledge that they varies with the organisational structure of a sector. CATRIN will establish the micro-aspects of cost recover above marginal costs, including the results of applying a club approach and the implication of who bears the costs for cost recovery under alternative allocation rules, using game theoretic analytical tools.

CATRIN will develop the understanding of policy need of new Member states and can give tailored recommendations. In a modal focus, with real world cases, CATRIN will develop proxies to marginal costs and test some of the allocation approaches. Based on engineering studies CATRIN will analyse the possibility to defining more differentiated pricing rules for vehicle/locomotive categories. Partners with strong engineering knowledge are included and CATRIN will blend the economic principles of pricing with engineering knowledge. CATRIN will outline the possibilities for a European Road Damage test that will give new evidences on the fourth-power-rule. CATRIN will develop financing alternatives for icebreaking and will explore cost allocation in the aviation sector. Finally, CATRIN will strongly address the implementation potential and constraints experienced by infrastructure managers

CATRIN -- Cost Allocation of TRansport INfrastructure cost

Track maintenance and renewal costs in Switzerland

Swiss Case Study within the EU research project CATRIN „Cost Allocation of Transport INfrastructure "

Final version

February 26, 2009

ECOPLAN
Forschung und Beratung
in Wirtschaft und Politik
CH - 3005 Bern, Thunstrasse 22
CH - 6460 Altdorf, Postfach
www.ecoplan.ch
info@ecoplan.ch

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Research team Ecoplan

Michael Marti

René Neuenschwander

Philipp Walker

Ecoplan

Forschung und Beratung
in Wirtschaft und Politik

www.ecoplan.ch

Thunstrasse 22
CH - 3005 Bern
Tel +41 31 356 61 61
Fax +41 31 356 61 60
bern@ecoplan.ch

Postfach
CH - 6460 Altdorf
Tel +41 41 870 90 60
Fax +41 41 872 10 63
altdorf@ecoplan.ch

Table of Contents

1 Introduction

1.1 Background

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.

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 transport, for passenger transport a concession for the conveyance of passengers is required. In freight transport 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 transport 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 transport the charge consists of the standardized marginal costs and a part of the revenues of transport services (contribution margin). Today the train path price in Switzerland consists of several components.

- “Minimum price”: Maintenance (0.0025 CHF/Gross-ton-kilometre), train operation service (0.4 CHF/train-km), purchase of energy (0.0029 – 0.0062 CHF/Grtkm) and supplements for nodes (big nodes: 5 CHF, small nodes: 3 CHF).
- Contribution margin: Long-distance passenger transport (8% share of revenue), regional passenger transport (14% share of revenue), goods transport (0.0052 CHF/Net-tkm)

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

1.2 Objective and approach

The objective of this paper is to estimate marginal costs of railway maintenance and renewal 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 gross-ton-kilometres or the number of trains as well as technical and spatial features of the railway system.

This work should provide some of the information needed for the introduction of a “smart charging” system for track access in Switzerland. Smart charging should ensure fair and non-discriminatory prices for users as well as revenues for future infrastructure investment. It should make time-differentiated charges possible in order to allocate scarce track capacities efficiently as well as allow for rewards to environmentally more efficient vehicles. This shows that it is not a strict marginal cost pricing rule that should be implemented in a modern track charging system. The vision is more complex: The charging system should set the right incentives, it tariffs should reflect the costs caused and it should ensure the financing of the railway infrastructure.

With the detailed and differentiated estimation of marginal costs of railway maintenance and renewal we try to show how track access charges should be shaped and according to which criteria they could be differentiated.

The case study has the following specific research objectives:

- Testing the possible econometric model specification in order to find the “best” model
- Analysis of track maintenance and renewal costs in Switzerland according to the following criteria:
  - Analysis of the cost per train-km as well as per gross-ton-kilometre
  - Analysis of the cost according to different train categories
  - Analysis of the cost wit respect to different regional types

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 of the basic model specification. Additionally we derive results with respect to marginal costs. In section 4 we extend our estimations to provide more detailed information for different train categories and for different regional sections respectively. 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 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 to 2007. This record contains:

- Infrastructure data
- Transport 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.

2.1 Infrastructure data

The Swiss national rail network comprises approximately 4,900 kilometres 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. 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.

For some reasons we could not use all track sections of the database: Some defined track sections are maintained by foreign railway companies (16 sections in border areas, maintained by DB, ÖBB, FS and SNCF) others by private Swiss railway companies (data not available). A certain number of track sections are marshalling yards where either no transport data or no cost data are available. Finally, a limited number of track sections have to be dropped because they have been redefined in the period 2003 - 2007 or have only been in operation since 2005. This results in 366 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 2007 state of the DfA for all observations.

Table 2-1: Infrastructure data used (366 track sections, data for 2003 to 2007)

Variable	Observations	Mean	Standard deviation	Minimum	Maximum[1]
Track length (main track) [km]	1823	12.85	13.22	.385	114.03
Fraction of switch metres of total track length [%]	1808	0.15	0.18	0	1.03[2]
Fraction of bridge metres of total track length [%]	1823	0.05	0.09	0	1.06[3]
Fraction of tunnel metres of total section length [%]	1823	0.06	0.22	0	2.71[4]
Fraction of radius metres <500m [%]	1823	0.20	0.21	0	0.97[5]
Fraction of slope > 2 percent [%]	1823	0.12	0.20	0	0.99[6]
Fraction of track length with noise/fire protection [%]	1823	0.03	0.07	0	0.61
Fraction of platform edge of total track length [%]	1823	0.17	0.26	0	0.97[7]
Fraction of sleepers with age > 25 years [%]	1803	0.20	0.26	0	1.00
Dummy for passenger stations [0/1]	1823	0.16	0.37	0	1.00
Dummy for marshalling yards [0/1]	1823	0.02	0.15	0	1.00
Dummy for one-track sections [0/1]	1823	0.40	0.49	0	1.00
23 regional dummies	1823			0	1.00

Table 2-1 shows some basic information for those infrastructure variables of the years 2003 - 2007 that will be used in the econometric estimation. The variables are all expected to affect

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[1] For few tracks, the maximum may exceed 1 due to the fact that we focus on the track length for main tracks while data on certain infrastructure variables contain information on the whole section (including all side tracks). For tunnel and platform edges information was only available on the whole section, not for a single track.

[2] For the track section Zurich Halle-Langstrasse the fraction of switch metres of total track length lies above 1.

[3] The track section Zurich Altstätten-Hard is equal to a bridge. The length specifications of the track data base sometimes do not match those of the bridge data base exactly. Since we are taking the length of bridges from the bridge data base, here we do not adjust the data.

[4] The fraction of tunnel metres is not measured in relation to track length but to section length. Therefore values above 1 are not lacking plausibility. The only value above 2 is found on the section Zurich Stadelhofen-Zurich Hottingen.

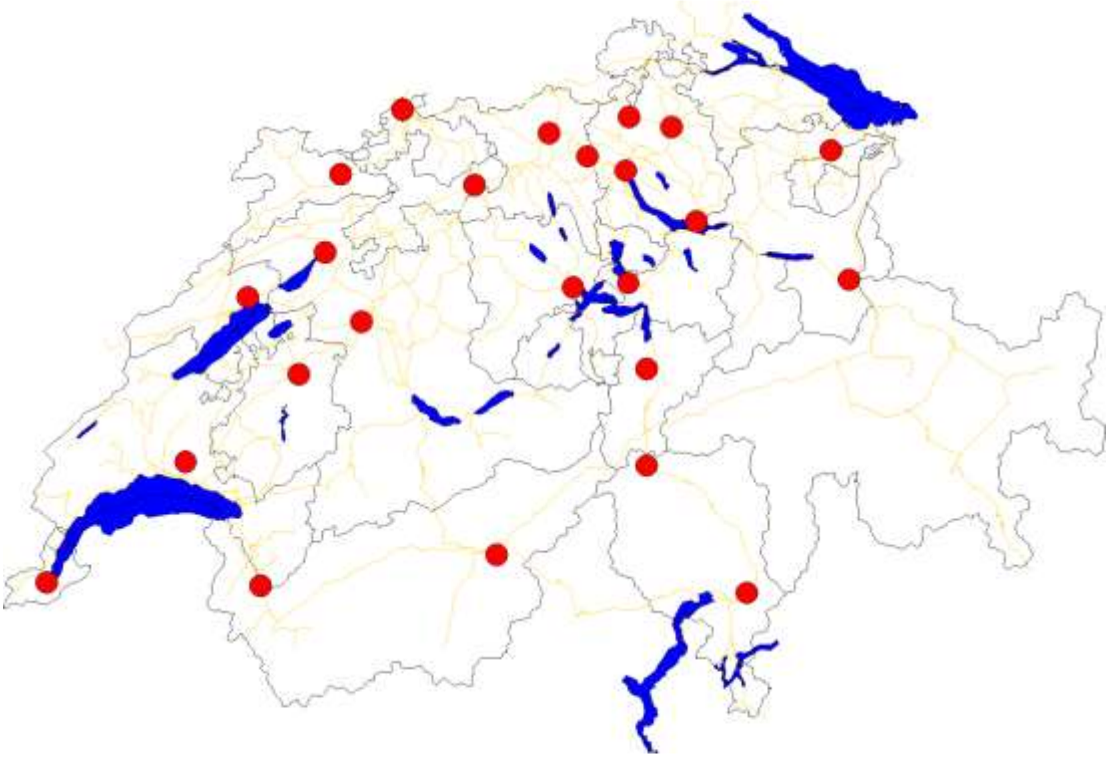
[5] For the three stations of Thun (freight yard), Brig (train station) and Koblenz (train station) we find values above 1 for the fraction of radius metres <500m. For estimation purpose we denote the station sections with a specific station dummy variable.

[6] For the train station of Brig we find a value above 1 for the fraction of slope > 2 percent. For estimation purpose we denote the station sections with a specific station dummy variable.

[7] For the stations of Altstätten SG, Chiasso, Chur, La Chaux-de-Fonds, Luzern und Vallorbe we find values above 1 for the fraction of platform edge metres of total track length. This finding might be explained by the fact that there are two platform edges per track. For estimation purpose we denote the station sections with a specific station dummy variable (0/1-variable).

maintenance and renewal costs. An analysis of correlation coefficients between variables shows that there are only little interdependencies. We have no 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 24 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 a private railway company ("Rhätische Bahn").

Figure 2-1: Locations of the 23 districts (regions) of SBB



2.2 Transport data

Transport data were provided by SBB through their transport 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 kilometres (train-km), axle load kilometres and gross-ton-kilometres per track (Grtkm) for the main lines. Analogous to the infrastructure data, table 2-2 gives the key values for transport variables of the years 2003 to 2007. Table 2-2 contains gross tons, gross-ton-kilometres and the number of trains per section.

Our estimations are focused both on the analysis of gross-ton-kilometres and train kilometres as main cost drivers. In analogy to recent work we split the variable gross-ton-kilometres into two separate variables: gross tons per track kilometre and track length. This separation isolates the costs driven by gross tons from length effects.

Table 2-2: Overview of transport variables

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
Total gross tons per track km[8]	1823	13'100'000	8'940'335	68'544	46'500'000
Passenger gross tons per track km	1823	8'728'224	6'771'962	0	36'000'000
Freight gross tons per track km	1823	4'282'288	5'530'353	0	28'600'000
Total gross-ton-kilometres [in '000]	1823	177'985	255'903	740	2'236'565
Passenger gross-ton-kilometres [in '000]	1823	108'872	132'357	0	767'738
Freight gross-ton-kilometres [in '000]	1823	68'148	164'924	0	1'762'664
Number of trains total	1823	32'292	16'892	296	109'079
Number of passenger trains	1823	25'658	15'822	0	106'483
Number of freight trains	1823	6'061	6'335	0	54'075

2.3 Cost data

SBB provided us with very detailed cost data per section for which SBB is responsible. 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 time period of five years. Similar to Andersson (2006), we observe that renewal costs per track

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[8] Total gross-ton-kilometres include passenger, freight and service trains. However, the fraction of service gross-ton-kilometres is very small.

section can vary significantly between years. According to cost experts of SBB there are four reasonable cost categories to estimate:

- Model type 1: Yearly arising maintenance costs only for operation and track maintenance
- Model type 2: Yearly arising maintenance costs that consider all expenditures for "Contracting A"
- Model type 3: Renewal costs that consider all expenditures for "Contracting B" (5-year-average renewals expenditure for each track section)
- Model type 4: Maintenance and renewal costs (all expenditures for "Contracting A" and "Contracting B"). Yearly maintenance costs were combined with the 5-year-average renewals expenditure for each track section.

The descriptive statistics of the cost variables used in the four model structures are shown in table 2-3. 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 CHF.

Table 2-3: Overview of cost variables in CHF

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
Operation and track maintenance costs (part of Contracting A)	1823	244'663	266'796	69	2'402'499
Maintenance costs (Contracting A)	1823	553'540	622'300	4'479	6'453'406
Renewal costs (Contracting B)	366	330'683	407'079	0	3'527'668
Maintenance and renewal costs (Contracting A and B)	1823	884'222	1'000'807	7'741	8'911'986

In the CATRIN project the analysis of the maintenance costs is the main focus. These costs should be compared across different countries. Of great importance is also the analysis of renewal costs: Swiss data on renewal costs might be the best Europe-wide.

3 Basis model specification

3.1 Specification of the basis models

3.1.1 General assumptions

Current work in estimating rail infrastructure cost functions is based on the work of Johansson and Nilsson (2004). Johansson and Nilsson apply a Translog specification, hence a log-linear model using total gross tones as output of the track, while controlling for infrastructure characteristics. Railway infrastructure maintenance cost functions have since then been estimated in different European countries: Austria (Munduch et al., 2002), Norway (Daljord, 2003), Finland (Tervonen and Idström, 2004), Switzerland (Marti and Neuenschwander, 2006), Sweden (Andersson, 2006 and 2007) and the UK (Wheat and Smith, 2008). All of these studies use log-linear model specifications and also an aggregate measure of output, i.e. total gross tones.

In order to compare the results of this study for former results we use log-linear model specifications for estimating.[9] In addition to the log-linear models we also will test for **Box-Cox models**. The Box-Cox transformation is a generalisation of the log-linear transformation (see section 3.1.3). We consider the Box-Cox models due to the interesting work of Gaudry and Quinet (2003) as well as Quinet (2005). Gaudry and Quinet use a large data set for French railways in 1999, and explore a variety of unrestricted generalised Box-Cox models to allocate maintenance costs to different transport categories. They come to the conclusion that applying a Box-Cox transformation is more efficient than a logarithmic transformation.

One of the main goals of the EU project CATRIN is to comparison marginal cost calculation across countries. To achieve this goal, a uniform methodical base is needed. Therefore each country involved in estimating railway infrastructure maintenance costs also will apply Box-Cox model specifications. Both the log-linear and Box-Cox approaches are explained in the following two sections.

3.1.2 Log-linear model specification

Our log-linear estimation model is given in equation (1) with

- C_{it} measuring the costs of section i at time t,
- q_{kit} measuring the traffic variable k for section i at time t,
- x_{mit} measuring the infrastructure variable m for section i at time t and
- z_{nit} indicating dummy variable or fraction variable n for section i at time t.

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[9] The log-linear model specifications are based on the work in the EU project GRACE by Marti and Neuenschwander (2006).

α, β_k, δ_m, γ_n, ε are parameters to be estimated.

$$\ln(C_{it}) = \alpha + \beta_k \ln(q_{kit}) + \delta_m \ln(x_{mit}) + \gamma_n z_{nit} + \varepsilon_{it} \quad (1)$$

The log-linear model corresponds to a logarithmic Cobb-Douglas cost function. The advantage of a log-linear can be seen in the fact that cost elasticities can be derived directly from the estimation results. In case there are neither quadratic nor multiplicative terms in the model specification the elasticity corresponds to the estimated beta coefficient (equation (2)).

$$\frac{\partial \ln(\hat{C}_{it})}{\partial \ln(q_{kit})} = \hat{\beta}_k = \hat{\phi}_k^{ll} \quad (2)$$

3.1.3 Box-Cox model specification

A log-linear model specification assumes that the most efficient transformation of our data is logarithmic. In reality, another transformation may lead to a more efficient transformation and to better estimation results. A Box-Cox transformation does not restrict our model. It allows a variable transformation of the data. It can be denoted as follows (see equation (3)).

$$w^{(\lambda)} = \frac{w^{\lambda} - 1}{\lambda} \quad (3)$$

We assume that the transformation parameter λ is identical for all variables.[10] A Box-Cox transformation takes advantage of the fact that it includes the logarithmic transformation as a special case. In case our data are log normal, λ will be zero. If not, the log-linear transformation will not be an efficient way of treating our data. An econometric model specification of a Box-Cox regression is presented in equation (4):

$$C_{it}^{(\lambda)} = \alpha + \beta_k q_{kit}^{(\lambda)} + \delta_m x_{mit}^{(\lambda)} + \gamma_n z_{nit} + \varepsilon_{it} \quad (4)$$

Cost (C), output (q) and single infrastructure variables (x) are transformed. In contrast, percent and dummy variables are estimated without transformation. In opposition to a log-linear estimation the calculation of the elasticities is more intense than in the log-linear case. It includes the estimated transformation parameter λ.

$$\frac{\partial \ln(\hat{C}_{it})}{\partial \ln(q_{kit})} = \hat{\beta}_k \frac{(q_{kit}{}^{\hat{\lambda}})}{(\hat{C}_{it}{}^{\hat{\lambda}})} = \hat{\phi}_k^{B-C} \quad (5)$$

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[10] Other specifications with different transformation parameters for different variables are possible. In comparison with other country studies within CATRIN we apply a simple Box-Cox specification with a common transformation parameter λ.

3.2 Estimation results

The estimation results of the four cost models are presented in table 3-1. The estimations are carried out with *Intercooled STATA 9.1*. In order to avoid inefficient estimations due to heteroskedasticity, we apply a robust estimator. As mentioned in chapter 2, the estimations have been run over 366 observations per year for five years.

First of all, the estimated transformation parameter λ is highly (at the 1 % level) significant for all cost models. This indicates that the transformation parameter is different from zero. Therefore the Box-Cox specification is superior to a log-linear model specification.

Generally, the explanation power of all three models is remarkably high. Adjusted R2-values are between 0.70 and 0.85. Similarly to the former experience we find the highest explanatory power for the cost models 1 (part of Contracting A) and 2 (Contracting A). However, including renewal costs does not harm the explanatory power significantly. The costs models 3 (average renewal costs per section) and 4 (yearly observed maintenance costs plus average renewal costs per section) still have an explanatory power of over 70%.

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 cost model 2 (maintenance costs, Contracting A) we see that most coefficients are significant at the 1 percent level and mostly have expected signs.

- Not surprisingly, the estimations show highly significant and positive values for track length, gross tons, switch meters, bridge meters, curvature, platform edge meters, steep slopes, noise/fire protection, and for the dummy variables for passenger stations, marshalling yards and one-track sections.
- At first glance, the negative sign for tunnel meters is irritating (significant at the 1% 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 in the model “Contracting A”). 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 and with steep slopes.
- Finally, time dummy variables for 2003 and 2006 are significant. While the costs were significantly higher in 2003, they are lower in 2006.

Not surprisingly, most of these results are also true for cost model 1 (part of Contracting A). Differences are found for bridge metres (not significant in cost model 1), noise/fire protection (not significant) and in maximum speed (significant at the 10% level). A remarkable difference can be seen in the time dummy variables: the years 2003 to 2005 show significantly higher costs for operation and track maintenance than later.

Looking at the results of cost model 4 (both maintenance and renewal costs) we find very similar results to the cost model 2 (maintenance costs). The sole differences are found in the noise/fire protection (not significant in cost model 4) and in the maximum speed (significantly negative in cost model 4).

Finally, a comparison of maintenance (cost model 2) and renewal costs (cost model 3) reveals some differences. Renewal costs are less influenced by variables such as slope, noise/fire protection and the dummy variable for passenger stations. In contrast, tunnel metres are not any more negatively related to costs and maximum speed has a negative impact on costs.

In summary, all cost models show meaningful, significant and robust estimation results in the basic model estimation. Moreover, the observed algebraic signs are plausible and correspond to the hypothesis. Finally, the results confirm earlier findings of Marti and Neuenschwander (2006) for Switzerland.

Table 3-1: Results of the Box-Cox estimations of the basic models

	Operation and track maintenance (Part of Contracting A)	**Maintenance costs** (Contracting A)	**Renewal costs** (Contracting B)	**Maintenance and renewal costs** (Contracting A+B)
Number of observations	1788	1788	351	1788
λ (lambda)	0.219*** (246.88)	0.159*** (12.32)	0.245*** (8.46)	0.179*** (14.84)
Constant	9.457	16.107	11.492	17.186
Transformed variables				
Track length [km]	7.939*** (2026.46)	5.023*** (2767.54)	12.212*** (370.81)	7.011*** (2961.02)
Gross tons [Grt]	0.127*** (257.54)	0.132*** (197.55)	0.181*** (59.60)	0.183*** (359.00)
Maximum speed [km/h]	-0.491* (3.58)	-0.219 (2.40)	-2.268** (5.88)	-0.724*** (16.79)
Non-transformed variables				
Fraction of switch metres of total track length [%]	23.229*** (246.88)	10.393*** (281.52)	33.022*** (35.05)	15.124*** (316.14)
Fraction of bridge metres of total track length [%]	2.508 (1.19)	2.115** (4.87)	29.436*** (11.00)	9.434*** (51.51)
Fraction of tunnel metres of total section length [%]	-5.834*** (49.35)	-1.905*** (30.52)	-0.004 (0.00)	-1.873*** (15.86)
Fraction of radius metres <500m [%]	6.239*** (34.22)	4.959*** (121.99)	15.997*** (14.51)	7.592*** (152.08)
Fraction of slope > 2 percent [%]	5.157*** (27.87)	2.174*** (28.50)	5.113 (1.87)	2.757*** (24.66)
Fraction of track length with noise/fire protection [%]	-3.372 (1.95)	-2.077** (4.26)	5.458 (0.34)	0.214 (0.024)

Fraction of platform edge of total track length [%]	6.264*** (55.46)	4.017*** (128.34)	7.790** (6.00)	5.027*** (108.93)
Fraction of sleepers with age > 25 years [%]	1.622** (4.82)	0.980*** (10.13)	6.263** (4.84)	2.172*** (26.59)
Dummy for passenger stations [0/1]	4.078*** (34.37)	2.187*** (56.47)	0.042 (0.00)	2.338*** (34.68)
Dummy for marshalling yards [0/1]	16.395*** (144.28)	9.709*** (271.03)	26.474*** (26.21)	13.350*** (276.29)
Dummy for one-track sections [0/1]	1.318*** (8.85)	1.466*** (62.24)	3.430** (3.93)	2.054*** (65.54)
Dummy for 2003 [0/1]	3.014*** (38.32)	0.710*** (12.35)	-	0.805*** (8.55)
Dummy for 2004 [0/1]	2.489*** (26.29)	0.295 (2.16)	-	0.330 (1.44)
Dummy for 2005 [0/1]	2.529*** (27.19)	0.188 (0.87)	-	0.181 (0.44)
Dummy for 2006 [0/1]	0.700 (2.10)	-0.597*** 8.80	-	-0.447*** (2.65)
Regional dummies	div.	div.	div.	div.

***/**/* denote significant variables at the 1/5/10% level. Values in parenthesis correspond to the Chi^2 statistics.

3.3 Marginal and average costs

3.3.1 Definition and calculation of marginal costs

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

$$MC_{it}^{j} = \frac{\partial \hat{C}_{it}}{\partial q_{it}^{km}} = \frac{\partial \hat{C}_{it}}{\partial q_{it}} \frac{1}{km_{it}} = \frac{\partial \ln(\hat{C}_{it})}{\partial \ln(q_{it})} \frac{\hat{C}_{it}}{q_{it}} \frac{1}{km_{it}} = \phi_{it}^{j} \frac{\hat{C}_{it}}{q_{it}^{km}} \tag{7}$$

$\hat{C}$ denotes the estimated costs, $q_{(it)}$ the gross tones and $q_{(it)}^{km}$ the gross-ton-kilometres respectively. Φ describes the estimated elasticities.

Marginal cost is the product of the cost elasticity and average costs. Calculating marginal costs therefore does not differ between log-linear and Box-Cox models. However, elasticities are calculated differently.

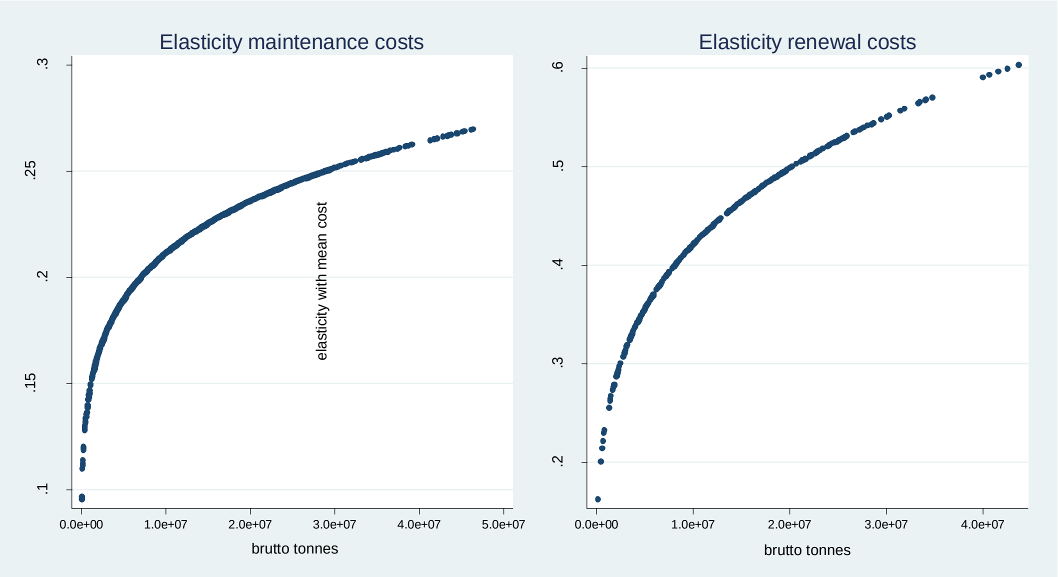
Given the marginal costs per section we derive the average marginal costs. To obtain the average marginal cost, we weight the marginal costs per section, using the number of gross-ton-kilometres on each section unit as a weight. The formula is presented in equation (8):

$$MC^{j}_{gew} = \sum \left[MC^{j}_{it} \frac{q^{km}_{it}}{\sum q^{km}_{it}} \right] \tag{8}$$

In a second step we calculate estimated average costs. Average costs per gross-ton-kilometre. Average costs are computed by using the fitted values divided per gross-ton-kilometre. The cost recovery is derived from the fraction of estimated marginal with respect to estimated average costs.

Figure 3-1 shows the plots of elasticities from the Box-Cox model for model type 2 (Yearly arising maintenance costs that consider all expenditures for “Contracting A”) and model type 3 (Renewal costs that consider all expenditures for “Contracting B”). In analogy to other studies, we find increasing elasticities with output, but at a decreasing rate.

Figure 3-1: Plot of elasticity against traffic density (tonne kilometre/track kilometre)



3.3.2 Average and marginal costs in the basic model specifications

In the table below the calculated average and marginal costs per gross-ton-kilometre are showed for all four cost models. The costs are presented both for the log-linear and the Box-Cox specifications.

Table 3-2: Results of the basic models: Costs per gross-ton-kilometre in CHF

	Operation and track maintenance (Part of Contracting A)	**Maintenance costs** (Contracting A)	**Renewal costs** (Contracting B)	**Maintenance and renewal costs** (Contracting A+B)
Log-linear model				
Marginal costs	0.00037	0.00061	0.00077	0.00135
Average costs	0.00126	0.00292	0.00177	0.00478
Cost recovery (in %)	29.1	20.8	43.4	28.3
Box-Cox model				
Marginal costs	0.00036	0.00061	0.00071	0.00132
Average costs	0.00127	0.00293	0.00172	0.00474
Cost recovery (in %)	28.6	20.7	41.4	27.9

Looking both at the maintenance cost model (Contracting A) and the operation and track maintenance cost model (part of Contracting A) no significant difference in marginal costs is seen for the log-linear and the Box-Cox model specifications. The marginal costs for maintenance are about 0.00061 CHF/Grtkm. They are close to those values found by Marti und Neuenschwander (2006) and comparable to the results of other countries.

While no significant difference is seen for maintenance costs, the marginal costs for renewal are around 0.00077 CHF/Grtkm in the log-linear specification. They are found to be slightly higher than in the Box-Cox specification (0.00071 CHF/Grtkm). A similar result is found for the sum of maintenance and renewal costs (0.00132 CHF/Grtkm in the Box-Cox case versus 0.00135 CHF/Grtkm in the log-linear specification). These values are about 8% below the findings of Marti und Neuenschwander (2006).

No remarkable differences are found in the cost recoveries across the log-linear and the Box-Cox approach. However, cost recovery varies significantly across the cost models. Renewal costs show a cost recovery which doubles the one of maintenance. Cost recovery in maintenance is lower than for operation and track maintenance.

The higher degree in cost recovery confirms the hypothesis that operation and track maintenance is more influenced by the output measure than maintenance (Contracting A) itself. The costs in maintenance are driven by other factors which are not in a direct connection to output variables neither to the number of driven kilometres nor to the weight of trains.

The high cost recovery of renewal costs reflects the estimation results. Renewal costs are more directly connected to output variables (trains or gross tons).

3.4 Estimating train kilometres instead of gross-ton-kilometres

Today, scientific literature in railway infrastructure maintenance cost analysis is clearly focussed on costs per gross-ton-kilometres. This includes the idea that weight is the main (only) driver for maintenance costs. However, we assume that there are at least fractions of wear which are not explained totally by weight but rather by the number of trains using the infrastructure.

Therefore we test an alternative model specification estimation train instead of gross tones.

3.4.1 Estimations results

We apply the identical estimations for testing trains instead of gross tones. The only change is logically the replacement of the variable gross tones by trains to measure the transport output. Table 3-3 shows the estimation results in a Box-Cox setting.

Table 3-3: Estimation results including the number of trains

	Operation and track maintenance (Part of Contracting A)	**Maintenance costs** (Contracting A)	**Renewal costs** (Contracting B)	**Maintenance and renewal costs** (Contracting A+B)
Number of observations	1788	1788	351	1788
λ (lambda)	0.216*** (15.80)	0.154*** (12.09)	0.239*** (8.25)	0.169*** (14.13)
Constant	11.254	16.248	13.027	17.820
Transformed variables				
Track length [km]	7.732*** (2032.02)	4.783*** (2800.56)	11.637*** (364.55)	6.322*** (2975.95)
Gross tons [Grt]	0.570*** (209.07)	0.445*** (230.78)	0.884*** (48.02)	0.639*** (368.87)
Maximum speed [km/h]	-0.599** (5.50)	-0.318** (5.51)	-1.988** (4.80)	-0.778*** (22.72)

***/**/* denote significant variables at the 1/5/10% level. Values in parenthesis correspond to the Chi^2 statistics.

The results in table 3-3 demonstrate that estimation the number of trains we observe a similar strong influence on the costs as estimating gross tones. The estimations still show a high explanatory power, the estimation results again are significant and robust. All other explanatory variables are not bothered by the substitution of gross tones by trains. We conclude that an analysis based on trains instead of gross tones is a valuable alternative.

3.4.2 Calculation and interpretation of marginal costs per train kilometre

The procedure for calculating marginal costs per train kilometre is analogous to the calculation of marginal costs per gross-ton-kilometre (see Table 3-4). Again we find little difference in marginal costs across the two model specifications (log-linear und Box-Cox). Only in renewal we find small differences. More interesting are the cost recovery results: First, the cost recoveries are higher for all estimations. Second, the ratio between the cost recoveries in the different cost models is very similar to those in the gross-ton-kilometre case.

Table 3-4: Results of the basic models: Costs per train kilometre in CHF

	Operation and track maintenance (Part of Contracting A)	**Maintenance costs** (Contracting A)	**Renewal costs** (Contracting B)	**Maintenance and renewal costs** (Contracting A+B)
Log-linear model				
Marginal costs	0.20072	0.36027	0.39450	0.76040
Average costs	0.55411	1.28361	0.77045	2.09356
Cost recovery (in %)	36.2	28.1	51.2	36.3
Box-Cox model				
Marginal costs	0.19560	0.35420	0.35662	0.72202
Average costs	0.56028	1.29245	0.75423	2.08660
Cost recovery (in %)	34.9	27.4	47.3	34.6

Marginal costs per train kilometre are close to 0.35 CHF per train kilometre, both for maintenance and renewal costs. In all cost models, marginal costs per train kilometre exceed marginal costs per gross-ton-kilometre approximately by a factor 500. A train with a weight of approximately 500 tons (which corresponds to the average weight of an intercity train in Switzerland) would have to pay approximately the same usage fee in a gross-ton-kilometre based access charging system than in a train-kilometre based track access charging system. A change towards a train-kilometre based track access charging system would favour mostly freight trains, which have a weight of about 1000 to 1500 tons. Freight trains would pay less on a train-kilometre based track access charging system than in the current charging scheme. On the other side under average weighted trains such as regional trains would have to pay higher fees if the charging scheme changes.

The cost recovery is clearly higher in a train-kilometre based analysis. Marginal costs per train kilometre cover a higher amount of average costs than marginal costs per gross-ton-kilometre.

We conclude that not only the weight but also the number of trains has a crucial impact on maintenance and renewal costs. A track access charging system which is only based on (marginal) costs per gross-ton-kilometre therefore covers only a part of (marginal) costs. Further research has to be done on the connection of train kilometres and both maintenance and renewal costs.

3.5 Applying quadratic terms

So far we assumed – by applying an appropriate transformation such as log-linear or a Box-Cox transformation – that there exists a constant relation between output and costs. However, it is possible that the relation between output and costs is not linear. We investigate these scale effects by adding in quadratic terms to increase the flexibility of the function.

3.5.1 Estimations including quadratic terms

In our main model of maintenance costs (Contracting A) we find the expected results: While the simple term of gross tones shows a positive coefficient, the quadratic term is slightly negative. This means, that marginal costs reflect a small scale effect with respect to gross-ton-kilometres. So, marginal costs tend to be a little bit smaller on strongly frequented sections than on weakly frequented ones. The quadratic term of gross tones is only significant in combination with the non-quadratic term.[11]

Table 3-5: Estimations results when introducing quadratic terms, Box-Cox model

	Operation and track maintenance (Part of Contracting A)	**Maintenance costs** (Contracting A)	**Renewal costs** (Contracting B)	**Maintenance and renewal costs** (Contracting A+B)
Number of observations	1788	1788	351	1788
λ (lambda)	0.218*** (15.83)	0.160 (12.32)	0.239*** (8.39)	0.178*** (14.83)
Constant	13.155	15.886	38.127	22.76
Transformed variables				
Track length [km]	7.872*** (2026.49)	5.025*** (2767.46)	11.513*** (373.85)	6.944*** (2964.25)
Gross tons [Grt]	0.066 (1.52)	0.140** (3.73)	-0.138 (0.89)	0.033 (0.24)
Quadratic gross tons (Grt)	0.001 (1.35)	-0.000 (0.011)	0.003** (5.13)	0.004** (5.29)
Maximum speed (km/h)	-0.443* (2.88)	-0.221 (2.40)	-1.917** (4.62)	-0.661** (13.96)

***/**/* denote significant variables at the 1/5/10% level. Values in parenthesis correspond to the Chi^2 statistics.

Looking at renewals, we find the opposite effect: The non-quadratic term is negative and non-significant while the quadratic term is positive significant at the 5% level. When we sum up maintenance and renewal costs we find that the quadratic is positive and significant. The non-quadratic term again is not significant but show a positive sign.

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[11] This is tested with a so called linear combination.

3.5.2 Marginal and average costs

By calculating marginal and average costs in the maintenance model we realise that the quadratic terms of gross-ton-kilometres are of impact. Marginal and average costs differ only to a very small degree when adding quadratic terms.

An opposite result can be found for marginal costs in the renewal model (Contracting B): Marginal costs are about 20% higher when using quadratic terms (see results in Table 3-6 and Table 3-2).

Conclusions: In the following analyses we renounce to introduce quadratic terms. Our estimation model has primarily been built for explaining maintenance costs (best data base). However, the model for maintenance costs hardly shows any reaction by introducing quadratic terms, both in estimation and in the calculation of marginal costs.

On the other hand, renewal costs tend to be connected more closely to higher density than maintenance costs. For renewals the assumption of constant marginal costs will have to be analysed further. So far, we can say that the introduction of quadratic terms in renewals raised marginal costs for renewals about 20%. An analysis with more data might lead to more robust results.

Table 3-6: Results when introducing quadratic terms: marginal and average costs per gross-ton-kilometre in CHF

	Operation and track maintenance (Part of Contracting A)	**Maintenance costs** (Contracting A)	**Renewal costs** (Contracting B)	**Maintenance and renewal costs** (Contracting A+B)
Log-linear model				
Marginal costs	0.00042	0.00061	0.00100	0.00149
Average costs	0.00126	0.00292	0.00177	0.00478
Cost recovery (in %)	32.9	21.1	56.1	31.3
Box-Cox model				
Marginal costs	0.00038	0.00061	0.00084	0.00142
Average costs	0.00127	0.00292	0.00172	0.00474
Cost recovery (in %)	30.8	20.6	48.7	30.0

3.6 Conclusions: which model specification should be used for further estimations?

The recent estimations and calculations lead to the following conclusions:

- A Box-Cox model specification is superior to a log-linear specification. The parameter λ (lambda) is highly significant in all estimations.
- Concerning the question whether to prefer a simple or quadratic specification, we go for a simple specification. For our main model, maintenance costs, the estimations results and the marginal costs do not vary. Only for renewal costs a quadratic specification shows different results. However, the differences are too small to exchange our simple specification.
- The question whether to apply gross-ton-kilometres or train kilometres became more important during the project. We focus on gross-ton-kilometres without neglect the potential importance of train kilometres.

4 Extensions of the basic models: analysing different train categories and regional aspects

The different results per gross-ton-kilometre and per train kilometre respectively lead to the hypothesis that marginal costs will also vary for different train categories. Concerning the discussion about future track access charging models the analysis of marginal costs per train category is of great importance. With such a differentiation we can provide empirical evidence for a track access charging scheme with differentiated charges per train category.

We investigate in this chapter in a first step the differences between freight and passenger transport. In a second step we analyse the differences between several train categories.

4.1 Estimations of freight and passenger trains

In our model specification we consider output data (tonnages) for freight and passenger transport. Since the cost data to explain is only available for all train categories together we introduce in our estimation an additional multiplicative term (tonnage_freight multiplied with tonnage_passenger). This additional term takes the dependency between the tonnage in freight transport and the tonnage in passenger transport into account. Including the multiplicative term we will be able to calculate marginal costs for freight transport taking into consideration a fixed level of passenger transport and vice versa calculate marginal costs for passenger transport taking into consideration a fixed level of freight transport. This information is important for discussing the track access charging system for freight and passenger trains in a differentiated way.

The following table shows the marginal costs for freight and passenger transport per gross-ton-kilometre.

Table 4-1: Results for freight and passenger transport: marginal costs per gross-ton-kilometre in CHF, Box-Cox model

	Operation and track maintenance (Part of Contracting A)	**Maintenance costs** (Contracting A)	**Renewal costs** (Contracting B)	**Maintenance and renewal costs** (Contracting A+B)
Freight transport				
marginal costs (at a given level of passenger transport)	0.00024	0.00035	0.00025	0.00055
Passenger transport				
marginal costs (at a given level of freight transport)	0.00032	0.00050	0.00078	0.00130

The calculations in table 4-1 show that marginal costs per gross-ton-kilometre in passenger transport are higher than in freight transport. This result reflects the debate of chapter 3: Gross-ton-kilometres are not the only responsible variable for determining marginal costs. The average weight of a passenger train is by far lower than of an average freight train. In case gross-ton-kilometres are considered to be the only performance-related variable for calculating marginal costs we get substantially higher values for passenger than for freight trains.

Taking a detailed look at table 4-1, we especially see differences between maintenance costs (Contracting A) and renewal costs (Contracting B). Concerning maintenance costs the observed difference between freight and passenger transport is quite small. This suggests that weight, i.e. gross-ton-kilometres are a key factor determining the maintenance needs.

However, we do not see the same picture for renewals: Marginal costs for passenger transport are three times the costs for freight transport. This shows that renewal costs are less weight-dependent than maintenance costs. We conclude that renewals depend more heavily on other factors such as e.g. traffic density. We will investigate this in the following chapter. Our result of higher marginal costs per gross-ton-kilometres in passenger transport is confirmed by European studies.

The following table now shows the marginal costs for freight and passenger transport per train kilometre.

Table 4-2: Results for freight and passenger transport: marginal costs per train kilometre in CHF, Box-Cox model

	Operation and track maintenance (Part of Contracting A)	**Maintenance costs** (Contracting A)	**Renewal costs** (Contracting B)	**Maintenance and renewal costs** (Contracting A+B)
Freight transport				
marginal costs (at a given level of passenger transport)	0.27940	0.41942	0.37223	0.73441
Passenger transport				
marginal costs (at a given level of freight transport)	0.12542	0.21121	0.24732	0.47948

The results of our analysis with train kilometres can be summarised as follows: Marginal costs per train kilometre are higher in freight transport than in passenger transport. This is no surprise. Freight trains on average are considerably heavier than passenger trains. This leads us to the following conclusions. As we have showed before, gross tones are not the only factor to explain marginal costs. However, gross tones are – as indicated in praxis and science – an important cost driver. A deepened analysis shows that on average the relation between the weight of a freight train and a passenger train is higher than the relation between marginal costs per train kilometre of a freight train and a passenger train. This confirms our previous result where we find lower marginal costs per gross-ton-kilometre for freight trains.

An interesting aspect is given by the analysis of renewal costs per train kilometre. Marginal costs for passenger trains are still lower, but the difference is reduced. This again confirms our findings whereas renewal costs are less dependent from weight that maintenance costs.

4.2 Estimations with additional train categories

Given the results in chapter 4.1 the main question is whether a stronger differentiation with additional train categories leads to even more differentiated marginal costs. To answer this question we have data on gross-ton-kilometres for about 40 different train categories. We summarise these data in seven categories.

- Intercity trains (IC trains): intercity trains and international trains
- Regional express trains (RE trains): regional express trains
- Suburban trains (passenger transport): regional and suburban
- Rolling motorway (ROLA)
- Unaccompanied combined transport (UKV)
- Wagon load (WLV)
- Other freight transport

For each section we calculated the fraction of these seven categories. In order to get some sensible results we added to our basic models one variable „fraction of gross tons for train category XY on the total of gross tons“. For each of the seven categories we run a regression. Having the estimated beta coefficients we are able to say whether a high fraction of gross tons for train category XY leads to costs below average or above average. A positive beta coefficient means that a high fraction of gross tons for train category XY increases the maintenance and the renewal costs respectively.

Looking at the results in table 4-3 we see very interesting results per train category. A high fraction of intercity trains (IC) leads to lower maintenance costs (Contracting A) but to significant higher renewal costs (Contracting B). For suburban and regional trains we find in all cost models a positive and significant beta coefficient.

In comparison, unaccompanied combined transport (UKV) and wagon load (WLV) cause costs below average. For rolling motorway (ROLA) we find positive beta coefficients. It is possible that this type of trains cause higher tear and wear costs due to especially small wheels.

Table 4-3: Estimated coefficients for different train categories, Box-Cox model

	Operation and track maintenance (Part of Contracting A)	Maintenance costs (Contracting A)	Renewal costs (Contracting B)	Maintenance and renewal costs (Contracting A+B)
Coefficients in the Box-Cox model				
Fraction of IC trains	-3.736***	-1.693***	7.981*	-0.468
Fraction of RE trains	-0.932	-0.873**	-1.105	-0.848*
Fraction of suburban/ regional trains	3.097***	2.029***	6.749**	3.047***
Fraction of ROLA	11.291**	2.038	18.234	4.672*
Fraction of UKV	-0.739	-0.319	-10.613**	-2.743***
Fraction of WLV	-1.416	-1.309**	-17.811**	-3.989***

***/**/* denote significant variables at the 1/5/10% level.
IC trains = Intercity trains; RE trains = Regional express trains; ROLA = rolling motorway; UKV = unaccompanied combined transport; WLV = wagon load

4.3 Estimations with regional differentiation

In this chapter we investigate whether there are different marginal costs across different regions. We analyse the following regional differentiations:

- In chapter 4.3.1 we analyse whether marginal costs differ between freight corridors and all the other sections. The same aspect we investigate by looking at intercity corridors.
- In chapter 4.3.2 we look at the marginal and average costs in different types of regions: alpine area, Jura (hilly region at the border to France), agglomerations and other sections.

4.3.1 Analysis of freight and intercity corridors

a) Freight corridors versus other sections

The results presented in chapter 4 raise the question whether marginal costs per gross-ton-kilometre differ significantly between the main lines in freight transport (so called freight corridors) and other sections. Our findings so far indicate that sections in freight corridors should have marginal costs below average. In chapter 4.1 we realised that marginal costs for freight transport per gross-ton-kilometre are lower than for passenger transport.

As main freight corridors we define the two corridors Basel-Domodossola via Olten/Bern and Basel-Chiasso via Brugg/Rothrist. Not available are the sections between Spiez and Brig on the route Basel-Domodossola. These sections are not part of the SBB infrastructure.

In order to analyse freight corridors and all other sections we add a dummy variable (1 for sections of the freight corridors; 0 for other sections) to our basic models. The dummy variable is significantly positive. We explain this with a higher fraction of fix costs for sections of the freight corridors.

Table 4-4: Estimations results for freight corridors versus other tracks: Marginal and average costs per gross-ton-kilometre in CHF, Box-Cox model

	Operation and track maintenance (Part of Contracting A)	**Maintenance costs** (Contracting A)	**Renewal costs** (Contracting B)	**Maintenance and renewal costs** (Contracting A+B)
Freight corridors				
Marginal costs	0.00024	0.00039	0.00049	0.00086
Average costs	0.00086	0.00186	0.00115	0.00306
Cost recovery (in %)	28.3	20.9	42.2	28.2
Other sections				
Marginal costs	0.00041	0.00070	0.00082	0.00152
Average costs	0.00150	0.00351	0.00203	0.00564
Cost recovery (in %)	27.1	19.9	40.6	27.0

Table 4-4 shows marginal and average costs. For all cost models, marginal costs of other sections are twice as high as in freight corridors. This confirms our hypothesis. The results from table 4-4 are in line with our findings of chapter 4.1.

b) Intercity corridors versus other sections

Analogous to the observations of freight corridors we analyse marginal costs for intercity corridors versus other track sections. We define those sections as intercity corridors where at least every half an hour an intercity is circulating. Again we are using a dummy variable to differentiate the intercity corridors from the other track sections.

Given the results of chapter 4.2 we assume that maintenance costs for intercity sections are lower than for other sections. More puzzling is the result for renewal costs: the analysis of chapter 4.2 indicates that sections with a high fraction of intercity trains show costs above average.

Overall, the results show a similar picture like the analyses for freight corridors. The sections of the intercity corridors have lower marginal costs than the other sections. While this result is no surprise for maintenance costs (Contracting A), it is a quite interesting result for renewals (Contracting B), given the results in chapter 4.2. At least the difference between sections of the intercity corridors and other sections is lower for renewal costs than for maintenance costs.

Table 4-5: Estimations results for intercity corridors versus other tracks: Marginal and average costs per gross-ton-kilometre in CHF, Box-Cox model

	Operation and track maintenance (Part of Contracting A)	**Maintenance costs** (Contracting A)	**Renewal costs** (Contracting B)	**Maintenance and renewal costs** (Contracting A+B)
Intercity corridors				
Marginal costs	0.00034	0.00054	0.00061	0.00114
Average costs	0.00109	0.00237	0.00154	0.00396
Cost recovery (in %)	31.0	22.9	39.4	28.7
Other sections				
Marginal costs	0.00047	0.00084	0.00078	0.00164
Average costs	0.00158	0.00390	0.00207	0.00605
Cost recovery (in %)	29.6	21.5	37.7	27.1

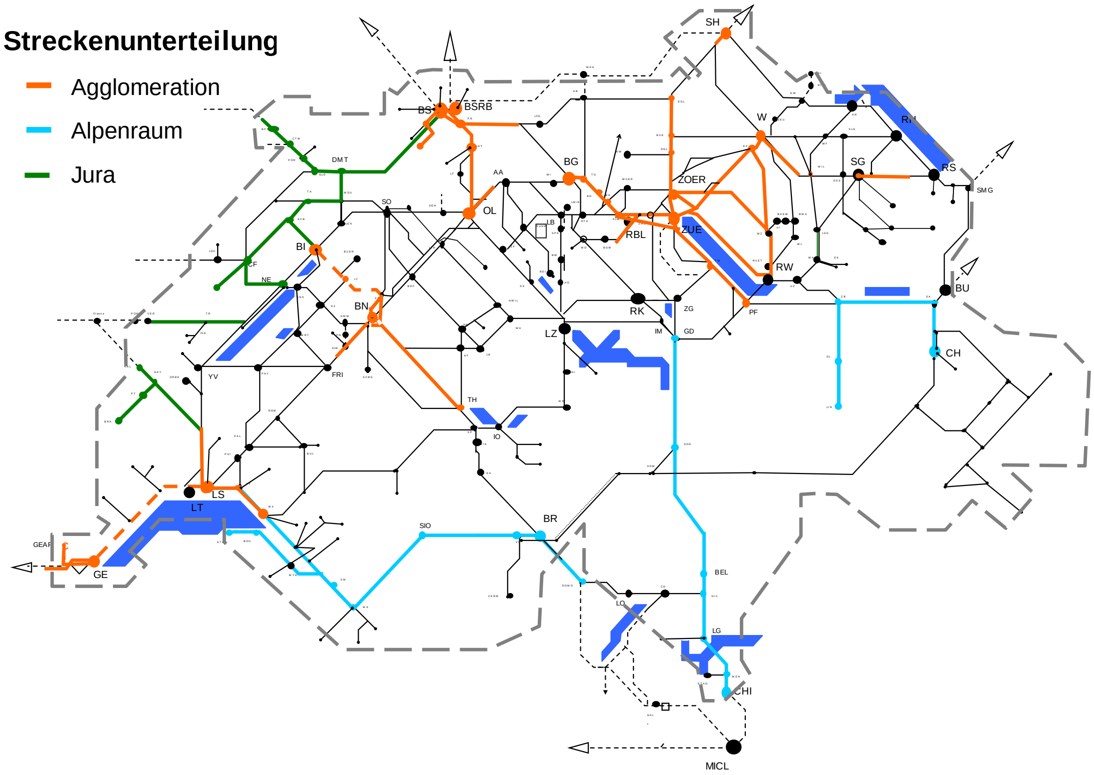
4.3.2 Analysis with respect to different regional types

The goal of the analysis with respect to different regional types is to provide an empirical basis for a differentiation in track access charging. The following regional types have been defined:

- Alpine area (without the „Lötschberg“ sections between Spiez and Brig where no data are available)
- Jura (hilly region at the border to France, without the sections Jura-Südfuss – flat area)
- Agglomerations (including regional nets)
- Other sections (flat area without agglomerations)

To estimate the different types of regions we introduce three dummy variables in the basic model. For calculating marginal costs of each region we sum up the weighted average marginal cost per type of region. Due to this analysis we can do a statement whether and how marginal costs per gross-ton-kilometre differ in the different types of regions. Given the results from chapter 4.1 (differentiation between freight and passenger transport) we clearly expect renewal costs in agglomerations to be above average.

Figure 4-1: Structuring track sections in alpine area, Jura and agglomerations



Discussing the results in table 4-6 for different regional areas, we immediately see the high marginal costs in the Jura. A statistic look at the data explains the result: Both total maintenance and total renewal costs are high in comparison to the number of gross-ton-kilometres. This leads to high marginal and average costs.

In comparison to the results of the basic model which includes all types of sections, the agglomeration section show average marginal costs. When analysing the numbers in detail we observe renewal marginal costs to be slightly above average. The lowest marginal costs are found in the alpine region. At first glance, this result is surprising. We expected higher marginal costs in the alpine region because the difficult topographic situation. However, when taking into account that most topographic aspects are intercepted by other cost driving factors such as slope and curvature and that the alpine region is part of the most important transport corridors the result is less puzzling. In the previous chapter 4.3 we observed freight and intercity corridors to have marginal costs below average. Moreover, in the alpine area with the transalpine transport the fraction of heavy trains is extraordinarily high.

Table 4-6: Results for different regional areas: marginal and average costs per gross-ton-kilometre in CHF, Box-Cox model

	Operation and track maintenance (Part of Contracting A)	**Maintenance costs** (Contracting A)	**Renewal costs** (Contracting B)	**Maintenance and renewal costs** (Contracting A+B)
Alpine area				
Marginal costs	0.00026	0.00046	0.00052	0.00099
Average costs	0.00096	0.00231	0.00136	0.00374
Cost recovery (in %)	27.1	19.8	38.2	26.4
Jura				
Marginal costs	0.00117	0.00170	0.00164	0.00349
Average costs	0.00385	0.00968	0.00503	0.01508
Cost recovery (in %)	23.2	17.6	32.0	23.2
Agglomeration				
Marginal costs	0.00039	0.00061	0.00075	0.00134
Average costs	0.00129	0.00275	0.00166	0.00451
Cost recovery (in %)	30.5	22.0	45.4	29.7
Other sections				
Marginal costs	0.00038	0.00065	0.00075	0.00140
Average costs	0.00133	0.00315	0.00183	0.00505
Cost recovery (in %)	28.9	20.5	34.5	27.6

5 Conclusions

The main findings can be summarised as follow:

1. **Results prove to be robust:** The results of the various estimations and the calculations of marginal and average costs clearly show that they are robust. All estimated models deliver qualitatively similar results, not depending whether we choose a log linear or a Box-Cox specification. This is also true for estimations both with only simple terms and quadratic terms.

   The level of marginal costs varies only slightly when using different model specifications (+/- 10%). This confirms the robustness of our results. Only renewal costs tend to have marginal costs to be higher by 10 to 20% when introducing quadratic terms.

   The comparison of estimated average costs and effective average costs shows the good fit of our results. For all calculated models the difference between estimated and effective average costs is not higher than 10%.

2. **Marginal costs cover one fifth of maintenance costs and two fifth of renewal costs:** In absolute terms marginal costs for maintenance (Contracting A) are found to be 0.00061 CHF (0.00040 €) per gross-ton-kilometre. Renewal costs (Contracting B) are about 0.00071 CHF (0.00048 €) per gross-ton-kilometre. On the other hand, average costs amount to 0.00293 CHF (0.00196 €) for maintenance, and 0.00172 CHF (0.00115 €) for renewal. These numbers indicate that the cost recovery for renewal is almost twice as high as for maintenance (41% versus 21%). We conclude that maintenance costs with respect to gross-ton-kilometres are by far less variable than for renewal costs. Within the work of Contracting A there are a lot of tasks – e.g. the maintenance of power supply lines or of hedges – which obviously have only a small reference to gross-ton-kilometres.

3. **Different marginal costs per gross-ton-kilometre exist for freight and passenger transport:** A key result of our study is that marginal costs per gross-ton-kilometre are higher for passenger transport than for freight transport. Our findings show that a passenger train on average is causing 42% higher marginal maintenance costs per gross-ton-kilometre than a freight train. Considering renewal marginal costs we see that passenger trains cause even more than 200% higher costs than freight trains. A determination of marginal maintenance and renewal costs based only on gross-ton-kilometres which penalises the heavier freight trains seems not appropriate.

4. **Train kilometres should be included in marginal cost analysis:** A limited number of estimations with train kilometres instead of gross-ton-kilometres confirm our finding whereas the weight of trains is an important variable but not the only one to explain marginal costs properly: marginal costs per train kilometre are as to be expected higher for freight transport (50% higher for maintenance and renewal costs). However, freight trains weight on average more than twice as much as passenger trains.

5. **Different marginal costs per kind of track:** Track sections both in freight corridors and in intercity corridors show marginal costs below average (compared to all other sections). This result is further evidence that a large part of maintenance and renewal work is independent from traffic density and has to be done also on less frequented track sections. Therefore, marginal costs per gross-ton-kilometre tend to be higher for less frequented sections than for sections with high traffic density.

6. **Different marginal costs per type of region:** By analysing different types of regions we realise that the highest marginal costs are found for less frequented sections in remote areas in the Jura. Sections in the alpine area and in agglomerations have lower marginal costs. As the Jura region includes the lowest frequented section, these results confirm the results above.

7. **Combined track charges for maintenance and renewal costs:** The above results provide useful results for a more incentive oriented design of track access charges with respect to maintenance and renewal costs. The most important findings can be summarised as follows:
   - Constant track charges per gross-ton-kilometre do not reflect sufficiently the cause-and-effect relation for maintenance and renewal costs. If track charges for maintenance and renewal costs are only based on gross-ton-kilometres heavy trains should have lower charges per gross-ton-kilometre than light trains.
   - More elegant seems to be a combined track charging system for maintenance and renewals costs with a charging component per gross-ton-kilometre and a charging component per train-kilometre.

6 Appendix: Estimation results for the log-linear basic model

Table 6-1: Results of the log-linear estimations of the basic models

	Operation and track maintenance (Part of Contracting A)	**Maintenance costs** (Contracting A)	**Renewal costs** (Contracting B)	**Maintenance and renewal costs** (Contracting A+B)
Number of observations	1788	1788	351	1788
Track length [km]	0.951 *** (55.25)	0.925*** (73.65)	1.111*** (19.34)	0.982*** (78.48)
Gross tons [Grt]	0.291*** (12.07)	0.208*** (12.03)	0.434*** (6.42)	0.283*** (16.28)
Maximum speed [km/h]	-0.035 (-0.46)	-0.011 (-0.21)	-0.300** (-1.70)	-0.112** (-1.96)
Fraction of switch metres of total track length [%]	1.481*** (11.53)	1.203*** (12.81)	1.442*** (4.29)	1.233*** (13.73)
Fraction of bridge metres of total track length [%]	0.042 (0.17)	0.190 (1.19)	1.500*** (2.82)	0.898*** (6.97)
Fraction of tunnel metres of total section length [%]	-0.452*** (-4.97)	-0.235*** (-3.23)	0.139 (0.87)	-0.141* (-1.83)
Fraction of radius metres <500m [%]	0.487*** (5.07)	0.659*** (8.62)	0.789** (2.2)	0.725*** (9.57)
Fraction of slope > 2 percent [%]	0.399*** (4.63)	0.291*** (4.40)	0.238 (1.02)	0.261*** (4.5)
Fraction of track length with noise/fire protection [%]	-0.175 (-0.80)	-0.216** (-1.59)	0.560 (1.11)	0.142 (1.12)
Fraction of platform edge of total track length [%]	0.606*** (4.59)	0.611*** (6.63)	0.593** (2.46)	0.567*** (6.63)
Fraction of sleepers with age > 25 years [%]	0.124** (2.05)	0.135*** (3.07)	0.270 (1.45)	0.204*** (4.70)
Dummy for passenger stations [0/1]	0.345*** (5.84)	0.325*** (7.44)	0.040 (0.19)	0.278*** (6.26)
Dummy for marshalling yards [0/1]	1.016*** (12.11)	1.055*** (15.52)	1.067*** (3.90)	1.015*** (13.66)
Dummy for one-track sections [0/1]	0.088** (2.41)	0.180*** (6.73)	0.143 (1.52)	0.181*** (6.98)
Dummy for 2003 [0/1]	0.195*** (4.83)	0.082** (2.88)	-	0.066** (2.35)
Dummy for 2004 [0/1]	0.163*** (4.35)	0.030 (1.12)	-	0.024 (0.89)
Dummy for 2005 [0/1]	0.172*** (4.52)	0.019 (0.73)	-	0.012 (0.45)
Dummy for 2006 [0/1]	0.038 (0.96)	-0.079** (-2.95)	-	-0.043 (-1.60)
Regional dummies	div.	div.	div.	div.
Constant	4.556*** (10.38)	6.963*** (20.65)	3.366** (2.53)	6.443*** (19.53)

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SIXTH FRAMEWORK PROGRAMME
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Sustainable Surface Transport

CATRIN

Cost Allocation of TRansport INfrastructure cost

D8 – Rail Cost Allocation for Europe

Annex 1C - Marginal costs of rail maintenance and renewals in Austria

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Authors:
Heike Link (DIW)

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1 Introduction

Over the recent years, both a political and academic interest in the estimation of wear & tear costs for rail infrastructure has emerged. First of all, this interest has been motivated by the EU policy of transport infrastructure charging by means of social marginal cost pricing. On the other hand, the separation between infrastructure and transport operations by the national rail companies with track access charges to be paid for using the network has generated a demand on cost estimates. Against this background, several European projects as well as national initiatives have dealt with the estimation of marginal rail infrastructure costs. So far, the available research has produced a rather broad range of elasticities and cost estimates and to some extent diverging results on the shape of the cost curve. A generalisation of these results and policy conclusions require a systematic analysis and comparison of different case studies, and, although various marginal cost studies have been conducted over the recent years, also further cost studies.

Against this background the work reported in this paper attempts to estimate marginal costs for maintenance and renewals of the Austrian rail network, more precisely of the network operated by ÖBB. It refers to WP5 – rail infrastructure cost – of the CATRIN project and belongs to a set of six case studies for the rail sector.

The study is based on a three years cross-sectional data set on maintenance and renewal costs, various types of traffic measures and a set of variables on infrastructure characteristics for the ÖBB network. The purpose of the analysis presented in this report is threefold. First, to test several functional forms such as Cobb Douglas, translog and Box Cox specifications. Second, to test the impact of variables on infrastructure characteristics on costs and to analyse the interaction between these variables with traffic volume. Third, to derive estimates on the cost elasticities and the marginal costs for the Austrian rail network.

The paper is organised as follows: Chapter 2 briefly summarises the state of the art in estimating marginal costs for rail infrastructure. Chapter 3 describes the data. Chapters 4 and 5 introduce the modelling approaches and report the modelling results. Chapter 6 concludes.

2 State of the art

The policy interest at the European level on the one hand and the need for cost estimates to determine track access charges by national rail companies on the other hand, have motivated a number of European projects as well as national studies on the estimation of marginal costs for rail infrastructure. The majority of available research is econometric cost function analysis which attempts to estimate a functional relationship between the costs of maintaining and/or renewing infrastructure and traffic volume, infrastructure characteristics and infrastructure quality.

Most of this type of research has emerged following the seminal paper by Johansson and Nilsson 2002. This study has applied a single-equation reduced translog specification with gross-tonne defined as output of the rail infrastructure whereby the model controls for infrastructure characteristics. The model does not consider factor input prices. Since the advent of this paper, rail infrastructure cost functions have been estimated for Austria (Munduch et al. 2002), Finland (Johansson and Nilsson 2002, Tervonen and Idstrom 2004), Switzerland (Marti and Neuenschwander 2006), Sweden (Andersson 2006 and 2007) and for the UK (Wheat and Smith 2008). Except Johansson and Nilsson 2002, Andersson 2006 (both using reduced translog specifications) and Gaudry and Quinet 2003 (Box-Cox models), all studies use log-linear specifications and gross-tonne kilometres as a single measure of output. Gaudry and Quinet 2003 have applied a generalized Box Cox functional form and have been able to estimate separate cost elasticities and marginal costs for different types of trains. Due to the fact that most studies use gross-tonne kilometres as the single measure of output, the results do not allow for any systematic variation of vehicle characteristics and – in absence of data on freight and passenger trains – do not provide marginal cost estimates for different types of trains. An exception is the study by Gaudry and Quinet 2003 mentioned above, and the attempt to incorporate passenger and freight gross-tonne kilometres variables in Wheat and Smith 2008.

Most studies have attempted to include, as far as such data was available, variables on infrastructure characteristics (for example number of tunnels, bridges, gradients, radii), infrastructure capability and quality (for example maximum line speed, track quality class, maximum axle load allowed) and on the condition of assets (for example ages of rails, sleepers, ballast). Munduch et al. 2002 has also tested interaction terms between infrastructure use and measures of infrastructure characteristics and condition.

A meta-analysis of available studies performed in Link et al. 2008 has shown that the average elasticity of costs with respect to usage and the marginal cost estimates differ considerably between the studies. Even when scaled by the proportion of costs considered in each study, the range of scaled elasticities is still very high (0.07 – 0.26 for maintenance, 0.18 – 0.302 for maintenance plus renewals) and consequently, the range of marginal cost estimates is high too.

This brief review of the state of research reveals several open issues which require further analysis. These include i) the differentiation of estimates for different types of trains, ii) an analysis of the interaction between infrastructure characteristics with usage, and iii) a systematic comparison of different functional forms. The work reported in this paper contributes to the last two issues, while the type of data available does not allow to obtain estimates for different types of trains.

3 The data

The study had access to a three years cross-sectional data set at the level of track sections which was also used in an earlier Austrian study[1] (see Munduch et al. 2002). It contains for each of the years 1998, 1999 and 2000 observations for 220 track sections of the ÖBB network. For each track section, the costs of maintenance and renewals, the gross-tonne kilometres, train-kilometres as well as loaded and empty wagon-axle kilometres is reported. Furthermore, data on infrastructure characteristics (track length, track class, length of single and double track tunnels, bridges, gradients etc.) and on infrastructure condition (age of tracks) is available. The cost data were deflated at 2000 prices[2] and are expressed in Euro. The original dataset was corrected by implausible observations (such as share variables of more than 100%), coding errors and incomplete observations across the three years for some of the sections. The dataset finally used for this case study contains 211 sections, e.g. 633 observations. A detailed list of variables is given in Table 1.

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[1] The delivery of a new dataset by ÖBB covering the years 2005-2007 was delayed until October 2008 and was therefore too late for this case study.

[2] We have used the construction price index as deflator (1.11 and 1.06 for 1998 and 1999 respectively).

Table 1: Type of variables

Variable	Description	Unit of measurement
Cost data		
C1	Maintenance costs	€
C2	Renewal costs	€
Usage data		
q1_km	Total train kilometres	
q1_km_el	Train kilometres in electrified traction	
q2_km	Gross-tonne kilometres total	
q2_km_el	Gross-tonne kilometers in electrified traction	
q3_km_loaden	Wagon-axle kilometres of loaded wagons	
q3_km_empty	Wagon-axle kilometres of empty wagons	
Infrastructure characteristics		
l	Track length[1)]	km
tun_1	Length of single tracked tunnels	m
tun_2	Length of double tracked tunnels	m
snum_main	Number of switches	
sl_main	Length of switches	m
snum_sec	Number of switches at shunting tracks	
sl_sec	Length of switches at shunting tracks	m
stat	Station tracks	% of track length
r_250	Track radius of less than 250m	% of track length
r_500	Track radius of less than 500m	% of track length
grad_10_20	Tracks with a gradient between 10% and 20%	% of track length
grad_20	Tracks with a gradient of more than 20%	% of track length
Infrastructure capability		
age_5_15	Tracks with an age between 5 and 15 years	% of track length
age_15_25	Tracks with an age between 15 and 25 years	% of track length
age_25	Tracks with an age of more than 25 years	% of track length
Additional information on maintenance expenditures		
exp1	Average expenditures for protection against avalanches and falling rocks	€
exp2	Average expenditures for bridges	€
exp3	Average expenditures for crossings	€

[1)] Refers to genuine track length, e.g. the section length for double-tracked sections is twice the track length reported here.

Source: ÖBB.

Maintenance expenditure as described in this dataset refers to inspection, ongoing maintenance, winter maintenance, fault clearance and repairs. It covers the following infrastructure assets: Subgrade, tracks, engineering constructions such as tunnels and bridges, electric and signalling equipment, information and telecommunication equipment, radio communication equipment, control & safety technology, energy supply, overhead wiring.

Table 2 gives a descriptive summary of the data. The average track length in our sample is 33 km, with the smallest sections amounting at 0.4 km and the longest at 185 km. On average over the sections and the three years, ÖBB has spent € 9.68 million for maintaining the tracks. The topographic situation of the Austrian rail network is reflected in the variables *grad*, *tun* and *r_500*. 17% of an average track section has a gradient of more than 10%, 20% has a radius of less than 500 m and 4.5% of an average track section contains tunnels (one- or double-tracked tunnels). Over the observation period (1998-2000), the average cost related to gross-tonne km was 0.0022 €, expressed at 2000 prices. This figure was cross-checked with Munduch et al. 2001[3] and with new data from ÖBB for the period 2005-2007 and is consistent with these sources.

Table 2: Descriptive statistics

Variable	Observations	Mean	Std. Dev.	Minimum	Maximum
C1$^{*)}$	633	703228.31	733272.19	1396.92	4152673.04
C2$^{*)}$	633	167478.09	340507.19	0.00	3880920.47
q1_km	633	690467.19	932721.85	947.00	5659281.00
q2_km	633	319037848.00	537511004.00	63601.00	5659281.00
q3_km	633	24990251.00	42637370.30	43332.00	304887496.00
q1	633	24252.09	30185.91	246.90	395534.29
q2	633	10057950.60	42637356.60	64.0	179302031.0
q3	633	801590.82	1149864.03	160.0	15433297.10
l	633	33.29	31.72	0.40	185.00
stat	632	27.12	22.22	0.00	97.75
age_25	628	23.95	24.85	0.00	97.46
grad$^{1)}$	633	17.48	26.33	0.00	100.00
tun$^{2)}$	627	4.50	21.60	0.00	26.17
r_500	633	19.28	20.00	0.00	100.00

$^{*)}$ Expressed in € at 2000 prices.- $^{1)}$The variable grad is the sum of grad_10-20 and grad_20. – $^{2)}$ The variable tun is the sum of the variables tun_1 and tun_2, divided by track length and is given as % variable .

Source: Own estimations.

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[3] Munduch et al. 2001 give a total maintenance cost of 6129097193 Austrian Schilling (table 2.4) and total gross-tonne km of 202000 million (table 2.4) which yields an average cost of 0.03033 Austrian Schilling (e.g. 0.0022€).

4 Modelling issues

Preliminary analysis has revealed various problems with modelling renewal costs. We focus in this study therefore on maintenance costs only. For our modelling work we assume that the level of maintenance cost on a track section is influenced by a variety of factors, foremost by output, e.g. traffic, factor input prices but also by infrastructure characteristics, infrastructure condition, climate and managerial skills. We can therefore formulate a relationship between the costs for infrastructure maintenance (***C***), the level of output (**q**) and a vector of factor input prices (**p**), other characteristics of the infrastructure (**z**) and dummy variables (**d**) as

$$C = f\,(\mathbf{q}, \mathbf{p}, \mathbf{z}, \mathbf{d}). \qquad (1)$$

We have reasons to believe that spatial variation in factor prices can be neglected for our analysis due to regulated salary agreements across ÖBB and in-house production of maintenance services. We will therefore exclude the factor price vector **p** from our model. This means that we test single-equation models without share equations for factor inputs. For our modelling work we have chosen three functional forms:

- Cobb Douglas cost function,
- Translog cost function,
- Box Cox cost function.

1. Cobb Douglas cost function (loglinear model)

The **log-linear regression model** which corresponds with a Cobb-Douglas cost function is given in expression (2), where i denotes observations, t time and ε are the residuals. $\alpha, \beta, \delta, \gamma$ are the parameters to be estimated.

$$\ln C_{it} = \alpha + \beta \ln q_{it} + \delta \ln z_{it} + \gamma d_{it} + \varepsilon_{it} \qquad (2)$$

We use this form for three different models regarding the type of traffic variable(s) q included, namely for $q1$ (number of trains), $q2$ (gross tonnes) and $q3$ (wagon-axles). In the following, we describe the model in general form for q. Initial analysis has indicated that for the vector of infrastructure characteristics (**z**) the variables *l, age_25, stat, grad, tun* and *switch* should be included. Furthermore, the variables *exp1, exp2* and *exp3* give additional information on the average expenditures for specific infrastructure components such as bridges, lehnen and crossing and are used to control for the level of maintenance costs at such sections where an extraordinary level of expenses for maintaining such infrastructure components might be spent.

$$\begin{aligned}\ln C_{it} &= \alpha_0 + \alpha_1 class_{it} + \alpha_2 \ln \exp 1_{it} + \alpha_3 \ln \exp 2_{it} + \alpha_4 \ln \exp 3_{it} + \alpha_5 d\_1999 + \alpha_6 d\_2000 \\ &+ \beta_1 \ln q_{it} + \beta_2 \ln l_{it} + \beta_3 \ln stat_{it} + \beta_4 \ln switch_{it} \\ &+ \beta_5 \ln grad_{it} + \beta_6 \ln tun_{it} + \beta_7 \ln age\_25_{it}\end{aligned} \tag{3}$$

The cost elasticity in the log-linear model (3) is the derivative of the cost function with respect to the variable of interest. If the model does not include higher-order or interaction terms, the elasticities for our traffic variables q1, q2 and q3 are expressed in general form as

$$\frac{\partial \ln C_{it}}{\partial \ln q_{it}} = \hat{\beta}_1 = \hat{\phi}^{LL} \tag{4}$$

2. Translog cost functions

The most popular functional form for cost function analysis has been the translog cost function. In contrast to the loglinear form it includes second-order and interaction terms and allows therefore to analyse the impact of influence factors in their interaction. In this case study we have tested the following translog model which includes all of our relevant variables

$$\begin{aligned}\ln C_{it} &= \alpha_0 + \alpha_1 class_{it} + \alpha_2 \ln \exp 1_{it} + \alpha_3 \ln \exp 2_{it} + \alpha_4 \ln \exp 3_{it} + \alpha_5 d\_1999 + \alpha_6 d\_2000 \\ &+ \beta_1 \ln q_{it} + \beta_2 \ln l_{it} + \beta_3 \ln stat_{it} + \beta_4 \ln switch_{it} \\ &+ \beta_5 \ln grad_{it} + \beta_6 \ln tun_{it} + \beta_7 \ln age\_25_{it} + \frac{1}{2}(\gamma_1 \ln^2 q_{it} + \gamma_2 \ln^2 stat_{it} \\ &+ \gamma_3 \ln^2 switch_{it} + \gamma_4 \ln^2 grad_{it} + \gamma_5 \ln^2 tun_{it} + \gamma_6 \ln^2 age\_25_{it}) \\ &+ \delta_1 \ln q_{it} \cdot \ln stat_{it} + \delta_2 \ln q_{it} \cdot \ln switch_{it} + \delta_3 \ln q_{it} \cdot \ln grad_{it} \\ &+ \delta_4 \ln q_{it} \cdot \ln tun_{it} + \delta_5 \ln q_{it} \cdot \ln age\_25_{it}\end{aligned} \tag{5}$$

Since we expected that this full cost model might not be significant in all of the parameters, we have also tested several reduced forms which exclude specific infrastructure characteristics both from the first- and second-order terms and from the interaction terms.

The cost elasticity in the translog model (5) with respect to traffic is non-constant and can be expressed as

$$\frac{\partial \ln C_{it}}{\partial \ln q_{it}} = \beta_1 + \gamma_1 \ln q_{it} + \delta_1 \ln stat_{it} + \delta_2 switch_{it} + \delta_3 \ln grad_{it} + \delta_4 \ln tun_{it} + \delta_5 \ln age\_25_{it} \tag{6}$$

3. Box-Cox models

Both the log-linear and the translog model impose a restriction on our model as it assumes that the most efficient transformation of our data is logarithmic. An alternative model to the logarithmic transformation is the **Box-Cox regression model**, making use of the formula for variable transformation by Box and Cox (Greene, 2003).

$$w^{(\lambda)} = \frac{w^{\lambda} - 1}{\lambda} \tag{15}$$

For λ to be defined for all values, w must be strictly positive. The benefit of using the Box-Cox transformation is that it includes the log transformation as a special case. All Box-Cox models described below, use a common transformation parameter for both the left and right-hand side.

$$\begin{aligned} C_{it}^{(\lambda)} &= \alpha_0 + \alpha_1 class_{it} + \alpha_2 d\_1999 + \alpha_3 d\_2000 \\ &+ \beta_1 q_{it}^{(\lambda)} + \beta_2 l_{it}^{(\lambda)} + \beta_3 stat_{it}^{(\lambda)} + \beta_4 switch_{it}^{(\lambda)} + \beta_5 grad_{it}^{(\lambda)} \\ &+ \beta_6 tun_{it}^{(\lambda)} + \beta_7 age\_25_{it}^{(\lambda)} + \beta_8 \exp 1_{it}^{\lambda} + \beta_9 \exp 2_{it}^{(\lambda)} + \beta_{10} \exp 3_{it}^{(\lambda)} \end{aligned} \tag{7}$$

In these models, traffic (*q*) and infrastructure variables (*l, stat, rad_500, grad, tun, age_25*) are transformed, while the constant, variables with genuine zeros and dummy variables (d) are left un-transformed. The elasticity in the Box-Cox model includes the estimated transformation parameter λ and is expressed as

$$\frac{\partial \ln C_{it}}{\partial \ln q_{it}} = \hat{\beta}_1 \left(\frac{q_{it}}{C_{it}} \right)^{\hat{\lambda}} = \hat{\phi}_{it}^{BC} \tag{8}$$

This elasticity will be non-constant and vary with traffic and cost level.

5 Modelling results

5.1 Econometric specification

We have attempted to estimate three types of functional forms, e.g. Cobb-Douglas, Translog and Box-Cox models. As to be expected, a systematic comparison of models is restricted by the fact that each model class includes a different set of significant variables. In particular, the translog model failed to estimate significant second order terms and interaction terms between traffic and infrastructure characteristics (except for the variable *stat*) and failed to estimate models for the number of trains and the number of wagon-axles. Nevertheless, for both the loglinear and the Box-Cox model we found a common set of significant variables. These commonly significant variables are apart from the traffic variables: the track length, the age of tracks, the share of tunnels, the number of switches, the class of the track section and the control variables *exp1, exp2, exp3* as well as the dummy variables for the years. Note, that some of the variables had to be aggregated in order to yield significant estimates. For example we had to aggregate the two gradient variables *grad_10_20* and *grad_20* into one variable grad. Furthermore, we found only for one of the three age variables a significant relationship with the level of maintenance costs (*age_25*).

Table 3: Estimation results – Loglinear model (model 1)

	parameter estimate	significance level	parameter estimate	significance level	parameter estimate	significance level
	Trains (q1)		Gross-tonnes (q2)		Waggon-axles (q3)	
AIC	2.25		2.15		2.17	
R^2	0.704		0.732		0.728	
Const.	0.07943	0.1971	-0.07907	0.5470	-0.01145	0.9303
q	0.20158	0.0000	0.35472	0.0000	0.33023	0.0000
l	0.97147	0.0000	0.89718	0.0000	0.89712	0.0000
stat	-0.11417	0.0144	-0.21277	0.0000	-0.21222	-
age_25	0.03538	0.0887	0.06420	0.0014	0.05947	0.0032
tun	-0.06381	0.0697	-0.11815	0.0005	-0.11792	0.0005
switch	0.45281	0.0000	0.42025	0.0000	0.43152	0.0000
exp1	0.07890	0.0065	0.07545	0.0070	0.07988	0.0046
exp3	0.08858	0.0007	0.13490	0.0000	0.13623	0.0000
class	-	-	0.47833	0.0136	0.41674	0.0000
d_2000	-0.20536	0.0011	-0.18721	0.0000	-0.17714	0.0033

Source: Own estimations.

The finally estimated models are as follows:

1. Loglinear model (model 1) with the variables *q, l, stat, age_25, tun, switch, exp1, exp2, exp3* as log-variables and the untransformed variable *class* and the dummy variable for 2000, estimated for each of the three traffic variables *q1*, *q2* and *q3*.
2. Translog model (model 2) with the first order terms for *q, l stat, exp1, exp3,* the second-order terms for *q* and *stat* and an interaction term between *q* and *stat,* plus the untransformed variable *class* and the dummy for 2000, estimated for each of the traffic variable *q2* (models with *q1* and *q3* failed).
3. Box-Cox model (Model 3) with the BC-transformed variables *q, l, age_25, grad, tun, switch, exp1, exp3* and the untransformed variable *class* and the dummies for 1999 and 2000, estimated for each of the three traffic variables *q1, q2* and *q3.*

Table 4: Estimation results – translog model (model 2)

	gross tonnes (q2)	
	parameter estimate	significance level
AIC	2.295	
R^2	0.697	
Const.	-0.49237	0.0050
q	0.30015	0.0000
l	0.74805	0.0000
stat	-0.31035	0.0017
exp1	0.05201	0.0000
exp3	0.10357	0.0002
q_sq	0.03607	0.1291
stat_sq	-0.05102	0.3944
q*stat	-0.058994	0.0288
class	0.24328	0.0005
d_1999		0.0000
d_2000	-0.17503	0.0013

Source: Own estimations.

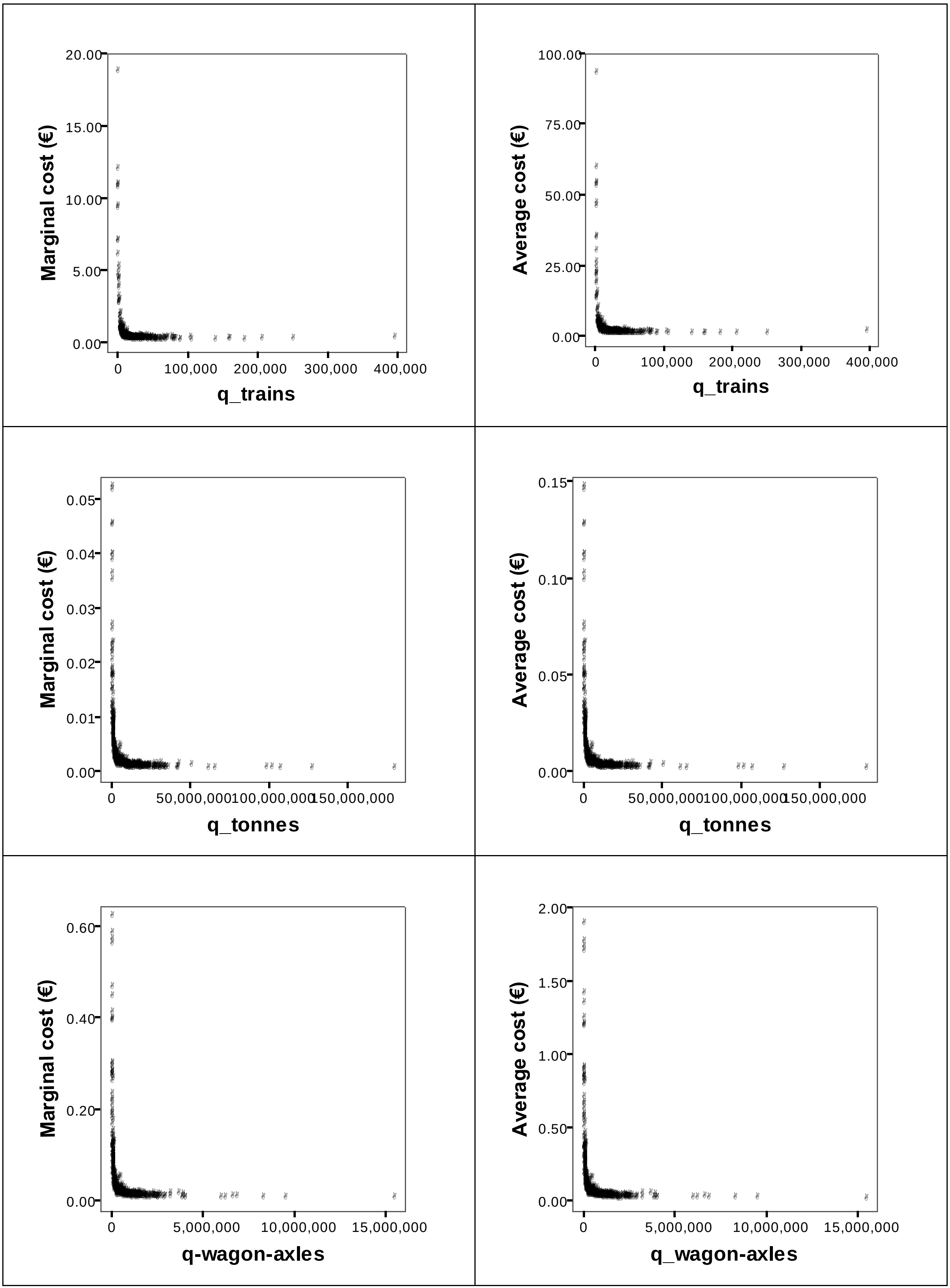
The tables 3-5 summarise the parameter estimates and the model characteristics for the loglinear, Box-Cox and Translog models. Both the loglinear and the translog models have an R^2 of around 70%, e.g. a good fit for such type of cross-sectional analysis. The parameter estimates are significant for most of the variables at 5% level (except the constant in all loglinear models, and the squared terms for *q* and *stat* in the translog model). However, the estimate of the transformation parameter λ in all Box-Cox models is significantly different from zero (0.2727 for the BC models with the number of trains and the gross-tonnes and 0.2929 for the BC model with wagon-axles). Consequently, the logarithmic transformation of our dependent variable and of the transformed independent variables has to be rejected. Furthermore, the BC models include apparently a larger set of significant variables than the loglinear and the translog specification and are characterised by a higher significance level.

Table 5: Estimation results - Box-Cox model (model 3)

	parameter estimate	significance level	parameter estimate	significance level	parameter estimate	significance level
	Trains (q1)		Gross-tonnes (q2)		Waggon-axles (q3)	
Log L	-154.46		-155.15		-168.66	
AIC	1.47		1.48		1.49	
R^2	0.776		0.773		0.769	
λ	0.272730	0.0000	0.272730	0.0000	0.29293	0.0000
Const.	0.270258	0.0042	0.254010	0.0088	0.44057	0.0000
q	0.438449	0.0000	0.381532	0.0000	0.32213	0.0000
l	0.700525	0.0000	0.657782	0.0000	0.66068	0.0000
stat	-0.063205	0.0191	-	-	-	-
age_25	-	-	0.047630	0.0011	0.04807	0.0017
tun	-0.026739	0.0210	-0.039922	0.0000	-0.04393	0.0003
grad	0.026011	0.0232	0.030893	0.0077	0.03677	0.0018
switch	0.101439	0.0002	0.128819	0.0000	0.13034	0.0000
exp1	0.087299	0.0000	0.080542	0.0000	0.08379	0.0000
exp2	0.030216	0.0827	0.043950	0.0121	0.04748	0.0097
exp3	0.068721	0.006	0.107627	0.0000	0.10572	0.0001
class	0.122689	0.0577	0.172997	0.0136	-	-
d_1999	-0.132689	0.0061	-0.114847	0.0185	-0.11762	0.0168
d_2000	-0.224793	0.0000	-0.212880	0.0000	-0.20450	0.0000

Source: Own estimations.

Figure 1: Marginal and average costs -loglinear model (model) 1)



1) Based on predicted costs. Both average and marginal costs refer to train-km, gross-tonne km and wagon-axle km.

Source: Own estimations.

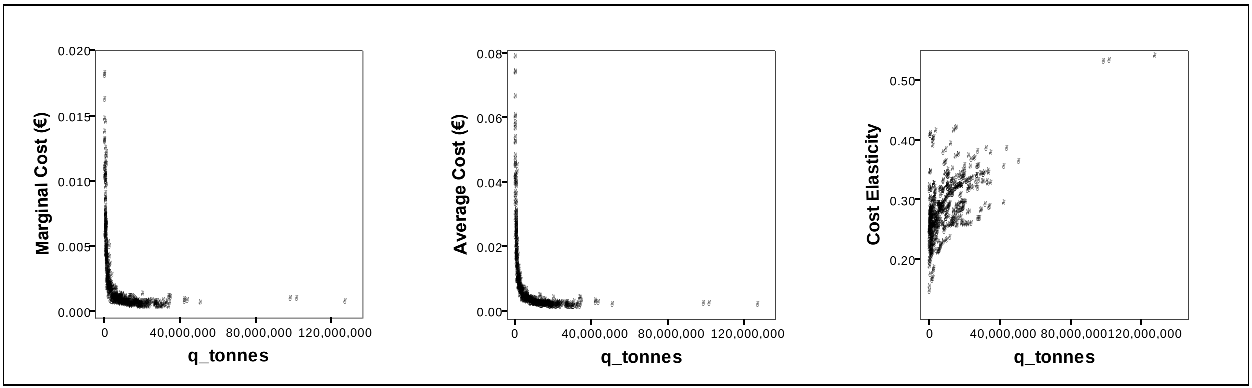
All variables on infrastructure characteristics have a positive, e.g. cost increasing relationship to maintenance costs. An exception is the tunnel variable which has a negative sign, a result which was also found in the Swiss CATRIN case study (Marti et al. 2008) and in an earlier Austrian study (Munduch et al. 2001). An explanation for this is the fact that tunnels provide a natural protection against snow and rain which reduces maintenance costs. A further exception is the station variable with a negative sign, again a result which was also found in Munduch et al. 2001. We explain this result by a similar argument as for the tunnels.

Regarding the type of traffic measure used as explanatory variable we found that for both the loglinear and the Box-Cox specification, models with gross-tonnes yield the highest R^2 and LogLikelihood, e.g. contribute most to the explanatory power (except the BC model with trains).

5.2 Cost elasticities, average and marginal costs

Figures 1-3 show the cost elasticities, average and marginal costs for the loglinear model, the translog model and the Box-Cox model. We found for both the translog and the Box-Cox model a digressively increasing cost elasticity while for the loglinear model the elasticity is per definition constant. For all three model classes, marginal costs are falling. Note, that the cost elasticity refers to the number of trains, gross-tonnes and wagon-axles respectively, while average and marginal costs are expressed in € per train-km, gross-tonne km and wagon-axle km.

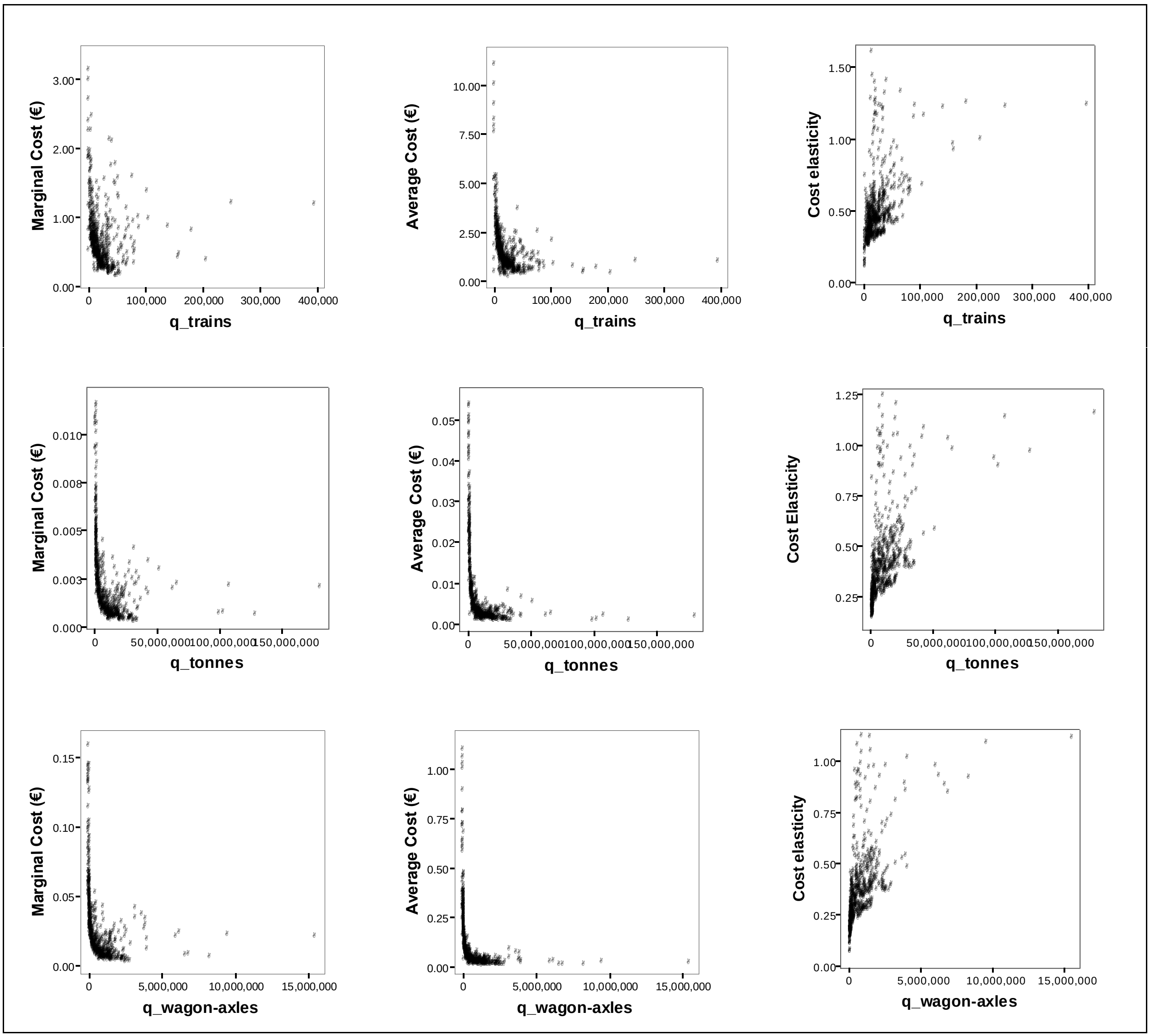
Figure 2: Cost elasticity, marginal and average costs - translog model (model 2) 1)



1) Based on predicted costs. While the cost elasticity refers to traffic volumes, both average and marginal costs refer to train-km, gross-tonne km and wagon-axle km

Source: Own estimations.

Figure 3: Cost elasticity, marginal cost and average costs –Box-Cox model (model 3)[1]



[1] Based on predicted costs. While the cost elasticity refers to traffic volumes, both average and marginal costs refer to train-km, gross-tonne km and wagon-axle km.
Source: Own estimations.

Table 6 gives the mean and median values for the estimated cost elasticities and the weighted average cost elasticity, calculated as

$$\hat{\Phi}^{weighted} = \Sigma_{it}\left[e_{it}\cdot\frac{q_{it}}{\Sigma_{it}q_{it}}\right] \qquad (9)$$

Furthermore, the lower part of table 6 contains the predicted and observed average cost, related to the density measures train-km, gross-tonne km and wagon-axle km, as well as marginal costs based on predicted and observed costs. The estimates of marginal costs for each observation *i* was derived by using the elasticity estimates and the predicted cost $\hat{C}$

$$MC_{it} = \hat{\phi}_{it} \cdot \frac{\hat{C}_{it}}{q_{it}}, \tag{10}$$

where *i* is the observation, *t* is time and *q* represents the traffic variable. For expressing marginal costs related to train-km, gross-tonne km and wagon-axle km, we have used the expression

$$MC = \frac{\partial C}{\partial q^{km}} = \frac{\partial \ln C}{\partial \ln q^{km}} \cdot \frac{C}{q^{km}} = \frac{\partial \ln C}{\partial \ln q} \cdot \frac{C}{q^{km}} = \phi_{it} \cdot \frac{C}{q^{km}} \tag{11}$$

In order to adjust for the variation of marginal costs over the sections, a weighted average marginal cost (lower part of table 6) was calculated analogous to the weighted average elasticity as

$$WMC = \Sigma_{it}\left[MC_{it} \cdot \frac{q_{it}}{\Sigma_{it} q_{it}}\right] \tag{12}$$

A comparison of the figures presented in table 6 and in figures 1-3 leads to the following observations:

- First, the Box-Cox model produces for each of the three traffic variables the highest elasticity figures and leads therefore to the highest marginal cost figures.
- Second, the elasticity figure of 0.55 for gross-tonnes (weighted average) is a relatively high value compared to the results from the other CATRIN case studies (where the French study obtains the highest elasticity of 0.4) while the results from the loglinear model seem to be more in line. However, as table 6 shows the (unweighted) mean and median cost elasticities are considerably lower, indicating that using the weighting scheme from eq. (9)appears to drive the elasticity figure upwards. This impact is particularly strong for the Box-Cox model.
- Third, the Box-Cox model achieves out of all models the highest precision in predicting average costs, e.g. the lowest deviation between predicted and observed average cost (see table 6).
- Fourth, marginal costs derived with respect to train-km are about 490 times higher than those derived for gross tonne-km (based on the weighted average marginal cost, Box-Cox model). This would mean that in a marginal cost pricing scheme based on gross tonne-km, a train with a weight of around 490 tons would have to pay the same charge as in a

train-km based charging scheme while trains above this weight would be favoured and trains below this weight range would be disfavoured.

Table 6: Cost elasticity, average and marginal cost – Model comparison

	Loglinear (model 1)		Translog (model 2)		Box-Cox (model 3)	
	Predicted C	Observed $C^{1)}$	Predicted C	Observed $C^{1)}$	Predicted C	Observed $C^{1)}$
Cost elasticity						
- number of trains -						
weighted average	0.2016	0.2016	-	-	0.6108	0.5840
mean	0.2016	0.2016	-	-	0.4929	0.5128
median	0.2016	0.2016	-	-	0.4357	0.4296
- gross tonnes -						
weighted average	0.3547	0.3547	0.3175	0.3175	0.5534	0.5284
mean	0.3547	0.3547	0.2839	0.2811	0.3996	0.4198
median	0.3547	0.3547	0.2756	0.2761	0.3663	0.3545
- wagon-axles -						
weighted average	0.3302	0.3302	-	-	0.5185	0.4988
mean	0.3302	0.3302	-	-	0.3657	0.3851
median	0.3302	0.3302	-	-	0.3324	0.3198
Average cost (weighted average)						
Train-km	0.9104	1.1804			1.0422	1.2344
Gross-tonne km	0.0022	0.0028	0.0023	0.0030	0.0025	0.0029
wagon-axle km	0.0270	0.0350			0.0308	0.0367
Marginal cost						
- Train-km -						
weighted average	0.1835	0.2379			0.5940	0.6346
mean	0.5105	0.4665			0.7195	0.8411
median	0.2051	0.2376			0.5660	0.5296
- Gross-tonne km -						
weighted average	0.0008	0.00098	0.00068	0.0009	0.0012	0.0013
mean	0.0035	0.0042	0.0024	0.0029	0.0026	0.0028
median	0.0011	0.0013	0.0009	0.0010	0.0015	0.0015
- wagon-axle km -						
weighted average	0.0089	0.0115			0.0137	0.0145

mean	0.0422	0.0495			0.0307	0.0328
median	0.0133	0.0154			0.0181	0.0179

1) Differences in observed average costs between the models are caused by a different number of observations in each model.

Source: Own estimations.

5 Conclusions

This case study has analysed the cost behaviour of rail maintenance work at the Austrian ÖBB network based on cross-sectional data for the years 1998-2000. We have estimated three types of models: Loglinear, translog and Box-Cox models. Each of these models was estimated with three types of traffic variables (number of trains, gross tonnes and wagon-axles, except the translog model which could only estimated for gross-tonnes), a set of variables on infrastructure characteristics and dummy variables for the influence of observation years. All models have produced significant parameter estimates and a good model fit. The transformation parameter λ in the Box-Cox models was for all types of traffic variables significantly different from zero, e.g. for our data the log transformation was rejected. Furthermore, the Box-Cox model has proven as the model with the best prediction of cost.

All models have estimated a positive relationship between traffic and maintenance cost and a positive, e.g. cost-increasing effect of infrastructure characteristics such as the class of tracks, the gradient, the age of tracks and the length of switches on a section. For the share of tunnels and of station tracks on a section we have obtained a negative relationship to the level of maintenance costs.While the cost elasticity in the loglinear model is constant per definition, we found for the translog and the Box-Cox model an increasing cost elasticity curve. For all three model types, marginal costs are falling with usage. All models with gross-tonnes produced the highest R^2 and LogLikelihood respectively.

The fact that we have estimated a significant transformation parameter λ which rejects the log transformation, together with the better prediction of costs by the Box-Cox model, leads to a preference for this model, even though it produces, compared to other CATRIN case studies, rather high cost elasticity and marginal cost estimates. In this context it should be borne in mind that the type of average measure for the cost elasticity influences considerably the level of cost elasticity. Using a weighted average elasticity implies for our sample a rather high value for the cost elasticity (0.55 - related to gross-tonnes) while using the unweighted average or the median leads to figures of 0.399 and 0.366.

Average weighted marginal costs per gross tonne-km amount at 0.0012 € (Box-Cox model). The figures derived from the loglinear and the translog model are considerably lower (0.0008 €/gross-tonne km and 0.0007 €/gross-tonne km respectively) due to the lower elasticity but should be treated cautiously since the precision to predict average costs is lower in these models. A further finding is that marginal costs derived with respect to train-km exceed those for gross tonne-km by a factor of 490 (BC model). This means that in a marginal cost pricing scheme based on gross tonne-km, a train with a weight of around 490 tons would have to pay the same charge as in a train-km based charging scheme while trains above this weight would be favoured if prices are derived from gross tonne-km estimates but used for a train-km price.

There remain issues for further research. First, Box-Cox models with different transformation parameters for the left- and right-hand side should be tested and compared with Box-Cox models estimated in this case study which include the same transformation parameter for all variables. Second, the results reported here should be compared with an analysis of the new Austrian dataset for the period 2005-2007.

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CATRIN -- Cost Allocation of TRansport INfrastructure cost

SIXTH FRAMEWORK PROGRAMME
PRIORITY 1.6.2
Sustainable Surface Transport

CATRIN

Cost Allocation of TRansport INfrastructure cost

D8 – Rail Cost Allocation for Europe

Annex 1Di – Track Maintenance Costs in France

Version 2.1
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Authors:
Marc Gaudry (INRETS and Université de Montréal) and Emile Quinet (PSE-ENPC)

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Project summary

CATRIN is a Research project to support the European Transport Policy, specifically to assist in the Implementation of Transport pricing. CATRIN will increase the probability that new progressive pricing principles can be implemented which facilitate a move towards sustainable transport. CATRIN is both intermodal and interdisciplinary, emphasizes the need of new Member states, understands that different organisational forms require different recommendations, that recommendations need to be given in short and long-term perspective and that they have to be thoroughly discussed with infrastructure managers.

CATRIN will clarify the current position on allocation of infrastructure cost in all modes of transport. Pricing principles will be dealt with under the knowledge that they vary with the organisational structure of a sector. CATRIN will establish the micro-aspects of cost recover above marginal costs, including the results of applying a club approach and the implication of who bears the costs for cost recovery under alternative allocation rules, using game theoretic analytical tools.

CATRIN will develop the understanding of policy need of new Member states and can give tailored recommendations. In a modal focus, with real world cases, CATRIN will develop proxies to marginal costs and test some of the allocation approaches. Based on engineering studies, CATRIN will analyse the possibility to define more differentiated pricing rules for vehicle/locomotive categories. Partners with strong engineering knowledge are included and CATRIN will blend the economic principles of pricing with engineering knowledge. CATRIN will outline the possibilities for a European Road Damage test that will give new evidences on the fourth-power-rule. CATRIN will develop financing alternatives for icebreaking and will explore cost allocation in the aviation sector. Finally, CATRIN will strongly address the implementation potential and constraints experienced by infrastructure managers.

1 Introduction

The purpose of this analysis is to present econometric estimates and derived calculations made about rail maintenance costs in France: indeed, many European countries have provided estimates of railway infrastructure maintenance functions, most of which also obtained from econometric studies of these maintenance costs. Among surveys of these studies, one finds notably that:

- Wheat & Smith (2008) show dispersion among both methods and results. Methods differ according to the measures of traffic, to the technical variables describing the state of the infrastructure, and according to the mathematical specification of the cost function. Results, expressed in terms of ***elasticities of costs to the traffic*** and in terms of ***marginal costs***, vary rather widely;

- Abrantes *et al.* (2007), drawing conclusions from these differences, propose an agenda for further research to clarify various questions, such as:

1. Why do estimates of ***usage elasticity*** differ so much among countries?
2. Why do estimates of ***marginal costs*** differ so much among countries?
3. Do ***usage elasticity and marginal cost fall indefinitely*** with traffic levels, or is that result purely due to limitations in model specification and data availability?

and recommend in particular a new focus on:

4. Better usage and elasticity and marginal cost estimates obtained as a function of ***vehicle characteristics*** and ***type of traffic***;
5. More systematic account of the role of ***infrastructure characteristics***, capability and condition measures;
6. Further studies of ***renewals costs***.

This study aims at being a part of this agenda, building further on existing French results (presented in Gaudry & Quinet, 2003) which are rather at odds with the other studies according to their data, methods and results. Using the same French data for 1999, we will here process them through methods similar to those used in other countries in terms of specification of the cost function and in terms of the exogenous variables used, in particular the number of traffic categories considered. Analysing how the results depend on these hypotheses will hopefully enable to shed light on points 4 and 5, and to contribute to points 1, 2 and 3.

Section 2 is devoted to a review of the available literature on the subject for France: it is more detailed than such surveys usually are because the results need to be presented at some length due to the fact that none are yet published in scientific journals and also because they provide the effective baseline for the work carried out here. Section 3 will be devoted to a summary presentation of the French 1999 data structured in ways that make it as comparable as possible to what is available in other European studies. Building on the results of these two previous sections, Section 4 summarizes the methodology to be used for both statistical and economic results of the modelling exercises.

Section 5 purports to summarize some key CATRIN-inspired streams of results obtained by going well beyond the baseline specifications and suggests hypotheses for explaining some differences remaining with results found in other European studies. A short conclusion precedes two appendices.

2 Literature review for France

A. Fixed *vs* flexible form, a first step: One-Quality Five-Traffic pared down models (2002). The first known study in the field in France (Quinet, 2002) deals with the complete spectrum of marginal social cost components: environmental, renewal, congestion and maintenance costs.

Yearly maintenance costs are explained by an econometric analysis of 1 146 segments covering 95% of maintenance expenses. For each way segment, the available information for 1999 is:

- **C**: the maintenance **Cost** (dependent variable);
- **S**: technical or **State** variables such as the number of tracks, the number of switches, the type of control devices (automatic or not), the type of power (electrified or not), the length of the section;
- **Q**: variables indicating **Quality**, such as the age of rails, the age of sleepers, the share of concrete sleepers and the maximum allowed speed;
- **T**: measured by the number and average weight (tons) of 5 types of trains, **Traffic** consists in: long distance passenger (GL = *Grandes Lignes*), Ile-de-France passenger (IdF), other[1] regional passenger (TER = *Trains Express Régionaux*), freight trains (F) and track servicing trains (Other).

Various specifications were used on a model that included all available State variables but only one Quality variable (Maximum allowed speed) and kept all 5 train Traffic categories, each defined by total tonnage, within the analysis. The emphasis of the tests was primarily on a comparison of Translog and Box-Cox models, but Linear and Logarithmic forms were also specified. A significant part of the work consisted in selecting, for each form, the most statistically significant explanatory terms in such a way as to retain 12 explanatory variables in all models.

As the Translog specification retained was not kept whole in this paring down model exercise but only its most significant terms were preserved, it became almost indistinguishable from a Log-Log (CES) model [with LL -15533.9]. The retained Box-Cox models were also minimal. In consequence, these tests can best be summarized with the four specifications found in Table 1: note that, because considerable gains were achieved by using 5 train-specific Box-Cox transformations, the less restricted form of that Box-Cox model is included as well in Column D.

Table 1. Explorations with pared down One-Quality, Five-Traffic models of 12 variables (2002), France, 1999 network (1146 observations)

Model	A	B	C	D
Specification of form	**Linear**	**Translog (pared down)**	**Box-Cox on y distinct from Box-Cox on Xs**	**Box-Cox on y and on multiple groups of Xs**
Log likelihood LL	-16 069.7	-15 535.8	-15 349.0	-15 322.9
Beta regression coefficients	12	12	12	12
Box-Cox transformations	0	0	2	7
Cost elasticity w.r.t. weighted traffics, evaluated at the sample mean of observations	0,42	0,34	0,36	0,36

Retaining only the most significant terms of the Translog form biases the comparison in its favour, as it then has about the same number of estimated coefficients as the other forms. Despite this generosity, the 2-parameter Box-Cox dominates by 185 Log likelihood points even without using

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[1] The distinction between TER and IdF traffic deserves some explanation: IdF traffic is the local traffic around the Paris area (11 million inhabitants) and is mainly suburban while TER traffic corresponds to local traffic in other parts of France and is a mix of suburban (around large agglomerations) and rural traffic.

5 additional train-specific Box-Cox transformations, a removal of restrictions which further raises the advantage to 213 points. Such results clearly pointed to the need for a more detailed Box-Cox study, as there are many possible Box-Cox transformation (BCT) specification options, especially with multiple outputs.

Formally speaking, as Column C of Table 1 uses two Box-Cox transformation parameters, its pared down specification is already both a “***Multi-product***” and an “***Unrestricted***” Generalized Box-Cox (U-GBC) extension of the simpler R-GBC defined in Khaled (1978) for a single output case and with a single Box-Cox transformation. Basically, as we shall see, more refined work since 2002 on full by-the-book (not pared down) models has not modified the structure of these results, and neither will current CATRIN-inspired or CATRIN-specific tests: the popular Translog was always found to be dominated by the restricted Box-Cox (R-BCT), itself vastly inferior to the unrestricted Generalized ***Box-Cox (U-GBC) that implies train-specific effects.***

That first step study of 2002 included another analysis pertaining to the standards used to distribute the funds among the various segments. If these standards, involving various variables such as traffic and the age of rail and sleepers, were used to re-estimate marginal costs and elasticities with about 1 000 selected “observations”, the resulting elasticity of cost with respect to traffic was then 0,24, *i.e.* lower than the range of model values found in Table 1 without this filter.

B. Fixed *vs* flexible form: a second step exploring the Box-Cox model further (2003). Gaudry & Quinet (2003) did explore further the issue of Box-Cox form by performing a series of tests which included primarily an analysis of the role of different BCT on the distinct categories of trains, but also some other refinements and tests of robustness. Take them in turn.

> a) To examine the impact of different BCT on each output measure, consider Table 2 where the first and last columns detail Column D and Column E of Table 1. As one moves to the right, successively allowing each output measure to obtain its own BCT, the log likelihood increases -from 15349.0 to 15322.9-, a gain of 26 points (for 5 degrees of freedom). This evidence suggests that each train type generates specific maintenance costs.
>
> (b) Further refinements involved: (i) searching for various specifications of potential interactions among Traffic types, (ii) including regional dummy variables to account for systematic cost difference among 19 administrative divisions of the French National Railways (SNCF) in charge of track maintenance represented in the sample; (iii) distinguishing between the number of trains by category and their average weight instead of using tonnage by train type as the relevant Traffic output measurement variable.

Generally speaking, the most sophisticated formulations won easily in terms of statistical fit, although this was somewhat less decisive for (iii), but nothing modified the general bearings of the 2002 results of Table 1, at least in statistical terms.

The study found that the elasticity of cost with respect to traffic level, evaluated at the mean value of the observations, was 0,37; it also provided equivalence coefficients between types of traffics (distinguishing between numbers of trains and their average weight by class) found in Table 3, calculated from a specification using 9 Box-Cox transformations, 2 more than the number used in Column D of Table 1 due to the break-up of Traffic indicators between numbers of trains and their average weight.

Table 2. Adding a specific BCT to each traffic measure, starting from Column D of Table 1 (2003)

```
================================================================================
 I. MODEL VARIANT                           1.BC2    2.BC3    3.BC4    4.BC5    5.BC6     6.BC7
================================================================================
II.PARAMETERS: BOX-COX TRANSFORMATIONS and their UNCONDITIONAL [T-STATISTIC=0]/[T-STATISTIC=1
================================================================================
   LAMBDA(Y)             mtkm            .240     .240     .243     .245     .246     .247
   COUT PAR KM                         [25.96]  [25.47]  [26.00]  [26.85]  [25.91]  [26.53]
                                      [-82.01] [-80.73] [-81.00] [-82.55] [-79.38] [-80.66]
   -----------------------------------------------------------------------------
   LAMBDA(X)             tbc1                     .617     .520     .546     .530     .469
   TONNES BRUTES TGV ET GRANDES LIGNES           [5.12]   [4.93]   [4.96]   [4.82]   [4.34]
                                                [-3.18]  [-4.55]  [-4.12]  [-4.28]  [-4.92]
   LAMBDA(X)             tbc2                             1.074    1.114    1.059    1.098
   TONNES BRUTES TER                                     [5.28]   [5.51]   [5.21]   [5.31]
                                                          [.36]    [.57]    [.29]    [.47]
   LAMBDA(X)             tbc3mod                                    .735     .742     .706
   TONNES BRUTES ILE DE FRANCE                                    [5.87]   [5.79]   [5.67]
                                                                 [-2.12]  [-2.01]  [-2.36]
   LAMBDA(X)             tbc4mod                                           1.348     .979
   TONNES BRUTES FRET                                                      [2.46]   [1.91]
                                                                            [.64]   [-.04]
   LAMBDA(X)             tbc5mod                                                    .813
   TONNES BRUTES AUTRE                                                             [1.47]
                                                                                   [-.34]
   -----------------------------------------------------------------------------
   LAMBDA(X) - GROUP  1   LAM  1         .430     .372     .325     .213     .138     .122
   3 VARIABLES: (A ; N ; V)            [10.66]   [7.75]   [7.15]   [4.78]   [2.91]   [2.24]
                                      [-14.15] [-13.11] [-14.84] [-17.66] [-18.10] [-16.13]
================================================================================
III. GENERAL STATISTICS
================================================================================
 LOG-LIKELIHOOD                      -15349.0 -15347.1 -15339.7 -15330.4 -15323.8 -15322.9
 PSEUDO-R2 : - (L)                       .913     .913     .914     .916     .917     .917
 NUMBER OF ESTIMATED PARAMETERS : BETAS    12       12       12       12       12       12
                                BOX-COX     2        3        4        5        6        7
 ===============================================================================
```

In the literature, other values can be found reported by the French civil service (Dehornoy *et al.*, 2007): (i) a set of indirect estimates of costs supplied without documentation on their derivation; (ii) a comparison of revenues implied by charging in accordance with such marginal costs, both from those derived after Gaudry & Quinet (2003) and from yet another set computed by the French Infrastructure Manager RFF (Réseau Ferré de France), again without information on their construction. In consequence, the differences shown in Table 4 cannot be understood.

Table 3. Relative marginal costs among train types

Type of traffic	Long distance Passenger	Regional Passenger	Ile-de-France Passenger	Freight
Equivalence coefficient	1	5,5	1,9	0,4

Table 4. Potential revenue from marginal cost charges (French Ministry of Transport, 2007)

Revenue from marginal cost pricing	Long distance passenger	Regional passenger	Ile-de-France passenger	Freight
From Gaudry & Quinet (2003)	440	453	165	287
From Réseau ferré de France	490	279	155	467

C. Going by the book: Four-Quality, Four-Traffic, full models (2004-2008). Clearly, better use could be made of the exceptionally rich 1999 database by a more systematic analysis specifically aimed at the derivation of marginal costs. This argued for exploiting all 4 Quality variables when available, for focusing formally on the 4 Outputs (trains classes) and neglecting the input-type service trains and for allowing for a full specification (no paring down) of the Translog form, despite the large number of additional parameters. To compare it with the GBC forms, the latter specifications had to allow nesting, *i.e.* include as many of the Translog interactions among variables as possible.

This extensive formal work, to be reported in Gaudry & Quinet (2009), was ongoing[2] between 2004 and 2008 when the CATRIN tests were considered: it defines the background for the latter tests, including a ***preferred model***. Formal background tests, motivated by favourable comments on the exploratory work, were based on rules for the inclusion of variables and their interactions, for the specification of competing forms, and for the inclusion of zeroes. Consider them in turn.

a) Rules for the inclusion of ***variables:***

A. **S**: when required by the Form, transform the two non-dummy State variables, ***Number of track apparatus*** and ***Length of section***. To simplify, the symbolic representation of form specifications found in Table 5 below will pretend that all 11 State variables included in S are left in their linear form, although only 9 effectively are in the Log, Translog and Box-Cox cases; the others, being dummy variables, *per force* cannot be transformed;
B. **Q**: use all 4 available Quality factors;
C. **T**: use the 4 traffics that correspond to outputs and neglect the 5th, an input factor;

b) Rules for ***interactions***, represented by (*). As State variables are numerous and consist mainly of dummy variables, do not consider interactions among the 11 State variables and all other variables but retain those among quality Q and traffic T terms (namely Q*Q, Q*T, and T*T) and:

D. **Q*T**: define the interactions among track qualities and traffics (i) as products of ***Age of rails*** or ***Age of sleepers*** (traverses) and the relevant traffic levels; and (ii) as ratios of the relevant traffic levels and ***Maximum allowed speed*** or ***Proportion of concrete sleepers*** (vs wood). Note in passing that the ratio form of interaction is only identifiable if the Linear or the Box-Cox model is appropriate: in Log-Log and Translog forms, the distinction is not meaningful or identifiable;
E. **Q*Q**: as the interactions among qualities were long found to add nothing in the Box-Cox models, remove them from the Box-Cox forms although this makes a small difference to the strict nesting of the Translog form: if necessary, use implicit non-nested tests to compare such models. But do not further pare-down the Box-Cox form in order to keep it as close as possible to the (now almost) nested Translog, itself written in full, by the book.

c) Rules for the ***definition of 5 basic Forms***. The basic competing structures can be stated with simplified symbols in Table 5 where, for the U-GBC, the four Box-Cox Transformations (BCT) indices do not denote the exact number of distinct BCT actually used (as many as 11 in some tests) but simply express the generality of the U-RBC, as compared to its R-GBC source.

Table 5. Structure of basic model form specifications (without distinct BCT indices)		
1	Linear	$C = \text{li}\,[\,S;\ Q;\ T\,]$
2	Log-Log or CES	$C = \ln[\,S;\ Q;\ T\,]$
3	Trans-Log	$C = \ln[\,S;\ Q;\ T;\ Q*Q;\ [T*Q];\ (T*T)\,]$
4	R-GBC	$C^{(\lambda)} = \text{bc}\,[\,S;\ Q^{(\lambda)};\ T^{(\lambda)};\ \text{----};\ [T*Q]^{(\lambda)};\ (T*T)^{(\lambda)}\,]$
5	U-GBC	$C^{(\lambda y)} = \text{bc}\,[\,S;\ Q^{(\lambda x1)};\ T^{(\lambda x2)};\ \text{----};\ [T*Q]^{(\lambda x3)};\ (T*T)^{(\lambda xk)}]$

d) ***Rules for the inclusion of variables containing zeroes***. But Table 5 hides other hard issues. For instance, when a normal (non dummy) variable contains some zero values (for instance not all segments carry all 4 train traffic types), such zeroes must be dealt with. This problem has long been recognized, for instance in Winston (1985, p. 63) where it is stated that:

---

[2] The authors are grateful to assistants Bryan Breguet and Cong-Liem Tran who made contributions during that period.

> "*To be sure, the Translog approximation runs into difficulty for zero values of output. In this case, a transformation using the Box-Cox metric (Caves, Christensen & Tretheway, 1980a) can be used to apply this functional form*."

Indeed, zero values cannot be easily handled if a logarithmic transformation of a variable is involved, but that is also a problem in Box-Cox models, contrary to what the author implies. In reality, there are only two remedies, F-1 and F-2, at least in the Log-Log and Box-Cox models, short of removing all observations that contain zeroes (F-3):

F-1. Replace the zeroes by a very small value;
F-2. Add an associated dummy variable to a transformed variable that contains some zeroes;
F-3. Remove all observations containing zeroes.

In the fully documented TRIO software that we used (Gaudry *et al.*, 1993), normal variables that contain zeroes are defined as "quasi-dummy" variables to distinguish them analytically from pure dummy variables to which BCT are not applicable.

The zero replacement remedy F-1, a rough and approximate approach, is the basic option chosen in the second series of tests to be summarized presently, as it was in the above tests of Table 1. It clearly is not a very good option if there are too many zeroes in the sample (not our case), because the logarithmic transformation generates very large negative values that can behave as outliers.

The second remedy F-2 is used in our section below dealing explicitly with the influence of zeroes. Indeed, this strict, tedious and exact remedy, usable here in both Log-Log and Box-Cox models (but not in Translog models involving here ratios and products of zeroes), consists, for each standard variable that includes zeroes, in building an associated dummy variable that compensates for the shift at 0 when the Box-Cox transformation is applied (as the zero values are left untransformed). That is the adopted practice in the TRIO software algorithm (Liem *et al.*, 1993) which generates such additional regressors automatically: they are defined conventionally as equal to 1 if the (quasi-dummy) variable is positive and to 0 otherwise, but using the complementary definition would simply change the regression sign of the associated dummy variable and have no effect on other parameters and on the Log Likelihood (LL). Naturally only one such dummy is necessary if two or more variables have zeroes in the same locations: in our most general U-GBC model, only 4 associated dummies are needed despite the much larger number of transformed variables containing zeroes.

However, in this context, no remedy whatsoever was in fact applied in the 1-BCT Box-Cox tests carried out by Caves *et al.* (1980a, 1980b and 1985) and referred to by Winston, as confirmed by a co-author. This means that their results on form are not invariant to changes in the units of measurement of the transformed Output explanatory variables, which casts doubts on their reported value.

A preferred model: core statistical results on the U-GBC. Using, as in all our previous work above in 2002 and 2003, the F-1 replacement rule for zeroes and the new specification in terms of Quality (Condition B) and Traffic variables (Condition C), we established a reference set of results on the 4 basic Forms (defined in Table 5) first using the 985 observations available for the whole of the French network. Their key statistics are shown in Table 6, ***Series 1.4T***.

In terms of Form, these results follow the pattern exhibited in Table 1 with fewer explanatory variables: all non linear forms dominate the Linear one; the Translog is (depending on how certain one wants to be) comparable with, or somewhat inferior to, the Log-Log model because 36 degrees of freedom are involved in the comparison; the U-GBC dominates, clearly out of reach of the models based on the logarithmic transformation (Log-Log and Translog) which are found to be woefully inadequate. This domination could be increased further by removing some inadequate interaction terms. Clearly, many interactions used by definition in the Translog are unrealistic and those that may be relevant are not of logarithmic shape: removing irrelevant or improperly specified interactions just increases the relative performance of the U-GBC specifications. If complexity and interactions are of interest, the U-GBC is the only adequate specification.

Further work on this U-GBC model involved comparing, for France as a whole and by geographical region (Ile-de-France *vs* Province), the impact of the very few high speed links. It was found that: (i) the 18 pure high speed (TGV) infrastructure links, insufficiently numerous to be treated separately, were not homogeneous with the rest of the links (in terms of technical characteristics and traffic mix) and should be removed to increase the precision of estimates; (ii) one could reject the view that Ile-de-France results differred significantly from those for the rest of the country, but not the converse view. It was also found, as before with the simpler models of Table 1, that: (iii) a case could be made for some regional administrative differences; (iv) the construction of a ***Fictional Traffic variable*** obtained by weighing train types as specifically recommended by the UIC (UIC, 1989) for maintenance purposes, explained a very small part of the maintenance cost, as compared to the U-GBC form.

Table 6. The Four-Quality, Four Traffic, multi-BCT reference model with and without pure high speed links (Zero replacement rule F-1)

Form as defined in Table 5	**1**	**2**	**3**	**4**
	LIN	**LOG/CES**	**TLOG**	**U-GBC**
France as a whole including high speed (TGV) sections (985 observations)				
Series 1. 4T [4 Traffics]				
Log-Likelihood LL	**-13 795,340**	**-13 373,516**	**-13 336,523**	**-13 109,576**
Difference in degrees of freedom w.r.t Log	**0**	**0**	**36**	**32**
France as a whole excluding high speed (TGV) sections (967 observations)				
Series 2.4T [4 Traffics]				
Log-Likelihood LL	**-13 547,642**	**-13 129,267**	**-13 092,508**	**-12 866,366**
Difference in degrees of freedom w.r.t Log	**0**	**0**	**36**	**32**

The decision to neglect the high speed sections yielded ***Series 2.4T [4 Traffics]*** estimates, also found in Table 6 with our preferred U-GBC reference model framed: not surprisingly, the comments on form just made for ***Series 1. 4T [4 Traffics]*** are maintained.

D. Other literature. Although maintenance costs become an input to optimal maintenance strategies, we will not address here this literature on strategic renewal or its French developments (*e.g.* Antoni, 2008; Antoni & Meier-Hirmer, 2008).

3 Data

The data used for the CATRIN tests are the same as those for Quinet (2002) and Gaudry & Quinet (2003). They are made possible by a decomposition of the French network into a large number of segments, about 1000, which allows a large degree of modelling freedom, even with a relatively large number of explanatory variables. Included are:

- The dependent variable, drawn from the analytical accounts of SNCF, encompasses maintenance costs allocated to tracks and represent 81 % of the total maintenance costs: the rest consists of triages, intermodal freight platforms and service tracks, none of which can clearly be assigned to a given track. It also covers catenaries, signalling, tracks, works of art. No renewal (regeneration/reconstruction) is included except for some Large Maintenance

Operations (*Opérations de Grand Entretien*, OGE): according to the definition adopted for renewals, they could have been included there instead.

- Technical information, covering both State and Quality factors distinguished and listed at the beginning of Section 2.
- Traffic information, also listed at the beginning of Section 2. In the earlier study (Gaudry & Quinet, 2003), traffic was accounted for both in terms of total weight (ton*km) by type of train and through the number of trains distinguished from their average weight (number of trains; tons per train). Further adjustments have shown that this latter specification was not significantly better[3] and gave roughly the same marginal costs as the usual specification in ton*km used in most European studies. So all baseline and more recent adjustments reported on here systematically use the ton*km specification of traffic variables.

The baseline reference models of Table 6 are estimated with 967 observations. But CATRIN tests include experiments with a reduced sample to determine the role of zeroes by removing them. This is to avoid the difficulties alluded to above when Translog and Log-log variants are estimated after substitution of small values for zero values, especially for the traffic variables: the results of the adjustments are very sensitive to the value which is substituted for zero.

We therefore describe in Table 7 the relevant variables of the reduced sample of 928 observations that excludes 0 values of traffic when two kinds of traffic are considered: passenger and freight. These data correspond to a total length of the network of 18 402 km (but the number of tracks per segment, which varies from 1 to 18, is not shown). It is not possible to exclude all observations containing 0 values of traffic on the basis of 4 traffic categories because this reduces the sample to only 208 observations.

Table 7. Properties of the retained sample of 928 (non zero traffic) observations

Variable	Average	Maximum	Minimum
Cost (dependent) variable			
cost per km	464 801	7 604 163	480
State variables			
switches per segment	22	345	1
length in meters	19 197	157 924	238
power type	0,68	1,00	0,00
type of traffic control	0,77	1,00	0,00
Quality variables			
age of rail	26	92	4
age of sleepers	27	92	4
maximal allowed speed	127	220	60
share of concrete sleepers	0,58	1,00	0,00
Traffic variables			
T1 : tons long distance passenger trains	1 116 095	16 809 701	0
T2 : tons regional passenger trains	426 421	4 476 021	0
T3 : tons Ile-de-France passenger trains	878 439	32 778 126	0
T4 : tons freight trains	2 478 063	16 442 960	281

Comparisons with data used in the other countries drawn from Abrantes *et al.* (2007, Table 5) show that French data present some specific characteristics vis-à-vis other country data:

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[3] The slight gains in terms of fit suggest that there is some truth to the idea that, after taking into account specific damage due to weight or speed, there remains some diffuse damage assignable to each train. This point merits further research, preferably with more detailed information on speeds, vehicle characteristics and weights.

- In general French data are richer in technical information than those available in other countries. Furthermore, due to the large number of segments, all of this technical information can be used in the adjustments: in other countries, the technical information is not fully used (*e.g.* Andersson 2006).
- There is more information on traffic and its break-down into different categories. Generally, most of the other studies use only one category of traffic (total traffic), some just two (passengers and freight).
- But the data are just cross-sectional, and for a rather ancient year (1999). No information is available about a sequence of years, making panel econometrics impossible.
- In addition, the information on the past renewal history of each segment is poor. The information on the age of rail and sleepers is a poor proxy, though probably correlated to the substance or standing of the track. Neither is there information on the planning of the next renewal, which usually impacts the maintenance policy.

4 Methodology

Statistical methodology of optimal form. We provide maximum likelihood estimates, under the assumption of Normality and[4] Constancy of the variance of independent u_t, of the parameters of the classical Box-Cox regression model:

$$y_t^{(\lambda_y)} = \sum_{k=1}^{K} \beta_k \cdot X_{kt}^{(\lambda_{X_k})} + u_t. \qquad (1)$$

where an X_k denotes in our case any regression term, including cross-product of variables. In our detailed tables of results such as those found in Appendix 1, the reader can find, in addition to the value of the maximized Log Likelihood and complementary information such as the numbers of parameters estimated, ***unconditional*** values of the *t*-statistics of the BCT with respect to both 0 (the logarithmic case) and 1 (the linear case) and, for the β_k regression coefficients, *t*-statistics with respect to 0 that are ***conditional*** upon the estimated value of the form parameters.

The reason for this reporting asymmetry is that, in the presence of BCT, the unconditional *t*-values of these β_k depend on units of measurement of the X_k (Spitzer, 1984). Obtaining *t*-statistics that depend on units of measurement of the transformed variables would make them useless because one could in fact decide on their desired values and then adjust the units of all X_k accordingly: conditional *t*-values are therefore an inescapable second best indicator for the β_k unless one wishes to rely exclusively on Log Likelihood ratio tests that remain exact in the presence of BCT.

Fitted values, elasticities and marginal costs. How does one evaluate the quality of adjustments in the presence of Box-Cox transformations? Our interest is in ***observed y*** and on how well it is accounted for, not in ***transformed y***. A problem of evaluation of fit arises because it is now impossible to “unroll” the Box-Cox transformation to obtain the desired fitted y. To see this, write this “unrolled” value from (1) simply as:

$$y_t = f^{-1}[\, g(X_t) + u_t \,] \qquad (2)$$

and note that, in the case of Log-Log and Trans-Log models, the expected value of y is simply:

$$E(\, y_t \,) = \{\, \exp[g(X_t)] * [\exp(u_t)] \,\} = k*\exp[g(X_t)] \qquad (3)$$

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[4] The procedure allows, if necessary, for simultaneous corrections for heteroskedasticity and autocorrelation but they were not used for the models reported on here.

where $\exp(u_t)$ is a log-normal random variable whose mean is a constant k over the sample and for which the adjustment provides an estimate.

In the Box-Cox case however, the ratio between $E(y_t)$ and $f^{-1}[\ g(X_t)\ ]$ is not constant and needs to be calculated for each observation. Fortunately, TRIO provides a documented procedure (see Dagenais *et al.*, 1987 or the detailed description of the algorithm in Liem *et al.*, 1993) to do this with a two-limit Tobit calculation of $E(y_t)$. Our estimates of traffic elasticities of $E(y_t)$ and of marginal cost below will be calculated as the means of these values obtained ***for each observation*** and not by evaluating the elasticity or marginal cost formulas at the means of the sample.

Note finally that, as the β_k regression coefficients of variables transformed by a BCT have lost the intuitive contents they had in simpler (*e.g.* linear, logarithmic) forms, it is crucially important to calculate the elasticities in order to evaluate the reasonableness of results. This is why they are printed for all regressors (dummy variables included) in Appendix 1 where they are evaluated at the means of the sample.

Measures of overall adjustment quality. The program also provides two extension of the R^2: a first obtained by substituting $E(y_t)$ for y_t in the usual formula (which then loses its simple property of being restrained between 0 and 1); a second, based on Log Likelihood values, that in linear cases collapses exactly to the standard R^2.

5 Results

As we consider that the second series of models found in Table 6 and their results, listed in detail in Appendix 1[5], constitute a proper comparison of competing Forms and yield the U-GBC model as our reference, they also provide the natural baseline for CATRIN tests. These tests pertain to the number of Traffics used and to the impact of the treatment of zeroes, to the effect of State and Quality variables present and to the role of interactions among explanatory variables.

5.1 Functional form, traffic aggregation and the role of zeroes

We recall that, in the explorations of various functional forms and numbers of train traffic types of Table 8, all 11 State variables are included but no interaction is specified between them and other variables.

Table 8. Form and aggregation of traffic classes

impact of functional form and number of traffics

Specification	number of traffic categories	Quality variables	Interaction between traffic categories	Interaction between qualities	Interaction between qualities and traffics	LL ratio	number of estimated parameters	Marginal cost coverage
Box-Cox	4	yes	yes	yes	yes	-12866.366	51	0,39
translog	4	yes	yes	yes	yes	-13092.508	55	0,19
Log-log	4	yes	no	no	no	-13129.267	19	0,05
Box-Cox	2	yes	yes	yes	yes	-12891.292	35	0,32
Translog	2	yes	yes	yes	yes	-13099.112	38	0,24
Log-log	2	yes	no	no	no	-13137.707	17	0,06
Box-Cox	1	yes	no	yes	yes	-12921.412	29	0,34
translog	1	yes	no	yes	yes	-13097.894	31	0,33
log-log	1	yes	no	no	no	-13118.611	16	0,26

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[5] The table successively presents in columns from left to right, the Linear, Logarithmic, Trans-Log and Generalized Box-Cox specifications of the 4-Traffic models reported in the first section of Table 8. The three sections of the Appendix table contain: (Section I) for each variable, up to four elements: regression coefficients, elasticities and *t*-statistics of the coefficients, and an identifier of the Box-Cox Lambda transformation applied to the variable; (Section II) Fixed or estimated values of the Box-Cox transformations, with two *t*-statistics (with respect to 0 and to 1); (Section III) general statistics.

The first 3 cases correspond to the baseline results already presented in Table 6 with 4 traffics (3 passenger and one freight) and the next cases correspond, *mutatis mutandis*, to results obtained if the 4 types of trains are successively aggregated first into 2 traffics (passenger and freight) and then into 1 traffic (total). The last column provides an estimate of cost recovery under marginal cost pricing.

An examination of this table leads to several conclusions, all of which confirm our baseline preference for a Box-Cox specification. The first concerns the number of traffics used:

- **Optimal form and traffic aggregation**. Table 8 provides a confirmation of the preference for a Box-Cox specification found in the baseline model. It appears that the Box-Cox specification is of uniformly better statistical significance than the other two specifications, as assessed through the LL ratio (higher LL ratio with more degrees of freedom), not just in the baseline 4-traffic model but ***independently from the number of types of trains used***.
- **Optimal aggregation: how many traffics?** But are these Box-Cox adjustments significantly different across the three sets of results? An examination of LL ratios[6] tends to show that ***the 2-traffic adjustment is better than the 1-traffic adjustment*** because the gain in log-likelihood of 30.110 points ([-12921.412 (-) -12891.292 = 30.110] involves a sacrifice of only 6 degrees of freedom [29 – 35 = - 6], a level of significance well above 99%. Also, the further gains made with a 4-traffic adjustment consist in 24.926 log-likelihood points [-12891.292 (-) -12.866.366 = 24.926] but require 16 additional parameters (35- 51 = -16], a level of significance around 95%: acceptable enough, but nothing to write home about. Although the 4-traffic disaggregation remains the most likely statistically speaking (in terms of best fit), it does not dominate the 2-traffic option sufficiently to reject the hypothesis that the latter aggregation level is optimal.

But there is a second reason for maintaining our preference for the Box-Cox specifications as a class, independently from the number traffics, a reason linked to the presence of zeroes.

- **Cost recovery and the number of traffics in the presence of zeroes.** First note in Table 8 that the recovery ratio following the application of marginal cost pricing drops dramatically with the number of traffics with Translog and Log-Log forms. This may be due to segments where some traffic is null: it happens for 39 segments with the 2-traffic specification, much more with the 4-traffic specification (for instance on many segments there is no Ile-de-France traffic) and never with the 1-traffic specification. Our tests have shown that this cost coverage result is very sensitive to the arbitrary value by which the 0 value is replaced. ***This does not happen with the Box-Cox transform*** which is insensitive to the zero values of variables ***provided that the powers of the transform be positive***, which is always the case for our sample.
- **The role of zeroes.** This hypothesis is confirmed by the following graphs where the X axis shows the number of traffic categories used and the three lines indicate the cost recovery for Logarithmic, Translog and Box-Cox specifications of form. In the first graph, the adjustments are those of the baseline model of Table 6, done with all observations, including those where some traffic values are zero (there is no observation where traffic has zero value when there is just one traffic aggregate).

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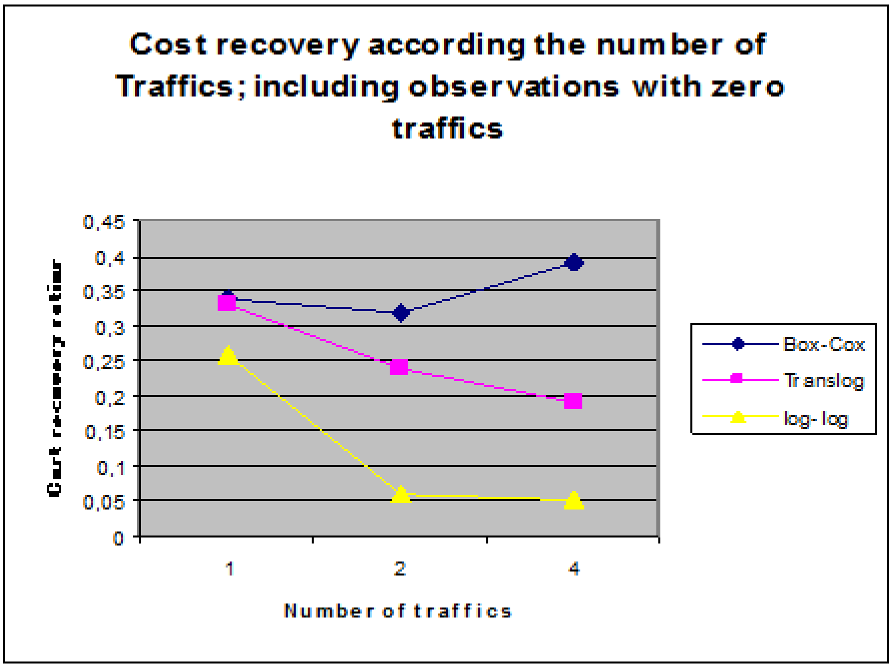
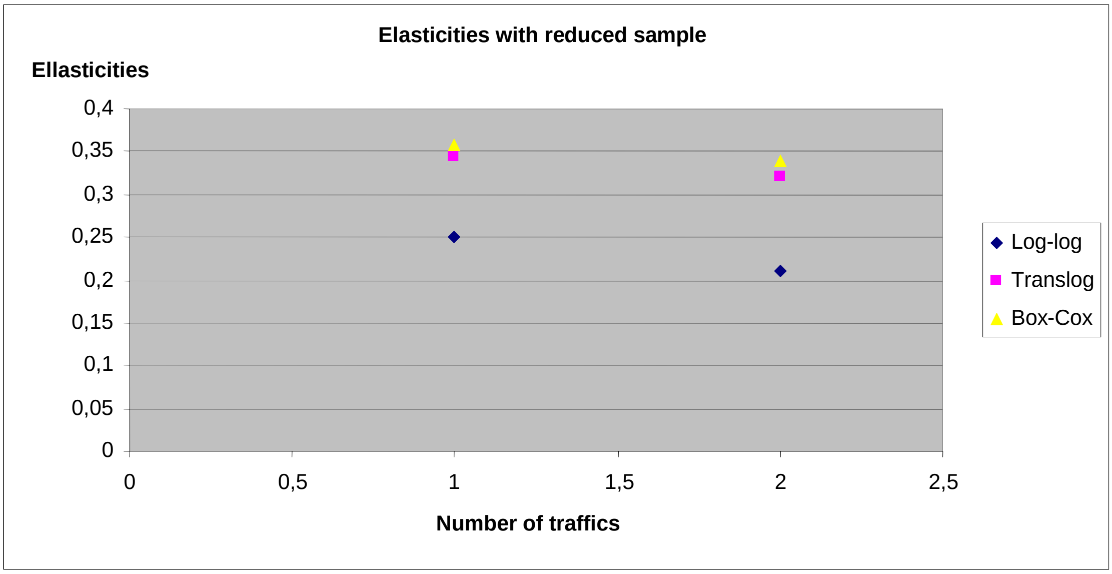
[6] We realize that going from 4 to 2, and then to 1, traffic category does not imply nested models. However, a comparison is possible in terms of Log-Likelihood if one considers any pair of values as special cases of a very general model involving all traffic variables. This “all in” model is of course silly, but allows for a formal nesting of non-nested models.

Graph 1. Cost recovery and traffic types *including* traffics equal to zero



- The second graph shows what happens when the set of observations is slightly reduced from 985 to 967 to exclude the 39 observations for which there are some zero[7] value traffic. It is clear in this case that using one or two traffics makes no difference to cost recovery rates. This result also favours Box-Cox specifications, vis-à-vis Translog or Log-Log specifications: not only are they more robust to the range of traffic values but also to the presence of zero value outputs.

- **Graph 2. Cost recovery and traffic types *excluding* traffics equal to zero**



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Finally, there may even be a third reason for maintaining our preference for the Box-Cox models that generally support higher numbers of traffics (less aggregation) –even if there are grounds for preferring only two-traffic formulations on the basis of significance– if, in the

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[7] The 4 traffic case is not feasible because there are too few observations left if all observations containing 0 traffic for any of the four traffic types are removed. The Box-Cox cases shown use a single BCT on the dependent variable y and on all transformable X_k explanatory variables.

absence of problems caused by the presence of zeroes and their treatment, we look at the relation between number of traffic classes and the level of cost recovery.

- **Cost recovery levels and the number of traffics without the interference of zeroes.** Considering the unproblematic Box-Cox adjustments in Graph 1, it appears that the cost coverage is higher for the 4 traffics variant than for the 1 or 2 traffic ones, thereby implying that the Box-Cox models imply higher recovery rates. This result makes sense, as we presently argue.

  Should the cost be explained just by traffics (or should the other variables be uncorrelated with traffics) and should the relation be linear, the adjustments would be written, successively for the "one-traffic" and the "two-traffic" models as:

  $$C = b_1 + a_1 * (T1 + T2) + e_1 \qquad (4)$$

  $$C = c_2 + a_2 * T1 + b_2 * T2 + e_2 \qquad (5)$$

  where T1 and T2 denote traffic types. It is clear that the multiple R^2 correlation coefficients necessarily verify $r_2 > r_1$ because of the restriction $a_2 = b_2$ imposed in the first model, as compared with the second. It is also clear that, as both expressions are positive, we have by the properties of Least Squares $\sum(a_2 * T1 + b_2 * T2) > \sum a_1 * (T1 + T2)$, which implies that the recovery rate with 2 traffics is higher than with 1 traffic and, similarly, that the recovery rate with 4 traffics is higher than with 2 traffics.

  The differences between this simple case and those of Table 8 are that the latter relations are not linear and that their other variables are somewhat correlated with their traffics. Nevertheless, the result holds as long as the relation is not "too" non linear and the other variables are not "too" correlated with the traffics: it gives a hint that recovery rates are presumably larger with 4 than with 2, and with 2 than with 1, traffic, an ordering similar to that suggested by the comparison of Box-Cox models made above across levels of traffic aggregation.

5.2 State variables, Quality variables and Quality-Traffic interactions

Let us turn to the effects of technical variables. They are very important, as shown by the following Table 9 where one (i) starts, in Case C, with variants where only Traffic and State are used as explanatory variable and (ii) successively adds in Case B the four Quality variables before finally (iii) adding in case A all interactions among Quality and Traffic variables. This table presents some interesting features:

- First, Quality variables are very significant when cases B and C are compared.
- Second, taking into account the interactions among Quality variables and Traffic variables only slightly improves the quality of the adjustments in the Translog case but improves it considerably in the Box-Cox cases, which suggests that the proper form of interaction matters but that the simple product of logarithms does not.
- Third, reading the table upwards from the bottom line, which shows the most complete adjustment, the cost coverage first decreases when the quality variables are dropped. This point would deserve more thorough investigation along the following lines: the adjustment with Traffics, Quality and State variables together can be seen as representing the short run cost function, while the adjustments including only State and Traffic variables can be seen as the medium run cost function. The fact that short run marginal cost is higher than the medium run marginal cost supports the Rivier & Putallaz (2005) diagnostic that renewal policy is under-optimized.

- Fourth, taking interactions into account in the Translog cases makes no difference to the recovery ratios. This makes sense: if the translog is insufficiently parsimonious in the sense that it includes too many second degree interaction terms and that removing those makes little difference to the quality of adjustment, then we do not expect terms with coefficients barely different from zero to have much impact on derived calculations of cost recovery. By contrast, in the Box-Cox cases where interactions have a more significant role the cost recovery ratios change.

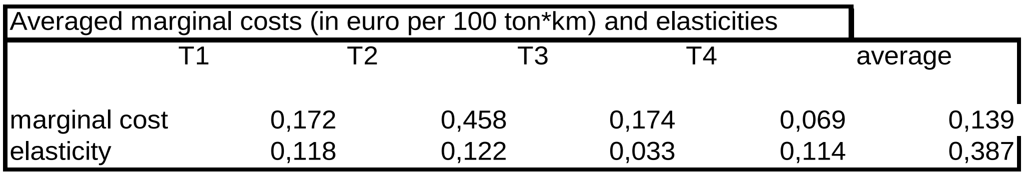
Table 9. Effect of State, Quality and Quality-Traffic interaction variables

		Translog			Box-Cox (*)		
		Log likelihood	**Param.**	**Elast.**	**Log likelihood**	**Param.**	**Elast.**
4 traffics (database 5 with all observations, Rule F-1, 967 observations)							
Case C-4	T, S	n.a.	--	--	-12978	16	0,37
Case B-4	T, S, Q	-13104	39		Does not converge	--	--
Case A-4	T, S, Q, Q*T	-13093	55		-12906	42	0,38
2 traffics (database 7 without observations containing zeroes, Rule F-3, 928 observations)							
Case C-2	T, S	n.a.	--	--	-12475	14	0,23
Case B-2	T, S, Q	-12598	30	0,32	-12433	18	0,37
Case A-2	T, S, Q, Q*T	-12593	38	0,32	-12421	29	0,34
1 traffic (database 7 without observations containing zeroes, Rule F-3, 928 observations)							
Case C-1	T, S	n.a.	--	--	-12468	13	0,24
Case B-1	T, S, Q	-12595	27	0,34	-12433	17	0,34
Case A-1	T, S, Q, Q*T	-12592	31	0,34	-12421	22	0,36
* = in Box-Cox cases, a unique BCT is used on the dependent and all transformable explanatory variables.							
Param. = number of regressors and Box-Cox transformations estimated.							
Elast. = elasticity of the cost with respect to traffic (weighted by traffic share, evaluated at the mean).							

5.3 Elasticities and marginal costs of the preferred model

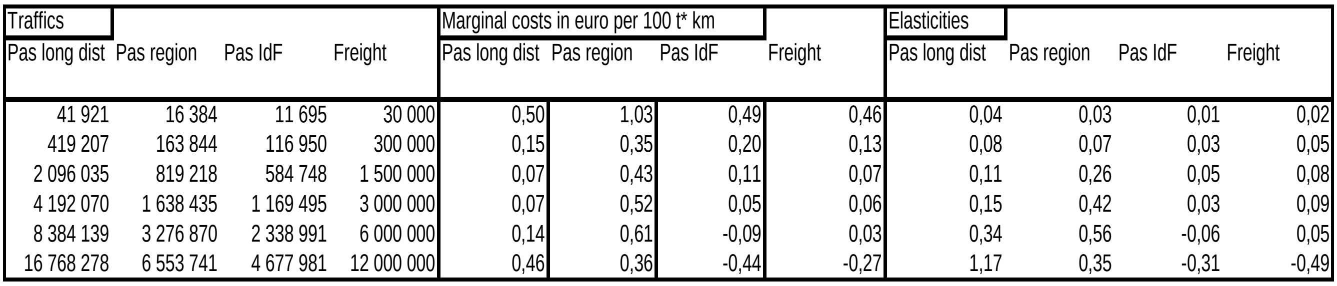
Table 10 presents results of interest for our preferred U-GBC model (found in Table 6): the average elasticities of the cost with respect to traffic and the marginal cost by traffic type, and globally. Table 11 varies the traffic homothetically and derives the marginal costs and elasticities conditionally upon the average value of the State and Quality variables.

Table 10. Elasticities and marginal costs of the preferred model



Averaged marginal costs (in euro per 100 ton*km) and elasticities					
	T1	T2	T3	T4	average
marginal cost	0,172	0,458	0,174	0,069	0,139
elasticity	0,118	0,122	0,033	0,114	0,387

Table 11. Simulated elasticities and marginal costs of the preferred model with varying traffic levels



Traffics				Marginal costs in euro per 100 t* km				Elasticities			
Pas long dist	Pas region	Pas IdF	Freight	Pas long dist	Pas region	Pas IdF	Freight	Pas long dist	Pas region	Pas IdF	Freight
41 921	16 384	11 695	30 000	0,50	1,03	0,49	0,46	0,04	0,03	0,01	0,02
419 207	163 844	116 950	300 000	0,15	0,35	0,20	0,13	0,08	0,07	0,03	0,05
2 096 035	819 218	584 748	1 500 000	0,07	0,43	0,11	0,07	0,11	0,26	0,05	0,08
4 192 070	1 638 435	1 169 495	3 000 000	0,07	0,52	0,05	0,06	0,15	0,42	0,03	0,09
8 384 139	3 276 870	2 338 991	6 000 000	0,14	0,61	-0,09	0,03	0,34	0,56	-0,06	0,05
16 768 278	6 553 741	4 677 981	12 000 000	0,46	0,36	-0,44	-0,27	1,17	0,35	-0,31	-0,49

It is noteworthy that, in Table 11, the marginal cost for long distance passenger trains exhibits a U shape with a minimum roughly at mid-point of the traffic level, i.e. not too far from the mean level of 1 116 095 indicated in Table 7.

This table also shows a noticeable feature: the marginal cost of freight is lower than the marginal cost of passenger traffics. This point is paradoxical as the engineering approach concludes that freight trains are more damageable than passenger ones. Several reasons may explain this point. These reasons are based on the fact that maintenance costs depend not only on the damages but also on the cost of maintenance works, on the required level of quality and on the available funds:

- The first one is the track possession. Works are more expensive when track possessions are short, and this is the case in France in day periods for passenger trains, whose timetable cannot easily be adapted to needs of maintenance, while freight trains time–tables are easier to change: this point is specially relevant in France, where very short track possessions are traditionally accepted, a policy that is currently changing. Of course, track possession were specially short on segments with a large numbers of trains (which is the case of tracks with regional trains) and induced more expensive maintenance cost, except when the maintenance is achieved during the night, which is rarely the case in France.
- The maintenance cost depends not only on the damages of the trains but also on the quality level objective; in that respect it is clear that segments with a large proportion of freight trains do not require a high level of quality while segments with a large proportion of passenger trains require a high quality level. A model of social optimization of maintenance shows that when the traffic is composed of trains of type A demanding no quality but damaging the track (the case of freight trains) and trains of type B demanding a high quality but giving no damage to the track (the case of passenger trains), trains B can have a marginal cost higher than trains A (see Appendix 2).
- This effect is enhanced when there is a shortage of funds for maintenance, a fact which leads to favour (in terms of prevention and renewals) the most circulated tracks and to increase the marginal cost of the other ones (which are then more subject to curative maintenance, thereby inducing higher marginal costs).

6 Conclusion

It is possible to summarize the results of these analyses and to draw conclusions both for the methodology of cost estimation and for a comparison of results with those for other countries.

6.1 Findings linked to methodology

About the methodology, the following provisional conclusions can be drawn:

- Trans-Log and Log-Log specifications are not convenient if some traffic variables are null: they do not represent well the behaviour of cost functions drawn from engineering knowledge. From this point of view, the Box-Cox transform is innocuous, as well as the linear one.
- Technical (both Quality and State) variables are highly significant. It is important to use them in the adjustments, in order to properly estimate the short run cost function: without them, the cost function would be more akin to a long run cost function, under the assumption that the capital level is optimal.
- It appears that interactions among Quality variables and Traffics are not significant except in the Box-Cox cases. This point is a bit worrying as these interactions should incorporate

the substance of the track, which is acknowledged by the engineers as an important factor of maintenance costs: when the age of the track approaches a level expressed in cumulated ton*km, damages increase sharply and maintenance costs increase. Unfortunately, the present adjustments fail to reproduce this point for the Trans-Log case. Further research is needed on this point, and more generally on the links between maintenance and renewal.

6.2 Comparison with results from other European countries

Our results allow assessing the impact of econometric methods in the explanation of the oddness of French results (cost recovery around 35 %) vis-à-vis the average European results (between 15 and 20%).

The same holds for the break-down of traffic variables: using 4 traffic variables produces higher marginal costs than using just 1, as it is the case for most European studies. But here the consequences are small, even if cumulated with the fact that Box-Cox forms tend to yield higher recovery rates than those found with other mathematical forms.

The influence of quality variables is another explanation for the difference, as cost recovery falls when they are dropped from the regression.

These three combined effects (disaggregation, form, multi-quality specification) provide for cost recovery a range of values, derived from the above mentioned adjustments, where the lowest value reaches the higher values of the acknowledged European range, as shown in Table 12.

Table 12. Range of recovery rates

Cost recovery rate	Box-Cox	Translog	Log-Log
4 traffics with quality variables	0,39 (source table 8)	0,19 (source table 8)	0,05 (source table 8)
1 traffic with quality variables	0,34 (source table 10)	0,33 (source table 8)	0,26 (source table 8)
1 traffic without quality variables	n. a.	0,24 (source table 9)	0,18 (source table 9)

6.3 Other sources of specificity and potential divergence

The econometric process, though having a clear effect on the level of marginal cost, is not sufficient to explain the whole of the difference with the average range of European results. It is then necessary to explore other sources of differences. Among them, let us mention:

- The classification of maintenance and renewal expenses, a classification which may be different from one country to another.
- The links between maintenance and renewal policy.
- The impact of the policy and habits of track possession to make the maintenance operations; it seems that these policy and habits are different from one country to another; it seems that possession is especially short in France, thereby increasing work cost.
- The impact of maintenance policy in situations of budget constraint: the budget constraint on rail maintenance is particularly tight in France.
- More generally, it must be considered that the cost functions which the econometric methods aim at reproducing are the expression of the maintenance policies adopted by the operators. A further check would try to extract these policies from the engineers and staff in charge of the infrastructure operators and to compare them both to the econometric results and across countries.

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8 Appendix 1. Results, 4 model forms and 4 types of traffic

```
           Linear, Logarithmic, Translog and Box-Cox cases
                (967 observations, France, 1999)
___________________________________________________________________________________________
                              VARIANT =  lineaire        log        translog     bc10tbt
                              VERSION =      3             2             2             2
___________________________________________________________________________________________

              SECTION I : Beta, Elasticity, Conditional t-Statistic

 ----------------------
 STATE OF LINE SEGMENTS
 ----------------------
  appareils de voies     apdv            .944565E+04  .284286E+00  .258685E+00  .952066E+01
                                                .451         .284         .259         .244
                                             (18.12)      (10.42)       (8.92)      (10.51)
                                                          LAM  1       LAM  1       LAM  1

  ligne                  elec2           .138483E+05  .296261E+00  .205043E+00  .575277E+01
  electrifiee ou non     =====                  .031         .296         .205         .104
                                               (.49)       (4.91)       (3.09)       (1.98)

  regulation             regu            .768618E+05  .134630E+00  .958490E-01  .396063E+01
  automatique ou non     ====                   .169         .135         .096         .072
                                              (2.57)       (2.03)       (1.40)       (1.33)

  longueur du segment    long           -.693227E+01 -.298105E+00 -.290187E+00 -.466321E+01
                                               -.291        -.298        -.290        -.255
                                             (-9.98)     (-11.93)     (-11.00)     (-12.57)
                                                          LAM  1       LAM  1       LAM  1

  dummy                  nbv1           -.249457E+05 -.133686E+00 -.583253E-01 -.180296E+00
  nombre de voies=1      ====                  -.055        -.134        -.058        -.003
                                              (-.79)      (-1.92)       (-.77)       (-.06)

  dummy                  nbv3           -.536128E+05  .263310E+00  .795729E-01  .639502E+01
  nombre de voies=3      ====                  -.118         .263         .080         .116
                                              (-.60)       (1.40)        (.42)        (.85)

  dummy                  nbv4            .117379E+06  .572994E+00  .370290E+00  .153658E+02
  nombre de voies=4      ====                   .259         .573         .370         .279
                                              (2.20)       (5.81)       (3.45)       (2.89)

  dummy                  nbv5           -.560778E+06  .154673E+00 -.112451E+00 -.863505E+01
  nombre de voies=5      ====                 -1.237         .155        -.112        -.157
                                             (-3.48)        (.47)       (-.34)       (-.40)

  dummy                  nbv6            .174589E+06  .751124E+00  .494342E+00  .350354E+02
  nombre de voies=6      ====                   .385         .751         .494         .636
                                              (1.44)       (3.50)       (2.20)       (2.85)

  dummy nombre           nbv1018         .243181E+05  .105129E+01  .816354E+00  .345156E+02
  de voies=10 ou 18      =======                .054        1.051         .816         .627
                                               (.10)       (2.28)       (1.73)        (.02)
 --------------------------
 QUALITIES OF LINE SEGMENT
 --------------------------
  age des rails          agerail         .937586E+03  .632211E-01  .459787E+01  .382681E+01
                                                .056         .063        4.598         .100
                                               (.65)        (.73)       (2.01)       (1.19)
                                                          LAM  1       LAM  1       LAM  1

  age des traverses      agetrav         .601023E+03  .238226E-01 -.432062E+01  .196243E+01
                                                .036         .024       -4.321         .052
                                               (.41)        (.25)      (-1.83)        (.66)
                                                          LAM  1       LAM  1       LAM  1

  taux de traverses      ttra           -.994285E+05  .208647E-02 -.504440E-01  .992414E+00
                                               -.126         .002        -.050         .017
                                             (-2.46)        (.36)      (-1.09)       (1.53)
                                                          LAM  1       LAM  1       LAM  1

  vitesse                vma            -.367809E+04 -.458504E+00 -.365234E+01 -.154626E+02
  maximale autorisee                          -1.017        -.459       -3.652        -.482
                                             (-8.24)      (-3.88)       (-.91)      (-4.42)
                                                          LAM  1       LAM  1       LAM  1
```

```
__________________________________________________________________________________________
                              VARIANT =  lineaire       log        translog     bc10tbt
__________________________________________________________________________________________
 ------------------------------
 QUALITY INTERACTIONS
 ------------------------------
   ln(agerail)*ln(agerail lnagrp2                                 -.223679E+00
   )                                                                    -2.292
                                                                       (-1.47)

   ln(agetrav)*ln(agetrav lnagtp2                                  .602166E-01
   )                                                                      .622
                                                                         (.36)

   ln(vma)*ln(vma)        lnvmap2                                  .202674E+00
                                                                         4.689
                                                                         (.53)

   ln(ttra)*ln(ttra)      lnttrap2                                -.310538E-02
                                                                         -.056
                                                                       (-1.18)

   ln(agerail)*ln(agetrav lnagragt                                 .746290E-01
   )                                                                      .765
                                                                         (.29)

   ln(agerail)*ln(vma)    lnagrvma                                -.554973E+00
                                                                        -8.390
                                                                       (-1.22)

   ln(agerail)*ln(ttra)   lnagrttra                                .208791E-01
                                                                          .028
                                                                         (.63)

   ln(agetrav)*ln(vma)    lnagtvma                                 .761306E+00
                                                                        11.561
                                                                        (1.65)

   ln(agetrav)*ln(ttra)   lnagtttra                               -.188022E-01
                                                                         -.026
                                                                        (-.56)

   ln(vma)*ln(ttra)       lnvmattra                               -.193638E-02
                                                                         -.003
                                                                        (-.17)
 ----------------------------
 QUALITY-TRAFFIC INTERACTIONS
 ----------------------------
   ln(agerail)*ln(tbt1)   lnagrtb1                                 .185743E-02
                                                                          .068
                                                                         (.05)

   ln(agerail)*ln(tbt2)   lnagrtb2                                 .328774E-02
                                                                          .122
                                                                         (.09)

   ln(agerail)*ln(tbt3)   lnagrtb3                                -.862752E-03
                                                                         -.013
                                                                        (-.10)

   ln(agerail)*ln(tbt4)   lnagrtb4                                -.592445E-01
                                                                        -2.386
                                                                       (-2.37)

   ln(agetrav)*ln(tbt1)   lnagttb1                                -.476807E-02
                                                                         -.176
                                                                        (-.13)

   ln(agetrav)*ln(tbt2)   lnagttb2                                 .166505E-01
                                                                          .622
                                                                         (.47)

   ln(agetrav)*ln(tbt3)   lnagttb3                                 .336615E-03
                                                                          .005
                                                                         (.04)

   ln(agetrav)*ln(tbt4)   lnagttb4                                -.992771E-03
                                                                         -.040
```

`(-.04)`

```
___________________________________________________________________________________________
                              VARIANT =  lineaire        log        translog     bc10tbt

___________________________________________________________________________________________

   ln(ttra)*ln(tbt1)      lntratb1                                -.164423E-02
                                                                         -.008
                                                                        (-.82)

   ln(ttra)*ln(tbt2)      lntratb2                                -.356795E-03
                                                                         -.002
                                                                        (-.21)

   ln(ttra)*ln(tbt3)      lntratb3                                -.999516E-03
                                                                         -.017
                                                                        (-.76)

   ln(ttra)*ln(tbt4)      lntratb4                                 .548149E-03
                                                                          .003
                                                                         (.39)

   ln(vma)ln(tbt1)        lnvmatb1                                 .553413E-02
                                                                          .319
                                                                         (.38)

   ln(vma)ln(tbt2)        lnvmatb2                                -.142561E-01
                                                                         -.812
                                                                        (-.90)

   ln(vma)ln(tbt3)        lnvmatb3                                 .369125E-02
                                                                          .089
                                                                         (.65)

   ln(vma)ln(tbt4)        lnvmatb4                                 .447824E-01
                                                                         2.811
                                                                        (3.36)

   agerail*tbt1           agrtbt1                                              -.928739E-04
                                                                                      -.026
                                                                                     (-.43)
                                                                                     LAM  2

   agerail*tbt2           agrtbt2                                              -.905200E-04
                                                                                      -.016
                                                                                     (-.35)
                                                                                     LAM  2

   agerail*tbt3           agrtbt3                                               .286656E-03
                                                                                       .071
                                                                                     (1.95)
                                                                                     LAM  2

   agerail*tbt4           agrtbt4                                               .250585E-03
                                                                                       .109
                                                                                     (3.13)
                                                                                     LAM  2

   agetrav*tbt1           agttbt1                                              -.219089E+00
                                                                                      -.004
                                                                                     (-.56)
                                                                                     LAM  3

   agetrav*tbt2           agttbt2                                               .989171E+00
                                                                                       .019
                                                                                     (3.08)
                                                                                     LAM  3

   agetrav*tbt3           agttbt3                                               .854290E-01
                                                                                       .002
                                                                                      (.55)
                                                                                     LAM  3

   agetrav*tbt4           agttbt4                                               .484839E+00
                                                                                       .009
                                                                                     (2.32)
                                                                                     LAM  3
```

```
__________________________________________________________________________________________
                              VARIANT =  lineaire       log        translog     bc10tbt
__________________________________________________________________________________________

   tbt1/vma               tbt1vma                                              .293598E-08
                                                                                      .010
                                                                                    (1.70)
                                                                                    LAM  4

   tbt2/vma               tbt2vma                                             -.149261E-07
                                                                                     -.008
                                                                                    (-.76)
                                                                                    LAM  4

   tbt3/vma               tbt3vma                                             -.253252E-09
                                                                                     -.001
                                                                                   (-1.10)
                                                                                    LAM  4

   tbt4/vma               tbt4vma                                              .118119E-08
                                                                                      .025
                                                                                    (3.79)
                                                                                    LAM  4

   tbt1/ttra              tbt1ttra                                             .732800E-19
                                                                                      .001
                                                                                    (2.40)
                                                                                    LAM  5

   tbt2/ttra              tbt2ttra                                             .678639E-19
                                                                                      .001
                                                                                    (1.67)
                                                                                    LAM  5

   tbt3/ttra              tbt3ttra                                             .565905E-20
                                                                                      .000
                                                                                     (.02)
                                                                                    LAM  5

   tbt4/ttra              tbt4ttra                                            -.383543E-20
                                                                                     -.000
                                                                                   (-1.19)
                                                                                    LAM  5
 -------------------
 TRAFFIC INTERACTIONS
 -------------------
   ln(tbt1)*ln(tbt1)      lntbt1p2                                .117821E-02
                                                                         .181
                                                                        (.77)

   ln(tbt2)*ln(tbt2)      lntbt2p2                                .212171E-02
                                                                         .317
                                                                       (1.86)

   ln(tbt3)*ln(tbt3)      lntbt3p2                                .152204E-02
                                                                         .208
                                                                       (2.75)

   ln(tbt4)*ln(tbt4)      lntbt4p2                                .160924E-02
                                                                         .291
                                                                       (1.71)

   ln(tbt1)*ln(tbt2)      lntb1tb2                               -.568287E-03
                                                                        -.084
                                                                       (-.34)

   ln(tbt1)*ln(tbt3)      lntb1tb3                                .161023E-02
                                                                         .099
                                                                       (1.66)

   ln(tbt1)*ln(tbt4)      lntb1tb4                               -.406585E-03
                                                                        -.065
                                                                       (-.24)

   ln(tbt2)*ln(tbt3)      lntb2tb3                               -.122969E-03
                                                                        -.007
                                                                       (-.12)
```

```
___________________________________________________________________________________________
                              VARIANT =  lineaire       log        translog     bc10tbt
___________________________________________________________________________________________

   ln(tbt2)*ln(tbt4)      lntb2tb4                                 .389264E-03
                                                                          .061
                                                                         (.22)

   ln(tbt3)*ln(tbt4)      lntb3tb4                                -.249109E-02
                                                                         -.168
                                                                       (-2.41)

   tbt1*tbt2              tbt1tbt2                                             -.952887E-09
                                                                                      -.013
                                                                                     (-.38)
                                                                                     LAM  6

   tbt1*tbt3              tbt1tbt3                                             -.172403E-08
                                                                                      -.058
                                                                                    (-2.86)
                                                                                     LAM  6

   tbt1*tbt4              tbt1tbt4                                              .438758E-09
                                                                                       .019
                                                                                      (.65)
                                                                                     LAM  6

   tbt2*tbt3              tbt2tbt3                                              .325553E-09
                                                                                       .003
                                                                                      (.26)
                                                                                     LAM  6

   tbt2*tbt4              tbt2tbt4                                             -.730913E-09
                                                                                      -.014
                                                                                     (-.53)
                                                                                     LAM  6

   tbt3*tbt4              tbt3tbt4                                             -.124198E-08
                                                                                      -.030
                                                                                    (-3.00)
                                                                                     LAM  6
 ---------------
 TRAFFIC CLASSES
 ---------------
   trafic tonnes brutes   tbt1          .684658E-01  .126643E-01 -.601038E-02  .327617E-01
   trains 1                                    .162         .013        -.006         .111
   (grandes lignes)                          (8.26)       (1.53)       (-.34)       (1.59)
                                                          LAM  1       LAM  1          LAM

   trafic tonnes          tbt2          .192736E+00  .193954E-01  .161840E-01  .394774E-05
   brutes trains 2 (TER)                       .176         .019         .016         .130
                                             (8.36)       (2.79)       (1.26)       (2.15)
                                                          LAM  1       LAM  1       LAM  7

   trafic tonnes          tbt3          .433234E-01  .115278E-01  .110006E-01  .769367E-06
   brutes trains 3 (IdF)                       .084         .012         .011         .059
                                            (10.06)       (4.47)       (3.14)       (2.89)
                                                          LAM  1       LAM  1       LAM  7

   trafic tonnes          tbt4          .132432E-01  .164950E-01  .110205E-01 -.198213E-22
   brutes trains 4 (Fret)                      .069         .016         .011        -.004
                                             (3.18)       (3.14)       (1.08)      (-2.58)
                                                          LAM  1       LAM  1          LAM

   REGRESSION CONSTANT    CONSTANT      .568450E+06  .157782E+02  .225701E+02  .230274E+03
                                                -            -            -            -
                                             (7.28)      (27.16)       (2.13)      (10.22)
```

```
__________________________________________________________________________________________
                              VARIANT =  lineaire       log        translog     bc10tbt
__________________________________________________________________________________________

SECTION II : Box-Cox transformations, [T-STATISTIC=0] / [T-STATISTIC=1]

   LAMBDA(Y)              mtkm                1.000         .000         .000         .308
                                              FIXED        FIXED        FIXED      [19.90]
                                                                                  [-44.75]

   LAMBDA(X)              tbt1                                                        .377
                                                                                    [1.39]
                                                                                   [-2.31]

   LAMBDA(X)              tbt4                                                       3.458
                                                                                    [1.68]
                                                                                    [1.20]

   LAMBDA(X) - GROUP  1   LAM  1                            .000         .000         .112
                                                           FIXED        FIXED       [1.39]
                                                                                  [-11.06]

   LAMBDA(X) - GROUP  2   LAM  2                                                      .574
                                                                                    [2.55]
                                                                                   [-1.90]

   LAMBDA(X) - GROUP  3   LAM  3                                                      .004
                                                                                     [.03]
                                                                                   [-9.39]

   LAMBDA(X) - GROUP  4   LAM  4                                                     2.129
                                                                                    [3.29]
                                                                                    [1.75]

   LAMBDA(X) - GROUP  5   LAM  5                                                     1.594
                                                                                    [2.00]
                                                                                     [.75]

   LAMBDA(X) - GROUP  6   LAM  6                                                      .743
                                                                                    [3.24]
                                                                                   [-1.12]

   LAMBDA(X) - GROUP  7   LAM  7                                                     1.114
                                                                                    [4.12]
                                                                                     [.42]
__________________________________________________________________________________________

                            SECTION III : General statistics

 LOG-LIKELIHOOD                           -13547.642   -13129.267   -13092.508   -12866.366

 PSEUDO-R2 : - (E)                              .727         .651         .676         .823
             - (L)                              .720         .882         .891         .932
             - (E) ADJUSTED FOR D.F.            .722         .644         .657         .813
             - (L) ADJUSTED FOR D.F.            .715         .880         .884         .928

 AVERAGE PROBABILITY (Y=LIMIT OBSERV.)          .161         .000         .000         .000

 SAMPLE : - NUMBER OF OBSERVATIONS               967          967          967          967
          - FIRST OBSERVATION                     12           12           12           12
          - LAST  OBSERVATION                    978          978          978          978

 NUMBER OF ESTIMATED PARAMETERS :
   - FIXED PART :
       . BETAS                                    19           19           55           41
       . BOX-COX                                   0            0            0           10
       . ASSOCIATED DUMMIES                        0            0            0            0
   - AUTOCORRELATION                               0            0            0            0
   - HETEROSKEDASTICITY :
       . DELTAS                                    0            0            0            0
       . BOX-COX                                   0            0            0            0
       . ASSOCIATED DUMMIES                        0            0            0            0
__________________________________________________________________________________________
```

9 Appendix 2. Effect of quality adjustment on marginal costs

Consider a track on which 2 types of traffic are running and define:

> $C(Q1, Q2, q)$ as the ***maintenance*** cost of such a track with two traffics (1 and 2) and the quality of which is measured by the variable q;
>
> $F(Q1, Q2, q)$ as the ***transport*** cost of these traffics 1 and 2, including monetary, time and comfort costs.

Assume that the first derivatives of C and F with respect to $Q1$ and $Q2$ and of C with respect to q are positive, but that the derivative of F with respect to q is negative.

If finding a social optimum implies a minimization of the ***total cost*** with respect to the quality level q, namely:

$$\text{Min. (with respect to } q) (C+F),$$

the first order conditions may then be written as :

$$C'q+F'q=0, \qquad (1)$$

and solved for the optimal value of q for given values of $Q1$ and $Q2$:

$$q=q(Q1, Q2). \qquad (2)$$

Then the marginal cost of traffic 1 is:

$$C'(Q1) = C'Q1 + (C'q)*(dq/dQ1) \qquad (3)$$

Let us note that this relationship takes into account the fact that the change in quality due to the change in traffic is different from the "technical" marginal cost which does not take into account the change in quality. Deduced from (2), the latter, $C'Q1$, is $dq/dQ1)$; and similarly for traffic 2.

It turns out that the ratio of marginal costs $(dC/dQ1)/ (dC/dQ2)$ generally differs from the ratio of technical equivalence coefficients $(\partial C1/\partial Q1)/ (\partial C/\partial Q2)$.

To see it in an extreme case, write simple functions satisfying the above assumptions:

$$C=C_0+C_1*Q1+0{,}5*C_2*Q1*q^2$$

$$F=F_1*Q1+F_2*Q2-F_3*Q2*q^2$$

which have the built-in property that traffic 1 is damaging but not sensitive to quality, while traffic 2 is not damaging but sensitive to quality, as one expects from freight and passenger traffics.

Trivial calculations lead to the following results:

$$q= (F_3/C_2)*(Q2/Q1)$$

and, from (3), to the marginal costs:

$$C'(Q1) =C_1-C_2 (F_3*Q2/C_2*Q1)^2$$

$$C'(Q2) =C_2*(Q1/Q2)*(F_3*Q2/C_2*Q1)^2$$

It is clear that, depending on the values of the parameters C_1, C_2 and F_3, $C'(Q1)$ and $C'(Q2)$ can take any value; and it may happen that $C'(Q1) < C'(Q2)$ though traffic 2 causes no damage to the track.

The above simple model assumes that the infrastructure manager aims at maximising social welfare, but other objectives are possible such as maintaining a given quality level, or making the quality proportionate to the traffic level, or any other option. In those cases the marginal costs would exhibit different relationships from those derived here.

SIXTH FRAMEWORK PROGRAMME
PRIORITY 1.6.2
Sustainable Surface Transport

CATRIN

Cost Allocation of TRansport INfrastructure cost

D8 – Rail Cost Allocation for Europe

Annex 1Dii – Description of Maintenance and Renewal Costs in France

Version 2.1
February 2009

Authors:
Emile Quinet (PSE-ENPC)

Contract no.: 038422
Project Co-ordinator: VTI

Funded by the European Commission
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CATRIN Partner Organisations

VTI; University of Gdansk, ITS Leeds, DIW, Ecoplan, Manchester Metropolitan University, TUV Vienna University of Technology, EIT University of Las Palmas; Swedish Maritime Administration, University of Turku/Centre for Maritime Studies

CATRIN D8 - Rail Cost Allocation for Europe – Annex 1Dii – Description of Maintenance and Renewal Costs in France
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Partners: VTI; University of Gdansk, ITS Leeds, DIW, Ecoplan, Manchester Metropolitan University, TUV Vienna University of Technology, EIT University of Las Palmas; Swedish Maritime Administration, University of Turku/Centre for Maritime Studies

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CATRIN D8 - Rail Cost Allocation for Europe – Annex 1Dii – Description of Maintenance and Renewal Costs in France
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Description of Maintenance and Renewal Costs in France

Emile Quinet

Maintenance and renewal costs can have different definitions in various countries, and it may be misleading to compare the costs of each of these two categories from one country to another if the definitions are not the same. This section aims at shedding some light on this issue through a precise definition of these two categories of work in France. Doing so implies to have a view on the policy and on the organizational structure of maintenance operations. Therefore we will first recall the organization of maintenance in France, then explain the maintenance policy hitherto implemented and the changes at work before setting the precise boarder between maintenance and renewal.

The French maintenance organization.

French maintenance organization is quite specific as it involves both the infrastructure manager RFF and the historical rail operator SNCF. Both are public enterprises, and their statuses bear the obligation for RFF to rely on SNCF staff for maintenance achievement and for SNCF to implement the maintenance policy decided by RFF.

So, though in charge of the management of infrastructure, RFF is a small structure (of about 500 employees) and its decisions on maintenance are to be implemented by SNCF, through its infrastructure division: the Reform Law demands RFF to use SNCF services to operate the railway infrastructure, on a contractual basis, called the “*Convention de Gestion*” (Management agreement). For that purpose an agreement is concluded every year between both bodies. In this agreement, RFF give a fixed amount of money for the achievement of maintenance and SNCF has to implement the maintenance. The fee is quite stable along the years. The maintenance contract is generally assumed to be vague and soft, not including enough incentives, and without clear quality objectives, though it is improving on these grounds from year to year.

This unusual type of relations between the historical operator and the infrastructure manager is supposed to meet several objectives:

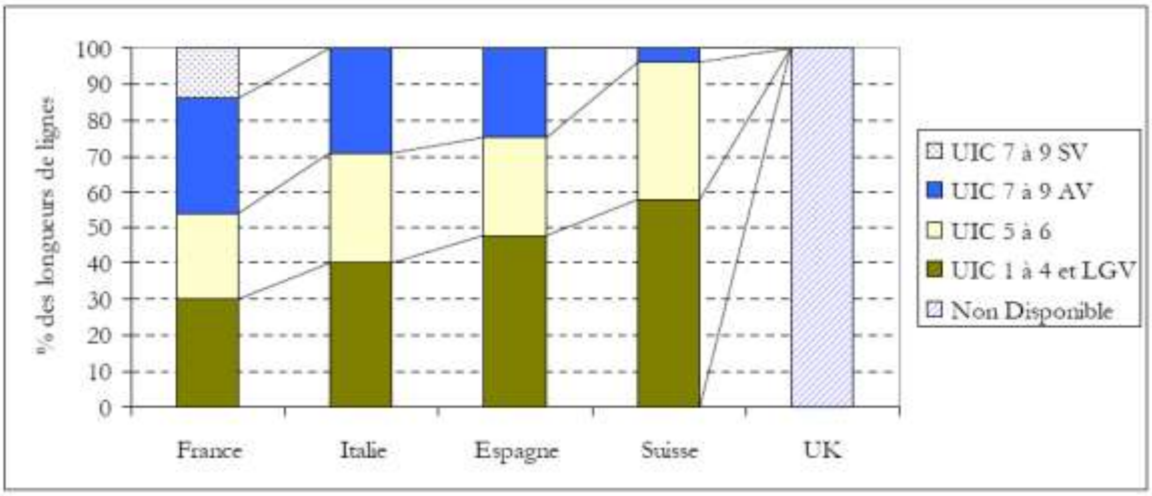
- To be acceptable from a political point of view, especially vis à vis trade unions, which are specially opposed to liberalisation and to fragmentation of the hirtorical operator
- To maintain connection between infrastructure and services, a point which was deemed desirable by many French rail specialists.

The picture is rather different for renewals. They are decided and paid by RFF, on an itemized basis. The involvement and control of RFF are much higher for renewal than for maintenance. Let us note that, for the implementation of renewals, SNCF provides the supervision (not including the maintenance and renewal staff) and the materials (rails, ballast) but the huge equipments (*suites rapides*) are contracted out to private firms.

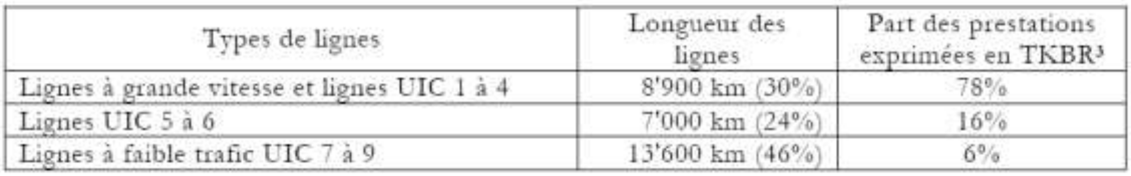
The State of the Network

The state of the network has been by and large studied by Rivier and Putallaz (2007) from which the following considerations are largely drawn. The characteristic of the French network compared to other countries are:

-The large proportion of low traffic tracks. The following graph drawn from Rivier and Putallaz shows this point:



Furthermore, the low traffic segments (UIC classification 7 to 9) are nearly half the network and bear only a small fraction of the total traffic:



Types de lignes	Longueur des lignes	Part des prestations exprimées en TKBR[3]
Lignes à grande vitesse et lignes UIC 1 à 4	8'900 km (30%)	78%
Lignes UIC 5 à 6	7'000 km (24%)	16%
Lignes à faible trafic UIC 7 à 9	13'600 km (46%)	6%

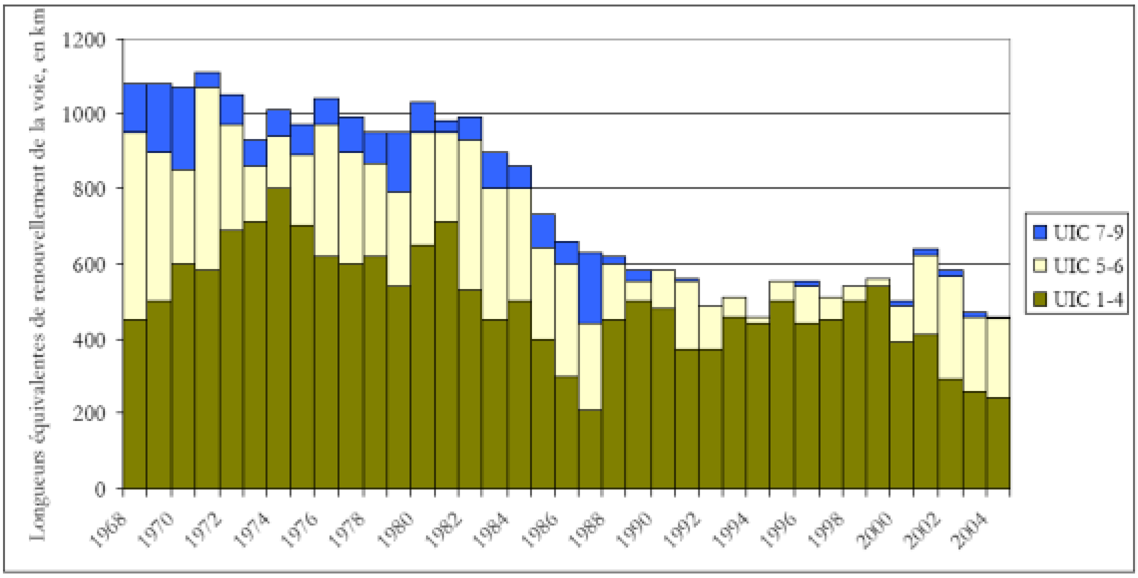
An audit of the technical situation of the network shows that, while the dense segments (UIC 1 to 4) are rather well kept, the UIC track 5 to 6 and furthermore 7 to 9 are under-maintained; the damages are frequent and the maintenance is mainly a curative one, not a preventive one.

Generally speaking, the age of the equipment is high; the age of the main equipments (rail switches) is increasing by about 5 years for the last 15 years, due to a lack of renewal.

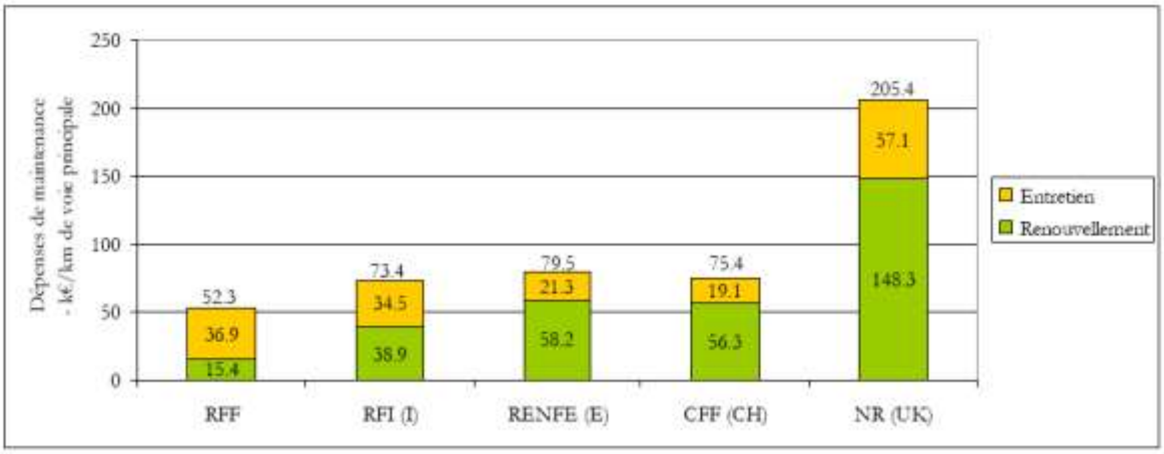
Maintenance and Renewal Policy

Maintenance and Renewal Policy in French Railways offers specificities which has been widely documented in Rivier and Putallaz. On the whole, the share of renewal in the total “maintenance+renewal” is low compared to other European countries, and this share is especially low for small track, poorly frequented. It happens too that these low traffic tracks are much more important in length than in other countries. The low substance of these tracks induces, in the opinion of the experts, higher maintenance costs and higher risks of damages and destruction of the tracks, which can be prevented only through speed reduction.

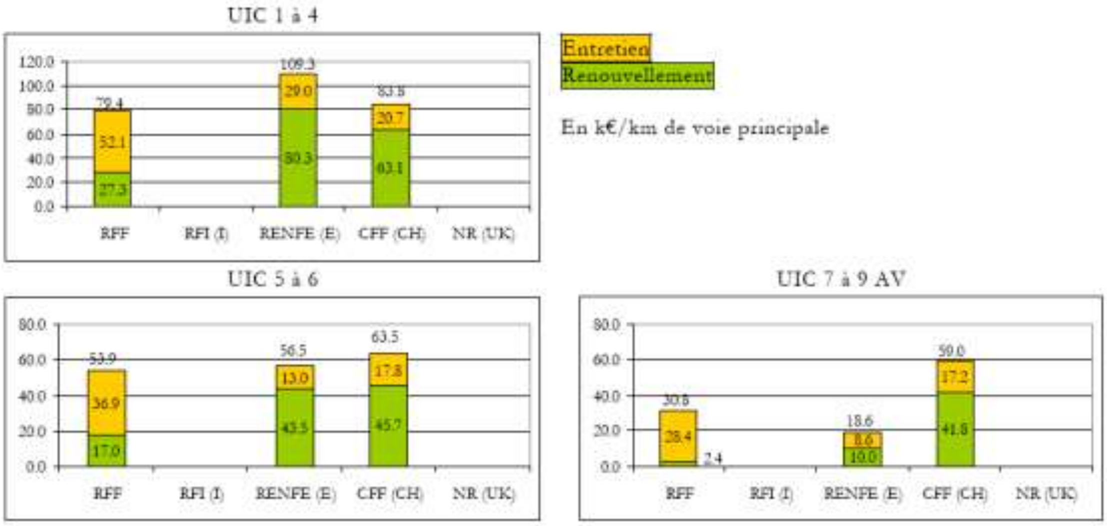
The rhythm of renewals has steadily decreased along the past decades as shown by the following graph, exemplifying the increase of the age and providing the length of renewals for each year between 1968 and 2004.



Decrease in renewal inducing higher maintenance costs to keep the network in a situation of operation induces higher maintenance costs, and the share of maintenance to renewal is much higher than in other countries:



but this difference applies mainly to small segments:



As a consequence of the audit, the general maintenance policy is slowly changing in France, increasing the total amount of money and devoting a larger share to renewal.

Technical operations of maintenance and renewal

Maintenance operations are usually classified in several categories:

- Inspection and detection. These tasks are achieved through visual and manual inspection (mainly for the state of the rail and ballast) and through mechanical devices (mainly for the geometrical characteristics of the track).
- Correction maintenance, which aims at curing the damages which the inspection has shown to be both important and local (other ones are included in renewal programs)
- Prevention maintenance, which aims regularly at correcting small defaults and divergences on a regular and systematic basis.

These categories are quite similar to those used in other countries, to the exception that the inspection tasks and the correction maintenance are, according to the experts, more important than in other countries due to the low average substance of the network.

More specific is the following category of maintenance, named *Operation de Grand Entretien* (OGE) which could be translated in "operation of huge maintenance". These operations are at the threshold between maintenance and renewal, and are precisely defined. They are identified by their origin and end. An evaluative cost is made for each of them. The frontiers between OGE and usual maintenance are fixed for each type of work. The box shows these limits.

Box 1 Hints about the size characteristics of OGE

Financial amount: 150 000 Euro

Technical standards: OGE are mainly, but not exclusively, directed towards low traffic segments (UIC 6 to 9), with priority to the segments where maximal speed has been reduced (reduced speed threshold) and second where the intervention threshold has been reached.

Rail replacement: more than 200 meter long and no more than 1 000 meters long

Sleepers: on UIC 7 to 9 with wooden sleepers

Ballast: when the renewal does not happen before ten years

The amount spent on OGE is increasing, 80 M€ in 2008, 120 M€ in 2010. It is in a certain way a "low cost" renewal, though they accounted for in the *Convention de Gestion* and as such considered as maintenance. On the whole, it can be said that there are three broad categories of cost:

1. maintenance (which includes as sub-categories, inspection and detection, correction, and prevention) – which would include small renewals up to 200m
2. OGE (“huge maintenance”) which includes renewals between 200m and 1000m
3. Renewals (in excess of 1000m)

The present rules of accounting and classification adopted in France classify OGE in maintenance costs and as such they are included in the maintenance costs subjects of the econometric analysis (cf the file “econometrics of maintenance costs”).

While the financial amount of maintenance expenses does not vary much along the years, it is not the same for renewals. The amount of renewals was small before the audit (about a few hundred Million Euro) and is now nearly as large as maintenance expenses.

Renewals are much more important operations. The financial amount is at least 0,5 M€ and can often go to 50 M€. Renewal operations are individualized, they are planned 3 years in advance, with at first a *dossier d’initialisation* (Initialization file), then a detailed scheme (which mainly details how the work will be implemented and the track possession policy)

Renewals are achieved through large track renewal trains (*Suite rapide*) about 1 km long, which can renew 1 km per day. They are owned and operated by private firms, which use SNCF inputs for raw materials and for control. The cost of a renewal is around 1 M€ per km of which 1/3 of raw material, 1/3 for the track renewal train, 1/3 for control and survey.

Conclusion for the cost function and the marginal costs

Some conclusions can be drawn from this presentation of the French maintenance policy.

First, several features of the maintenance policy fit well with the econometric results and provide hints to improve them.

Secondly, the differences between maintenance and renewal are clear cut; the proportion of misallocation of both types in the accounts is certainly low, and the French data is consistent in terms of allocation between maintenance and renewal at the track section level.

SIXTH FRAMEWORK PROGRAMME
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Annex 1Diii – Analysis of operation costs in France

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Analysis of operation costs in France

Emile Quinet

Short run costs of rail infrastructure do not include just the maintenance costs, but also the operation costs, due to the traffic management activities: management of the switches and time table setting. Though rarely addressed, these costs are not at all negligible; in France for instance, they represent about 35% of pure maintenance costs (i.e. about 25% of the total maintenance+operation costs). This text aims at providing some insights on them and on the associated marginal costs. The approach is primarily an econometric one, based on top-down process where correlation is assessed between operation costs and traffic level at some aggregate level of segments of track; the literature is very poor; indeed we have found no European reference on the subject. We will first present the technical content of this type of expense, second the framework of the econometric analysis, third the results.

Technical content

Operation costs include the costs of time-table setting and the operation costs of switch management (exclusive of operation maintenance costs which are included in the maintenance costs). In France at least, they are performed by similar staff, going through one of these positions to the other all along their professional career. Manpower is one of the main inputs. The main other one is capital, represented by switches and by the equipment of the time-table setting (telematics, software, and computers); depending on the age of the device, the shares of capital and labour may be different, and the production functions too. In older systems switches manipulations are made by hand, while in the most recent ones, they are made through automatic electronic and electric systems. Similarly, time table setting was formerly done by hand, while there is now software which helps their implementation. In face of these two categories of inputs, the other inputs are negligible.

Contrarily to most of the maintenance costs, operation costs cannot be allocated to a specific section. They are network costs. This point is clear for switches which are for most of them at the crossing of two or more tracks and which do not exist in the case of a unique track in the absence of crossovers to another one. It is also clear that the size of the time-table setting problem is greatly influenced by the complexity of the network structure.

Nevertheless, these costs clearly depend on the traffic level; if the traffic grows from one circulation by day to 100 circulations by day on a given network, it is clear that the costs of switching operations and time table implementation increase.

Econometric analysis

Two approaches could be used to assess this dependency. The first one would be engineering simulation of a given network with such and such crossings and switches and a structure of traffic on the various links of the network, followed by a simulation of an increase of traffic on a link and assessment of the effect on time-table setting and on switching operations. This micro-simulation would need a lot of work and give probably very widespread results depending on the structures of the network and of the traffic.

A rough proxy for this detailed simulation has been to ask specialists what is their feeling or experience in that matter. The result is that, up to saturation levels of infrastructure, the increase in cost due to traffic increases should be rather small: for switches for instance, with modern equipment, the task is almost entirely automatic and the role of staff is just to be present and monitor; an increase of cost coming from an additional circulation would appear only if this additional circulation is out of the former circulation time-span.

The present approach is an econometric one, which does not reproduce the technical process but first finds out heuristically the main drivers of these operation costs, and than proceeds to the formal econometric analysis of their impact. The main variables involved are traffic, expressed as a total of train*km, manpower, expressed as a total of wages or men-month multiplied by average salary, and capital equipment expressed as a number of switches of such and such standard, computers for time-table, and their costs. With such a basis, a production function could be calculated, expressing the traffic managed in terms of labour input and capital input:

TM = P(quantity of capital, quantity of labour)

From this production function, a short run cost function can be derived:

SRC = SRC(TM, quantity of capital)

From this relation, short run marginal cost can be calculated as:

SRMC = ∂SRC/∂TM.

Capital optimization would lead to the long run cost function and long run marginal cost:

LRC(TM, quantity of capital) = SRC [(TM, quantity of capital)+(quantity of capital)(capital cost)]*

Optimizing this relation in (quantity of capital) would lead to a relation between capital quantity and TM:

(Quantity of capital)=G(TM)

and finally to the optimized long run cost function:

OLRC (TM)=SRC(TM, G(TM))+G(TM)(cost of capital)*

From which it is possible to derive the Long Run Marginal Cost (LRMC):

LRMC(TM)=dOLRC(TM)/d(TM)

Available data do not allow to fully follow this process. Nevertheless, existing studies in France provide insights on some of these points.

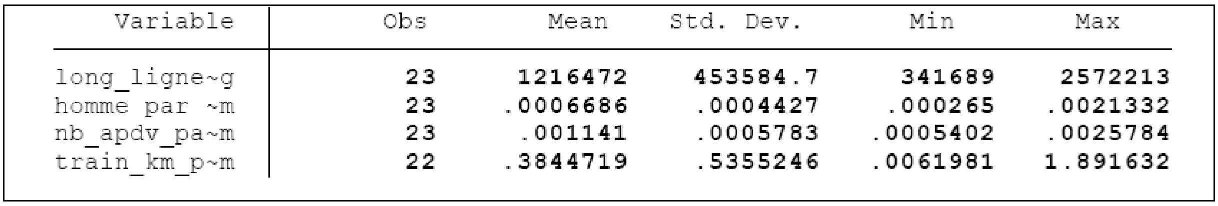
A recent study by RFF relates operation costs to traffic (quoted in Chapulut, Dehornoy, and St Pulgent, *Rapport sur la tarification du réseau ferré*, 2007). The result, expressed in terms of the ratio (marginal cost)/ (average cost) is 0,75. this study presents two characteristics: first it relates operation costs directly to traffic, in that respect it is like a long run cost function, with the heroic assumption that capital cost is optimized. Second, it is based on a relation between operation costs and traffic on the basis of about 10 track clusters, with arbitrary allocation of costs to the tracks.

The present study aims at avoiding this draw-back, noting that operation costs cannot be allocated to segments, as they relate to crossings of segments (for switches) or to connections of segments (for time-table). In this view the econometric analysis should take as observations geographical areas, for which the main parameters will be related.

From the geographical point of view, information available in France is related to regions (SNCF is divided in about 25 regions), and for each region we can obtain the exact number of staff devoted to the tasks (there are also staff at the national level, especially for the time-table task, but they are very few and can be neglected)[1], and the number of switches, plus of course the total traffic level, expressed in train*km. Some assumptions are not too demanding, for instance the assumption that the salaries are the same all over the regions; others are more so, for instance that capital value of switches and equipment for time-table setting in each region is proportional to their number (i. e. that their age and type is evenly distributed over the regions). All variables have been divided by the length of the network of each region. The following notations are used:

- long_ligne~g: ***length of track in each region***
- homme_par_reg_par_km : ***number of staff in each region per km of track in the region***
- train_km_par_reg_par_km : ***number of train*km in each region, divided by the length of the network in the region or in short traffic density***
- nb_apdv_par_reg_par_km : ***number of switches in each region divided by the length of the network in the region***

The following table describes the variables:



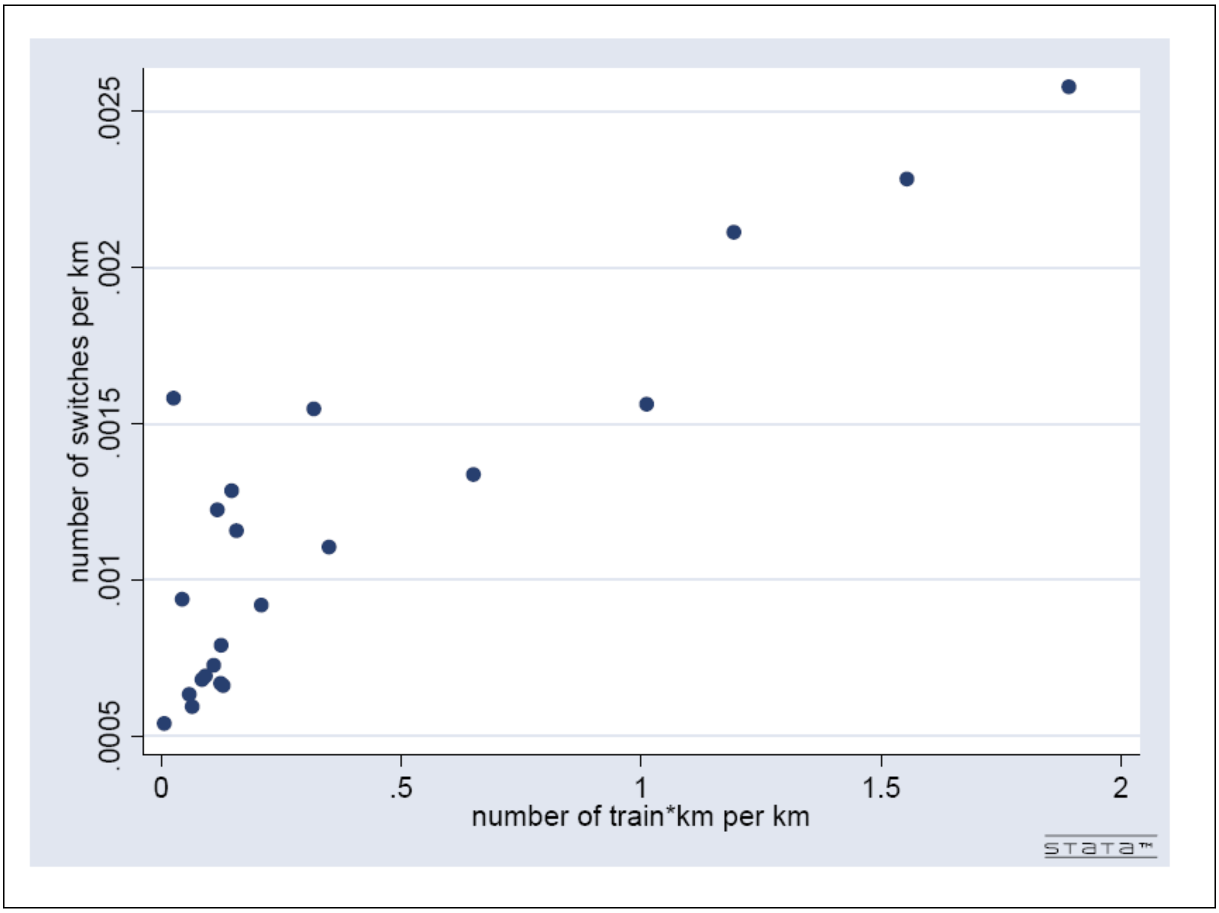
```
    Variable |       Obs        Mean    Std. Dev.       Min        Max
-------------+--------------------------------------------------------
long_ligne~g |        23     1216472    453584.7     341689    2572213
homme par ~m |        23    .0006686    .0004427    .000265   .0021332
nb_apdv_pa~m |        23     .001141    .0005783   .0005402   .0025784
train_km_p~m |        22    .3844719    .5355246   .0061981   1.891632
```

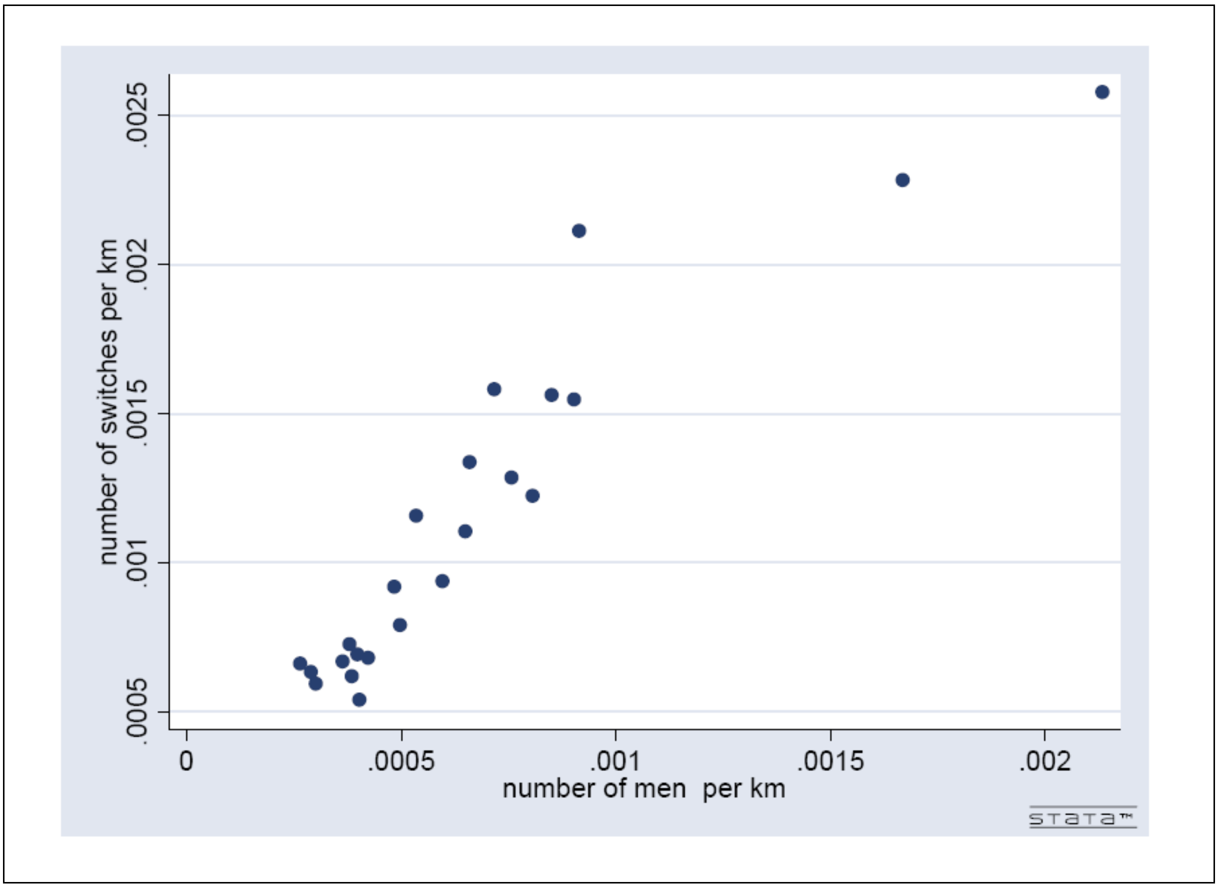
The choice of these variables, which are expressed per km of track, implicitly assumes constant returns to scale in terms of track length; more precisely, when the network length and the number of switches double, the traffic density being kept constant, the cost of operation is doubled. This assumption is in line with the engineering knowledge. It is probably just an approximation, but the poor data does not allow achieving an exhaustive analysis of returns to scale. This point should be a subject of further research.

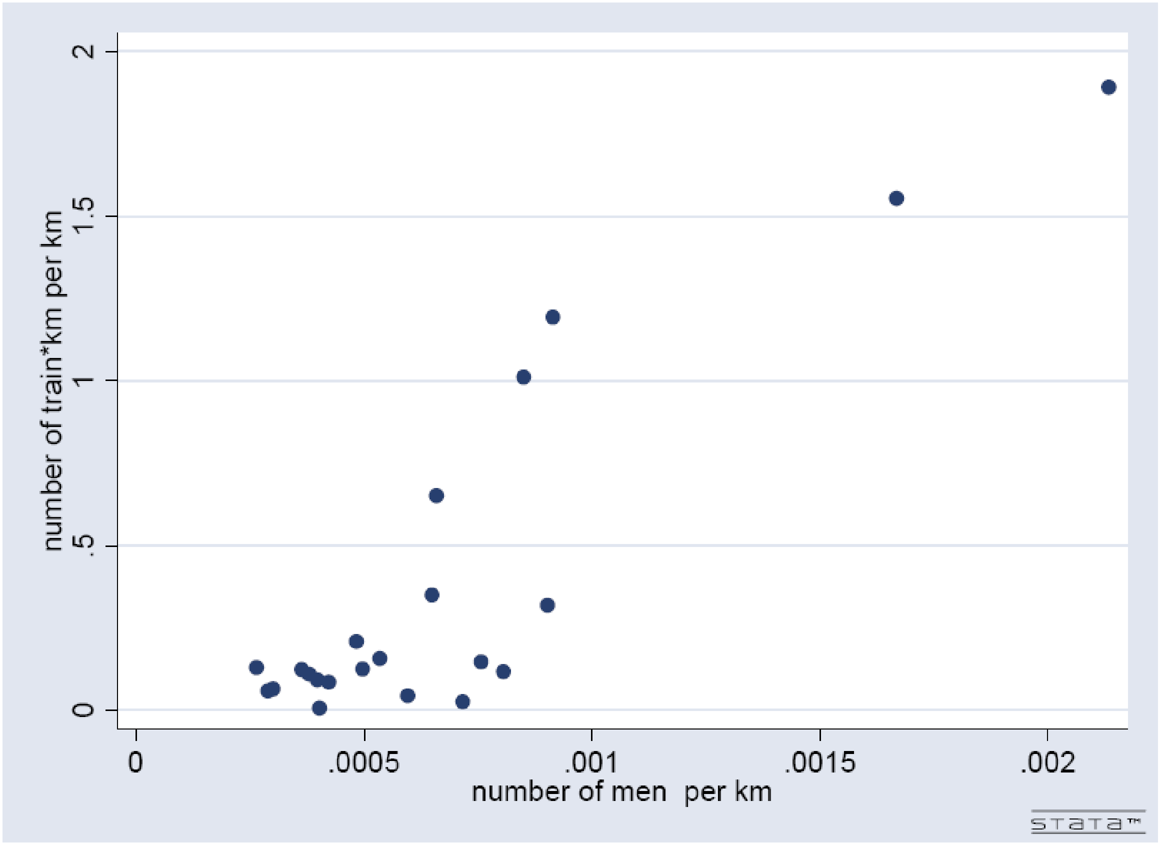
The following pictures show the relation between the 3 last variables:

---

[1] It would be interesting to distinguish the staff devoted to switches and the staff devoted to time-tables. Unfortunately there is no available information on this distinction, except that at the national level the staff for timetabling is about half the staff for switches; but the proportion is not stable and not well ascertained.


number of switches per km
.0005
.001
.0015
.002
.0025
0
.5
1
1.5
2
number of train*km per km
stata™


number of switches per km
.0005
.001
.0015
.002
.0025
0
.0005
.001
.0015
.002
number of men per km
stata™

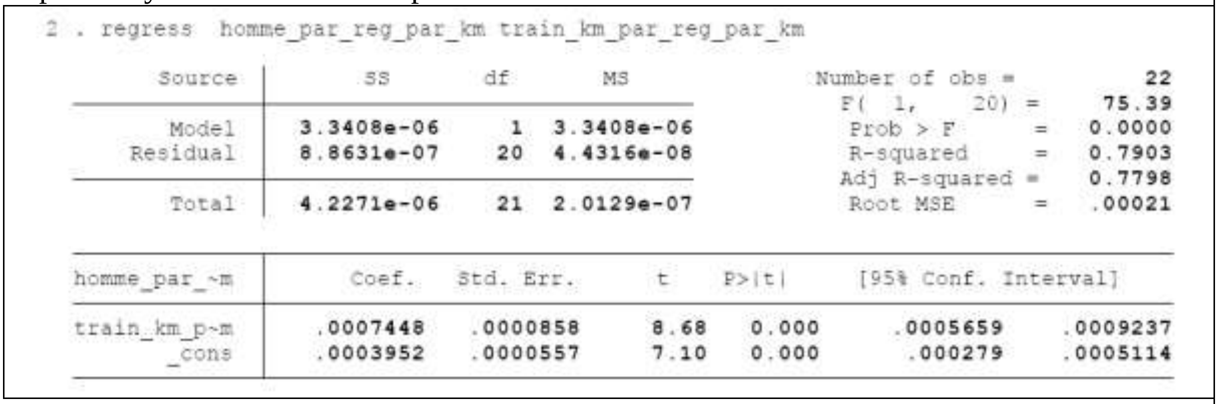


Three adjustments have been performed, listed successively in the table below, followed by results for each. Due to the poor available data (a small number of observations, proxies for costs), the adjustments are limited to linear regressions.

Dependent		Explanatory				Recovery
[Staff/ track-km]	⟵ {	[Switches/ track-km]	[Train-km/ track-km]	[Train-km/ track-km]^2	}	
√			√			30%
√		√	√			13%
√		√	√	√		10%

To understand the three sets of results, note that the first box contains the results of the (regression or) adjustment and the second one the total cost of operation and the revenue which would be drawn from the marginal cost:

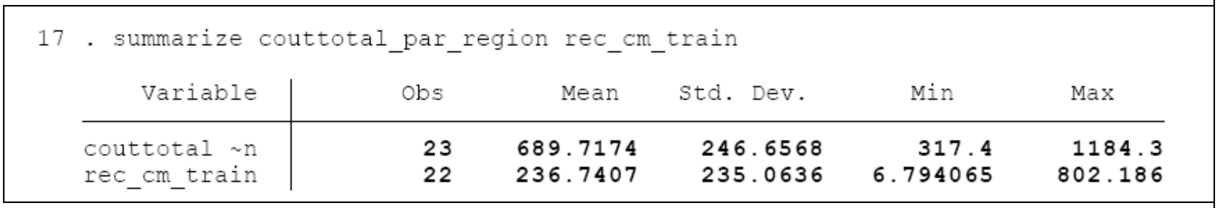
Explanatory variable: train*km per km



```
2 . regress  homme_par_reg_par_km train_km_par_reg_par_km

      Source |       SS       df       MS              Number of obs =      22
-------------+------------------------------           F(  1,    20) =   75.39
       Model |  3.3408e-06     1  3.3408e-06           Prob > F      =  0.0000
    Residual |  8.8631e-07    20  4.4316e-08           R-squared     =  0.7903
-------------+------------------------------           Adj R-squared =  0.7798
       Total |  4.2271e-06    21  2.0129e-07           Root MSE      =  .00021

------------------------------------------------------------------------------
homme_par_~m |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
train_km_p~m |   .0007448   .0000858     8.68   0.000     .0005659    .0009237
       _cons |   .0003952   .0000557     7.10   0.000      .000279    .0005114
------------------------------------------------------------------------------
```

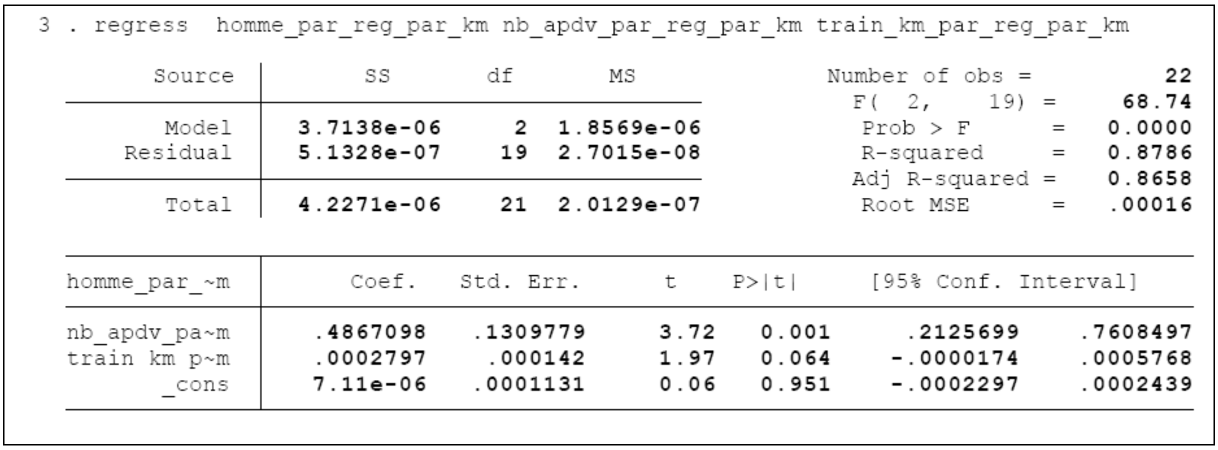


```
17 . summarize couttotal_par_region rec_cm_train

    Variable |       Obs        Mean    Std. Dev.       Min        Max
-------------+--------------------------------------------------------
couttotal ~n |        23    689.7174    246.6568      317.4     1184.3
rec_cm_train |        22    236.7407    235.0636   6.794065    802.186
```

Average recovery ratio of marginal cost pricing: 236/689=30%

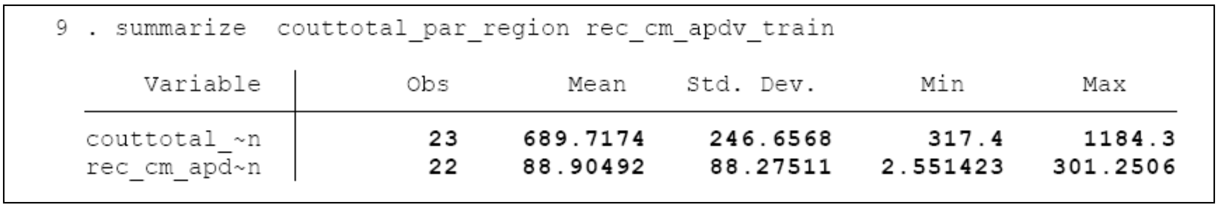
Explanatory variables: (number of switches per km), (train*km per km)



```
3 . regress  homme_par_reg_par_km nb_apdv_par_reg_par_km train_km_par_reg_par_km

      Source |       SS       df       MS              Number of obs =      22
-------------+------------------------------           F(  2,    19) =   68.74
       Model |  3.7138e-06     2  1.8569e-06           Prob > F      =  0.0000
    Residual |  5.1328e-07    19  2.7015e-08           R-squared     =  0.8786
-------------+------------------------------           Adj R-squared =  0.8658
       Total |  4.2271e-06    21  2.0129e-07           Root MSE      =  .00016

------------------------------------------------------------------------------
homme_par_~m |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
nb_apdv_pa~m |   .4867098   .1309779     3.72   0.001     .2125699    .7608497
train km p~m |   .0002797    .000142     1.97   0.064    -.0000174    .0005768
       _cons |   7.11e-06   .0001131     0.06   0.951    -.0002297    .0002439
------------------------------------------------------------------------------
```

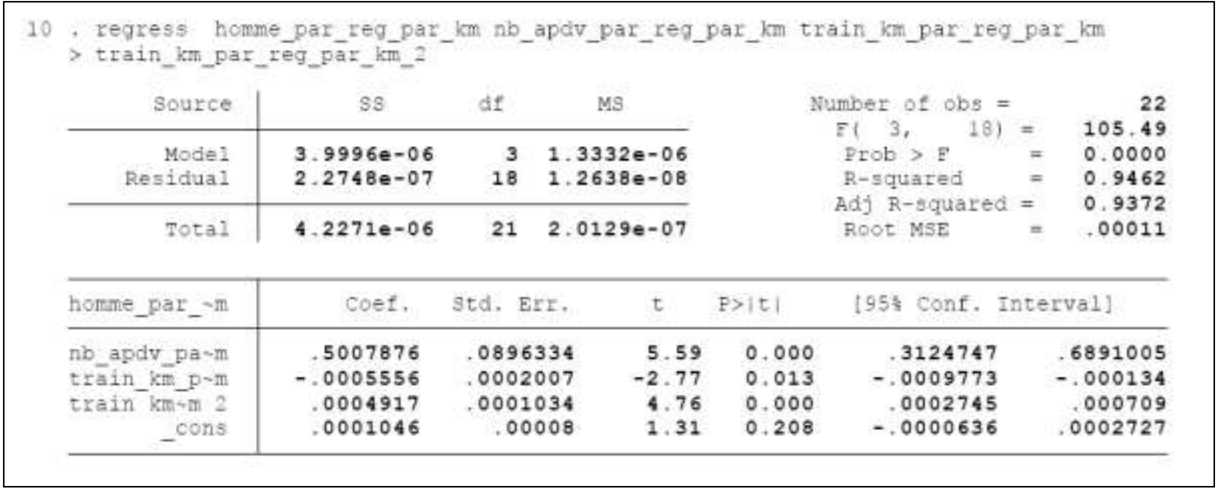


```
9 . summarize  couttotal_par_region rec_cm_apdv_train

    Variable |       Obs        Mean    Std. Dev.       Min        Max
-------------+--------------------------------------------------------
couttotal_~n |        23    689.7174    246.6568      317.4     1184.3
rec_cm_apd~n |        22    88.90492    88.27511   2.551423   301.2506
```

Average Recovery ratio of marginal cost pricing:88/689=13%

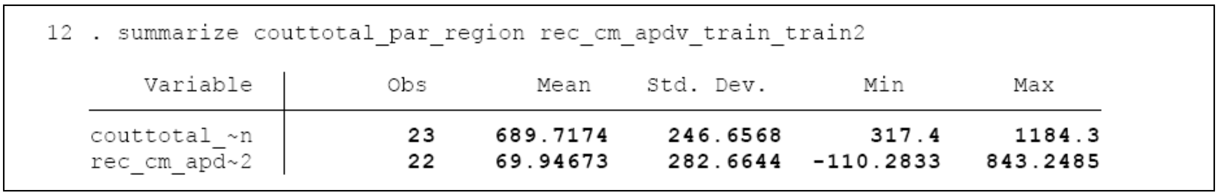
Explanatory variables: (number of switches per km), (train*km per km), (train*km per km)²



```
10 . regress  homme_par_reg_par_km nb_apdv_par_reg_par_km train_km_par_reg_par_km
   > train_km_par_reg_par_km_2

      Source |       SS       df       MS              Number of obs =      22
-------------+------------------------------           F(  3,    18) =  105.49
       Model |  3.9996e-06     3  1.3332e-06           Prob > F      =  0.0000
    Residual |  2.2748e-07    18  1.2638e-08           R-squared     =  0.9462
-------------+------------------------------           Adj R-squared =  0.9372
       Total |  4.2271e-06    21  2.0129e-07           Root MSE      =  .00011

------------------------------------------------------------------------------
homme_par_~m |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
nb_apdv_pa~m |   .5007876   .0896334     5.59   0.000      .3124747    .6891005
train_km_p~m |  -.0005556   .0002007    -2.77   0.013     -.0009773   -.000134
train_km~m_2 |   .0004917   .0001034     4.76   0.000      .0002745    .000709
       _cons |   .0001046     .00008     1.31   0.208     -.0000636    .0002727
------------------------------------------------------------------------------
```

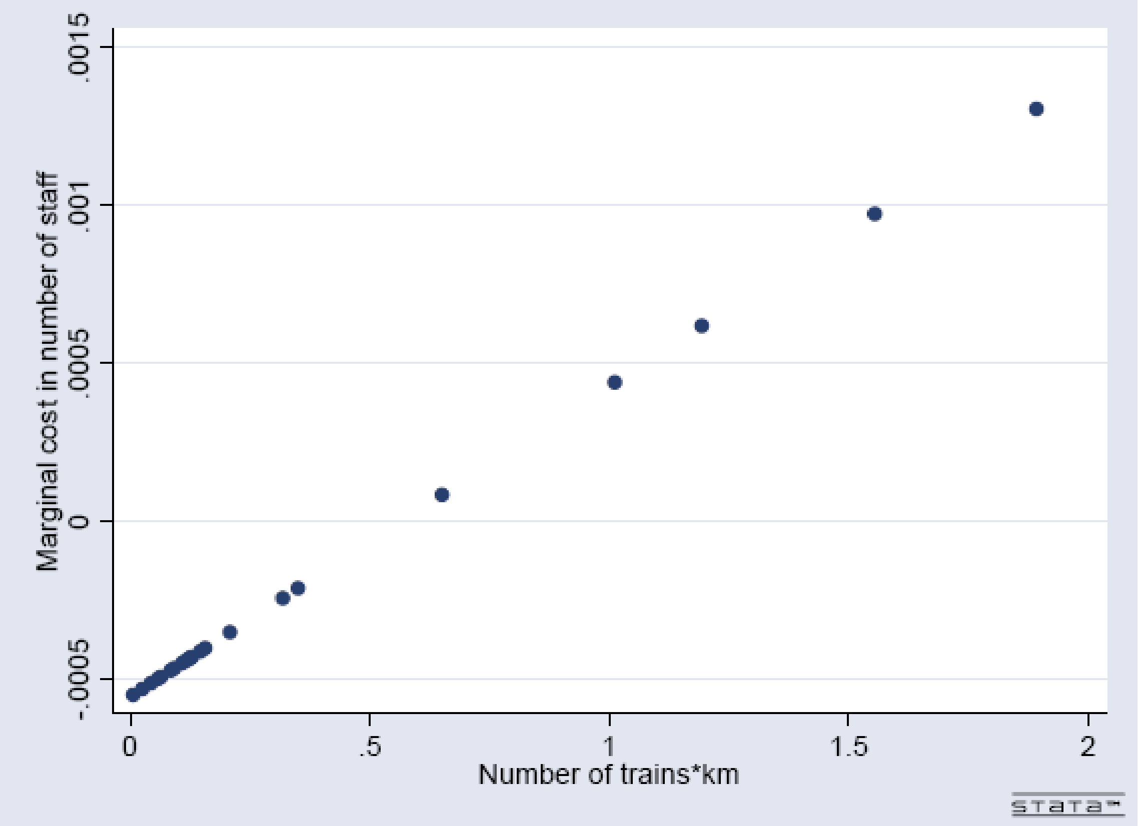


```
12 . summarize couttotal_par_region rec_cm_apdv_train_train2

    Variable |       Obs        Mean    Std. Dev.       Min        Max
-------------+--------------------------------------------------------
couttotal_~n |        23    689.7174    246.6568      317.4     1184.3
rec_cm_apd~2 |        22    69.94673    282.6644  -110.2833   843.2485
```

Average Recovery ratio of marginal cost pricing: 69/689=10%

The following graph plots the marginal cost per km against the traffic level expressed by density. Negative values for the marginal cost for small values of traffic are evidently spurious, and show the limit of the adjustment. The conclusion is that marginal cost is increasing with density, under the above mentioned assumption that operation costs exhibit constant return to scale with respect to network size.



Conclusions

First, some words of caution: the endogenous variable is not a cost but a proxy for the costs; the number of observations is small, the statistics for capital are crude, they relate just to the number of switches, a poor proxy; furthermore the ages of the switches are widespread, some are very old and need more manpower, unfortunately there is no information on age which could be taken into account in the adjustments. One point of question is that operations could be contracted out in some parts of the country; fortunately, all works are done by SNCF staff and equipment. Due to these errors and misspecifications in variables, it is probable that the coefficients are underestimated. Consequently, the results should be interpreted as magnitudes and not as precise values.

If nevertheless we draw conclusions, we see that the first box replicates the adjustment done by RFF on clusters of tracks. These two results aim at representing a long run cost function and assume that the capital level is optimal, an assumption certainly not fulfilled. If nevertheless we interpret the results, we see that our recovery ratio is about 30%, much smaller than the recovery ratio found by RFF, which was around 80%. Our result is perhaps a bit underestimated due to the errors on exogenous variables, but it avoids the arbitrariness of allocating operation costs to a specific track. Anyhow, these two results provide estimates of the long run marginal cost, and are thus improper in the framework of the European doctrine.

The second and third boxes present variations around short run marginal costs, the first one being the simplest linear adjustment, the second one aiming at traducing the curvature which appears in the previous graphs. Both provide the same overall result, and showing that the recovery ratio (ratio between marginal cost and average cost) is around 10-15%, in accordance with the rough engineer experience previously recorded.

SIXTH FRAMEWORK PROGRAMME
PRIORITY 1.6.2
Sustainable Surface Transport

CATRIN

Cost Allocation of TRansport INfrastructure cost

D8 – Rail Cost Allocation for Europe

Annex 1E – Renewals costs in Great Britain

Version 1.0
January 2009

Authors:
Phill Wheat and Andrew Smith (ITS)

Contract no.: 038422
Project Co-ordinator: VTI

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CATRIN Partner Organisations

VTI; University of Gdansk, ITS Leeds, DIW, Ecoplan, Manchester Metropolitan University, TUV Vienna University of Technology, EIT University of Las Palmas; Swedish Maritime Administration, University of Turku/Centre for Maritime Studies

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Project summary

CATRIN is a Research project to support the European Transport Policy, specifically to assist in the Implementation of Transport pricing. CATRIN will increase the probability that new progressive pricing principles can be implemented which facilitate a move towards sustainable transport. CATRIN is both intermodal and interdisciplinary, emphasizes the need of new Member states, understands that different organisational forms require different recommendations, that recommendations need to be given in short and long-term perspective and that they have to be thoroughly discussed with infrastructure managers.

CATRIN will clarify the current position on allocation of infrastructure cost in all modes of transport. Pricing principles will be dealt with under the knowledge that they varies with the organisational structure of a sector. CATRIN will establish the micro-aspects of cost recover above marginal costs, including the results of applying a club approach and the implication of who bears the costs for cost recovery under alternative allocation rules, using game theoretic analytical tools.

CATRIN will develop the understanding of policy need of new Member states and can give tailored recommendations. In a modal focus, with real world cases, CATRIN will develop proxies to marginal costs and test some of the allocation approaches. Based on engineering studies CATRIN will analyse the possibility to defining more differentiated pricing rules for vehicle/locomotive categories. Partners with strong engineering knowledge are included and CATRIN will blend the economic principles of pricing with engineering knowledge. CATRIN will outline the possibilities for a European Road Damage test that will give new evidences on the fourth-power-rule. CATRIN will develop financing alternatives for icebreaking and will explore cost allocation in the aviation sector. Finally, CATRIN will strongly address the implementation potential and constraints experienced by infrastructure managers

1 Introduction

During the last twenty years the European rail industry has been transformed. The former model of vertically-integrated, state-owned railways has been replaced with one based on separating rail infrastructure from train operations - to a greater or lesser degree. Sweden was the first country to go down this route. The Swedish move was followed by European legislation, starting with a European Directive in 1991 (91/440). Whilst this Directive, and subsequent legislation, did not require complete separation of infrastructure from operations, a number of countries have followed the Swedish model, most notably Britain. Others have adopted less radical responses, for example, the German model, where rail infrastructure and train operations have been created as separate divisions within a common holding company (see Nash, 2006). Directive 91/440 also required accounting separation of infrastructure and operations, which was intended to encourage clearer understanding of costs in these areas.

One of the main aims behind vertical separation in Europe was the introduction of competition on the network, initially with respect to freight. A number of countries have also sought to introduce competition in passenger markets, both through franchising and, to a much lesser extent, open-access (or “on-track”) competition. As part of further European legislation (for example, Directive 2001/14) aimed at facilitating competition, and promoting efficient allocation and use of capacity, countries are required to set rail infrastructure charges based on the direct cost of running different services, including: additional “wear and tear” costs of running more trains; scarcity charges; and environmental charges. Non-discriminatory mark-ups are also permitted.

The changed model for organising rail transport in Europe has therefore created a key research need; namely to estimate the direct cost of running extra traffic on the network. In this Annex we are specifically concerned with estimating a sub-set of direct costs for the British rail network - namely “wear and tear” costs, and more specifically, the maintenance and track renewal cost part - using econometric methods. In other words, our emphasis is on the maintenance and track renewal element of short-run marginal cost.

During the GRACE project, Wheat and Smith (2008) undertook analysis of maintenance costs for 53 Maintenance Delivery Units (MDUs) for a single year. They found average marginal costs of 1.8 per thousand gross tonne-km which are high relative to other available evidence from European infrastructure managers. However they found an elasticity of cost with respect to traffic which was more inline with evidence from other counties.

In this Annex, we update this work to consider both maintenance and renewal costs, again for only a single year and now for a slightly redefined 51 MDUs[1]. This analysis is therefore a step forward as compared with that undertaken as part of the GRACE project, and is the first time that econometric evidence has been brought to bear on the question of renewal cost variablility with respect to traffic in Britain. Indeed, there are few studies (for any country) that have considered renewals costs as part of their analysis. We find MC estimates that are approximately 8€ per thousand gross tonne-km which, while high relative to (limited) evidence from other infrastructure managers, and also reasonably high relative to from work undertaken by the British Office for Rail Regulation (ORR), however our results are still of a comparable magnitude. Driving our high result is that we find an elasticity of cost with

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[1] 4 of the original 53 MDUs are merged into 2 MDUs in the new dataset.

respect to traffic of 0.48 where the ORR's consultants (Booz Allen Hamilton, 2005) found 0.31 over a similar cost base.

We note that we only have a cross section of data to apply our model. While this was adequate for the analysis of maintenance cost only, we note the reduced model fit and lower precision of parameter estimates (particularly on infrastructure variables) from considering renewals in addition to maintenance in the dependent variable. This is perhaps not a surprising result given the lumpy nature of renewals expenditure (particularly at a disaggregated level within a country) and that renewals expenditure is driven by cumulative usage over a number of years rather than just usage over a single year. As such the key to developing this approach is to collect data over a number of years.

Following this introduction, Section 2 describes the data available for the study and Section 3 summarises the method employed. Section 4 outlines the results and section 5 concludes.

2 Data

The dataset has been described at length in Wheat and Smith (2008) and we direct the interested reader to this paper. We have cost data on maintenance and track renewal cost. As in Wheat and Smith (2008) we consider the sum of permanent way and general maintenance as the relevant measure of maintenance cost. This is 45% of total maintenance cost for the year. The reason for using this narrow definition of cost is that only this cost and signalling and telecoms maintenance costs are available at MDU level. Since we believe a priori that signalling and telecoms expenditure is not (substantially) usage related we exclude it from the analysis. Our dataset only includes track renewal costs at the MDU level. This cost category covers renewal of rails, sleepers and ballast and accounts for roughly 30% of total renewal cost. While we expect that there are other elements of renewal expenditures that have significant variability with traffic, track renewals is still the element which should be most variable with traffic (evidence from Booz Allen Hamilton (2005) supports this).

Table 1 shows the explanatory data used in the study.

Table 1 Data available for analysis

Name	Description	Mean	St. Dev.	Minimum	Maximum
TON	Total tonne density (total gross tonne-km per track-km).	4809570	2304830	1172371	9027768
TRACK	Length of Track km (in logs)	591	246.8	213	1405
MAL	Proportion of track length with maximum axle load greater than 25 Tonnes	0.55799	0.21334	0	0.93397
MLS	Proportion of track length with maximum line speed greater than 100 mph	0.1743	0.19006	0	0.68408
PRCWR	Proportion of track length which is CWR	0.75918	0.11362	0.42322	0.91572
WAGE	Labour price index £ per hour (in logs)	13	2.02219	10	17

Source: Own analysis. Note CWR stands for continuously welded rail.

We have traffic data available by gross tonne-km and train-km for three traffic types; intercity passenger, regional passenger and freight. We adopt a single measure of traffic, tonne-km, since we had little success with incorporating any further disaggregation of traffic by type and found tonne-km performed better than train-km.

In order to control for the impact on cost of the fixed factors in estimation of short run marginal cost, it is necessary to select variables which reflect the quantity, capability and quality of the fixed infrastructure. Our data set includes a wide variety of measures per MDU. The chosen variables included in our model are listed in Table 1 above. These were selected from the list of available variables based on theoretical considerations – drawing on engineering expertise from within Network Rail and our own understanding and research - and statistical criteria.

We have data on the price of labour in each MDU and this is summarised in Table 1. This represents (regional) hourly wage rates for workers derived from national statistics data for 2005 (Office of National Statistics (2005))[2]. Note that this data refers to all workers and is not restricted to those in railway maintenance. We use this data since the data supplied by Network Rail on wages was deemed unreliable after inspection. This was due to data extraction issues, which is ultimately a symptom of reliable maintenance data only recently becoming available.

We do not have data on the price of materials and machinery, however we assume that this is constant between MDUs and thus its effect is absorbed within the constant term.

3 Methodology

The econometric approach proceeds by estimating a variable cost function that relates total variable costs to output variables, prices of variable inputs (labour, energy etc) and levels of fixed inputs (route-km, number of switches and crossings etc.); see, for example, Caves, Christensen and Swanson (1981). Where we have cross-section data based on observations for different regions or track sections within an individual country, as in our case, the variable cost function can be written as:

$$\mathrm{C_i} = \mathrm{f}\left(\mathrm{Q_i}, \mathrm{V_i}, \mathrm{P_i}\right) \quad i = 1,2,\ldots,n \qquad \textbf{(1)}$$

Where

- $\mathrm{C_i}$ is the maintenance and renewal cost per annum for region i;
- $\mathrm{Q_i}$ is a vector of outputs for region i – in the study of railways, the definition of output is context specific; there are many possible (intermediate) outputs from the system, for example volume of renewal work completed in a period, number of trains run or number of passengers carried. Here we consider output to be traffic-movement related measures of output, primarily because this is the stage of production for which we wish to derive marginal costs;
- $\mathrm{V_i}$ is a vector of fixed input levels for region i – in the short run several factors of production are fixed. These are assumed to be the infrastructure. Therefore, measures

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[2] A mapping exercise was required to translate the regional wage data from ONS to the Network Rail MDUs in our analysis.

that naturally fit in here are track length, track quality, track capability and track age in a region;

- P_i is a vector of input prices; and
- n is the number of regions.

The variable cost function can be used to determine the short run marginal cost of extra traffic since the formulation allows the marginal impact of extra utilisation on variable cost to be evaluated holding the levels of the network characteristics and track length constant.

In keeping with the majority of the literature we adopt a double log functional form[3]:

$$\begin{aligned}\ln(C_i) = \alpha + \beta_1 \ln(Q_{1i}) + \cdots + \beta_q \ln(Q_{qi}) + \gamma_1 \ln(V_{1i}) + \cdots + \gamma_v \ln(V_{vi}) \\ + \delta_1 \ln(P_{1i}) + \cdots + \delta_p \ln(P_{pi}) \qquad \textbf{(2)}\end{aligned}$$

where $Q_{xi}, V_{yi}, P_{zi} \quad x = 1,\dots,q,\; y = 1,\dots,v \quad z = 1,\dots,p$ are elements of the vectors Q_i, V_i, P_i defined earlier.

The specification allows for non-constant marginal costs, although it is restrictive since it assumes constant cost elasticities. However, the data did not support the estimation of the more complex translog functional form, given the relatively small sample size. We did, however, test the inclusion of second order terms for the key traffic density. We could not reject the null hypothesis that the associated coefficient was equal to zero at any reasonable significance level. Hence we adopt the Cobb Douglas model outlined above.

We note that when we analysed maintenance only cost in Wheat and Smith (2008) we did find evidence for second order and indeed third order effects. We have not found such effects here, however this is probably a symptom of the noise in the dataset (particularly with respect to the renewals cost element).

4 Results

Table 2 shows the results of the statistical cost model. The names of the variables are given in Table 1. Where “L” proceeds a variable name this indicates that this variable was entered in natural logarithms into the model.

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[3] In line with the main deliverable we define a double log functional form to be any functional form where the dependent and the explanatory variables are in logarithms. This may include first order terms and second order terms (including interaction terms) in explanatory variables. Therefore as defined, this form nests both the translog and Cobb-Douglas.

Table 2 Results of the statistical model

```
+----------------------------------------------------+
| Ordinary    least squares regression               |
| Model was estimated Jan 27, 2009 at 03:46:30PM     |
| LHS=LMPRCOST Mean                 =   16.79886     |
|              Standard deviation   =   .4581345     |
| WTS=none     Number of observs.   =         51     |
| Model size   Parameters           =          7     |
|              Degrees of freedom   =         44     |
| Residuals    Sum of squares       =   5.857816     |
|              Standard error of e  =   .3648728     |
| Fit          R-squared            =   .4418131     |
|              Adjusted R-squared   =   .3656967     |
| Model test   F[  6,    44] (prob) =   5.80 (.0002) |
| Diagnostic   Log likelihood       =  -17.18262     |
|              Restricted(b=0)      =  -32.05069     |
|              Chi-sq [  6]  (prob) =  29.74 (.0000) |
| Info criter. LogAmemiya Prd. Crt. =  -1.887795     |
|              Akaike Info. Criter. =  -1.889539     |
|              Bayes Info. Criter.  =  -1.624386     |
| Autocorrel   Durbin-Watson Stat.  =  1.9040384     |
|              Rho = cor[e,e(-1)]   =   .0479808     |
+----------------------------------------------------+
+--------+--------------+----------------+--------+--------+----------+
|Variable| Coefficient  | Standard Error |t-ratio |P[|T|>t]| Mean of X|
+--------+--------------+----------------+--------+--------+----------+
|Constant|    16.2630***      1.06568929    15.261   .0000            |
|LTON    |     .47813***       .13865950     3.448   .0013   -.1333374|
|LTRACK  |     .75198***       .14447306     5.205   .0000   -.0823945|
|MAL     |    -.03739          .32731807     -.114   .9096    .5650736|
|MLS     |    -.00879          .35683954     -.025   .9804    .1765733|
|PRCWR   |    -.95375          .66770547    -1.428   .1602    .7590334|
|LWAGE   |     .55825          .38897544     1.435   .1583   2.5224268|
+--------+-------------------------------------------------------------+
| Note: ***, **, * = Significance at 1%, 5%, 10% level.               |
+---------------------------------------------------------------------+
```

Several features should be noted. First the fit of the model is worse than the equivalent maintenance models reported in Wheat and Smith. They reported models with R-squared's between 0.69 and 0.78. Here the R-squared is 0.44 which indicates a poorer fit of the data to the model. This is to be expected given the lumpy nature of renewals expenditure (particularly at the disaggregate level) and that renewals is driven not just by traffic in the current year but cumulative traffic over a number of years. We are however a little bit surprised that the fit of our model is not better given the geographical aggregation of our data which should remove some of the lumpiness of the renewals expenditure. As such we would expect a better fit of the data by looking at renewals expenditure over a number of years (possibly aggregated over the years) against traffic over the years (again possibly aggregated).

We also note that individually all the infrastructure quality variables are statistically insignificant at any sensible significance level. A joint test of the significance of all three infrastructure variables can also not reject the null that all coefficients are zero at any sensible significance level. Thus there are grounds for dropping these variables. When we do so the coefficient on LTON drops to 0.34. For this reason we retain these variables in our model, since we wish to avoid even weak omitted variable bias in our estimate on LTON.

The coefficient on LTON is the elasticity of cost with respect to traffic which is constant for all traffic in this model. This estimate is 0.48 and this is statistically significant at the 1 percent level. However the coefficient is high relative to the results from other studies which have found results of approximately 0.2-0.3[4]. One explanation for our high result is that we have considered only 45% of maintenance cost and 30% of renewal cost. These elements of cost are likely to be the most variable with traffic and thus yield a high elasticity.

The ORR commissioned research by Booz Allen Hamilton (2005) on the variability of maintenance and renewal cost with respect to traffic. For approximately the same elements of cost that are considered in this study, they found that 31% was variable with traffic. This indicates that our result may be high.

However our estimate is still consistent with economies of density found in other studies (the elasticity is less than unity). Further the coefficient on log track length is 0.75 which is statistically significant at the 1% level. This indicates economies of scale in railway infrastructure renewal and maintenance which is the same finding as found in Wheat and Smith for maintenance only activity. However economies of scale are found to be weaker in maintenance and renewals case. Note that because other previous studies have considered track sections rather than areas it is not possible to compare the scale properties across models.

The marginal infrastructure wear and tear costs associated with running extra traffic on the network is calculated as follows. We first note the relationship between the marginal usage cost for MDUi ($\mathrm{MC_i}$) and the usage elasticity for that region:

$$\mathrm{MC_i} = \varepsilon_{\mathrm{i}} \cdot \mathrm{AC_i} \qquad \textbf{(3)}$$

where $\mathrm{AC_i}$ is the average cost, and is defined as in equation 4 below

$$AC_i = \frac{C_i}{Gross\ tonne - km_i} \qquad \textbf{(4)}$$

The estimate of $\mathrm{MC_i}$, $\mathrm{M\hat{C}_i}$, is therefore given by

$$M\hat{C}_i = \hat{\varepsilon}_i \cdot A\hat{C}_i = \hat{\varepsilon}_i \cdot \frac{\hat{C}_i}{Gross\ tonne - km_i}$$

We compute the average marginal cost weighted by tonne-km as a measure of the average marginal cost. This is because this measure has a useful property that charging all tonne-km at this level yields the same revenue as charging each tonne-km the appropriate modelled marginal cost. This measure of marginal cost is 8.12€ per thousand gross tonne-km[5]. The median marginal cost estimate (which does not so heavily rely on the tails of the distribution in its computation) is 8.38€ per thousand gross tonne-km. For comparison the comparable estimate from the Booz Allen Hamilton analysis is 5.24€ per thousand gross tonne-km[6].

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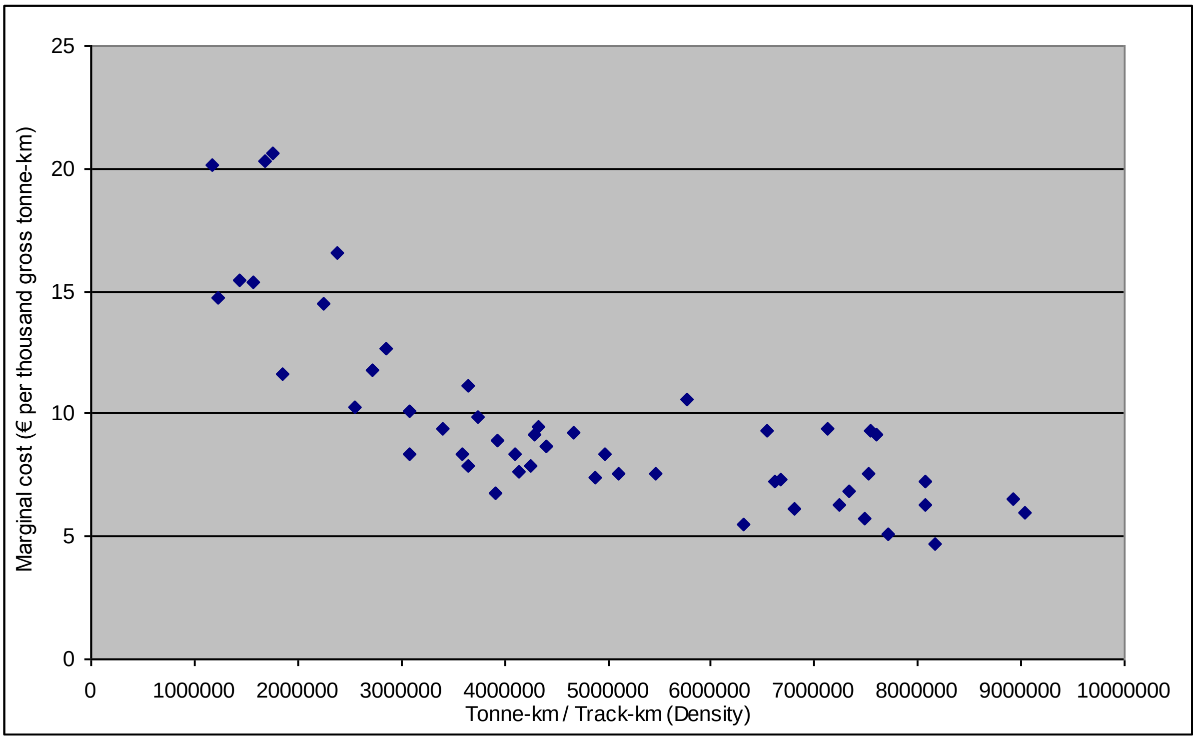
[4] For example Andersson (2006) reports 0.30 for Sweden, Marti and Neuenschwander (2006) report 0.27 for Switzerland and Tervonen and Idstrom (2004) report 0.28 for Finland.

[5] We have used the 2005 PPP exchange rate between €:£ of 0.703 in making these calculations (OECD, 2008) as our cost variable was in 2005/06 £.

[6] Computed as 8.12x0.31/0.48. This is valid as in both models the elasticity is constant across traffic levels.

Figure 1 plots the marginal costs against traffic density. This shows that marginal costs fall with traffic density, which is to be expected in a constant elasticity model (since average costs tend to fall with traffic).

Figure 1 Plot of marginal costs against traffic density



5 Conclusions

In this case study we have updated Wheat and Smith (2008) to include renewals as well as maintenance expenditure as the dependent variable. We find that the average marginal costs weighted by tonne-km is 8.12€ per thousand gross tonne-km[7]. The median marginal cost estimate (which does not so heavily rely on the tails of the distribution in its computation) is 8.38€ per thousand gross tonne-km. For comparison the comparable estimate from another study for Great Britain by Booz Allen Hamilton (2005) is 5.24€ per thousand gross tonne-km. As such our results appear high, but still comparable. Our high result is driven by our finding that the elasticity of cost with respect to traffic (the “usage elasticity”) is 0.48 which is higher than the equivalent Booz Allen Hamilton of 0.31. However we have estimated a model which has statically significant coefficient on both the traffic and scale variables and so our study is a useful contribution to the literature.

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CATRIN -- Cost Allocation of TRansport INfrastructure cost

SIXTH FRAMEWORK PROGRAMME
PRIORITY 1.6.2
Sustainable Surface Transport

CATRIN

Cost Allocation of TRansport INfrastructure cost

D8 – Rail Cost Allocation for Europe

Annex 1F – Marginal costs for Europe using pooled international data

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Authors:
Phill Wheat and Andrew Smith (ITS)

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VTI; University of Gdansk, ITS Leeds, DIW, Ecoplan, Manchester Metropolitan University, TUV Vienna University of Technology, EIT University of Las Palmas; Swedish Maritime Administration, University of Turku/Centre for Maritime Studies

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Project summary

CATRIN is a Research project to support the European Transport Policy, specifically to assist in the Implementation of Transport pricing. CATRIN will increase the probability that new progressive pricing principles can be implemented which facilitate a move towards sustainable transport. CATRIN is both intermodal and interdisciplinary, emphasizes the need of new Member states, understands that different organisational forms require different recommendations, that recommendations need to be given in short and long-term perspective and that they have to be thoroughly discussed with infrastructure managers.

CATRIN will clarify the current position on allocation of infrastructure cost in all modes of transport. Pricing principles will be dealt with under the knowledge that they varies with the organisational structure of a sector. CATRIN will establish the micro-aspects of cost recover above marginal costs, including the results of applying a club approach and the implication of who bears the costs for cost recovery under alternative allocation rules, using game theoretic analytical tools.

CATRIN will develop the understanding of policy need of new Member states and can give tailored recommendations. In a modal focus, with real world cases, CATRIN will develop proxies to marginal costs and test some of the allocation approaches. Based on engineering studies CATRIN will analyse the possibility to defining more differentiated pricing rules for vehicle/locomotive categories. Partners with strong engineering knowledge are included and CATRIN will blend the economic principles of pricing with engineering knowledge. CATRIN will outline the possibilities for a European Road Damage test that will give new evidences on the fourth-power-rule. CATRIN will develop financing alternatives for icebreaking and will explore cost allocation in the aviation sector. Finally, CATRIN will strongly address the implementation potential and constraints experienced by infrastructure managers

1 Introduction

To date econometric infrastructure wear and tear marginal cost studies have been conducted through analysis of cost, traffic and infrastructure data on a country-by-country basis (see Deliverable 1 (Link et al, 2008) for a survey). However, each study utilises data with subtly different definitions in respect of the cost categories covered and the level of geographical disaggregation (track sections versus zones[1]); and the datasets tend to contain a different mix of infrastructure. In addition, the statistical methods applied and specification used in each study differ from case study to case study. This situation presents a challenge for making recommendations from the results of such studies, since it is not clear whether differences in elasticity and marginal cost estimates between studies are genuine differences between countries or are simply artefacts of the data / method differences.

In this Work Package, a number of country specific case studies have been undertaken. However these have been coordinated such that the sensitivity of the results to method can be established (see Deliverable 8 section 4 (Wheat et al, 2009)). However an alternative approach to the problem is to pool data across several counties and analyse this data through one statistical model. This second, pooling approach is the subject of this paper.

We utilise a bespoke dataset on six countries (five of which are in the European Union) for which data collection has been undertaken over a number years in cooperation with infrastructure managers. The data was initially used as part of the 2008 Periodic Review of Network Rail undertaken by the Office for Rail Regulation (ORR) in Great Britain (Smith, Wheat and Nixon, 2008)[2]. For that study, the primary use of the data was to assess the efficiency of Network Rail and other infrastructure managers. However the dataset is also suitable for measuring marginal costs.

At this stage it should be noted that the pooled sample used in this paper is not a pooling of all of the data for the individual CATRIN case studies (Sweden, Switzerland, France, Great Britain and Austria). Such an approach would have been highly desirable, but was not possible due to confidentiality agreements / understanding between the individual CATRIN partners and the data providers. However, the sample used in this paper includes data for two of the countries covered by the CATRIN case study (Great Britain and Austria) and so comparisons can be made for those countries. The other countries covered in this study are the US (Amtrak), Belgium (Infrabel), Ireland (Irish Rail) and The Netherlands (ProRail).

The paper examines three important research issues that were identified in Deliverable 1.

Firstly, to what extent do elasticity and marginal cost estimates differ in the pooled international model as compared with those derived from considering each country separately. Given the countries in the sample, we can only make this comparison for Great Britain and Austria. Secondly, to what extent do elasticity and marginal cost estimates differ when utilising zonal rather than track section data. This is important for two reasons: firstly, because in previous work the econometric work for Britain has been carried out based on maintenance areas, whilst all other studies have been based on track sections; and secondly

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[1] Here the term "zone" relates to some geographical area or region within a country at which maintenance cost data can sensibly be analysed.

[2] As part of the CATRIN project data for Austria was added to the sample used in the ORR study.

because the pooled study reported in this paper also utilises zonal data, and this point therefore needs to be taken into account when comparing the results against previous results utilising track section data.

Finally, to what extent do the smaller number of infrastructure variables available for the pooled analysis (in this case) affect the estimates of marginal cost.

It should also be noted that whilst our dataset includes data for Austria, at both the zonal and track section level, this data was collected independently of the CATRIN project for the purpose of an internal benchmarking exercise. Thus, the main individual case study for Austria reported as part of CATRIN is that carried out by Heike Link (DIW) (Link, 2009), using a different dataset which was put together specifically for the purpose of marginal cost estimation. Of course, we compare the results for Austria based on the country case study, and those reported for Austria in this paper in Deliverable 8.

2 Dataset

For this study we utilise a bespoke dataset comprising zonal data on infrastructure maintenance costs, traffic and infrastructure characteristics of railways in six countries, five of which are in the European Union[3]. The participants are shown in Table 1. In total there are 96 observations comprising an unbalanced panel of zones[4] of each network. This data set is highly confidential and so we are unable to divulge marginal cost estimates for every country. Instead we confine ourselves to describing the results for the average of the sample infrastructure managers and also for the two countries for which we have supplementary data; Austria and Great Britain.

Table 1 List of participants

Company	**Country**
Network Rail	Britain
Infrabel	Belgium
ProRail	The Netherlands
Irish Rail	Ireland
OBB	Austria
Amtrak	US

The dataset was collected over the period 2006 to 2008 through a series of meetings and correspondence with participating infrastructure managers. The long period of data collection was important since it allowed collection of data which conformed to a standard set of definitions, which is essential when collecting data across countries.

The variables collected for every country that are applicable for analysis in this study are shown in Table 2 along with descriptive statistics. The cost data has been converted to 2005 US $ using purchasing power parity (PPP) exchange rates so that costs are comparable across

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[3] Data was also collected for a further country however the cost variable supplied by the country was not deemed consistent with that supplied by other countries.

[4] Zones refer to aggregations of adjacent track sections. Each country provided data on the whole of its network divided into a different number of zones (ranging from 3 to 18 zones comprising the whole network). In addition all countries, bar one, provided data for more 2 or more years.

countries. However for the discussion in this paper we report all currencies in 2005 Euros using a 2005 purchasing power parity rate of 1.084 $:€.

While we are relatively confident in the robustness of these variables in terms of conformity to a common definition, we do note that our dataset lacks a substantial number of infrastructure variables common to other studies. This potentially may bias our estimate of short run marginal cost. However we introduce unobserved effects for each zone in our modelling which should compensate for this lack of variables.

Table 2 Descriptive statistics for the whole dataset

Variable	Mean	Standard Deviation	Min	Max
Maintenance Cost €	48,310,426	36,992,750	8,397,823	174,423,820
Tonne Density (Tonne-km / Track-km)	8,134,674	5,938,737	1,077,481	21,808,976
Track-km	958	583	252	2,988
Proportion of track-km electrified	0.67	0.40	0.00	1.00

In addition, as mentioned in the introduction, we investigate the effect on marginal cost estimates of: (1) pooling data across countries; (2) using zonal rather than track section data; and (3) the effect of not including a full raft of infrastructure variables. We do this through a series of supplementary analyses on Austrian and Great British data in isolation from the wider panel. The data for Austria is available for 76 track sections (or 9 zones) over 5 years. Table 3 presents descriptive statistics for the available data for Austria that can be used in isolation at both the track section and zonal level. The data for Great Britain is only available for one year and at the zonal level only. Descriptive statistics are presented for this data in Table 4. As such the data for Great Britain can only be used to examine the affect of pooling.

Table 3 Descriptive statistics for data available for Austria

Variable	Mean	Standard Deviation	Min	Max
Maintenance Cost €	33,753,190	21,673,629	8,397,823	73,559,273
Tonne Density (Tonne-km / Track-km)	8,134,674	5,938,737	1,077,481	21,808,976
Track-km	958	583	252	2,988
Proportion of track-km electrified	0.67	0.40	0.00	1.00

Table 4 Descriptive statistics for data available for Great Britain

Variable	Mean	Standard Deviation	Min	Max
Maintenance Cost €	74,986,274	17,544,680	52,460,341	105,359,927
Tonne Density (Tonne-km / Track-km)	8,134,674	5,938,737	1,077,481	21,808,976
Track-km	958	583	252	2,988
Proportion of track-km electrified	0.67	0.40	0.00	1.00

3 Methodology

3.1 Pooled Model

As our primary model, we estimate a short run variable cost function for the unbalanced panel of zonal observations for the six infrastructure managers with zonal unobserved effects. The econometric model can be represented as:

$$\ln C_{its} = f\left(Q_{its}, L_{its}, Z_{its}, t\right) + \alpha_{is} + \varepsilon_{its} \quad i=1,\ldots,6,\ t=1,\ldots,T(i),\ s=1,\ldots,S(i)$$

where C denotes cost and is the sum of permanent way, signalling and telecoms and electrification and plant maintenance costs per zone, Q is the traffic per zone (note, this is traffic, and not traffic density in this study), L is the length of track in each zone, Z is the proportion of track length in each zone which is electrified, α is the unobserved effect for each zone which is constant over time, ε is the random error in the model, i denotes the i'th infrastructure manager, t denotes the time period for which there are T(i) time periods for each infrastructure manager, s denotes the s'th zone of zone i for which there are S(i) zones for each infrastructure manager and $f\left(\cdot\right)$ is a functional form.

For this function to be consistent with economic theory, we are implicitly assuming that input prices are constant for each zone over time or at least moving in line with the time trend, t. Across countries, input price variation is partly dealt with via the use of PPP exchange rates for translating local currency costs into a common currency.

For this study we utilise the general and highly flexible translog functional form and for reasons of parsimony[5] (which are important given the relatively small sample size) reduce the model to:

$$\ln C_{its} = f\left(Q_{its}, L_{its}\right) + Z_{its} + t + \alpha_{is} + \varepsilon_{its} \quad i=1,\ldots,6,\ t=1,\ldots,T(i),\ s=1,\ldots,S(i)$$

Therefore the model only retains the properties of the translog functional form for traffic and track length.

The motivation for incorporating α, a time invariant zonal effect, is to capture any resulting unobserved heterogeneity in the model potentially resulting from the failure to include many infrastructure characteristic variables. We model α as a random effect after conducting a Hausmann test which fails to reject the null hypothesis that the fixed and random effects estimator of the coefficients of $f\left(\cdot\right)$ are the same. As such we choose random effects as this is a more efficient estimator (greater precision) than fixed effects.

3.2 Determining the robustness of the approach

Analysing robust data for a number of countries within one statistical exercise has a number of advantages and disadvantages for generalisation purposes as opposed to carrying out separate case studies, and then comparing the results of these individual studies. First we discuss the generic issues concerning the choice between these two alternative approaches, before turning to the practical issues that we face for this particular project. We discuss the case where panel data (multiple observations on the same track section over time) exists for each country case study, although similar arguments apply to the case where only cross-sectional data exists.

One of the main disadvantages of the individual country case study approach to marginal cost estimation is that comparisons between studies are complicated by the fact that the individual

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[5] Our experience with this dataset indicates that any interactions introduced as part of a more general Translog function are statistically insignificant.

research teams may have adopted different data definitions and methodologies. Each research team will also have applied their own subjective judgement in selecting final models (whilst model selection should be based on statistical tests, usually an element of judgement has to be applied in practice).

One solution to this problem is to develop a co-ordinated approach, and thus ensure that each country case study is carried out to a common specification; which is the approach that we have taken in this project. In this way, in principle, the research co-ordinator can require all research teams to apply the same methodology (functional form and variables included in the model), work to a common data definition, and apply the same procedures for final model selection (and where there is ambiguity concerning the latter, the judgement regarding a final model could be taken collectively).

Thus, the benefits of the pooling approach – namely, that one model is estimated for all countries, with data compiled to the same definition, and where one researcher makes the judgement regarding final model selection can, in principle, be largely replicated by a rigorous, co-ordinated approach to individual country model estimation (although there may be a question as to whether a co-ordinated approach can ever work quite as smoothly as one research team working individually).

So given that co-ordination can largely replicate the pooling approach in terms of ensuring commonality of functional form, variable and model selection, and data definitions, how does the pooling approach compare to the alternative of carrying out individual case studies? One main advantage is that the pooled approach has the potential to substantially increase the number of observations for analysis, thus potentially enabling more precise estimates to be obtained. However, the disadvantage of the approach is that there is likely to be a much wider range in traffic densities and other quality variables within the new, enlarged sample, which may be more difficult to estimate (perhaps requiring a more flexible functional form, for example).

It is therefore not clear, a prior, whether the benefits will outweigh the cost. Certainly, where it is appropriate to use random effects methods, the degrees of freedom benefits will be the greatest. However, if there is concern over possible correlation between traffic and the effects (which effectively capture any network characteristic and efficiency effects not included in the model), or the desire to interact the effects with traffic, then random effects will not be appropriate. Of course, the fixed effects approach could be used, but this uses up more degrees of freedom than the random effects method. Alternatively, a random parameters approach could be adopted, which models the coefficients on the traffic variables as random variables. However, this approach is much more complex, and will use up some of the degrees of freedom benefits of pooling the data.

We would therefore see the two approaches as both being valid and useful for comparison against each other, and we cannot a priori, in general, express a clear preference of one approach over the other. However, for practical purposes in the present case, the disadvantages perhaps outweigh the advantages for the following reasons:

- For confidentiality reasons, we were not able to pool the data from the CATRIN case studies. We have therefore had to rely on a separate dataset which has only 96 observations in total;

- the pooled dataset that we utilise relies on zonal, rather than track section data, which may result in aggregation bias;

- it was possible only to include one infrastructure variable in the model for which the definition could be considered comparable across country which might lead to omitted variable bias (though this deficiency is potentially overcome via the panel data technique adopted);

- the panel is unbalanced in this case, and also contains zones of substantially different sizes.

We nevertheless proceed to show the results because we consider that this approach is potentially very powerful, particularly if the dataset can be expanded. Furthermore, we investigate these potential problems of the approach through a series of sensitivity tests described below.

3.2.1 Assessing the impact of pooling

In our pooled model we use the translog functional form which is a 2nd order approximation in logarithms to an arbitrary cost function. As such the functional form should be able to accommodate a wide range of variable values. Furthermore, an F-test of the Cobb Douglas restrictions in this model reveals that these restrictions can be rejected at the 5% level and so we conclude that the Translog has additional explanatory power relative to the more simple Cobb-Douglas.

However we try to investigate further the impact of pooling by re-estimating the model twice, once using the data from Great Britain and once using the data from Austria. To maintain comparability we include only the single infrastructure variable as used in the pooled model. We compare the usage elasticity and marginal cost estimates for both models.

3.2.2 Addressing the impact of aggregation

Our pooled model uses zonal data where each zone is an aggregation of heterogeneous track sections. This may introduce aggregation bias into parameter estimates. We investigate this by comparing models estimated on Austrian data, first using data on 76 track sections and then by using the aggregated 9 zone data. Again, we compare the usage elasticity and marginal cost estimates for both models.

3.2.3 Addressing the impact of having limited infrastructure variables

Our pooled model includes only one infrastructure characteristic. There is concern that this could bias parameter estimates due to omitted variable bias and thus bias estimates of short-run marginal cost which by definition require infrastructure variables to be considered constant.

Infrastructure variables tend to be approximately constant over time. We include zonal effects in our model. As such the effects should proxy for the majority of the effect of the omitted infrastructure variables. We also undertake the Hausman test on the difference between the coefficient estimates for the fixed and random effects estimators. The null that the two sets of coefficients are equal can not be rejected and so we opt for random effects. This result has implications because the Hausman test also tests the null of no correlation between regressors and effects. Given this could not be rejected at the 5% level, the Hausman test indicates that any biases in coefficients from exemption of time invariant infrastructure variables (or any other variables) is likely to be small.

However given that the Hausman test could be rejected at the 10% level (but not at the 5% level), we also examine the sensitivity of the models to exclusion of infrastructure variables using the Austrian data set. In particular we estimate the model using Austrian data only, first using the single infrastructure variable and then using the full set of available infrastructure variables. We use the track section data for Austria here.

4 Results

4.1 Pooled model

Table 5 shows the parameter estimates from the pooled model comprising the six infrastructure managers. We tested the Cobb-Douglas restriction and found that this restriction could be rejected. We also tested the restriction that the coefficients on LN(Q)^2 and LN(Q)*LN(L) are zero and found that we could not reject this. However when we did this the usage elasticity increased to 0.41. Given that we are interested in measuring marginal cost which relies on a robust estimate of the usage elasticity we decided to guard against omitted variable effects and retain these variables in our specification. Thus we retain the full translog model (in respect of the traffic and track length variables) as our preferred model.

Table 5 Results of pooled model

Variable	Coefficient	t-statistic
LN(Q)	0.310 ***	2.71
LN(L)	0.603 ***	4.54
Z	0.156	0.74
LN(Q)^2	-0.089	-1.26
LN(L)^2	-0.311 **	-2.22
LN(Q)*LN(L)	0.033	0.19
t	-0.010	-0.99
CONSTANT	17.923 ***	96.48
Hausman test statistic	13.680 *	

Note: ***, **, * = Significance at 1%, 5%, 10% level.

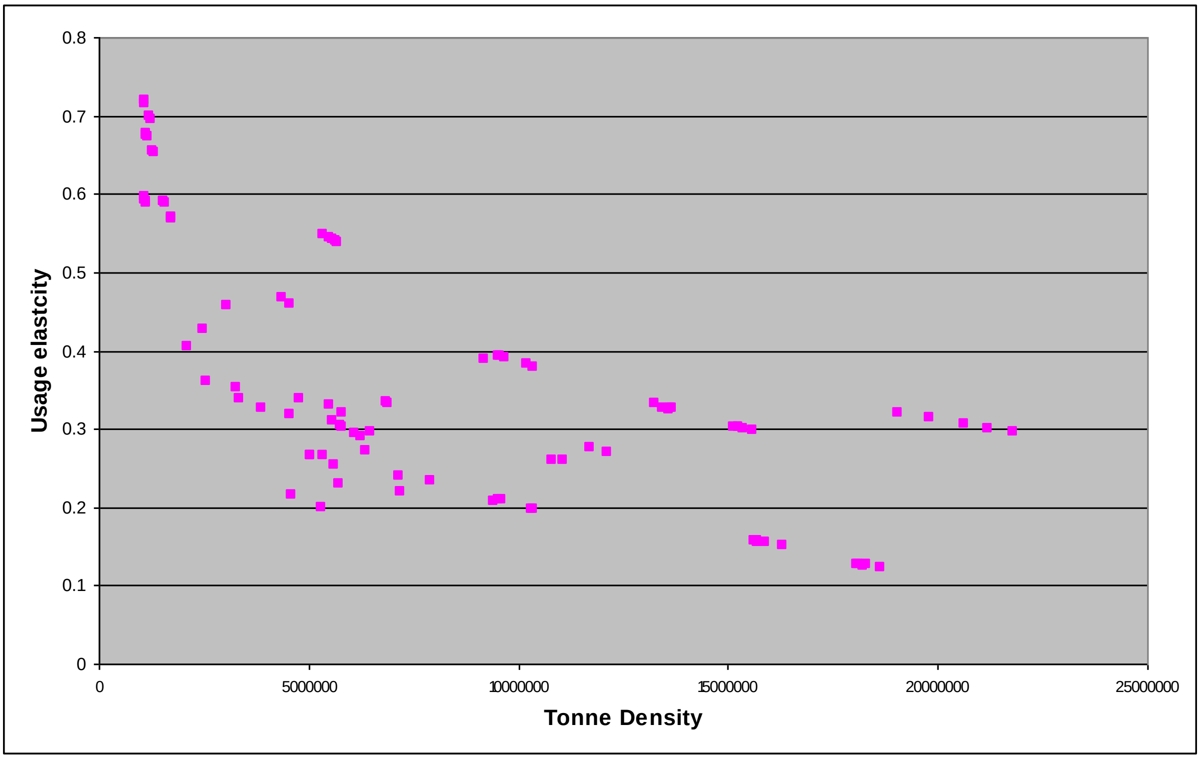
The estimated usage elasticity is 0.31 at the sample mean which indicates economies of density. As discussed in the main deliverable body, this is comparable to the estimates from the other studies in the CATRIN project. As discussed in the main body of Deliverable 8, there is consensus that ‘average’[6]. For completeness, Table 6 presents the other point summary measures of the elasticity for the study as used in the main deliverable body.

Table 6 Point summary measures for the elasticity

Preferred functional form	**Mean Tonnage density (Tonne-km / Track-km)**	**Whole Sample Averages**		
		Unweighted Mean	**Weighted Mean**	**Median of sample**
Double-log	8,135,000	0.33	0.23	0.29
Evaluated at sample mean	**Evaluated at average infrastructure quality and**		**Evaluated at average infrastructure quality and**	
0.28		0.38		0.18

Figure 1 show how the usage elasticity changes with traffic density. This shows a trend that the elasticity falls with greater traffic density. Further all other things equal, the estimated model implies such a falling elasticity although this fall is statistically insignificant. We do note that for some observations with high tonnage density the estimated elasticity is not statistically significantly different from zero at the 5% significance level.

Figure 1 Usage elasticity against traffic density



Marginal cost estimates for all observations are plotted in Figure 2. The average (weighted by tonne-km[7]) for all countries is 2.17 € per thousand gross tonne-km (TGTKM). For Austria the weighted average is 1.31 € per TGTKM and for Great Britain the weighted average is 2.88 € per TGTKM. These marginal cost estimates are above those estimated in the literature prior to

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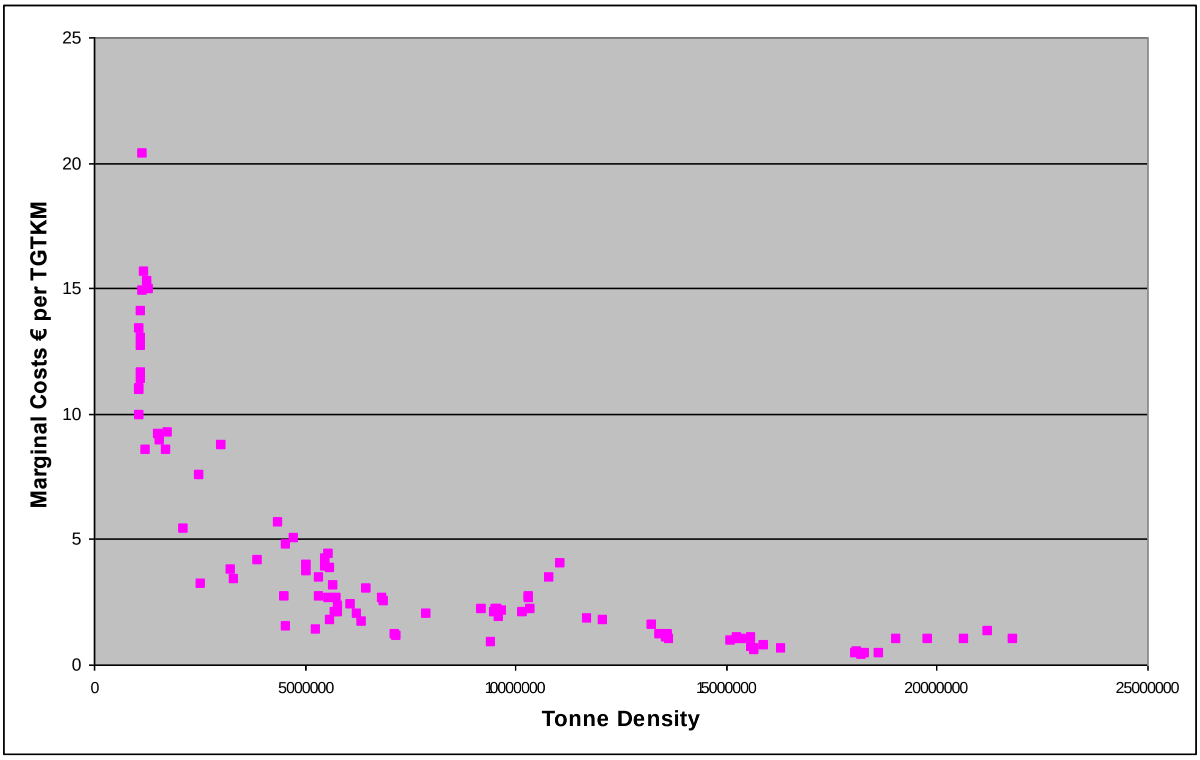
[6] The deliverable discusses in detail the different measures of the average for each country and how these can differ.

[7] That is, the marginal costs estimated for each zone within a country are weighted by tonne km in order to arrive at a weighted average marginal cost for that country.

CATRIN. The main deliverable (Wheat et al, 2009) compares the results of the studies with each other. Particular reference should be made to previous studies for Great Britain which found average marginal costs of approximately 1.80 € per TGTKM. While these results are found to be high for some countries they are still plausible. Also in this work package, a dedicated study has been undertaken for Austria (Link, 2009). This finds average weighted marginal costs 1.20 € per TGTKM, which is very close to our estimate of 1.31 € per TGTKM.

Figure 2 Marginal costs against traffic density



4.2 *Investigating the robustness of the pooling approach*

Here we report on the series of sensitivity tests undertaken to understand better the reasons for our high usage elasticity and marginal costs. The sensitivity tests were described in section 3.2 and the estimation output for each test is included in Appendix A. Below we describe the results of the tests.

4.2.1 The effect of pooling

Table 6 shows the comparison of the estimated usage elasticities and marginal costs from the pooled models and from the models estimated on single country data for Austria and Great Britain (based simply extracting the Austrian and British data from the pooled sample, and proceeding to estimate using first just the Austrian and then just the British data). As noted earlier, the reason that we focus on Austria and Britain is that these are the only two countries within our pooled dataset which are covered by the CATRIN project. It should also be noted that the British data is a cross-section only (18 zones[8] for one year), whereas the Austrian data is a panel, comprising 9 zones over 5 years (45 observations in total).

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[8] In Britain these zones are referred to as maintenance areas.

First we find that the average elasticity and marginal cost estimates do differ between the pooled and country specific model. However three factors should be noted. First from the limited evidence below there is not a tendency for the pooled model to under or over estimate the usage elasticity or average marginal costs. For Austria the pooled model provides estimates below the country only model, while the reverse is true for Great Britain. Secondly, the elasticity estimates are within the range of elasticities (scaled or otherwise) for previous European studies. Thirdly, while the magnitudes of the estimates of usage elasticities and marginal cost differ, the correlation between estimates for individual observations is strong in all cases.

Thus from this limited evidence we conclude that pooling does not seem to be producing biased estimates of either the usage elasticity or marginal cost. However the high standard error associated with these estimates does seem to imply that they can be potentially inaccurate.

Table 6 Estimated mean usage elasticities and marginal costs for Austria and Great Britain[9]

	Austria		**Great Britain**	
Model	**Usage Elasticity**	**Marginal Cost (€ per TGTKM)**	**Usage Elasticity**	**Marginal Cost (€ per TGTKM)**
Pooled Model	0.23	1.31	0.28	2.88
Country only model	0.34	1.68	0.23	2.18
Correlation	0.99	0.99	N/A[1]	0.98

Note 1 Usage elasticity for the Great Britain only model is constant so correlation is undefined

4.2.2 The effect of aggregation

Table 7 shows a comparison of estimates of the average usage elasticity and marginal costs between the Austrian only model estimated using Zonal data and the Austria only model estimated using track section data. Two models using track section data are reported, one having unobserved effects at the track section level (which is a natural way of incorporating unobserved factors with track section data) (Model A) and the other incorporating unobserved factors at the zonal level (Model B) (as is the case with the zonal analysis). This latter model may be motivated by the assumption that track sections in the same zone fall under common management.

First we note that the estimates of both measures are lower for the track section models than for the Zonal models. Further we note that the hypothesis that the usage elasticity is 0.34 (as estimated in the zonal model) can be rejected in both track section models at 10% and 5% significance levels for the A and B model respectively. However the converse that the usage elasticity in the zonal model can be 0.26 or 0.23 can not be rejected[10]. Thus we conclude that while the zonal model produces higher point estimates than the track section model, this is just as likely to be down to sampling error as any bias introduced as a result of aggregation. Of course, this result is based on the particular case being investigated here, and cannot be readily generalised, since it depends, inter alia, on the number of data points available for estimation.

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[9] Averages are weighted by tonne-km.

[10] Test conducted at the sample mean.

Table 7 Mean usage elasticities and marginal costs for Austria[11]

Model	Usage Elasticity	Marginal Cost (€ per TGTKM)
Zonal Model	0.34	1.55
Track Section Model A	0.26	1.42
Track Section Model B	0.23	1.25

4.2.3 The effect of limited infrastructure variables

Table 8 shows a comparison of estimates from track section models of Austria with and without the inclusion of all available infrastructure variables. The aim is to test whether omitting infrastructure variables has a big impact on the results. As in Table 7 we show the models with the two different panel data modelling assumptions, although these do not seem to affect the model results greatly. We do find that some of the extra infrastructure variables are statistically significant in the models. This has the effect of increasing both the estimates usage elasticity and mean marginal costs. However this finding may be due to the influence of statistical noise rather than any bias in the case of the restricted class of models.

Table 8 Mean usage elasticities and marginal costs for track section models for Austria[12]

Model	Usage Elasticity	Marginal Cost (€ per TGTKM)
Panel Track Section; Restricted infrastructure variables	0.26	1.42
Panel Zonal Restricted infrastructure variables	0.23	1.25
Panel Track Section; Full infrastructure variables	0.31	1.70
Panel Zonal Full infrastructure variables	0.29	1.61

4.2.4 Overall conclusions on the robustness of the approach

The above sensitivity analyses have shown that for Austria and in some cases Great Britain. First, we find little evidence that pooling data in itself results in any bias in estimates of the usage elasticity and marginal costs.

Regarding the second and third set of tests examining aggregation and the lack of infrastructure variables, we find weak evidence of systematic differences between point estimates of models which could indicate some bias in using aggregated and/or data which does not include a full set of infrastructure characteristics. However a common finding for both the aggregation and infrastructure characteristic sensitivity tests, is that any difference in point estimates could be due to statistical noise rather than systematic bias in the coefficients.

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[11] Averages are weighted by tonne-km.

[12] Averages are weighted by tonne-km.

Therefore while we conclude that we have no strong evidence of bias in our estimates from the pooled model, we have to comment that our model seems quite imprecise, which perhaps is the biggest limitation of pooling data across countries for this particular case (though not necessarily in general).

5 Conclusion

In this study we have utilised a bespoke dataset on six countries (five of which are in the European Union) for which data collection has been undertaken over a number years in cooperation with infrastructure managers. Unlike previous studies which have been country specific, we undertake the first attempt to combine data for a number of countries within a single statistical model.

We find that the average marginal cost estimate for all countries is 2.17 € per thousand gross tonne-km. This is high compared to some of the results from country specific case studies. To investigate whether this result is due to the pooling approach versus differences in the underlying data we compare the pooled results with those derived from analysing the data of two countries in the sample (Austria and Great Britain) in isolation. In particular we examine three issues.

First, to what extent estimates of marginal cost differ by pooling across countries versus considering each country separately. Second, to what extent estimates of marginal cost differ when utilising zonal rather than track section data. This is important for two reasons: firstly, because in previous work the econometric work for Britain has been carried out based on maintenance areas, whilst all other studies have been based on track sections; and secondly because the pooled study reported in this paper also utilises zonal data, and this point therefore needs to be taken into account when comparing the results against previous results utilising track section data. Third, to what extent the smaller number of infrastructure variables available for the pooled analysis (in this case) affect the estimates of marginal cost.

We find little evidence that pooling data in itself results in any bias in estimates of the usage elasticity and marginal costs. We also find weak evidence of systematic differences between point estimates of zonal versus track section models which could indicate some bias in using aggregated and/or data which does not include a full set of infrastructure characteristics. However any difference in point estimates could be due to statistical noise rather than systematic bias in the coefficients and so we can not reach a firm conclusion.

Therefore while we conclude that we have no strong evidence of bias in our estimates from the pooled model, we conclude that our model seems quite imprecise, which perhaps is the biggest limitation of pooling data across countries in this particular case (which is based on a relatively small sample). However we are still able to provide estimates of the usage elasticity and marginal costs which as discussed in detail in the main deliverable body are inline with those from other studies. As such we consider this approach to be one that should be pursued in tandem with country specific studies. We are hopeful that we can obtain a larger dataset (both in terms of number of observations and number of variables) and this will help us address some of our modelling concerns resulting in more precise estimates of the usage elasticity and marginal cost.

6 References

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Appendix A – Full estimation output

Pooled Model (reported in Tables 5 and 6):

```
+--------------------------------------------------+
| Random Effects Model: v(i,t) = e(i,t) + u(i)     |
| Estimates:  Var[e]              =   .132104D-01  |
|             Var[u]              =   .638429D-01  |
|             Corr[v(i,t),v(i,s)] =   .828555      |
| Lagrange Multiplier Test vs. Model (3) =   27.95 |
| ( 1 df, prob value =  .000000)                   |
| (High values of LM favor FEM/REM over CR model.) |
| Baltagi-Li form of LM Statistic =           9.70 |
| Fixed vs. Random Effects (Hausman)     =   13.68 |
| ( 7 df, prob value =  .057167)                   |
| (High (low) values of H favor FEM (REM).)        |
|             Sum of Squares          .714838D+01  |
|             R-squared               .880431D+00  |
| Wald test of  2 linear restrictions              |
| Chi-squared =    2.36, Sig. level =  .30685      |
+--------------------------------------------------+
+--------+--------------+----------------+--------+--------+----------+
|Variable| Coefficient  | Standard Error |b/St.Er.|P[|Z|>z]| Mean of X|
+--------+--------------+----------------+--------+--------+----------+
|LTTKM   |     .31006***       .11440916     2.710   .0067   -.3777192|
|LTRACK  |     .60309***       .13291919     4.537   .0000   -.1962157|
|PROELECT|     .15580          .21108016      .738   .4604    .6722504|
|LTTKMSQ |    -.08945          .07126673    -1.255   .2094   1.0756508|
|LTRACKSQ|    -.31144**        .14050939    -2.217   .0267    .4647612|
|LTRATON |     .03320          .17108645      .194   .8461    .3187150|
|TIME    |    -.01038          .01050731     -.988   .3230   5.7731959|
|Constant|    17.9231***       .18576702    96.482   .0000            |
+--------+------------------------------------------------------------+
| Note: ***, **, * = Significance at 1%, 5%, 10% level.               |
+---------------------------------------------------------------------+
```

Country only Model – Austria (reported in Tables 6 and 7)

```
+--------------------------------------------------+
| Random Effects Model: v(i,t) = e(i,t) + u(i)     |
| Estimates:  Var[e]              =   .114970D-01  |
|             Var[u]              =   .453787D-02  |
|             Corr[v(i,t),v(i,s)] =   .283000      |
| Lagrange Multiplier Test vs. Model (3) =    3.53 |
| ( 1 df, prob value =  .060227)                   |
| (High values of LM favor FEM/REM over CR model.) |
| Baltagi-Li form of LM Statistic =           3.53 |
| Fixed vs. Random Effects (Hausman)     =     .00 |
| ( 6 df, prob value = 1.000000)                   |
| (High (low) values of H favor FEM (REM).)        |
|             Sum of Squares          .609763D+00  |
|             R-squared               .968135D+00  |
+--------------------------------------------------+
+--------+--------------+----------------+--------+--------+----------+
|Variable| Coefficient  | Standard Error |b/St.Er.|P[|Z|>z]| Mean of X|
+--------+--------------+----------------+--------+--------+----------+
|LTTKM   |      .36468***      .09076138     4.018   .0001   -.2557303|
|LTRACK  |     1.02892***      .20652566     4.982   .0000   -.5422274|
|PROELECT|      .10760         .27924252      .385   .7000    .8822905|
|LTTKMSQ |     -.03729         .04402636     -.847   .3970    .7888373|
|LTRACKSQ|      .29490*        .16569980     1.780   .0751    .7167051|
|TIME    |     -.00723         .01130848     -.640   .5225   6.0000000|
|Constant|    17.6248***       .22459838    78.473   .0000            |
+--------+------------------------------------------------------------+
| Note: ***, **, * = Significance at 1%, 5%, 10% level.               |
+---------------------------------------------------------------------+
```

Country Only Model – Great Britian (reported in Table 6)

```
+----------------------------------------------------+
| Ordinary    least squares regression               |
| Model was estimated Jan 05, 2009 at 01:54:23PM     |
| LHS=LTMCOST  Mean                 =   18.18777     |
|              Standard deviation   =   .2330590     |
| WTS=none     Number of observs.   =         18     |
| Model size   Parameters           =          4     |
|              Degrees of freedom   =         14     |
| Residuals    Sum of squares       =   .3211531     |
|              Standard error of e  =   .1514579     |
| Fit          R-squared            =   .6521986     |
|              Adjusted R-squared   =   .5776697     |
| Model test   F[  3,    14] (prob) =   8.75 (.0016) |
| Diagnostic   Log likelihood       =   10.69499     |
|              Restricted(b=0)      =   1.189874     |
|              Chi-sq [  3]  (prob) =  19.01 (.0003) |
| Info criter. LogAmemiya Prd. Crt. =  -3.574224     |
|              Akaike Info. Criter. =  -3.581764     |
|              Bayes Info. Criter.  =  -3.383904     |
| Autocorrel   Durbin-Watson Stat.  =  1.4928049     |
|              Rho = cor[e,e(-1)]   =   .2535975     |
+----------------------------------------------------+
+--------+-------------+----------------+--------+--------+----------+
|Variable| Coefficient | Standard Error |t-ratio |P[|T|>t]| Mean of X|
+--------+-------------+----------------+--------+--------+----------+
|Constant|    17.9183***       .13394325   133.776   .0000           |
|LTTKM   |     .22785*         .12009132     1.897   .0786    .0889449|
|LTRACK  |     .15557          .16790202      .927   .3698    .5484384|
|PROELECT|     .38946**        .14683144     2.652   .0189    .4205370|
+--------+------------------------------------------------------------+
| Note: ***, **, * = Significance at 1%, 5%, 10% level.              |
+---------------------------------------------------------------------+
```

Track section Model A –Austria (Reported in Tables 7 and 8)

```
+--------------------------------------------------+
| Random Effects Model: v(i,t) = e(i,t) + u(i)     |
| Estimates:  Var[e]              =   .181814D+00  |
|             Var[u]              =   .102153D-01  |
|             Corr[v(i,t),v(i,s)] =   .053196      |
| Lagrange Multiplier Test vs. Model (3) =     .84 |
| ( 1 df, prob value =  .358218)                   |
| (High values of LM favor FEM/REM over CR model.) |
| Baltagi-Li form of LM Statistic =            .12 |
| Fixed vs. Random Effects (Hausman)     =     .00 |
| ( 5 df, prob value = 1.000000)                   |
| (High (low) values of H favor FEM (REM).)        |
|             Sum of Squares          .741900D+02  |
|             R-squared               .872993D+00  |
+--------------------------------------------------+
+--------+--------------+----------------+--------+--------+----------+
|Variable| Coefficient  | Standard Error |b/St.Er.|P[|Z|>z]| Mean of X|
+--------+--------------+----------------+--------+--------+----------+
|LTRACK  |     .70641***       .05730002    12.328   .0000   -.3772742|
|LTTKM   |     .22673***       .03220009     7.041   .0000  -1.4146010|
|PROELECT|     .34483***       .06886627     5.007   .0000    .5726849|
|YEAR    |     .01548          .01546983     1.001   .3170   3.0000000|
|LTRACKSQ|    -.06442***       .02362313    -2.727   .0064    .9338171|
|Constant|    15.1500***       .08951782   169.241   .0000            |
+--------+------------------------------------------------------------+
| Note: ***, **, * = Significance at 1%, 5%, 10% level.               |
+---------------------------------------------------------------------+
```

Track section Model B – Austria (Reported in Tables 7 and 8)

```
+--------------------------------------------------+
| Random Effects Model: v(i,t) = e(i,t) + u(i)     |
| Estimates:  Var[e]              =   .798757D-01  |
|             Var[u]              =   .113957D+00  |
|             Corr[v(i,t),v(i,s)] =   .587913      |
| Lagrange Multiplier Test vs. Model (3) =  258.31 |
| ( 1 df, prob value =  .000000)                   |
| (High values of LM favor FEM/REM over CR model.) |
| Baltagi-Li form of LM Statistic =         258.31 |
| Fixed vs. Random Effects (Hausman)     =     .00 |
| ( 4 df, prob value = 1.000000)                   |
| (High (low) values of H favor FEM (REM).)        |
|             Sum of Squares          .727625D+02  |
|             R-squared               .874678D+00  |
+--------------------------------------------------+
+--------+--------------+----------------+--------+--------+----------+
|Variable| Coefficient  | Standard Error |b/St.Er.|P[|Z|>z]| Mean of X|
+--------+--------------+----------------+--------+--------+----------+
|LTRACK  |     .72538***      .06860767    10.573   .0000   -.3772742|
|LTTKM   |     .25961***      .04461800     5.819   .0000  -1.4146010|
|PROELECT|     .34302***      .12230214     2.805   .0050    .5726849|
|YEAR    |     .01615         .01025475     1.576   .1151   3.0000000|
|Constant|   15.1081***       .12238906   123.444   .0000            |
+--------+------------------------------------------------------------+
| Note: ***, **, * = Significance at 1%, 5%, 10% level.               |
+---------------------------------------------------------------------+
```

Panel Track Section; Full Infrastructure variables – Austria (Reported in Table 8)

```
+--------------------------------------------------+
| Random Effects Model: v(i,t) = e(i,t) + u(i)      |
| Estimates:  Var[e]              =   .801946D-01  |
|             Var[u]              =   .109569D+00  |
|             Corr[v(i,t),v(i,s)] =   .577398      |
| Lagrange Multiplier Test vs. Model (3) =  247.91 |
| ( 1 df, prob value =  .000000)                   |
| (High values of LM favor FEM/REM over CR model.) |
| Baltagi-Li form of LM Statistic =         247.91 |
| Fixed vs. Random Effects (Hausman)     =     .00 |
| ( 6 df, prob value = 1.000000)                   |
| (High (low) values of H favor FEM (REM).)        |
|             Sum of Squares           .709641D+02  |
|             R-squared                .877775D+00  |
+--------------------------------------------------+
+--------+--------------+----------------+--------+--------+----------+
|Variable| Coefficient  | Standard Error |b/St.Er.|P[|Z|>z]| Mean of X|
+--------+--------------+----------------+--------+--------+----------+
|LTRACK  |     .71098***       .21795535     3.262   .0011   -.3772742|
|LTTKM   |     .30853***       .05767338     5.350   .0000  -1.4146010|
|MLSL80  |     .25724*         .15301908     1.681   .0927    .4666426|
|PROELECT|     .32801***       .12171364     2.695   .0070    .5726849|
|LROUTE  |    -.00214          .21843513     -.010   .9922   3.8173582|
|YEAR    |     .01661          .01028389     1.616   .1061   3.0000000|
|Constant|    15.0673***       .90443410    16.659   .0000            |
+--------+------------------------------------------------------------+
| Note: ***, **, * = Significance at 1%, 5%, 10% level.               |
+---------------------------------------------------------------------+
```

Panel Zonal Section; Full Infrastructure variables – Austria (Reported in Table 8)

```
+--------------------------------------------------+
| Random Effects Model: v(i,t) = e(i,t) + u(i)     |
| Estimates:  Var[e]              =   .173654D+00  |
|             Var[u]              =   .105687D-01  |
|             Corr[v(i,t),v(i,s)] =   .057369      |
| Lagrange Multiplier Test vs. Model (3) =    2.51 |
| ( 1 df, prob value =  .113044)                   |
| (High values of LM favor FEM/REM over CR model.) |
| Baltagi-Li form of LM Statistic =           .35 |
| Fixed vs. Random Effects (Hausman)     =     .00 |
| ( 7 df, prob value = 1.000000)                   |
| (High (low) values of H favor FEM (REM).)        |
|             Sum of Squares          .714237D+02  |
|             R-squared               .877564D+00  |
+--------------------------------------------------+
+--------+--------------+----------------+--------+--------+----------+
|Variable| Coefficient  | Standard Error |b/St.Er.|P[|Z|>z]| Mean of X|
+--------+--------------+----------------+--------+--------+----------+
|LTRACK  |     .77619***       .14941540     5.195   .0000   -.3772742|
|LTTKM   |     .29253***       .03903804     7.494   .0000  -1.4146010|
|MLSL80  |     .37818***       .08954757     4.223   .0000    .4666426|
|PROELECT|     .31208***       .06817972     4.577   .0000    .5726849|
|LROUTE  |    -.14411          .14232679    -1.013   .3113   3.8173582|
|YEAR    |     .01600          .01512033     1.058   .2899   3.0000000|
|LTRACKSQ|    -.09752***       .02432029    -4.010   .0001    .9338171|
|Constant|    15.6866***       .58309742    26.902   .0000            |
+--------+------------------------------------------------------------+
| Note: ***, **, * = Significance at 1%, 5%, 10% level.                |
+---------------------------------------------------------------------+
```

SIXTH FRAMEWORK PROGRAMME
PRIORITY 1.6.2
Sustainable Surface Transport

CATRIN

Cost Allocation of TRansport INfrastructure cost

D8 – Rail Cost Allocation for Europe

Annex 2 - Railway Infrastructure Wear and Tear for Freight and Passenger Trains in Sweden

Version 1.0
February 2009

Authors:
Daniele Ongaro (MMU) and Simon Iwnicki (MMU)
with contributions from Mats Andersson (VTI) and other Partners

Contract no.: 038422
Project Co-ordinator: VTI

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CATRIN Partner Organisations

VTI; University of Gdansk, ITS Leeds, DIW, Ecoplan, Manchester Metropolitan University, TUV Vienna University of Technology, EIT University of Las Palmas; Swedish Maritime Administration, University of Turku/Centre for Maritime Studies

CATRIN
FP6-038422
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Partners: VTI; University of Gdansk, ITS Leeds, DIW, Ecoplan, Manchester Metropolitan University, TUV Vienna University of Technology, EIT University of Las Palmas; Swedish Maritime Administration, University of Turku/Centre for Maritime Studies

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1 Summary

As part of the CATRIN project a detailed engineering assessment has been carried out to predict the precise levels of track damage caused by running individual vehicles on specific routes. A case study based on two routes in Sweden has been set up, one with predominantly passenger traffic and one dominated by freight traffic. Track data has been obtained from measuring vehicles and detailed models of the main vehicles running set up using vehicle dynamic simulation software. Algorithms to predict various types of track damage were applied to the predicted wheel-rail forces and used to give total vehicle damage according to the two main modes of maintenance activity. These were then grouped to establish the weighting of predicted maintenance work required for freight and passenger vehicles separately.

The findings the engineering analysis show that the damage caused by different vehicles is fairly consistent and independent of the route and traffic mix. The passenger vehicles are shown to cause greater damage to the rail head and therefore would result in higher costs due to grinding and rail replacement. The freight vehicles on the other hand cause higher track settlement and therefore would result in higher tamping costs. This work has not been able to demonstrate the overall effect of these factors on the total costs of running freight or passenger vehicles as the relative weight of the two modes of damage is not currently known for the routes analysed. This analysis is proposed as further work.

2 Background

CATRIN is a Research project which aims to support the European Transport Policy, specifically to assist in the Implementation of Transport pricing. CATRIN will increase the probability that new progressive pricing principles can be implemented which facilitate a move towards sustainable transport. CATRIN is both intermodal and interdisciplinary, emphasize the need of new Member states, understands that different organisational forms require different recommendations, that recommendations need to be given in short and long-term perspective and that they have to be thoroughly discussed with infrastructure managers.

Based on engineering studies CATRIN aims to analyse the possibility of defining more differentiated pricing rules for specific vehicle categories. CATRIN aims to blend the economic principles of pricing with engineering knowledge. And will address the implementation potential and constraints experienced by infrastructure managers.

3 The engineering approach

The cost of maintaining railway track is a very significant part of the overall cost of running a railway. A good understanding of the way in which the maintenance cost is affected by running of different vehicles and also by different maintenance strategies is vital in optimising these decisions and increasing the efficiency of the system.

A number of modelling techniques have been developed in recent years and several powerful computer simulation packages are now available which allow accurate prediction of the forces acting between the wheel and the rail, how these influence the rate of wear and other forms of damage to the various components making up the track (and also the vehicle). In order to obtain these damage predictions a detailed description of the track and the vehicles is required. This includes details of the masses and geometries of the vehicle and the suspension components and the track design and irregularities.

Several railway organisations use an engineering approach to determine appropriate charging regime or to inform certain aspects of this regime. The current charging regime in the UK has been in place since 2001. It uses a combined 'Top-Down' and 'Bottom-Up' approach where the sum of money to be recovered is determined by a top down assessment of the variability of maintenance and renewals and then this sum is allocated to the vehicle fleet using a bottom up model of marginal costs by vehicle type. The distribution to the vehicles is made according to an Equivalent Gross Tonne Mileage (EGTM) which is a weighting of the actual Gross Tonne Mileage with parameters derived by fitting regression relationships to a large amount of data from damage models.

The current Banverket track access charging regime takes no account of vehicle characteristics but a proposal from Banverket and the Royal Institute of Technology (KTH) addresses this with a model of track deterioration which aims to produce vehicle related marginal track deterioration costs. The proposed track deterioration model considers four mechanisms: track settlement, component fatigue, abrasive wear of rails and rolling contact fatigue (RCF) of rails. The determining factors behind these mechanisms are said to be the vertical and lateral wheel-rail forces and the energy dissipation at this interface. The authors of the report state that they have used the best 'state of the art' knowledge to construct a numerical tool (DeCAySS) which includes all four mechanisms. The model is based on a 'mean value' approach where marginal cost and damage to the track are distributed across the whole network being considered. The model is calibrated to the Banverket system.

A detailed description of these engineering techniques and a comparison of the way they are used in the UK method and the proposed Swedish method is given in [1].

3.1 Track deterioration

The forces between the vehicle and the track are carried through the wheel-rail interface and include vertical support, lateral guidance, acceleration and braking. The role of the supporting structure under the rails is to distribute these loads evenly and to provide continuous support through track features such as curves, switches, gradients, changes in ground conditions etc. If the support structure fails to provide this continuous support then the forces at the wheel rail interface will show greater peak values and this in turn will result in increased forces on the vehicle and on the track and substructure and on the sub components within these system and on levels of noise and vibration. The effect of these forces may depend on a great many variables such as the amplitude and frequency, location of the support changes. In conventional track with rails supported on sleepers, which in turn sit on a layer of ballast, any misalignments which develop can be periodically corrected by tamping. Other support structures which use concrete slabs instead of ballast (slab track) are increasingly common on high speed lines and may provide more stable support over a longer period but do not allow corrective action as easily as ballasted track.

Wear on the head and/or gauge corner of the rail is a natural process when railway vehicles run but the rate of material removal can increase significantly if the forces and the contact conditions are not well controlled. This can cause particularly severe problems if the wear causes significant changes to the cross sectional profile, resulting in a change of the running surface as seen by the wheel. Irregular surface wear can result in roughness or corrugation and a consequent increase in rolling noise. Rolling contact fatigue (RCF) occurs if the rail surface is subjected to repeated plastic deformation as is often caused by repeated wheel passages. If the forces generated are below what is known as the shakedown limit for the material it is possible for them to be accommodated through elastic deformation and RCF avoided. If rail wear levels are high then RCF is reduced or even prevented as the cracks are worn away faster than they grow. The dividing line between these cases is not easy to establish but the factors influencing the generation of RCF are the normal and tangential forces at the wheel-rail contact and also the contact conditions (mainly the contact pressure and prevailing coefficient of friction).

These various damage mechanisms have been modelled for several cases as part of the CATRIN project and these are described in the following sections.

3.2 Rail damage

The wear and RCF performance of the vehicle can be assessed using a method based on the ‘Tgamma’ number which is the product of the tangential or creep forces and the slippage or creepage in the contact patch between wheel and rail. Tgamma was originally used to predict wear but when combined with a non-linear damage function produces an RCF damage index as shown in Figure 1. This index is then used to interpret whether the vehicle is damaging the track due to wear, RCF or more commonly, a combination of both.

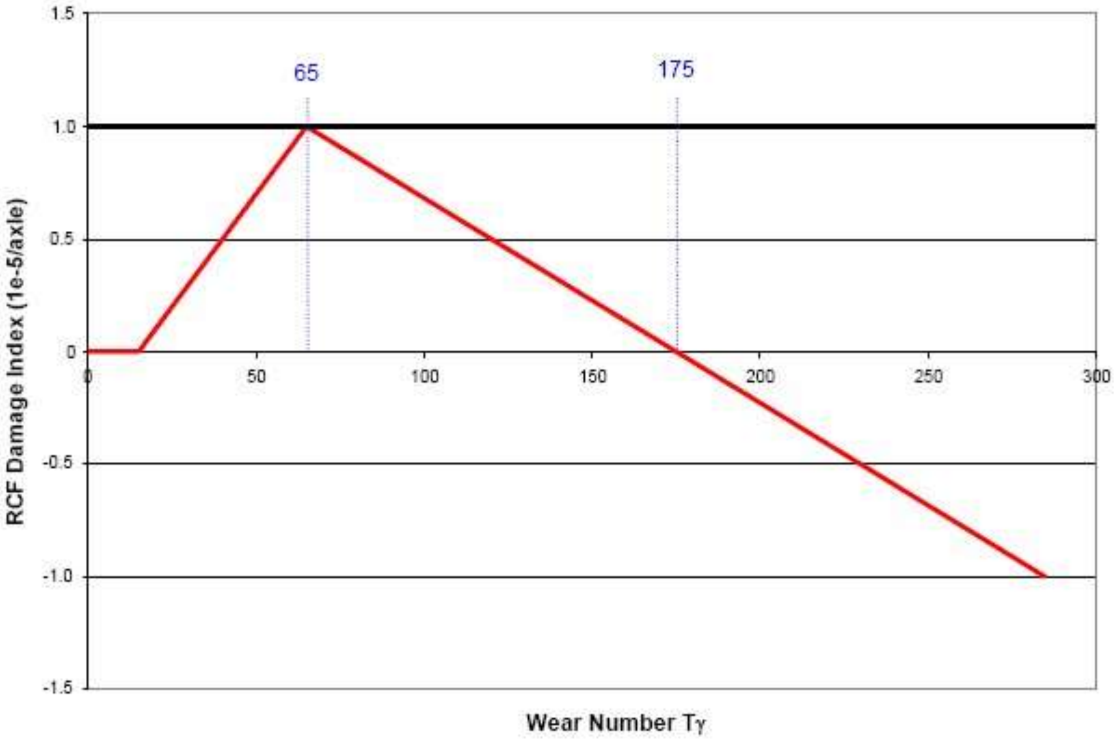

Figure 1 *– Relationship between wear number (T γ) and RCF damage index*

With reference to Figure 1 above, wear and RCF damage rates is combined to develop the RCF damage function.

The operation of the damage function is as follows:

- As Tgamma increase from 0 to 15 N, no RCF damage is generated as there is insufficient energy to initiate RCF cracks
- As Tgamma increase from 15 to 65 N, the probability of RCF incitation increase, to a maximum of 10 at a Tgamma value of 65 N.
- As Tgamma increase further from 65 to 175 N, the level of energy is such that the dominant form of surface damage is wear (rather than crack initiation), therefore the probability of RCF damage decreases as wear increases.
- Negative values of RCF damage indicate values of Tgamma greater than 175 N, resulting in wear and no RCF initiation.
- The units of the RCF damage index are 10-5 per axle. This indicates that for a damage index of 1, 100000 (One hundred thousand) axle passes would result in RCF initiation.

3.3 Track settlement

Track settlement may be defined as the sinking of the track (in the vertical plane) into ballast under a variety of conditions.

If the average ballast settlement over a large number of axle passes is measured, two distinct phases are evident. For a short initial period immediately after the tamping has taken place, the rate of the settlement will be high as the ballast bed become compacted and consolidated.

This is then followed by a largely linear phase in which settlement occurs at a slower rate (Figure 2).

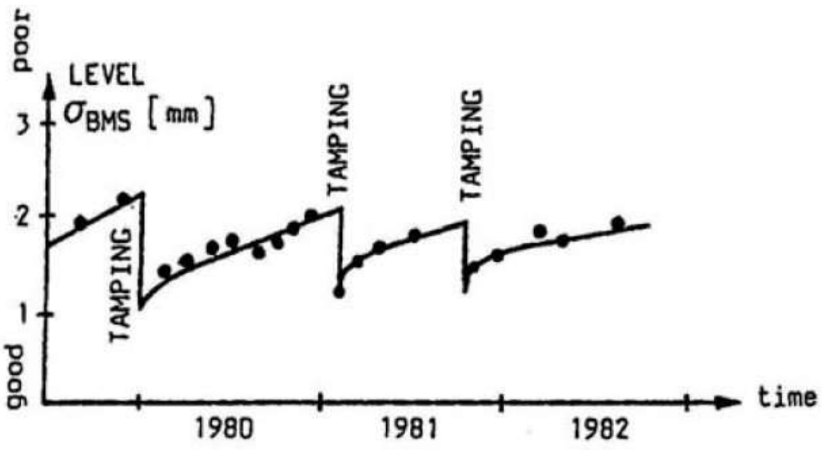

Figure 2 *– Track settlement over a period of time*

This topic has been studied by many researchers and a number of models have historically been used to predict track settlement. A fundamental problem occurs when conducting theoretical investigation of ballast performance since the models allow for the comparison of damage done by different vehicle types but not for the calculation of the actual deformed shape of the track after a number of vehicle passes. These models are able to predict an average settlement at a given point for a given set of conditions.

The Technical University of Munich studied the ballast settlement under controlled laboratory condition and developed from this work equation to calculate the settlement rate. Due to the scatter from the experiment results three equations were proposed to work out the optimistic, pessimistic and mean settlement. Here under reported the relation used for the prediction of the mean ballast settlement:

$$S_{med} = 1.89\ p \ln\Delta N + 5.15\ p^{1.21} \ln N \qquad [1]$$

Where:
N = number of axle passes
ΔN = number of axle passes<10000
p = ballast pressure
S_{med} = mean ballast settlement

The first part of the equation is connected to the initial settlement immediately after the tamping and the second part relates to the longer term and more gradual settlement after approximately 10000 axle passes. The method has been derived after considerable study and may be taken at least as an indication of settlements trends.

3.4 Combination of damage mechanisms

The weighting between rail damage and track settlement is difficult to establish by engineering methods as it depends not only on the track condition and vehicle behaviour but on the decisions regarding maintenance and renewal. If historical information on maintenance costs is available and can be separately into the different modes of deterioration then this can be used to allocate a weighting to the results from the engineering analysis.

These results could be compared with the approach used by the ORR where the sum of all variable costs estimated using the top-down approach is allocated to the different vehicles types by use of a bottom-up engineering model. The distribution of cost amongst vehicles type has been calculated according to the Equivalent Gross Tonne Mileage (EGTM) which is a weighting of the actual Gross Tonne Mileage.

$$EGTM_{track} = K\ Ct\ A^{0.49}\ S^{0.64}\ USM^{0.19}\ GTM \qquad [2]$$

Where:

K	is a constant
Ct	is 0.89 for loco hauled passenger stock and multiple units and 1 for all other vehicles
S	is the operating speed [mph]
A	is the axle load [tonnes]
USM	is the unsprung mass [kg/axle]
GTM	is gross tonne miles [Tonne.miles]

4 Case studies on Swedish track

4.1 Track data

The engineering analysis of railway track degradation described above requires the following input data:

- Track characteristics
- Vehicle characteristics
- Traffic details

The track quality data and topographic route information are the input data to calculate the time response of a vehicle. These measurements were provided by VTI (originally supplied by Banverket) for two different track sections. The data were obtained using a rail coach recording which provides, every 0.25 m along the route, the following measurements:

- Distance
- Curvature
- Cant
- Left and right rail alignment
- Left and right rail top
- Rail gauge

An example plot of this track data is shown in Figure 3.

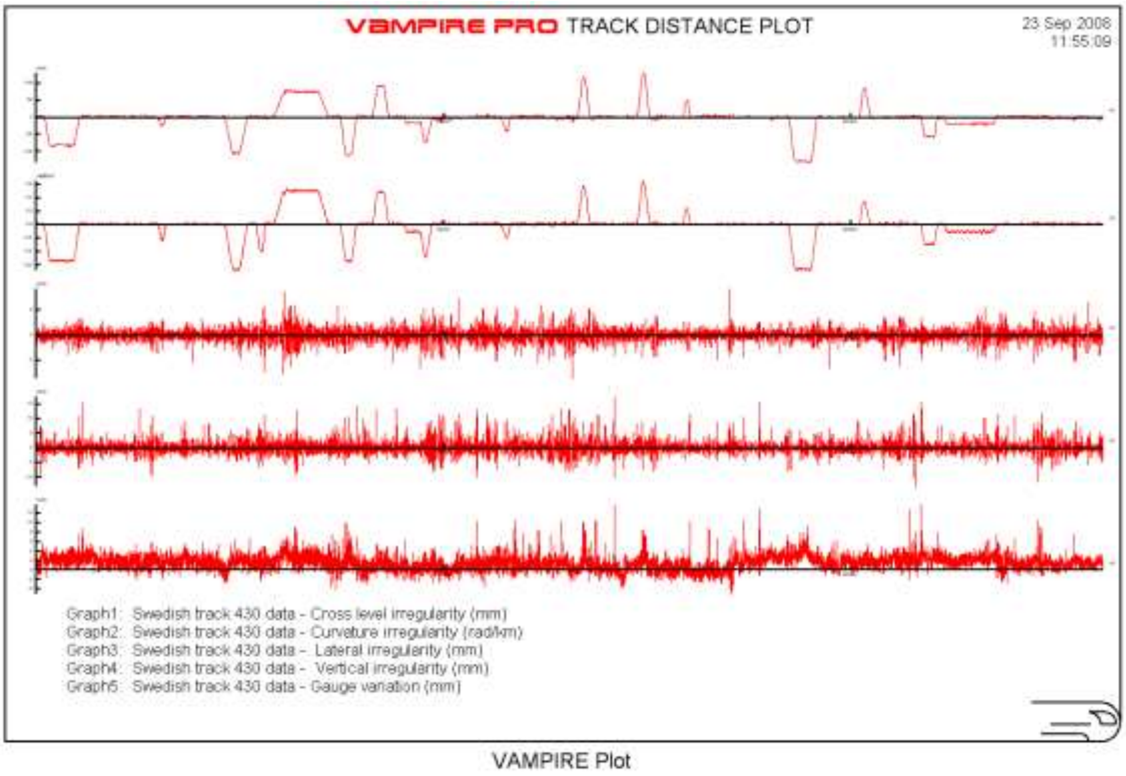

***Figure 3** – Track quality data from track section 430*

4.2 Vehicle model

The vehicle models have been built using the Vampire vehicle dynamics simulation software. The vehicle is described in term of:

- Mass properties
- Geometric characteristics
- Axle numbers
- Axle load
- Unsprung mass
- Wheel radius
- Suspension characteristic

The Vampire package generates the equations of motion for the vehicle according to the defined model and the parameters input and then solves these equations of motion using the track definition as an input. A time stepping integration is used with typical time steps of around 1.10-3 s. One the simulation is complete outputs are available for wheel-rail forces vehicle motions etc and can be used as inputs to the damage algorithms described above.

A sample vehicle model is shown in Figure 4.

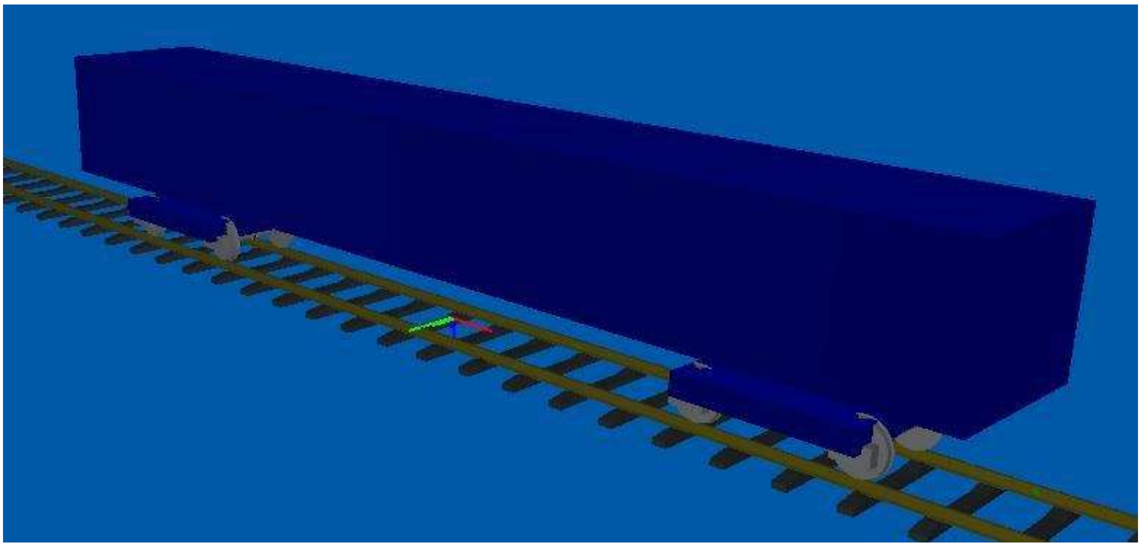

Figure 4 *– Vampire vehicle model*

Dynamic simulations of the vehicle track interaction were carried out for each vehicle type using the most recent measured irregularity data. From this data the track degradation rates were calculated for both rail damage (Figure 5) and track geometry deterioration.

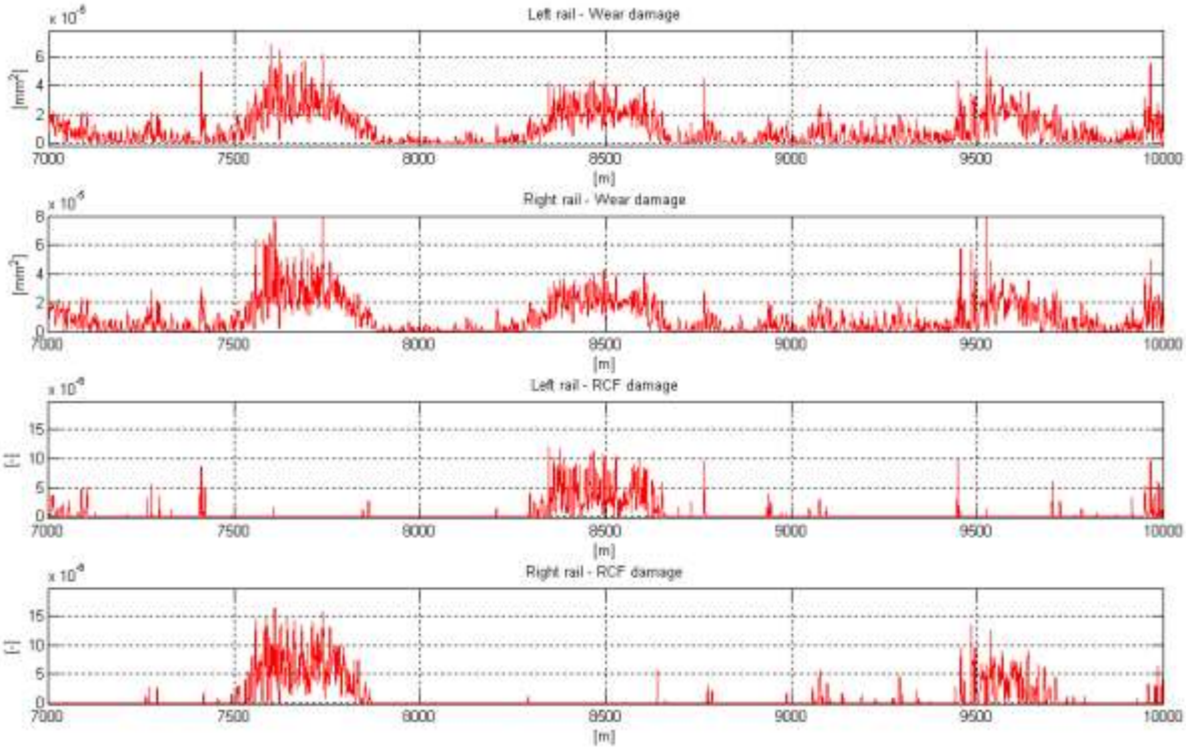

Figure 5 – *Wear and RFC damage output*

4.3 Track section 430 analysis

The first case study is based on the Ostkustbanan route from Stockholm to Uppsala. The traffic scenario over this track route is dominated by passenger traffic that is composed by both high speed and commuter train. Freight traffic makes up a relatively small proportion of the traffic at just over 6%.

A detailed breakdown of traffic is shown in table 1.

Vehicle type	Vehicles per year	Sum of axle load [ton]	Tonnage [ton]	Aggregate tonnage [%]	Speed [km/h]
Freight Loco	1024	78.0	79852	0.5	80
Freight Wagon T.	5375	23.3	125014	0.8	80
Freight Wagon L.	9981	90.0	898332	5.4	80
High speed Loco	3969	73.0	289710	1.8	200
High speed Coach	7937	51.0	404800	2.5	200
Passenger Loco	59529	78.0	4643297	28.1	130
Passenger Coach	216290	46.5	10057501	61.0	130

Table 1 *– Track section 430 – Traffic scenario*

4.3.1 Results

Vehicle models were prepared and run on the supplied track data. The results for track settlement are plotted per vehicle-km in Figure 6 and per tonne-km in Figure 7.

The raw damage values (per vehicle km) are in line with expectations with the three locomotives and the laden freight wagon showing the highest damage due to their high axle load. The tare freight wagon shows the lowest predicted damage. The influence of speed is seen in the higher value for the high speed coach than for the commuter coach.

When the values are normalised by tonne-km, the damage values fall much more closely into line with each other. The high speed locomotive results in the highest damage and the tare freight wagon is still lowest and the difference of settlement damage per tonne-km between the two vehicles is 33% (Table 2).

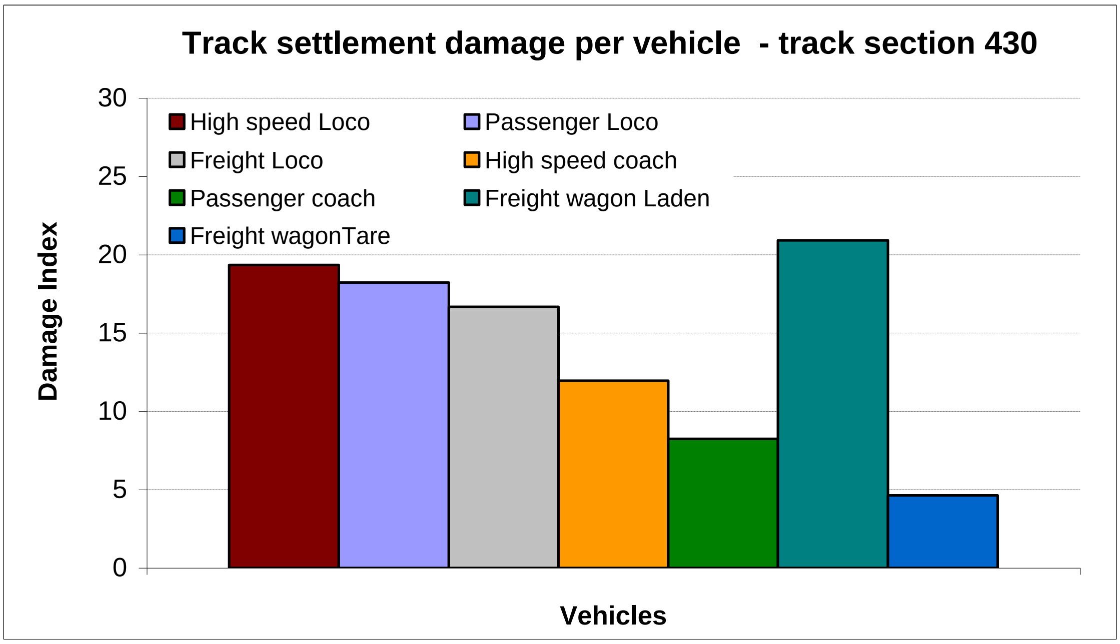

Figure 6 – *Track settlement damage per vehicle-km*

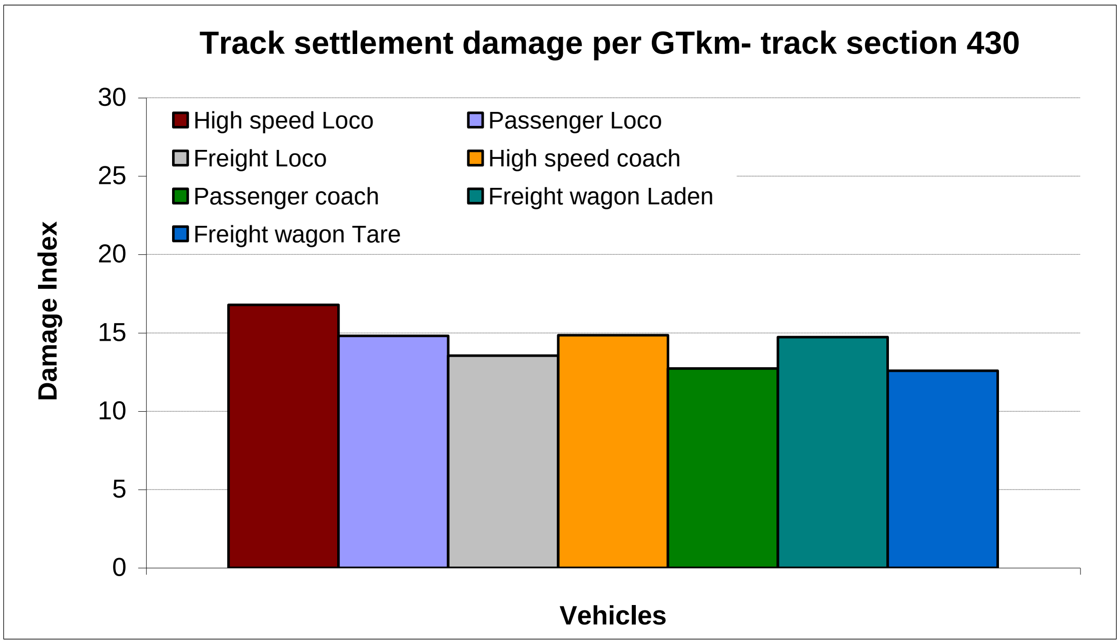

Figure 7 *– Track settlement damage per vehicle-GTkm*

The results for rail damage per vehicle-km are shown in Figure 8 and by tonne-km in Figure 9. The results for raw rail damage per vehicle-km are similar to that for track settlement but the laden freight vehicle is not this time significantly higher than the coaches and is lower than the locomotives. This is due to its relatively good lateral behaviour in curves. The weighted by tonne-km the results again become closer although this time the level of dispersion is higher (Table 2).

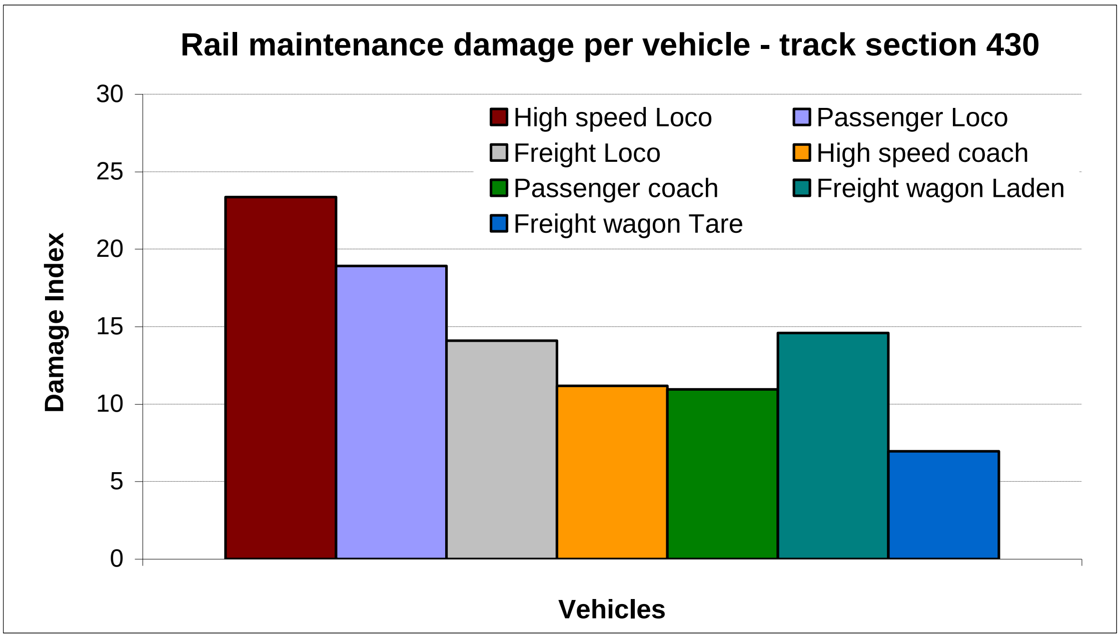

Figure 8 – Rail damage per vehicle-km

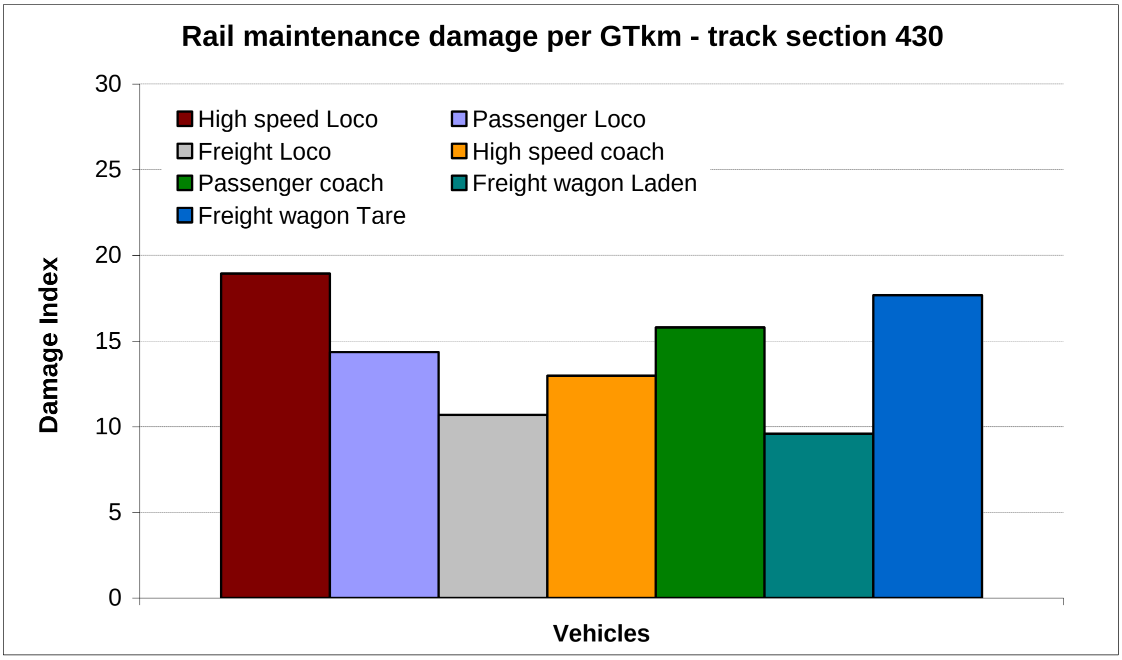

Figure 9 – Rail damage per vehicle-GTkm

The relation between the damage per GTkm caused by the different vehicles, for both track settlement and rail damage, has been calculated (Table 2) using the passenger coach as reference.

Vehicle type	**Relative track settlement**	**Relative rail damage**
High speed Loco	+31.9%	+19.9%
Passenger Loco	+16.3%	−9.1%
Freight Loco	+6.4%	−32.3%
High speed Coach	+16.6%	−17.9%
Passenger Coach	0.0%	0.0%
Freight Wagon L.	+15.7%	−39.3%
Freight Wagon T.	−1.1%	+11.8%

***Table 2** – Percentage of damage per vehicle -GTkm relative to the passenger coach*

Moreover EGTM damage, used by the ORR [2], has been applied to allocate the relative damage between the vehicles composing the traffic scenario.

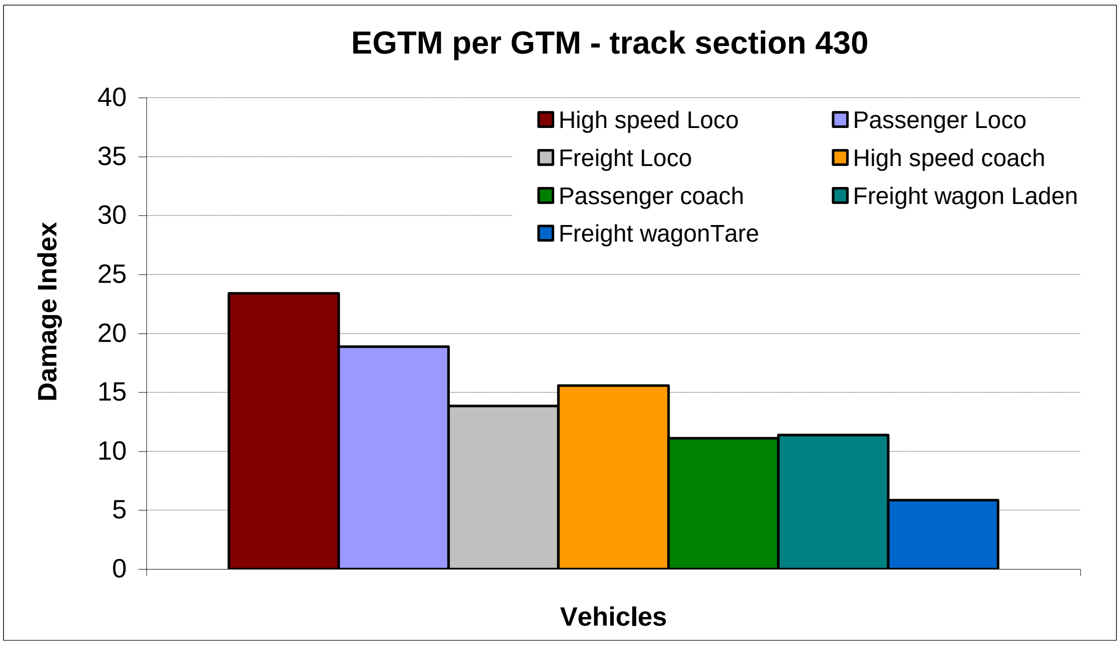

***Figure 10** - EGTM damage per vehicle-GTM*

The damage value for each vehicle were then combined, according to the traffic scenario, to give a total damage per GTkm for freight vehicles and for passenger vehicles and this is shown for track settlement in Figure 11 and for rail damage in Figure 12.
This result is interesting in that it shows that for track settlement the freight traffic causes more damage and will require more track maintenance (by tamping) whereas for rail damage (which is corrected by grinding or rail replacement) the passenger traffic does more damage.

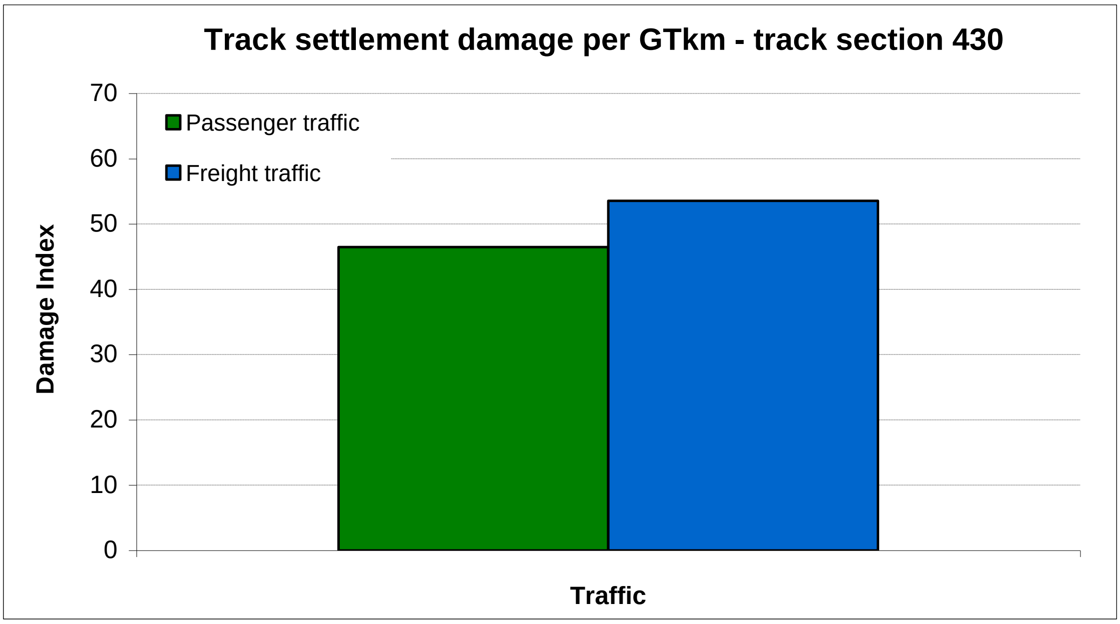

Figure 11 *– Track settlement damage per traffic-GTkm*

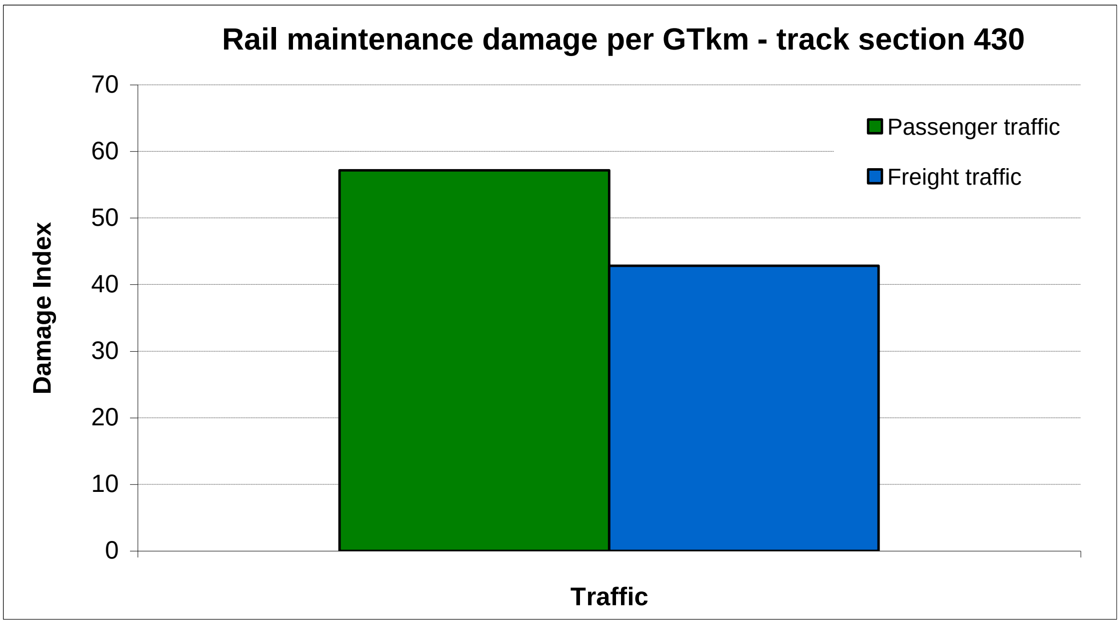

Figure 12 *– Rail damage per traffic-GTkm*

4.4 Track section 111 analysis

Track section 111 is a dedicated freight route known as Malmbanan running from Luleå, to Narvik in Norway. Traffic here is clearly dominated by freight vehicles most of which consist of vehicles with so called three piece freight bogies. These are known to have a very high unsprung mass (the mass of the wheels and axle and any part of the vehicle not separated from this by suspension).

A detailed breakdown of traffic is shown in Table 3

Vehicle type	**Vehicles per year**	**Sum of axle load [ton]**	**Tonnage [ton]**	**Aggregate tonnage [%]**	**Speed [km/h]**
Freight Loco	13791	190	2620319	11.0	60-70
Passenger Loco	2170	78	169260	0.7	110
Passenger Coach	13068	46.5	607662	2.5	110
Freight Wagon L.	161356	100	16135646	67.6	60
Freight Wagon T.	197213	22	4338696	18.2	70

Table 3 *- Track section 111 – Traffic scenario*

Vehicle models were prepared and run on the supplied track data. The results for track settlement are shown per vehicle-km in Figure 13 and per tonne-km in Figure 14. It can be seen that the freight locomotive dominates the damage but when weighted according to tonne-km the damage caused by all vehicles is more uniform although the maximum difference between the freight locomotive and the passenger coach is still about 33%.

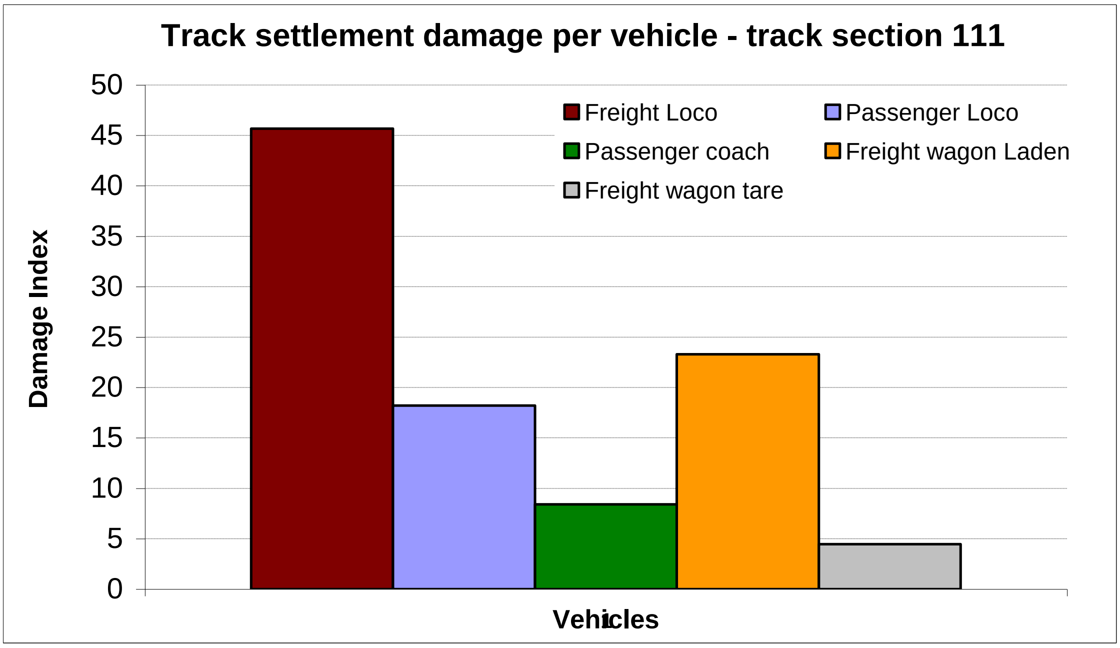

Figure 13 *– Track settlement damage per vehicle-km*

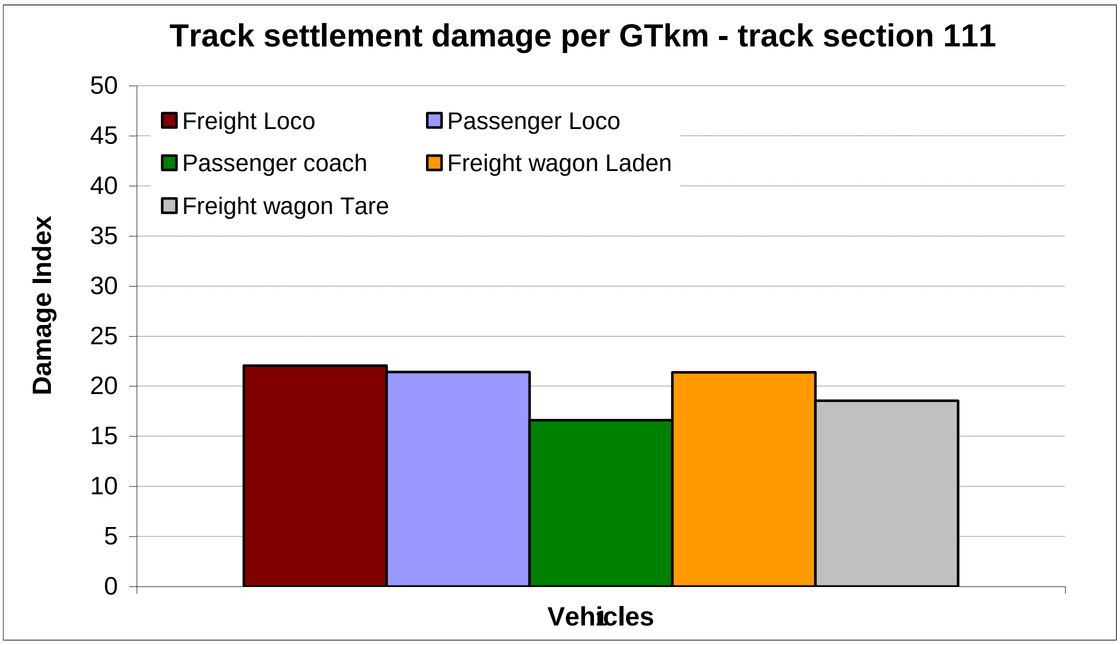

Figure 14 – Track settlement damage per vehicle-GTkm

The results for rail damage per vehicle-km are shown in Figure 15 and by tonne-km in Figure 16. For this damage mechanism the locomotives again dominate the raw damage but when weighted according to tonne-km the tare freight wagon is emphasised due to the relatively low mass.

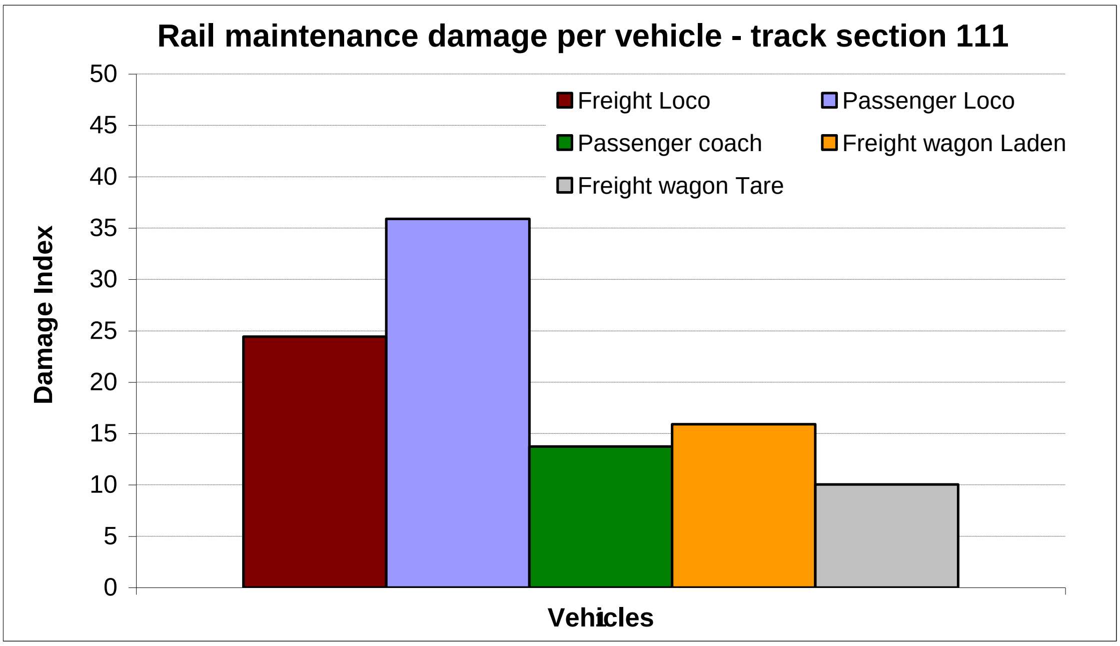

Figure 15 – Rail damage per vehicle-km

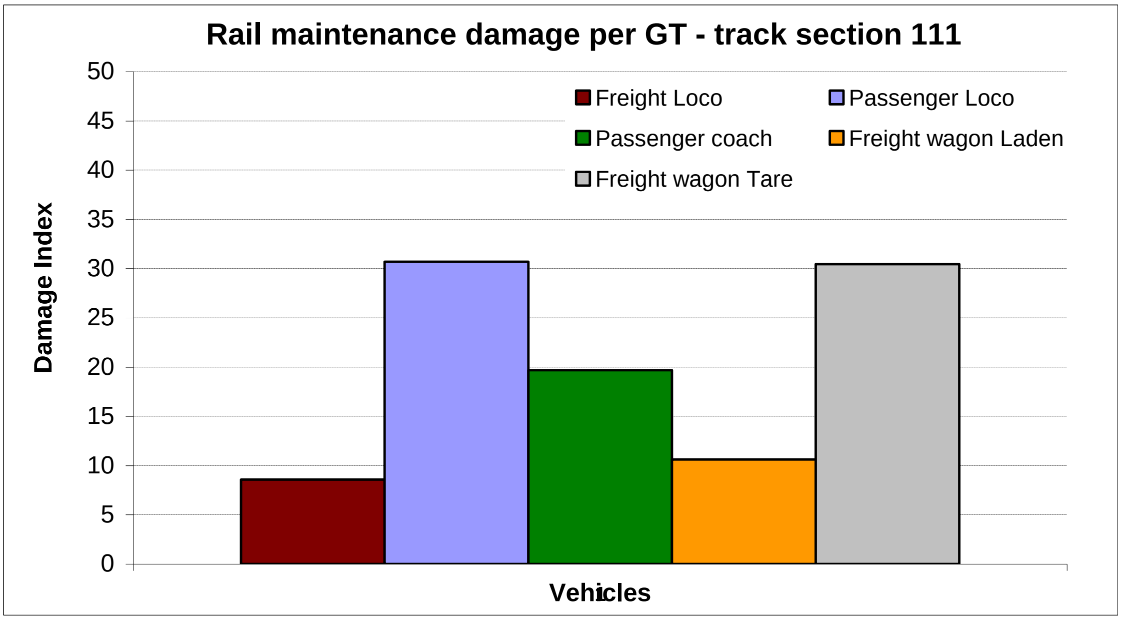

***Figure 16** – Rail damage per vehicle-GTkm*

The relation between the damage per GTkm caused by the different vehicles, for both track settlement and rail damage, has been calculated (Table 4) using the passenger coach as reference.

Vehicle type	Relative track settlement	Relative rail damage
Freight Loco	+32.8%	−56.4%
Passenger Loco	+28.9%	+55.9%
Passenger Coach	0.0%	0.0%
Freight Wagon L.	+28.7%	−46.1%
Freight Wagon T.	+11.5%	+54.7%

***Table 4** – Percentage of damage per vehicle-GTkm relative to the passenger coach*

In the 2002 the maintenance total cost recorded was £2,472,729 (30,855,962 SEK). The split between grinding and tamping activities which represent correction of track settlement and rail damage respectively is 21.4%.to 78.6%

On the basis of these figures the allocation between rail damage and track settlement can be established (Figure 17). Therefore a total damage index has been worked out for each vehicle.

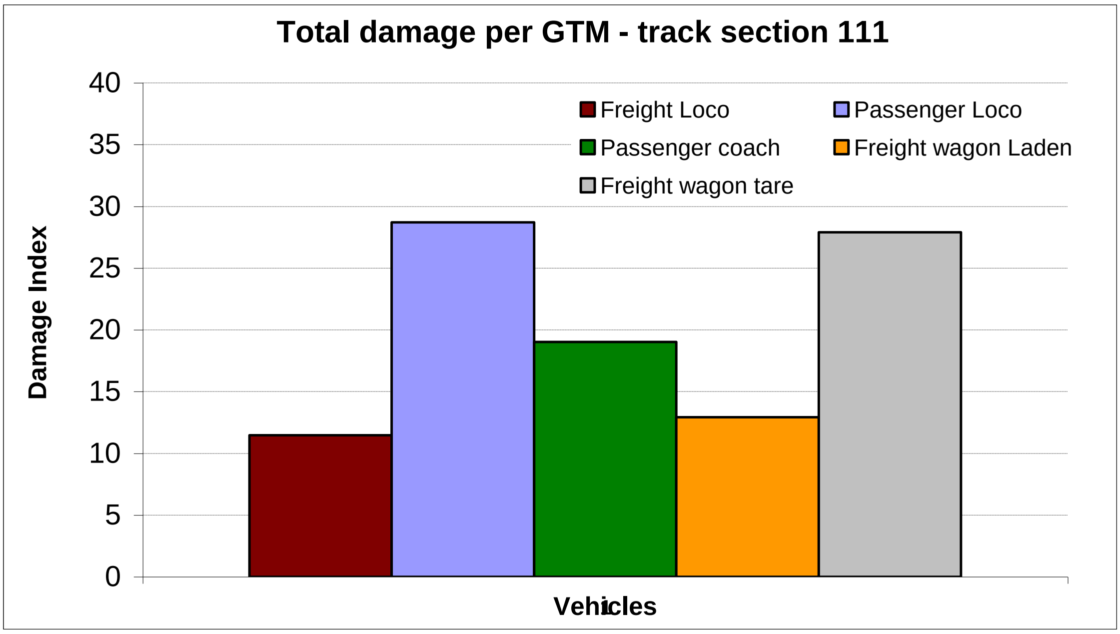

Figure 17- Total damage per vehicle-GTM

These results have been compared with the approach used by the ORR [2] (Figure 18) and a correlation index of -0.21 has been obtained.

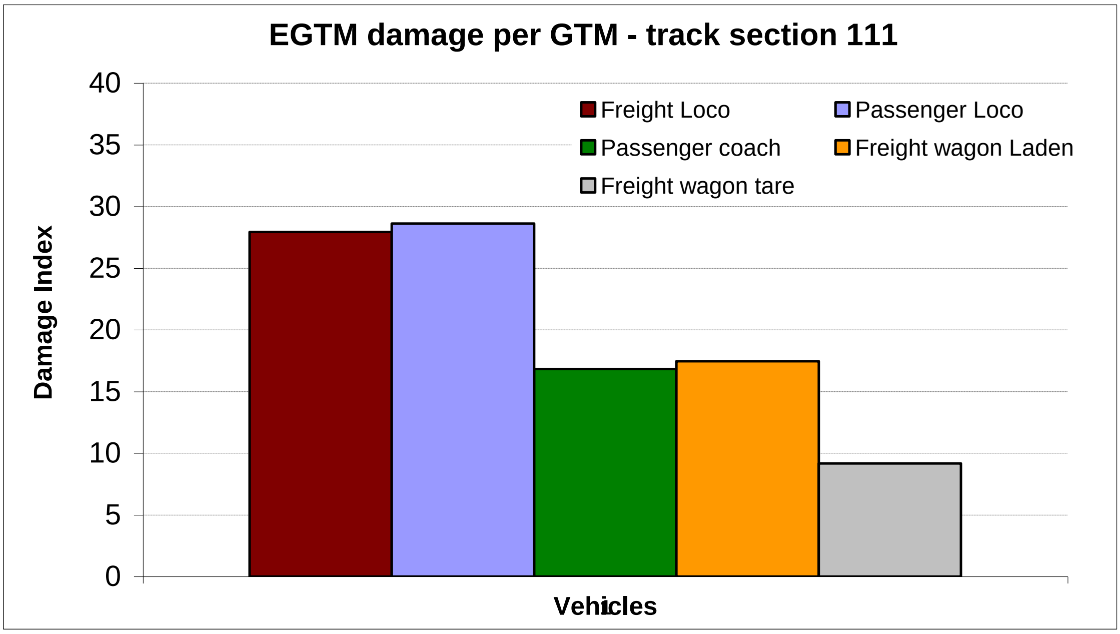

Figure 18 - EGTM damage per vehicle-GTM

The damage values for each vehicle were then combined, according to the traffic scenario, to give a total damage for freight vehicles and for passenger vehicles and these are shown for track settlement in Figure 19 and for rail damage in Figure 20. It can again be seen that for track settlement the freight traffic causes more damage (resulting in greater tamping) whereas for rail damage the passenger traffic does more damage (resulting in greater grinding).

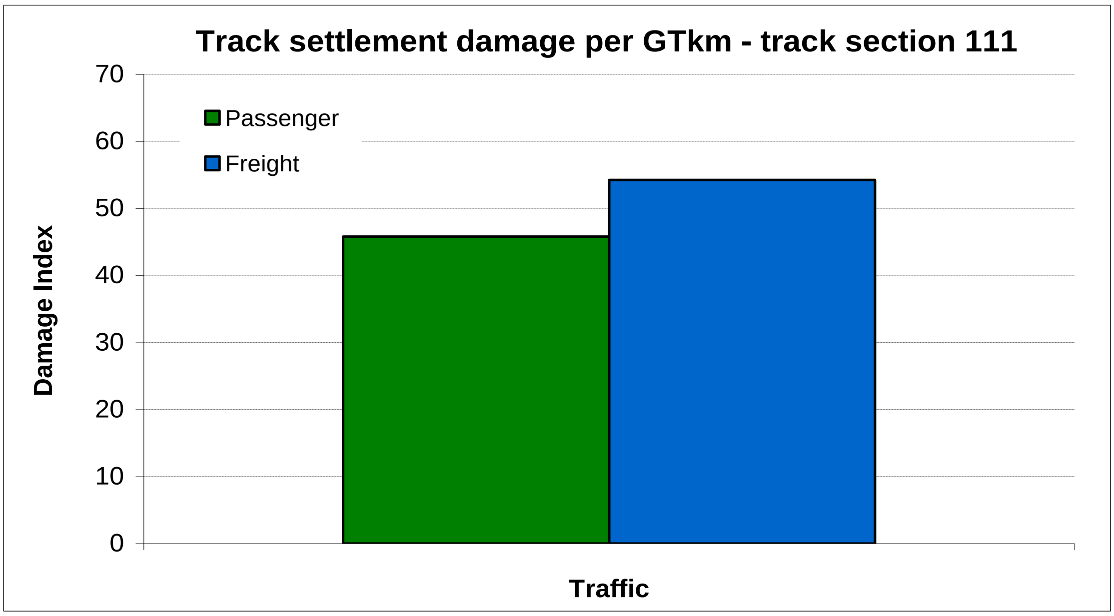

Figure 19 – *Track settlement damage per traffic-GTkm*

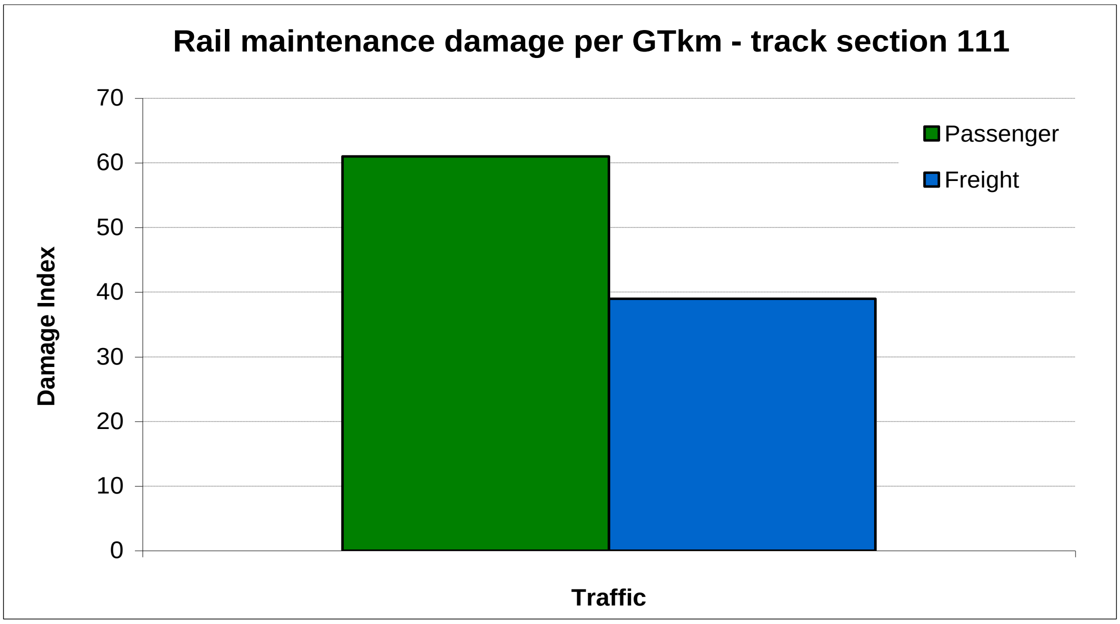

Figure 20 – *Rail damage per traffic-GTkm*

The summarised results for this track section from the engineering predictions are shown in Table 5.

Track settlement		Rail damage	
Passenger	Freight	Passenger	Freight
46%	54%	61%	39%

Table 5 - *Results from engineering predictions of track damage*

The damage predictions show that 46% of track settlement damage and 61% of rail damage is attributed to the passenger traffic.

5 Conclusions

The results from the engineering predictions are shown in Table 6

	Track settlement		Rail damage	
	Passenger	Freight	Passenger	Freight
Track Section 430	47%	53%	57%	42%
Track Section 111	46%	54%	61%	39%

***Table 6**– Results from engineering predictions of track damage*

From this table it can be seen that the damage predictions for the two modes appear reasonably consistent with around 47% or track settlement damage and 60% of rail damage being attributed to the passenger traffic.

6 Further work

The total maintenance costs resulting from the combination of the two modes included in this work is difficult to establish using engineering methods as there is a strong effect of the levels of intervention to rectify any damage caused. This needs to be further investigated and historical data obtained so that a total figure can be reliably produced.

A further case study using routes in Switzerland was planned during this project and track data has been obtained but due to lack of vehicle data this has not yet been possible. It is intended that this work will be completed in 2009 and will provide useful evidence relating to the effect of different maintenance strategies on the distribution of costs.

There is a tool called VTISM (Vehicle Track Interaction Strategic Model) under development in the UK which includes the engineering methods presented here and also has data relating to historical costs and intervention levels. This tool could potentially provide costs for the combined degradation modes and therefore total maintenance activity although this would be based on UK historical data and therefore UK costs and intervention rules.

7 References

[1] Link, H., Stuhlemmer, A. (DIW Berlin), Haraldsson, M. (VTI), Abrantes, P., Wheat, P., Iwnicki, S., Nash, C., Smith, A., CATRIN (Cost Allocation of TRansport INfrastructure cost), Deliverable D 1, Cost allocation Practices in the European Transport Sector. Funded by Sixth Framework Programme. VTI, Stockholm, March 2008

SIXTH FRAMEWORK PROGRAMME
PRIORITY 1.6.2
Sustainable Surface Transport

CATRIN

Cost Allocation of TRansport INfrastructure cost

D8 – Rail Cost Allocation for Europe

Annex 3A – Estimating the opportunity cost of slots – A case study in Great Britain

Version 1.0
January 2009

Authors:
Daniel Johnson, Richard Connors and Chris Nash (ITS)

Contract no.: 038422
Project Co-ordinator: VTI

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CATRIN Partner Organisations

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CATRIN D8 - Rail Cost Allocation for Europe – Annex 3A – Estimating the opportunity cost of slots – A case study in Great Britain

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Cost Allocation of TRansport INfrastructure cost

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CATRIN D8 - Rail Cost Allocation for Europe – Annex 3A – Estimating the opportunity cost of slots – A case study in Great Britain

Project summary

CATRIN is a Research project to support the European Transport Policy, specifically to assist in the Implementation of Transport pricing. CATRIN will increase the probability that new progressive pricing principles can be implemented which facilitate a move towards sustainable transport. CATRIN is both intermodal and interdisciplinary, emphasizes the need of new Member states, understands that different organisational forms require different recommendations, that recommendations need to be given in short and long-term perspective and that they have to be thoroughly discussed with infrastructure managers.

CATRIN will clarify the current position on allocation of infrastructure cost in all modes of transport. Pricing principles will be dealt with under the knowledge that they varies with the organisational structure of a sector. CATRIN will establish the micro-aspects of cost recover above marginal costs, including the results of applying a club approach and the implication of who bears the costs for cost recovery under alternative allocation rules, using game theoretic analytical tools.

CATRIN will develop the understanding of policy need of new Member states and can give tailored recommendations. In a modal focus, with real world cases, CATRIN will develop proxies to marginal costs and test some of the allocation approaches. Based on engineering studies CATRIN will analyse the possibility to defining more differentiated pricing rules for vehicle/locomotive categories. Partners with strong engineering knowledge are included and CATRIN will blend the economic principles of pricing with engineering knowledge. CATRIN will outline the possibilities for a European Road Damage test that will give new evidences on the fourth-power-rule. CATRIN will develop financing alternatives for icebreaking and will explore cost allocation in the aviation sector. Finally, CATRIN will strongly address the implementation potential and constraints experienced by infrastructure managers

Estimating the opportunity cost of slots

Daniel Johnson, Dr. Richard Connors and Professor Chris Nash
Institute for Transport Studies
University of Leeds

1 Introduction

When there is a shortage of capacity, train operators will fail to take into account the opportunity cost of the slots they demand when planning timetables. Moreover if they are only charged for the wear and tear they actually cause, then they will not be charged for reserving slots they do not use, even if by doing so they prevent other operators from using them. Various solutions to this have been proposed, including auctioning slots or levying reservation charges to reflect this opportunity cost.

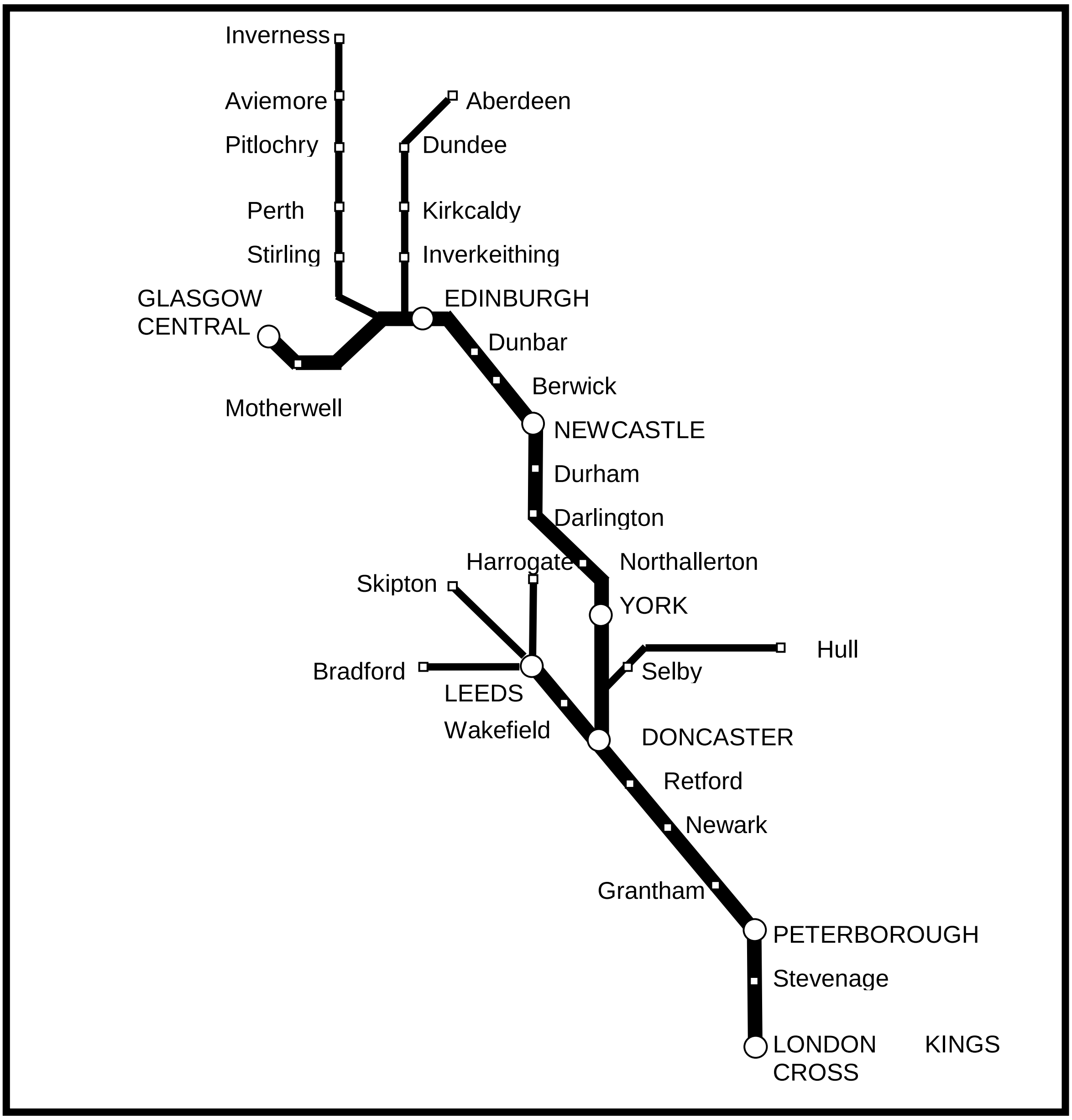
In this case study we focus on identifying the opportunity cost of a number of paths throughout the operating day. Our case study concerns the stretch of the East Coast Main Line from London to Doncaster. The East Coast Main Line forms the principal trunk route from London to Leeds, York, Newcastle and Edinburgh; many trains continue to Glasgow. It is heavily used, particularly between London and Doncaster, which is where the main lines to Leeds, Hull and an important route to Scunthorpe and Grimsby branch off. There is a shortage of capacity over the Peterborough-Doncaster stretch of the route, which is mainly double track with occasional passing loops. Several new open access operators are bidding for slots to operate over this section, whilst expanding freight operations are also seeking additional slots. There are also shortages of capacity south of Peterborough where long distance trains conflict with London commuter trains at junctions, on a double track section over a viaduct and at the London terminal.

Most passenger services over this route are provided by National Express East Coast under a franchise agreement. For the franchised passenger operator, the impact of changing track access charges is neutralized by the fact that, under the franchise agreement, it is simply passed through to the government as a change in subsidy or premium paid. Where capacity charges may play an important part is in reflecting the opportunity cost of the passenger franchise not using these paths. Currently, other operators only pay the variable part of the infrastructure charge and have no incentive to economize in their use of capacity, for instance by changing speeds, time of day or route. Thus, the approach we investigate in this paper is construction of a tariff based on the opportunity cost of the slot to the franchisee. If the open access or freight operator requires capacity that would deprive the franchisee of more than one slot (for instance, because their trains are slower than those of the franchisee), then they would be charged for the appropriate number of slots. Since the franchisee is known and is required to make data available to the regulator, this approach to charging should be feasible. Of course, if there are several other operators competing for the slot and they all have higher values than the franchisee, then this will understate the true opportunity cost of the slot. However, basing charges on the identity of unknown possible new entrants appears difficult, at least until they start operating and data becomes available.

The opportunity cost of a slot for this type of service can be estimated as the sum of:

- the additional amount of traffic attracted to rail by the presence of this train multiplied by the price it pays
- the consumers' surplus to rail users as a result of the additional quality and capacity provided by the train (including reduced crowding on other services)
- the savings of external costs to road users and the public at large from the train attracting passengers from road.
- less the train operating, infrastructure and external cost savings from failing to run this train.

Figure 1: East Coast Mainline route



As the opportunity cost of paths over this section of track will be the value of the paths in the highest value use, this will obviously vary by time of day. So, to develop a tariff for scarce capacity, we should really examine a whole range of uses of paths for a variety of times of day. Earlier work (Johnson and Nash, 2008) was constrained to looking at a handful of services due to the prohibitively large run times involved. Recent developments in the software implementation of the PRAISE model using MATLAB now means the model runs much faster. This allows us to estimate the value of paths throughout the day. We do this by separately removing eleven individual southbound services from Leeds to London to the franchisee and an additional four services from Hull to London. The improved PRAISE model also facilitates the accurate implementation of the impact of overcrowding on the network.

2 Methodology

The value of the passenger slots will be estimated using the PRAISE model. The PRAISE (Privatized Rail Services) model was developed at the Institute for Transport Studies, University of Leeds to look at the potential for open access competition following the privatization of rail services (Whelan *et al*, 1997; Preston *et al*, 1999). More recently, the model has been re-written and developed to be capable of assessing demand and costs for small networks of stations incorporating the services of any number of operators, each with a variety of different ticket types.

PRAISE forecasts demand for individual services and ticket type, taking account of fares, journey times, desired departure times and overcrowding, so it is very useful for looking at issues concerning capacity, detailed timetabling and fares and ticket restrictions, as well as competition between different operators. In this case, it will forecast the extent to which changes in the timetable will lead to changes in rail passenger traffic, taking account of the precise times of the trains affected, the possibility of passengers taking other trains in the timetable or ceasing to use rail at all, and the changes in the fares and levels of crowding passengers face on the different options.

There are four stages to the calibration of the demand model. The first involves the estimation of the generalized cost of travel for each return service and ticket combination. The second involves calibrating ticket specific constants to ensure that the base market shares can be replicated. The third involves setting the sensitivity of the model to replicate known elasticities of demand. The fourth stage iterates to adjust for overcrowding on trains. An upper level of the model scales overall changes in rail demand following service level changes based on generalized journey time elasticities as estimated in the standard British rail demand forecasting model. Ticket and service choices are generated by a multinomial logit model, calibrated to known ticket elasticities and market shares.

For a given individual, the generalised cost of each option is given as:

$$GC_n = F_n + (vot * GJT_n) + (vapr * APR) + CP + ASC_t \qquad (1)$$

where:

F	is the return fare
GJT	is the return service generalised journey time (minutes)

vot	is the behavioural value of time (pence per minute)
APR	is advanced purchase requirement (days)
vapr	is the value of advanced purchase requirement (pence per day)
CP	is a return service crowding penalty (pence)
ASC	is an operator specific Alternative Specific Constant for ticket t

The generalised journey time is expressed as:

$$\mathrm{GJT}_n = \mathrm{IVT}_n + \left(\frac{\mathrm{vat}}{\mathrm{vot}} * \mathrm{AT}_n\right) + \mathrm{IP}_n + \left(2 * \mathrm{OVT}_n\right) \qquad (2)$$

where:

IVT	is in-vehicle time on both legs of the journey (minutes)
vat	is the behavioural value of adjustment time (pence per minute)
AT	is adjustment time on both legs of the journey (minutes)
IP	is the interchange penalty on both legs of the journey (minutes)
OVT	is out of vehicle time on both legs of the journey (minutes)

The first 3 stages are described in detail in earlier work for the GRACE project and published in Johnson and Nash (2008), so it is not our intention to layout the detail of the model here.

The treatment of crowding here is worthy of more discussion. Passengers on overcrowded trains will typically experience discomfort associated with having to stand or sit in cramped conditions. The level of crowding, LOC = 100*X/C, where X is the number of passengers on the train having capacity C. The LOC is computed separately for first and standard class. C is constant for a given train, while X may change at any station where the train stops. Therefore, the per minute crowding cost experienced by an individual passenger may change (i) when the passenger changes trains, and (ii) when the train stops at a station allowing X to change.

When the passenger flows throughout the network are known, the occupancy and hence LOC is computed for each train for each of its node-to-node movements. The crowding costs experienced by passengers are then computed (by OD movement) for each journey in turn. For each node-to-node leg the additional crowding cost is CP(LOC)*travelTime, with CP the per minute crowding penalty as a function of the level of crowding, LOC first/standard class and London-weighted. In this way we compute a total crowding cost experienced on each journey for each OD movement in the network.

The overcrowding penalties used are calculated in accordance with the Passenger Demand Forecasting Handbook (PDFH) and are based on load factor and flow types as shown in Table 1.

Table 1: Overcrowding penalties (pence per minute)

Load Factor	Sit London	Sit Non-London	Stand London	Stand Non-London	Average London	Average Non-London
50%	0.00	0.00	0.00	0.00	0	0
60%	0.00	0.00	0.00	0.00	0	0
70%	0.46	0.19	0.00	0.00	0.46	0.19
80%	0.90	0.36	0.00	0.00	0.9	0.36
90%	1.78	0.63	0.00	0.00	1.78	0.63
100%	2.83	0.90	50.26	23.87	2.83	0.9
110%	3.91	1.39	55.11	24.51	8.56	3.49
120%	4.99	1.88	59.95	25.15	14.15	5.76
130%	6.07	2.37	64.80	25.79	19.62	7.77
140%	7.16	2.86	69.64	26.43	25.01	9.59
150%	8.24	3.35	74.49	27.07	30.32	11.26
160%	9.32	3.84	79.33	27.71	35.57	12.79

As we do not know whether individuals are sitting or standing we calculate an average crowding penalty (CP), shown in the last two columns of Table 1, using the following formula:

$$CP = (\text{Prob.of Sitting} * \text{Sit Penalty}) + (\text{Prob.of Standing} * \text{Stand Penalty}) \qquad (3)$$

Penalties based on factors between those given in Table 1 are interpolated. The maximum value is set for load factors of 160% based on observed loadings. However in our modelling, initial load factors could potentially be higher, so we used a penalty of 1000p per minute for any factors above 160 to ensure crowding never got above this level.

As an example calculation, imagine an individual boards at Station A, where the train is 70% full. The journey lasts for 25 minutes until it gets to Station B. At Station B more people board than alight, increasing the load factor to 120% for 15 minutes until the train gets to Station C. Here more people get off, so the load factor drops to 90% from Station C to Station D for further 20 minutes. The overcrowding penalty for this journey for this individual is therefore:

$$(25*0.46) + (15*14.15) + (20*1.78) = 259.35 \qquad (4)$$

The cost model employs a cost accounting approach incorporating costs that are related to operating hours, costs that are related to train kilometers and fixed costs. Costs can be varied by operator and rolling stock type based on figures from the Rail Industry Monitor (TAS,

2004) and can be combined with estimates of revenue to generate forecasts of operator profitability. More detail on this is provided in Johnson and Nash (2008).

PRAISE yields results for changes in consumer surplus, operating profits, modal switch values and vehicle kilometers, which can be used in conjunction with external cost valuations to undertake an appraisal. These external costs comprise those imposed by rail itself, and those imposed by other modes of transport whose volumes are changes by the change in rail frequencies. For external costs and benefits of other modes of transport, we use values from the study of Sansom *et al* (2001). To apply these values, we need to know how much traffic transfers to or from road and the types of road and time of day in question. This is covered in detail in Johnson and Nash (2008) and not replicated here.

The change in rail passenger trips can be used to calculate the modal shift between rail, car, coach and not travel or new journeys. An integral part of these calculations are the application of diversion factors to the change in passenger trips.

Using diversion factors based on Train Operating Company Figures from 1998, this information is used to calculate a number of the impacts outlined in the appraisal framework.

We looked at the effect of removal of eleven passenger trains throughout the day. These are listed in Table 2 and results are presented in Table 3.

Table 2: Scenarios

Scenario	Departure time	Operator	Comments
1	5:05	Franchisee	
2	6:05	Franchisee	
3	7:00	Franchisee	
4	8:05	Franchisee	First train to accept Business Saver tickets
5	9:05	Franchisee	First train to accept Saver tickets
6	10:05	Franchisee	
7	12:05	Franchisee	
8	14:05	Franchisee	
9	15:05	Franchisee	
10	16:05	Franchisee	
11	17:05	Franchisee	

3 Results

Table 3: Changes in passenger kms, external costs, operator profits and opportunity cost based on the removal of franchisee operated services throughout the day (£).

		505	605	700	805	905	1005	1205	1405	1505	1605	1705
Change in Train passenger kms		-6456	-9227	-5150	-15044	-14470	-12383	-2548	-1196	-2231	-1933	-562
Chage in car pass kms		4358	6228	3476	10154	9768	8359	1720	807	1506	1305	379
Change in buss pass kms		1459	2085	1164	3400	3270	2799	576	270	504	437	127
Change in Train vkms		-300	-300	-300	-300	-300	-300	-300	-300	-300	-300	-300
Change in car vkms		2724	3893	2173	6347	6105	5224	1075	504	941	816	237
Change in bus vkms		121	172	96	281	270	231	48	22	42	36	10
Environmental Cost												
Noise	Rail	40	40	40	40	40	40	40	40	40	40	40
	Car	-8	-11	-6	-18	-18	-15	-3	-1	-3	-2	-1
	Coach	-3	-4	-2	-6	-6	-5	-1	-1	-1	-1	0
LAQ	Rail	0	0	0	0	0	0	0	0	0	0	0
	Car	-16	-22	-12	-37	-35	-30	-6	-3	-5	-5	-1
	Coach	-12	-17	-10	-28	-27	-23	-5	-2	-4	-4	-1
Green house gase	Rail	22	22	22	22	22	22	22	22	22	22	22
	Car	-9	-12	-7	-20	-20	-17	-3	-2	-3	-3	-1
	Coach	-2	-3	-1	-4	-4	-4	-1	0	-1	-1	0
Safety	Rail	0	0	0	0	0	0	0	0	0	0	0
	Car	-32	-46	-26	-75	-72	-62	-13	-6	-11	-10	-3
	Coach	-7	-10	-5	-16	-15	-13	-3	-1	-2	-2	-1
Infrastructure Cost												
	Car	-2	-3	-1	-4	-4	-3	-1	0	-1	-1	0
	Coach	-8	-11	-6	-18	-18	-15	-3	-1	-3	-2	-1
Tax Revenues												
	Rail	307	275	150	280	251	45	-168	-119	-112	-88	-50
	Car	114	163	91	266	256	219	45	21	39	34	10
	Coach	-11	-16	-9	-27	-26	-22	-5	-2	-4	-3	-1
User Benefits												
CS	Rail	-1599	-2181	-866	-2942	-3288	-2283	-414	8	-408	-358	-140
Congestion	Car	-287	-410	-229	-669	-643	-551	-113	-53	-99	-86	-25
	Coach	-22	-31	-17	-51	-49	-42	-9	-4	-8	-7	-2
Mohring	Coach	19	27	15	45	43	37	8	4	7	6	2
Profits	Rail											
	Franchisee	-953	-823	432	-756	852	-296	1810	1131	1880	1620	1483
	Open access opera	68	73	-3	8	2	404	384	1	-5	155	43
	Others	525	572	104	538	-896	1029	157	937	158	120	153
	Coach	47	67	38	110	106	91	19	9	16	14	4
Total Welfare Change		-1829	-2361	-310	-3363	-3550	-1495	1738	1977	1492	1440	1529
Opportunity cost of slot		1829	2361	310	3363	3550	1495	-1738	-1977	-1492	-1440	-1529

The removal of individual services reduces patronage, increasing adjustment costs and making existing services more overcrowded, leading to a reduction in consumer surplus, and reduces train operating costs.

It will be seen that the opportunity cost of slot varies as would be expected from around -£1400 during the daytime inter peak period to £1500 in the shoulders of the peak and £3500 in the peak. This could readily form the basis of a tariff of reservation charges by time of day. A more serious issue is that the revenue to the train operator substantially understates the social benefits of the services. Assuming this is also the case for the bidders for the paths, for capacity charges to have the correct incentive effects, subsidies would need to be given to operators to reflect these external benefits.

Whilst we are confident the overall pattern of our results do offer useful indicative values of opportunity cost of slots throughout the day, there were many issues we encountered which may affect the accuracy of our findings.

- The inclusion of overcrowding generates many complexities in the modeling, as we have to track the numbers of people on each train at each station, following individuals on their journeys as they interchange at different stations. The overcrowding introduces interdependencies between different origin-destination pairs. Following the removal of a Leeds-London service, there is a change in train loadings between Leeds and London. This will have a knock-on indirect effect on the crowding and, through the change in the crowding penalty, the demand for other OD pairs on our network, even if the removed train does not form any journey opportunity for the other OD pairs.

- We have based our modeling on GJT and ticket elasticities for which we have had to use 'off-the-peg' values from the PDFH and these values may not be a particularly accurate reflection the true elasticities on services on ECML.

- Estimation of overcrowding penalties is a particularly difficult task, and the values we have used, which are not bespoke for the ECML may not be accurate.

- Also, we have used departure time profiles which again are approximate in nature and not specifically taken from observations on ECML.

- Our results are further complicated by the ticket restrictions operating in the peak on the reduced fare tickets. The removal of 9:05 or 8:05 services from Leeds to London will have the effect of moving some of the captive travellers onto more expensive (unrestricted) tickets.

- The removal of a slot would have a secondary impact on demand through the disruption of the regular interval and clock-faced nature of the timetable which we are not equipped to capture here, (see Johnson et al 2006).

- Our demand figures are based on the most recent data we have available from 2002 and since then there has been a large increase in passenger demand on the ECML.

- The calculation of changes in the upper level of the model (ie overall rail demand) and consumer surplus is based on a probability weighted average of Generalised Cost. In some situations this offers no guarantee that GC will rise following a service cut, if it increases the probability of getting better services than the one which has been removed. As a consequence, for some ODs we have seen very small increases in demand, (which may be partially explained through the nuances of overcrowding treatment on some services), and also an increase in consumer surplus, (eg on the 14:05), which is counterintuitive.

It is clear that the model is very sensitive to the input values used. A more accurate modelling could be undertaken only in conjunction with a large data collection exercise in order to gather bespoke data on departure times, elasticities and indeed costs for the case study in question.

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CATRIN -- Cost Allocation of TRansport INfrastructure cost

SIXTH FRAMEWORK PROGRAMME
PRIORITY 1.6.2
Sustainable Surface Transport

CATRIN

Cost Allocation of TRansport INfrastructure cost

D8 – Rail Cost Allocation for Europe

Annex 3B – Avoidable cost: Case study for Great Britain

Version 2.0
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Authors:
Phill Wheat and Chris Nash (ITS)

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Project summary

CATRIN is a Research project to support the European Transport Policy, specifically to assist in the Implementation of Transport pricing. CATRIN will increase the probability that new progressive pricing principles can be implemented which facilitate a move towards sustainable transport. CATRIN is both intermodal and interdisciplinary, emphasize the need of new Member states, understands that different organisational forms require different recommendations, that recommendations need to be given in short and long-term perspective and that they have to be thoroughly discussed with infrastructure managers.

CATRIN will clarify the current position on allocation of infrastructure cost in all modes of transport. Pricing principles will be dealt with under the knowledge that they varies with the organisational structure of a sector. CATRIN will establish the micro-aspects of cost recover above marginal costs, including the results of applying a club approach and the implication of who bears the costs for cost recovery under alternative allocation rules, using game theoretic analytical tools.

CATRIN will develop the understanding of policy need of new Member states and can give tailored recommendations. In a modal focus, with real world cases, CATRIN will develop proxies to marginal costs and test some of the allocation approaches. Based on engineering studies CATRIN will analyse the possibility to defining more differentiated pricing rules for vehicle/locomotive categories. Partners with strong engineering knowledge are included and CATRIN will blend the economic principles of pricing with engineering knowledge. CATRIN will outline the possibilities for a European Road Damage test that will give new evidences on the fourth-power-rule. CATRIN will develop financing alternatives for icebreaking and will explore cost allocation in the aviation sector. Finally, CATRIN will strongly address the implementation potential and constraints experienced by infrastructure managers

1 Introduction

The aim of this annex is to explain the economic rational for and discuss an application of the avoidable cost approach to allocating the costs of capacity. The term avoidable cost refers to the cost saving from discontinuing provision of a service or set of services. We discuss how this approach differs from short-run marginal cost and how incorporating these principles into pricing structures can recover a greater proportion of infrastructure total cost than relying on short-run marginal cost alone.

The avoidable cost approach is not relevant to the determination of appropriate charges to incentivise train operating companies to plan time tables which make the best use of existing capacity. That is the role of short run marginal social cost pricing. Rather avoidable costing is appropriate to long term planning, for instance where train operators enter into long term framework agreements with infrastructure managers which guarantee them a certain amount of capacity, although not particular slots. This may be associated with long term franchises. In such circumstances, appropriate incentives for the long term planning of and investment in train operations will be given by charging the train operator the avoidable cost of the capacity reserved for it, preferably as a fixed charge over the life of the agreement.

Our application is a study undertaken by the Office for Rail Regulation in Great Britain in 2005. While this has approach has not been fully adopted in the latest charging review in Great Britain, the study does provide a useful demonstration of the approach. It found that approximately 70% of infrastructure maintenance and renewals cost could be recouped through charging via avoidable cost whereas the work in CATRIN suggests that approximately 20-30% would be recovered through marginal cost pricing alone..

The annex is structured as follows. Section 2 reviews the economic principles of avoidable cost and Section 3 reviews the study in Great Britain. Finally Section 4 sets out further research issues.

2 Principles of the avoidable cost approach

In this section we review the economic principles of avoidable cost. We define avoidable cost as “the costs saved by discontinuing a service or set of services”. Of course assumptions have to be made about whether the other services sharing assets with the services in question will still be running or not. It is useful to relate avoidable costing to the concept of short-run marginal cost. This is defined as “the cost change resulting in a small (marginal) change in traffic holding the rail infrastructure fixed”. Avoidable cost differs from short-run marginal cost in two ways:

1. Avoidable cost generally considers a step change as opposed to a marginal change in service provision;
2. Avoidable cost is a long run concept, that is there is an allowance for the infrastructure to be adjusted following discontinuation of a service or set of services.

The avoidable cost principle is therefore useful in allocation of costs to different groups of services. For example, these maybe intercity versus regional versus commuter passenger service groups, or passenger versus freight. Implementing an avoidable cost approach for these groupings would charge each group the cost saving from the removal of the whole service group from the network, including the saving from removing any redundant infrastructure.

Several features of avoidable cost approach should be noted:

- The cost recovery from this approach may be less than 100% - This is because there are likely to be joint costs between service groups. This possibility is more likely the greater the number of service groups considered, since with more groups, the removal of one is unlikely to result in substantial infrastructure provision savings;
- However the cost recovery from this approach could be more than 100% - This is perhaps unlikely but still possible. It arises where removal of either service group (in isolation) results in a large infrastructure saving and thus the same saving is allocated to multiple service groups. It is possible that this could mean that more than 100% of cost is recovered. This situation is more likely to arise the smaller the number of service groups are considered, as this increases the scope for large infrastructure savings from removal of each group.

It should be clear that this approach is not a substitute for short-run marginal cost pricing. Instead it can be used to allocate (part) of the remaining fixed costs to service groups using economic principles as opposed to arbitrary allocation mechanisms. Indeed to implement this approach, marginal cost pricing should be maintained, with an additional charge for each service group (set as the difference between determined avoidable cost and expect marginal cost charges for each service group). This additional charge would not be usage related, but would be reviewed when the framework agreement was renegotiated.

Such a charging approach incentivises operators and the infrastructure manager to make efficient choices for train services in the long run as well as recovering an element of fixed cost in an efficient and transparent way. The avoidable cost information would also be useful to funders who would be able to see the likely cost savings from removal of certain services from the network.

We consider there to be the following stages in determining avoidable cost:

1. Define service groups - these should relate to the organisational structure of the railway system. For example, in the British study the service groups were individual train operating companies;
2. Define the cost base to apply the analysis to – this should be broad enough to capture any future renewals savings from discontinuing provision of some infrastructure and of a sufficiently long time horizon since cost savings will be differ from year to year (for example because of lumpy renewals)
3. Determination of what metrics drive each element of cost;
4. Determination of the proportion of each cost category that is variable with each metric;
5. Determination of how each metric changes with the removal of each service group;
6. Compute the difference in net present value terms of the cost saving from removing the service relative to the base scenario

By metric we mean a measure which determines the level of a cost category. For example signalling renewal costs will be partly determined by the number of signalling units on a particular section of the network, since there are obviously less signalling units to renew should some be removed following removal of a service group.

The above modelling approach has many stages, some of which require analysis at very detailed geographic levels, could involve many separate models and these could possibly rely heavily on judgement. To an extent the business planning models developed by infrastructure managers should be able to inform these stages. These include the Infrastructure Cost Model developed by Network Rail which relates asset and traffic databases to profiles of future costs through application of maintenance and renewal policy rules.

3 Case study: Great Britain

As part of the 2005 Structures of Costs and Charges Review, the Office of Rail Regulation commissioned AEA Technology to undertake a study on avoidable cost for the Great British rail network. They specified that they wanted the service groups to be the franchised train operating companies (TOCs) that comprise the core passenger network in Great Britain. ORR was interested in whether the pre-existing formula to allocate fixed charges between TOCs could be reformed to be more cost reflective.

Here we review the consultants report (AEA technology, 2005). The consultants undertook the study using the methodology outlined in section 2. The study considered how operations, maintenance and renewal costs would be effected by removal of each TOC. Within these high level cost categories, 75 individual cost categories were identified; for instance track renewals, track maintenance, signalling staff costs and signalling and telecoms renewals and maintenance.

The study identified the following metrics as drivers of each cost element:
- Route-km
- Track-km
- Equated track-km – a measure of track-km standardised to reflect differences in infrastructure characteristics and traffic characteristics
- Signalling Equivalent Units (SEUs) – a measure of the number of signalling elements present weighted by complexity
- Train-km
- Electrified track-km
- Electrified train-km

This choice of metrics was motivated both from the perspective of being true cost drivers but also, from a practical perspective, their availability for the study.

For each cost element a proportion variability with respect to each metric was identified. The sum of the variability proportions across all metrics for each cost category was not necessarily equal to 100% since there was allowance for a degree of non variable costs for some expenditure elements.

The variability proportions were determined through a mixture of engineering judgement and statistical analysis. The overall split between metrics is shown in Table 1.

Table 1 Proportion of total budget allocated to each cost driver metric

OUT OF SCOPE	Avoidable route km	Avoidable track km	Avoidable equated track km	Avoidable equated PLAIN track km	Avoidable equated S&C track km	Avoidable SEUs	Train km	Avoidable electrified track km	Common cost proportion
6%	6%	6%	14%	11%	5%	23%	3%	2%	22%

Source: Based on ITS calculations from the model underlying the AEA Technology report

An example is track maintenance which is assumed 100% variable with equated track-km. While this does have some merit (the less track, the less maintenance is needed), we note that this implicitly imposes constant economies of scale on the relationship, for which there is evidence against (for example see Table 2).

Track renewal was broken down into two parts: switches and crossing (S&C) renewal (assumed 100% variable with S&C track-km) and plain line renewal (assumed 100% variable with plain line track-km). Again this implicitly assumed constant economies of scale for which there is some evidence against (see again Table 2).

Table 2 Estimates of returns to track length from Railway infrastructure econometric studies

Study (maintenance costs only except where stated)	**Country**	**Elasticity of cost with respect to track length**	**Returns to track length**
Johansson and Nilsson (2004)	Sweden	0.796	1.256
Johansson and Nilsson (2004)	Finland	0.635	1.575
Tervonen and Idstrom (2004)	Finland	0.755[1]	1.325
Munduch et al (2002)	Austria	0.617 main lines, 0.690 secondary lines	1.621, 1.449
Tervonen and Idstrom (2004) (maintenance and renewals)	Finland	0.938[2]	1.066

For other elements of cost, there was little evidence produced to support the allocation of proportions to metrics and so it is assumed that this relied heavily on judgement. An overall comment is that this part of the approach relied on judgement or simplistic analysis. However this is not a limitation of the methodology, but rather the limited scope of this specific study.

Following allocating metrics to each cost category, it was then necessary to determine how each metric changed following removal of each TOC. For some metrics this could be done precisely. For example, for train-km, electrified train-km and tonne-km, this was determined with reference to a traffic database. However for other metrics determination utilised simple statistical models or judgement. We discuss some examples below.

---

[1] Average of 2000, 2001 and 2002 values

[2] Average of 2000, 2001 and 2002 values

For example the quantity of switches and crossings (S&C) was modelled through a statistical analysis of S&C density against the average number of running lines and train density. The estimated equation is given below:

$$\begin{aligned}\text{S\&C per route km} = {} & 0.014293706 * (\text{Track km per route km})^{\wedge 2} \\ & + 0.000000980868 * \text{Train km per route km} \\ & - 0.01451534\end{aligned}$$

We note that this model is simplistic in that it models switch density with only two variables while in fact there many other possible variables (such as measures of traffic mix) which could improve such modelling.

The change in SEUs was also determined by an estimated statistical relationship.

The equated plain line track km, equated train-km, equated train-km, track km, electrified track km were determined by professional judgement:

“Professional judgement was then applied on each of the 4314 sections in turn to determine whether the number of running lines could be reduced be reduced if each TOC in turn were removed from the network.” (AEA Technology, 2005 P.14)

This process may be highly subjective and given the large number of sections to consider there may be issues with quality control. Perhaps an alternative based on statistical analysis of the relationships between track-km per route km and the number and mix types of train, or an examination of alternative timetables could be employed. Although Network Rail does use a Capacity Utilisation Index which provides an objective benchmark, it should be highlighted that the index itself may be misleading, overstating potential capacity if there are many types of traffic and a high value on regular (e.g. clock face) time tabling.

There is no doubt that both the process of determining what metrics drive costs (and by what proportion) and the process of determining how these metrics change following removal of services can be improved upon. However, this study has demonstrated that the avoidable cost approach can be applied to a relatively large network.

It is found that approximately 70% of total costs can be allocated to TOCs via the avoidable cost principle. For charging purposes it would be necessary to reduce this charge for each TOC by the amount of variable access charges that the TOC is expected to pay in a given year. The remaining 30% of cost not allocated to specific train operators could either be paid directly to the infrastructure manager via a lump sum subsidy or recovered from operators using some kind of Ramsey rule. If the latter approach is adopted there should be clear distinction between what elements of the charge are variable (short run marginal cost) access charges, which are the remaining avoidable cost charge and which are the contribution to the remainder. This is to avoid blurring of the otherwise clear information to funders.

4 Summary and further research

This case study has demonstrated a method of allocating a substantial proportion of the fixed costs of rail infrastructure to individual train in a transparent and efficient way. These costs are the long run avoidable costs which would be saved if the services of this operator did not exist. It is not appropriate to add these costs to the charges for actual train km run, as this would give incentives to make less than optimal use of the existing infrastructure. Rather these costs, over and above those covered by short run marginal cost pricing, are best levied as a fixed charge, set when a long run framework agreement assuring the operator a certain amount of capacity is agreed, and modified when that framework agreement is renegotiated. The result is to provide valuable information to influence the long run planning of and investment in the train service, by the train operator or – in the case of subsidised services – the funding authority.

We have shown from examination of a British case study that the approach is feasible, although as currently applied it rests heavily on many assumptions and professional judgement. There is therefore a need for more research to examine the relationship between the train service provided and the assets required, and the cost implications of changes in those assets.

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SIXTH FRAMEWORK PROGRAMME
PRIORITY 1.6.2
Sustainable Surface Transport

CATRIN

Cost Allocation of TRansport INfrastructure cost

D8 – Rail Cost Allocation for Europe

Annex 3C – Allocation of Capacity Costs: The RFI Approach

Version 1.0
February 2009

Authors:
Riccardo Enei, Giovanna Giuffrè (ISIS)

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VTI; University of Gdansk, ITS Leeds, DIW, Ecoplan, Manchester Metropolitan University, TUV Vienna University of Technology, EIT University of Las Palmas; Swedish Maritime Administration, University of Turku/Centre for Maritime Studies; ISIS Institute of Studies for the Integration of Systems

CATRIN D8 - Rail Cost Allocation for Europe – Annex 3C – Allocation of Capacity Costs: The RFI Approach

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Project summary

CATRIN is a Research project to support the European Transport Policy, specifically to assist in the Implementation of Transport pricing. CATRIN will increase the probability that new progressive pricing principles can be implemented which facilitate a move towards sustainable transport. CATRIN is both intermodal and interdisciplinary, emphasize the need of new Member states, understands that different organisational forms require different recommendations, that recommendations need to be given in short and long-term perspective and that they have to be thoroughly discussed with infrastructure managers.

CATRIN will clarify the current position on allocation of infrastructure cost in all modes of transport. Pricing principles will be dealt with under the knowledge that they varies with the organisational structure of a sector. CATRIN will establish the micro-aspects of cost recover above marginal costs, including the results of applying a club approach and the implication of who bears the costs for cost recovery under alternative allocation rules, using game theoretic analytical tools.

CATRIN will develop the understanding of policy need of new Member states and can give tailored recommendations. In a modal focus, with real world cases, CATRIN will develop proxies to marginal costs and test some of the allocation approaches. Based on engineering studies CATRIN will analyse the possibility to defining more differentiated pricing rules for vehicle/locomotive categories. Partners with strong engineering knowledge are included and CATRIN will blend the economic principles of pricing with engineering knowledge. CATRIN will outline the possibilities for a European Road Damage test that will give new evidences on the fourth-power-rule. CATRIN will develop financing alternatives for icebreaking and will explore cost allocation in the aviation sector. Finally, CATRIN will strongly address the implementation potential and constraints experienced by infrastructure managers.

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EXECUTIVE SUMMARY

The structure of the charge for the use of rail infrastructure in Italy is composed of a fixed and a variable part, differentiated according to their application on a trunk line (main line) or a secondary line.

The fixed part addresses the quality of the line, i.e. the number of tracks, the average speed allowed and the general equipment of the infrastructure. This part, of which the table below shows the amount by each cost item, is independent from the traffic intensity and the capacity of the line.

Line category (Trunk line)	
Double track *(Max Speed 250km/h)*	64,56 €/section
Double track *(Max speed 200km/h)*	56,81 €/section
Double track *(Max Speed<200 km/h)*	54,23 €/section
Single track	49,06 €/section

Nodes	51,65 €/node
Secondary lines	46,48 €
Little used lines	0,00

The variable part addresses the capacity of the line and depends on a set of parameter as wear and tear, traffic demand (density) and inefficient use of capacity (through the speed of the train).

There are two types of capacity charge.

Firstly a charge per kilometre on the trunk line sections, differentiated by:

1. Speed relative to the option for the type of section and time of day
2. Traffic density, each section is allocated to a category varying by time of day.

Option speeds vary between 40 km p.h. for day time use of a metropolitan line and 170 km p.h. for day time use of a 250 km p.h. line. A speed difference of up to 20% leads to no surcharge; 20-50% a 30% surcharge; 50-100% a 200% surcharge and above that the surcharge is 400%.

Traffic densities are grouped into 3 categories; below 50% of capacity, 50-75% and above 75%. There is a 70% reduction for the first category and a 50% surcharge for the last.

Secondly, there is a charge per minute for time spent in key nodal sections.

These charges are differentiated by time of day, with a 20% discount for night time and 30% surcharge in the morning peak. For the five main stations (Torino, Milano, Firenze, Roma, Napoli), the charges are multiplied by 4.

Furthermore, the variable part of the charge also include parameters for taking into account wear and tear, with particular reference to electric wires damages (through the use of pantographs) and tracks.

It is important to stress that the costs allocated according to these criteria, are not estimated congestion, scarcity and wear and tear costs, but rather they are traffic management plus salary costs. Maintenance costs and renewal are funded by State budget, as shown in the table below, and therefore not paid directly by the rail operators.

Infrastructure charges cover the following costs:	Wholly	Partly	No	If the column "partly" or "no" is ticked indicate who covers the remainder
Traffic management	X			
Maintenance			X	State budget
Renewals			X	State budget
Investments			X	State budget
Infrastructure manager's salary costs and pension liabilities only		X		State budget
Accidents			X	-
Pollution			X	-
Other (specify):				

Summing up, the RFI approach for supporting the efficient use of rail infrastructure arises from the combination of three main parameters, determining the order of magnitude of the variable part of the rail charge:

a) density (a proxy of the congestion);
b) speed (measured as the difference between the speed of the train in question and the speed deemed optimal for the route in question)
c) wear and tear.

Scarcity is addressed through the imposition of higher charges to the extent that the route is more congested and the average speed of the train higher than the optimal speed of the line (distinguished by night time – 22.00-6.00; semi-peak hour – 9.00-22-00; and peak hour – 6.00-9.00).

A similar approach is assumed for supporting the efficient use of the most congested nodes, charging higher the time (in minutes) spent in congested nodes and in particular when the train is using the node during the peak hour.

1 INTRODUCTION: THE INSTITUTIONAL FRAMEWORK

This chapter describes the key aspects of the Italian railway liberalisation process in order to identify the institutions involved and the legislations adopted for the determination the rail access charge.

The first[1] and the second[2] railway Package have been implemented into the Italian legislation while the Directive 2007/58 and 2007/59 of the Third Railway Package are listed in the Community law for 2008[3].

The first step of the railway reorganisation started in 1992 with the transformation of the public body 'Ente Ferrovie dello Stato' into the join stock company ' Ferrovie dello stato (FS), owned by the Ministry of Economy and Finance. Then, between the years 2000- 2001, from the FS Holding, renamed FS S.p.a, two daughters companies have been created :

1. "Rete Ferroviaria Italiana Spa (RFI)[4] which has assumed the role of Infrustructure Manager (IM) and holds the concession for designing, constructing and maintaining the national railway industry, including passages stations, modal and intermodal freight systems, management of safety and control system. The relation between the RFI and the Ministry of Transport and Infrastructure is regulated by a 'Concession Agreement', valid up to the year 2060, and a 'Framework Agreement', renewed every five years, setting, among others things, the investments for ordinary and extra-ordinary maintenance.

2. Trenitalia which is the main Railway Undertakings (RU) carrying out the railway business and, at the moment, is the only operator which has licence to operate passengers transport on a national level.

FS S.p.a. has maintained the role of management, finance and governance direction.

The Ministry of Infrastructure and Transport, through its Railway Control Service Office, controls the management of the railway infrastructure management. In particular:

- It is competent to grant licences to railway operators that provide national passenger and freight service;

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[1] The Directive n. 91/440 was implemented in Italy by Presidential Decree n.277 of the 8th of July 1998. The Directive 95/18, 95/19 were implemented in Italy by the Presidential Decree n.146 of the 16th of March 1999.
The Directives n. 2001/12, 2001/13, 2001/14 were implemented by the Legislative Decree n.188 of the 8th July 2003 (Railway Act) which consolidates the previous legislations and repeals almost entirely the Decrees n.277/98 and n.146/99. On a number of issues, the law provides for implementing ministerial Decree and for the access charge refers to already adopted ministerial decree.

[2] The Directives 2004/51 and 2004/49 were implemented by the Legislative Decree n.162/2007

[3] However, it should be stressed that some remarks about the lack of a full implementation of the First Railway Package has been raised by the EC on June 2008 to 24 Member States. As far as Italy is concerned, the remarks concern the insufficient power and independence of the regulatory body

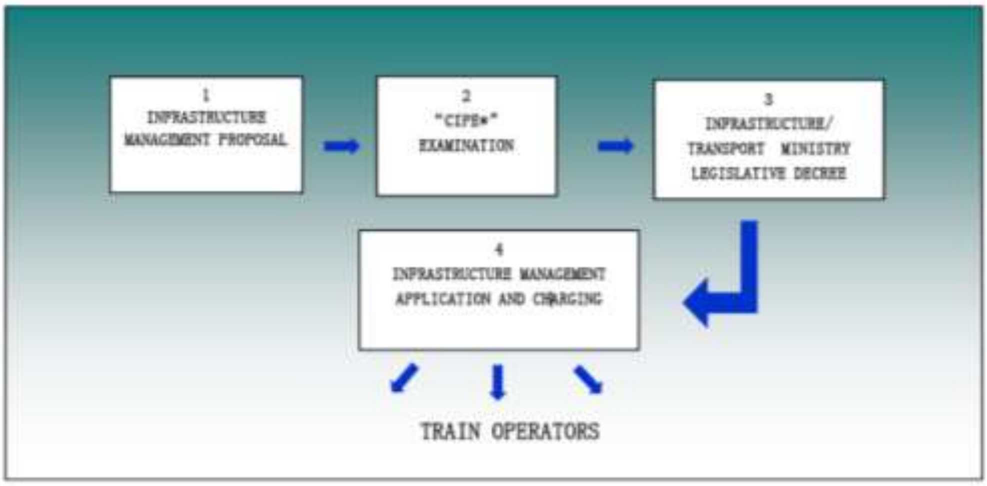
[4] Decree of the Ministry of Infrastructure and Transport, 31 October 2000 n.138T.

- It is competent, in consultation with RFI and CIPE (Inter-ministerial Committee for Economic Planning) to set and review the charge to be paid by railway undertakings.

The CIPE is the public body responsible for drafting strategic policy and drafting guidelines for all public authorities with regulatory functions in the public service sector. It evaluates the charging system to access to national infrastructure and approves the investment projects.

As described in the figure below, the institutional framework for the determination of the rail infrastructure usage charge (or access charge) is characterised by the Resolution of CIPE, based on a proposal advanced by the IM, and followed by the approval of a Decree of the Ministry of Infrastructure and Transport.

Figure 1: The institutional process for the determination of rail infrastructure charge



The following chapters analyse the principles for charging determination (chapter 2) and charging calculation (chapter 3) , as determined by the following acts:

- The CIPE Resolution n.180 of the 5th November 1999
- The Decree of the Ministry of Transport *'Determination of the criteria for calculating the access charge of the rail infrastructure'* n.44 of the 21st March 2000 (hereafter the Decree)

It's important to stress that this regulative framework and the charging system described in the following chapters related only to national passengers and freights transports.

A specific discipline in fact regulates the railway operators providing urban, suburban and regional transport[5]. Since 2001, the reform of the Italian constitution has attributed the competence for regulating local transport to the exclusive legislative competence to

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[5] The law n.422/1997 of the 19 November 1997

the Regional level[6]. Thus, on the basis of a Programme Agreement with the Ministry of Infrastructure and Transport, the Regions have replaced the central government in granting concessions to manage the regional railways.

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[6] Constitutional Law n.3 of the 8th of October 2001.

2 THE CHARGING PRINCIPLES

On the basis of the Infrastructure Manager Proposal, the Inter-ministerial Committee for Economic Planning (CIPE) defined the charging principles and the guidelines for their application through the approval of the Resolution n.180 of the 5th November 1999.

The Resolution established that the access charge shall be based on the 'usage/running cost', aiming at covering only the costs arising directly from the train movement, such as:

a) Costs related to traffic management (specified below);
b) Salary costs.

Is particular network sections characterised by technological constraints implying additional costs to the RU, e.g. the need of a second driver, speed limits, stops, delays, etc, the 'usage/running costs' considered for calculating the access charges are not the actual costs, but those estimated as if the network were efficiently managed. The extra costs due to unsatisfactory technological development of the network are funded temporarily by the State either by financing directly the extra cost to the IM or by recognising a discount on the access charges to the RU (the so called discounts K1/K2)[7].

The charges are based on the general conditions of the rail network; e.g. the average state of the type of lines and tracks, and not with reference to specific portions of the network or to individual lines (the so called 'network solidarity')

Through the 'Framework Agreement', the State funds the others costs including:

a) Ordinary and extraordinary maintenance,
b) Renewal
c) Investment

The Framework Agreement regulates the relationships between the States and the Infrastructure Manager, defining targets at economic level and balancing revenue and expenditures.

In October 2007, a new Framework Agreement has been signed between the Ministry of Infrastructure and RFI for the period 2007-2011. Over this period, the value of the on going infrastructures works is expected to be € 75 billions. The value of priority investments, for the same period, is € 32 billions.

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[7] DM 44/T of 22.3.2000 and DM 92/T of 11.7.2007 established the temporary discount to partially compensate the higher costs incurred for the technological underdevelopment of the railway sector.

The type of services that the IM shall supplies to the RU were firstly drafted in the Resolution 180 and then detailed in the L. D.188/03[8]. The **minimum access package** includes:

a) The use of running track points, connecting tracks and use of the electrical power supply system for the traction electricity, if available;
b) The control and regulation of train traffic, signalling and train routing and communication of all information on traffic;
c) Any other information needed for performing or managing the service for which the capacity has been granted.
d) The use of allocated capacity as the access to the lines and infrastructures for the time established on the ‘ general contract conditions’ that should in any case not be below to the time granted to other operators
e) The processing of infrastructure capacity applications for the purpose of concluding the contracts;

Upon request of the RU, the IM is responsible to provide a series of **mandatory services** whose requests may only be rejected if viable alternatives under the market conditions exists[9].

Upon request and where available, the IM shall also provide to train operating companies the range of **complementary services** and **ancillary services**[10] which will be charged at their operating costs.

The Resolution designs an approach that tries to promote rail transport, favouring an efficient use of the network and new entrants.

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[8] Legislative Decree 8 July 2003, n. 188 art.20 "Attuazione delle direttive 2001/12/CE, 2001/13/CE e 2001/14/CE in materia ferroviaria"; DM 43/T of 21.3.2000, art.4 ‘Services included in the charge’; RFI Network Statement – 5.2. Classification of service, 5.2.1 Basic Access Package

[9] RFI Network Statement lists as mandatory services:

1. Access to fuel supply facilities;
2. Access to passenger stations and attached buildings and installations;
3. Access to freight stations and terminals;
4. Access to yards and sidings for train marshalling and formation;
5. Access to yards, sidings and buildings for standing, parking and storing rolling stock and goods;
6. Access to maintenance facilities and all technical infrastructures;
7. Shunting operations;
8. Controlling the transport of dangerous goods;
9. Assistance to special trains;
10. Maritime rail link to/from Sicily (Villa S.Giovanni – Messina route) and Sardinia (Civitavecchia – Golfo Aranci route).
11. Access to GSM-R telecommunications network for ground-to-train connections.

[10] RFI Network Statement –lists as complementary services :

a) Traction electricity supply;
b) Pre-heating and air conditioning services of passenger trains;
c) Fuel and / or supply;

And as ancillary services:

a) Supply of complementary information and train path feasibility studies;
b) Opening/enabling of installations and/or closed/unmanned lines;
c) Technical verification of rolling stock.

In conclusion, the rail access charge is based on short run costs without taking into account depreciation and extraordinary maintenance costs. According to some, the proposed approach seems to be a mid-way choice between a pure marginal cost pricing, on one hand, and an average cost pricing on the other[11].

In 2004, the revenues from access charges covered approximately the 16% of total costs..

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[11] E. Marcucci 'The Process of Railway De-Verticalisation in Italy: State of Art and Possible Evolutions', Trasporti Europei.

3. THE CALCULATION OF THE ACCESS CHARGE

The chapter aims at presenting the calculation method of the access charge currently applied in Italy whose norms are contained in the Ministerial Decree of the Ministry of Transport *'Determination of the criteria for calculating the access charge of the rail infrastructure*' of the 21st March 2000. (hereafter the Decree).

The Decree is accompanied by 7 economic annexes as well as 17 technical annexes, which are listed below and quoted hereafter in order to describe the charging system.

Ministerial Decree n.44/2000- Economic and Technical Annexes
Economic Annex 1: Unitary Access cost for truck line network
Economic Annex 2: Unitary access cost for complementary line network
Economic Annex 3: Unitary access cost for nodal section
Economic Annex 4: Base unit of the cost per km of the truck line network
Economic Annex 5: Base unit of the cost per km of complementary line network
Economic Annex 6: Base unit of the cost per minutes of staying at the nodal section
Economic Annex 7: Per km cost of electric traction
Technical Annex 1: Truck line network: commercial line
Technical Annex 2: Complementary line network- the secondary line network
Technical Annex 3: Complementary line network - the lightly trafficked network
Technical Annex 4: Complementary line network - the shuttle service network
Technical Annex 5: Nodal Sections
Technical Annex 6: Minimum information included in the charge
Technical Annex 7: Time range of the lines
Technical Annex 8: Optimum Speed per truck line network/ per time range
Technical Annex 9: Speed Parameter
Technical Annex 10: Indicative of congestion/density per truck line network/time range
Technical Annex 11: Congestion Parameter
Technical Annex 12: Weights/values for the wear and tear parameter
Technical Annex 13: Parameter wear and tear
Technical Annex 14: Weight of the parameter values
Technical Annex 15: Time range for the use of nodal sections
Technical Annex 16: Coefficient for the use of the nodal sections
Technical Annex 17: Coefficient for the use of the main station of the nodal sections

The Decree has then been amended and supplemented by the subsequent Decrees,:

- Ministry of Transport Decree of the 11th April 2003 n.12T
- Ministry of Transport Decree of the 15th July 2003n.29T for charge adjustment to inflation rate (1,4% of the access charge) and Ministry of Transport Decree 24th of March 2004 for charge adjustment to inflation rate (1,7% of the access charge)
- Ministry of Transport Decree of the 18th August 2006 published in the O.J.n.227 of 29th September 2006.

These Decrees aim both at specifying better the technical annexes and at updating the economic annexes but do not entail the introduction of new approaches for the determination of access charge neither the modification to the charging system in itself.

It's important to stress that the Legislative Decree n. 188/03 (art. 17 para 1) foresaw the starting up of a political consultation and of a technical study to which should follow the review of the norms for calculating the rail infrastructure access charge.

However, both actions have been postponed year after year and the deadline for the submission of the study and the approval of the new regulation have been recently fixed[12] respectively at the 15th December 2008 and the 30th December 2008.

Generally, the Decree applies to all cases of uses of rail infrastructures and it is established that any amendments shall be made only after specific authorization by the Ministry of Transport and Infrastructure.

The calculation system of the rail charge takes into account the following 5 criteria[13]:

1. Type and quality of the track, on the basis of the maximum speed allowed and the type of facilities. This parameter is used to estimate the reservation right charge for using the infrastructure.
2. Situation of the line, on the basis of the number of the daily train and use of the nodes
3. Wear and tear of track and the electric line, on the basis of the gross weight of the train and the technical characteristics of the pantographs.
4. Average speed on the line, taking into account of the capacity, traffic and the slot ;
5. Energy consumption, on the basis of the type of traction.

Except the first criteria, the others are applied on the basis of distance travelled (kilometre charge).

The Technical Annex to the Resolution 180, links the adopted criteria with specific actions/behaviours of the RU to be deterred or promoted.

IM behaviours to be deterred	**Criteria**
No use of reserved track	Request to pay part of path/nodal sections charge advance as 'reservation fee'.

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[12] Legge 28 febbraio 2008, n. 31 Conversione in legge, con modificazioni, del decreto-legge 31 dicembre 2007, n. 248, recante proroga di termini previsti da disposizioni legislative e disposizioni urgenti in materia finanziaria"

[13] These criteria, formulated firstly in the Resolution 180, have been then recalled ? and further specified in the D. L. 188/03 art.17 para.5

IM behaviours to be deterred	**Criteria**
Partial use of slots on commercial track or nodes.	Application of variable charges according to the type of path/nodal section
Too many requests of high quality tracks	Determination of the congestion on the basis of the time schedule/types of tracks (Congestion Parameter)
Requests of slots with difference between the optimum and the operating train actual speed	Consideration of optimum speed for tracks /time schedule (Speed Parameter)
Overuse of nodal sections	Establishment of a higher price, on the ground of the minutes of use and the time schedule, for the use of the 8 more requested nodal section.(Nodal section values)
Infrastructures wear and tear	Establishment of a price related to the characteristics of the wagons (wear and tear parameter)

IM behaviours to be promoted	**Criteria**
Flexibility to shift slots from peak hours to others day time	Set of price differentiation (range) on the ground of the trucks/nodal section for each time schedule
Flexibility to move from congested line to less used lines	Set of price differentiation on the basis of the type of lines used - truck or complementary line
Flexibility to move from congested stations to less used stations	Set of a higher price for the utilisation of the identified congested nodal section.

In order to calculate the charges, the entire rail network is divided by the Decree[14] in the following three main categories:

1. **Trunk line network**, including 78 commercial and highly trafficked track sections expressly identified and comprising approximately 5 500 km.

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[14] DM 43T/2000; the technical annexes from 1 to 5 identify and codify the trunk and secondary lines, with its sub-categories, as well as the nodal sections.

2. **Secondary line network** including three sub-categories:
    i. The secondary network: comprising approximately 7 300 km with controlled traffic;
    ii. The lightly trafficked network: which lists tracks, approx. 2 500 km, with very limited traffic placed in areas where the demand is traditionally weak;
    iii. The shuttle service network: approx. 250 km of tracks where service of round trips are offered with frequency and without intersection with others tracks.

3. **Nodal sections:** 8 areas characterized by high concentration of rail infrastructure nodes. Through the identification of the relevant areas and cities, each nodal section perimeter is delimited in the Decree's Technical Annex 5.

The following table shows an example of the nodal section of Rome, characterised by eight stations towards and from north, south, east and west directions.

Table 1: The Ministerial Decree 43T/2000, (Technical Annex 5 Nodal Sections)

Code of the nodal section (r)	**Nodal Section**	**Nodal section delimitation**
7	**ROMA**	MACCARESE (da GROSSETO)
		SETTEBAGNI (da FIRENZE)
		FARA SABINA (da CHIUSI LL)
		GUIDONIA (da SULMONA)
		TORRICOLA (da FORMIA)
		CESANO (da VITERBO)
		CIAMPINO (da CASSINO/CASTELLI)
		FIUMICINO

The charge for each train path is estimated on the basis of :

1. The quality of the line;
2. The characteristics and performances of the trains which influence the wear and tear of the allocated infrastructures;
3. The cost of electricity calculated on the effective usage.

The charges paid by each train path is composed of the sum of the following three components:

1. **Path/nodal sections charge**: is the charge paid to access to the trunk or secondary lines and to the nodal sections. It is a fixed access charge and depends upon the quality of line used, e.g. the number of tracks, average speed and

technological equipments. On average, it accounts approximately by 40% of the total charge.

2. **Kilometres/ minutes charge***:* is the charge based on the use of infrastructure and depends for each train path on the kilometres travelled for trunk and secondary lines and on the minutes staying inside a node. It is a variable charge and takes into account, for truck line, for each train path: the speed, the density and the weight of the wagons. For secondary line path, a cost is established per km .
   Concerning the minutes charge, it is applied to all traffic in the same way only in the cases where the train path uses one or more of the 8 identified nodal section. The charges together account approx. by 48% of the total charge.

3. **Energy Consumption charge***:* it is the charge paid for the energy consumption. It is based on the kilometres travelled and on the minutes spent at the nodes. It accounts approx. by 12% of the total charge.

The following figures show the structure of the charge. It can be observed that the charge is divided in a fixed and in a variable part, differentiated according to their application on a trunk line or a secondary line.

The fixed part addressed the quality of the line, i.e. the number of tracks, the average speed allowed, the general equipment of the infrastructure, the presence of reservation fee and is independent from the traffic intensity.

The variable part depends on a set of parameter as wear and tear, traffic demand (density) and inefficient use of capacity (through the speed of the train).

The following paragraphs describes in detail formulas and calculation methods of the fixed part (paragraph 3.1) and the variable part (paragraph2 3.2 and 3.3).

Figure 2: Structure of the charge

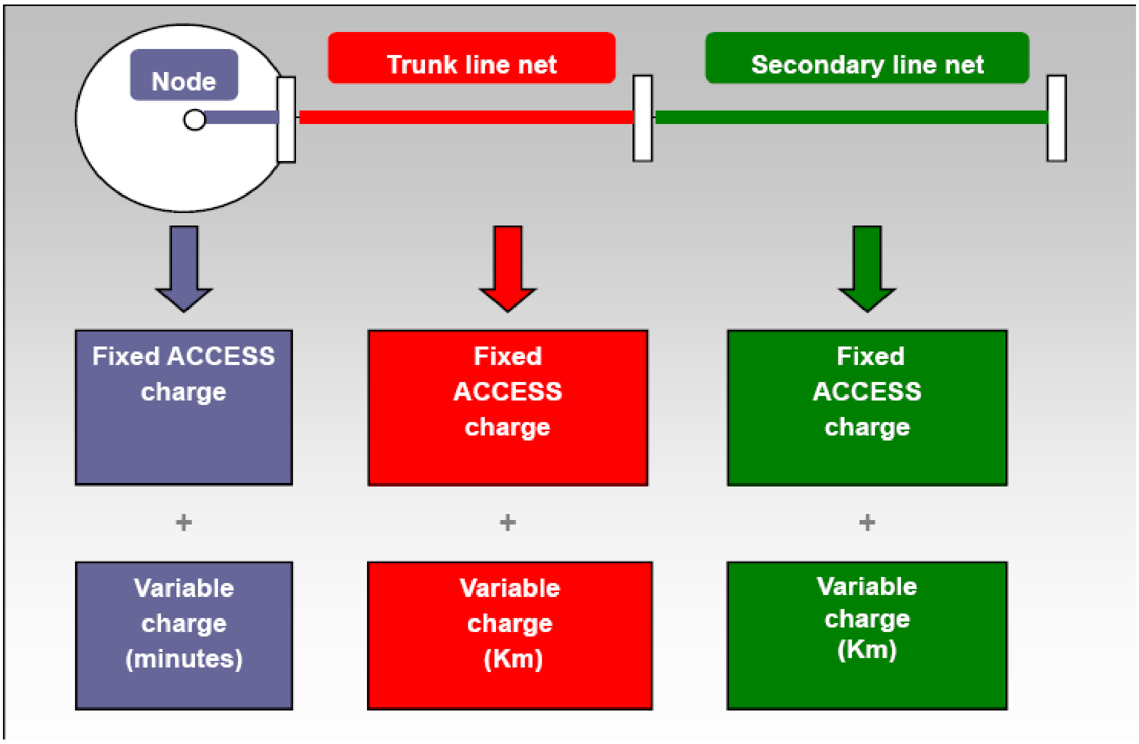
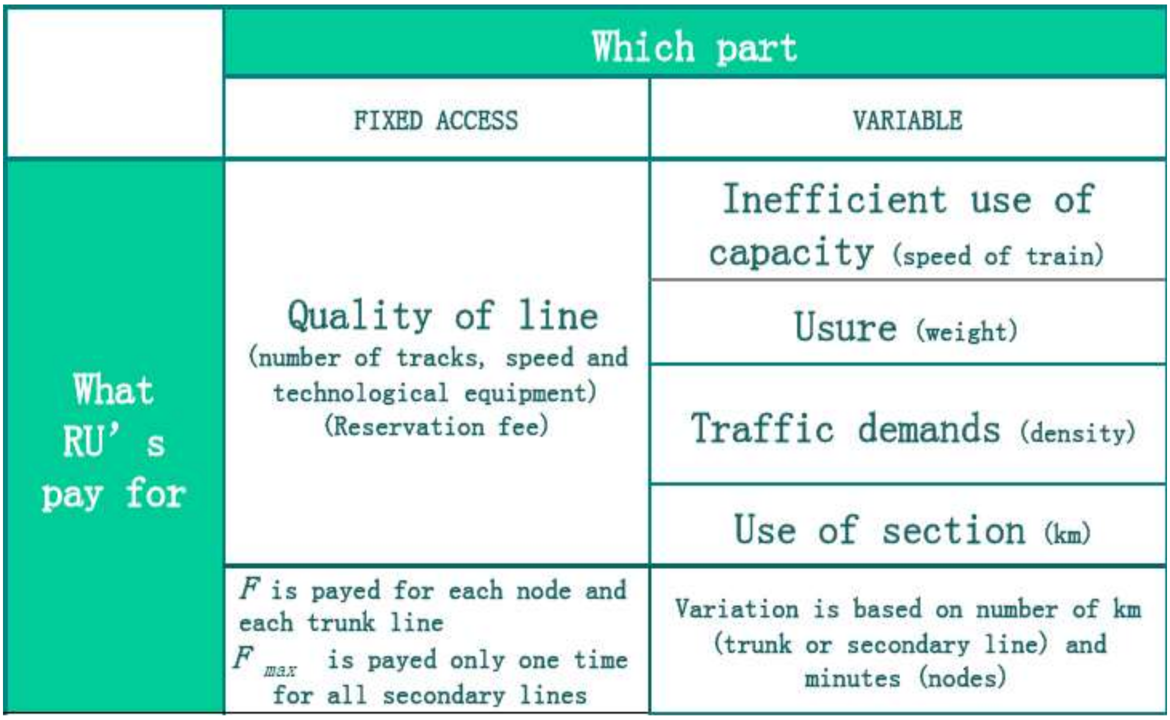


Table 2: Charging calculation scheme: the fixed and the variable components



	Which part	
	FIXED ACCESS	VARIABLE
What RU' s pay for	Quality of line (number of tracks, speed and technological equipment) (Reservation fee)	Inefficient use of capacity (speed of train)
		Usure (weight)
		Traffic demands (density)
		Use of section (km)
	F is payed for each node and each trunk line F_{max} is payed only one time for all secondary lines	Variation is based on number of km (trunk or secondary line) and minutes (nodes)

3.1 Path/nodal sections charge

The path/nodal section charge is the sum of the three unitary access cost of the lines used by the train path and it is calculated through the following algorithm:

$$\sum_{j=1}^{n} \mathrm{val}^{F}{}_{j} + max\left(\mathrm{val}^{C}{}_{k}\right) + \sum_{r=1}^{t} \mathrm{val}^{N}{}_{r}\,; \quad \text{con } k=1, 2, ...q$$

where:

j = the trunk line. Trunk lines have been identified and codified progressively by the Decree 44/2000[15].

n= the quantity of trunk lines out of the 78 identified by the Decree.

valFj= unitary access cost to the trunk line j [16].

k= the secondary line net. Secondary lines as well have been identified and codified progressively by the Decree 44/2000[17].

q= the quantity of the secondary lines out of the 248 identified by the Decree.

Max (ValCK) = unitary access cost to secondary line network calculated as the maximum unit value of different values which correspond to ValCk for the secondary network, the lightly trafficked network, the shuttle service network used by the train path.

r= the nodes. Nodes have been identified and codified progressively[18].

t= the quantity of nodes out of the 8 identified by the Decree.

ValNr= the unitary access cost of the node used by the line.

The unitary costs are determined by the Decree, taking in consideration the quality of the line: double or single track and maximum speed allowed.

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[15] DM 43T/2000; the Technical Annex 1 as updated by Ministry Transport Decree of the 18th August 2006

[16] DM 43T/2000, Economic Annex 1, as updated by Ministry Transport Decree of the 18th August 2006.

[17] DM 43T/2000, Technical Annex 2,3, 4 as updated by Ministry Transport Decree of the 18th August 2006

18 DM 43T/2000, Technical Annex 5 as updated by Ministry Transport Decree of the 18th August 2006

Table 3: Unitary access costs for trunk lines

Typology of the line	Number of trunk per typology	Maximum speed	Unitary Access cost (Price €)
Double track sections	1	250 km/h	66,5767
Double track sections	10	200 Km/h	58,5846
Other double track sections	54		55,9240
Single track sections	12		50,5957

Table 4: Unitary costs for secondary lines

Typology of the line	Number of trunk per typology	Unitary Access cost (Price €)
The secondary network (single tariff area - except for those codified as high speed rail lines)	191	47,9319
Lightly trafficked network	42	0,00
Shuttle service network	14	23,24
Shuttle service network Ancona-Ancona M.	1	24,53

The unitary access cost for the use of the nodes is established at € 51,65.

3.2 Kilometres/ minutes charge

As discussed in the structure of the charge paragraph, the variable charge is paid on all parts of the network and it is based on:

a) on the number of kilometres used by the train path on a certain time frame;
b) on the number of minutes spent in nodes.

2 a) Charge per kilometres

This charge is the sum of two parts: the first one relates to the kilometres covered on the trunk line network and the second on kilometres on the complementary line network.

The per km charge on the trunk line

The charge is calculated by multiplying the base cost per km path on the trunk line (€ 1.0312 [19]) for the sum of the km covered by the path and the time range of the train, conveniently corrected.

Three time ranges have been established[20] (22.00 - 6.00, 6.00 - 9.00, 9.00 - 22.00) and for each one, the optimum speed[21] and the density coefficient are calculated, by each trunk.

In order to define that, three parameters are considered:

- The speed (Pvelocità), as the gap between the speed of the single train and the standard optimum speed established by the Decree for the time range considered;
- The density (Pdensità), as the traffic congestion on the trunk line at the time range considered;
- The wear and tear (Pusura), based on the weight of the train, its speediness and the number of pantographs.

The weighted average of these three parameters is the corrective coefficient of the kilometres path in the line at the time range considered.

The per km charge formula on the trunk line is the following:

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19 DM 43T/2000, Economic Annex 4 , as updated by Ministry Transport Decree of the 18th August 2006.

[20] DM 43T/2000, Technical Annex 7

[21] In annex to this report

$$\text{Pbasekm}^{F} * \sum_{j=1}^{n}\sum_{w=1}^{s} \text{km}^{F}_{jw} * (\alpha_1 * \text{Pvelocità} + \alpha_2 * \text{Pdensità} + \alpha_3 * \text{Pusura})\,;\; \text{con } \alpha_{1+}\,\alpha_{2+}\,\alpha_3 = 1$$

where:

PbasekmF= unit base cost per Km (€ 1.0312);

J = the trunk line net as identified and codified progressively[22];

n= means the quantity of trunk lines out of the 78 identified by the Decree;

w= time according to the set time ranges;

S= the number of time ranges used by the considered train path;

Kmfjw= kilometres path on the truck line (J) on the time ranges concerned (w)

a1, a2, a3: is the weight associate to the parameter of the speed (Pvelocità), the density (Pdensità) and the tear and wear (Pusura). The decree establishes a weight of values of 1/3 for each parameters.

Pvelocità= the speed. The speed parameter is calculated with the following formula:

$$V\left(\frac{|vel_{jw} - velomo_{jw}|}{velomo_{jw}}\right) = V_i \quad \text{quando } m_{i-1} \le \frac{|vel_{jw} - velomo_{jw}|}{velomo_{jw}} < m_i \quad \forall i = 1,2,\ldots\ldots l$$

where

veljw= speed of the train on the trunk line j during the time range w;

velomojm= standard optimum speed established by Decree (see below).

l= number of ranges of l veliw-velomojw l / velomojw;

mi – l / mi= threshold below and above the range i.

i= range of l veliw-velomojw l / velomojw;

The values of Vì of the function V and all elements of range l are established by the Decree (see below)

Tacking in consideration the quality of the line net, the standard optimum speed is identified per trunk for each time for each time range by the Decree (in annex to this report)[23].

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[22] Ref. Footnote n. 10

[23] DM 43T/2000, Technical Annex 8

Table 5: Standard optimum speed

Characteristics of the lines	Speed paramether per time/schedule time (km/h) $velom_{jw}$		
	22.00-6.00 (w)	**6.00-9.00 (w)**	**9.00-22.00 (w)**
Max. speed 250	100	120	170
Double track sections max. speed 200	80	65	115
Traditional double track sections	70	60	90
Double track section with obstacles in the path	60	50	80
Mainly metropolitan line	60	40	40
Line with simple track	50	50	70

The annex 9 report the following table for processing the values of Vì of the function V and all elements of range[24].

Table 6: Speed Parameter: Conversion Table

Range i	Range's limit		Values of parameters of Speed ($P_{velocità}$) V_i
	m_{i-1}	m_i	
1	0	0.2	1.0
2	0.2	0.5	1.3
3	0.5	1	3.0
4	1	oltre	5.0

The RFI Network Statement specifies that the ***commercial speed*** referred to in the Decree means the Space/Time ratio inclusive of the stops, while the ***operating speed*** means the Space/Time ratio not including the stops, taking account of any variations of weight of the train.

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[24] DM 43T/2000, Technical Annex 9

Pdensità =Density. The traffic demand is calculated with the following formula:

$$D(dens_{jw}) = D_i \qquad \text{per } v_{i-1} \leq dens_{jw} < v_i \ \forall i = 1, \ldots\ldots k$$

where:

densjw= traffic demand on the line j on the time range w.

i= the range to which the value densjw belong to

k= the number of range of densjw

vi-l/Vi= limits below and above the range i

The value of density is established by the Decree[25] where the range i for each line is classified with a number from 1 to 3 per time range. The number correspond to:

1 = density below of 50%
2 = density included between 50%(included) and 75% (excluded)
3 = density up of 75%

Table 7: Abstract/extract from Annex 10 – Density for truck line/ time frame

Range (i) per density line ($dens_{jw}$)

Commercial line (for two-way)			
	22.00-6.00	**6.00-9.00**	**9.00-22.00**
VERONA - PADOVA	2	2	2
FOGGIA -BARI	1	2	1
(NAPOLI) PORTICI- PAOLA	1	3	2

The values of Di of the function D and all the factors described by k range are reported on the Decree[26].

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[25] DM 43T/2000, Technical Annex 10
[26] DM 43T/2000, Technical Annex 11 as updated by Ministry Transport Decree of the 18th August 2006.

Table 8: Density Parameter: Conversion Table

Tabella di conversioni valori			
Range **i**	**Range's limit**		Values for the paramether $P_{densità}$ $\mathbf{D_i}$
	$\mathbf{v_{i-1}}$	$\mathbf{v_i}$	
1	0	0.5	0.3
2	0.5	0.75	1.0
3	0.75	Oltre	1.5

Pusura=tear and wear. The tear and wear parameter is calculated with the formula:

$$U\left(\frac{\beta_1 * \left(velm_{j\bullet}{}^2 * pebl_{j\bullet}\right) + \beta_2\left(velm_{j\bullet} * pant_{j\bullet}\right)}{\beta_1 * \left(velmt^2 * peblt\right) + \beta_2\left(velmt * pantt\right)}\right) = U_i$$

$$\text{per } z_{i-1} \leq \left(\frac{\beta_1 * \left(velm_{j\bullet}{}^2 * pebl_{j\bullet}\right) + \beta_2\left(velm_{j\bullet} * pant_{j\bullet}\right)}{\beta_1 * \left(velmt^2 * peblt\right) + \beta_2\left(velmt * pantt\right)}\right) < z_i \qquad \forall i = 1,\ldots\ldots u$$

where:

velmj: speed of the train on the line j, without taking on considering the time range;

peblj: weight of the train on the line j, without tacking on considering the time range;

pantj: number of pantographs used by the train- just for electric train

velmt[27]: standard train speed. The standard speed is at 80 km/h

peblt: standard train weight. The standard weight is 500 tons

pant: standard number of pantographs used. The standard number of standard pantographs is 1.

$ß_1$, $ß_2$ assume the following values established for the tear and wear of the line:
$ß_1$= 0.85
$ß_2$= 0.15

The values of Ui of the function U and all the elements of the range u are shown in the table below:

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[27] 43T/2000, Technical Annex 12 as updated by Ministry Transport Decree of the 18th August 2006.

Table 9: Wear and tear Conversion Table[28]

Tabella di conversioni valori			
Indicativo range i	**Range limit**		**Values for the parameter P_{usura} U_i**
	z_{i-1}	**z_i**	
1	0	0.8	0.7
2	0.8	1.2	1.0
3	1.2	2	1.8
4	2	above	3.5

The charge for km on the complementary lines of the rail network

The charge is calculated by multiplying the base cost per km on the complementary line (€13, 1196 [29] for high speed and €1, 0312 for all the others) for the number of km covered by the path.

Being the formula for charge for km on the complementary line as follows:

$$PbasekmC*kmC$$

where

PbaseKmC = base cost per km on the complementary line.

KmC*= Kilometres covered by the train on the complementary line

In the cases where both truck and complementary lines net are used, the results of the last two formulas have be summed.

2 b) Charge per minutes on nodal sections

The charge is provided by multiplying the base cost per minute spent in the nodal section (€1,0312[30]) for the sum of minutes spent in each nodal section on each time range, corrected by a coefficients representing the first the traffic density on the considered time range and the second the main station use.

The charge is calculated with the following formula:

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[28] DM 43T/2000, Technical Annex 9

[29] DM 43T/2000, Economic Annex 4 , as updated by Ministry Transport Decree of the 18th August 2006.

[30] DM 43T/2000, Economic Annex 6 , as updated by Ministry Transport Decree of the 18th August 2006.

$$\text{Pbaseminuto}^{N} * \sum_{r=1}^{t} \sum_{p=1}^{h} \text{minuti}_{rp} * \varphi_{\bullet p} * \psi_{r\bullet}$$

Pbaseminuto: unitary base cost per minutes of staying in each nodes.

N: means the nodes. The nodes have been identified and codified progressively by the Decree.

t: quantity of the nodes used by the train out of the 8 identified by the Decree.

P : time range of the train staying at the nodes.

H= number of the time range used by the train line

Minutirp= minutes of staying of the train line in the node r during the time range

$\varphi_{\bullet p}$ = coefficient of nodes utilisation in the time schedule p.

$\psi_{r\bullet}$ = coefficient linked with the use of main stations.

The time range for the use of the nodal Section are determined by the Decree[31].

Table 10: Time range for the use of nodal section

Indicative time range (p)	***Time range***
1	*22.00 - 6.00*
2	*6.00 - 9.00*
3	*9.00 - 22.00*

The coefficient for the use of the nodal section are determined by the Decree as follows[32]:

Table 11: Coefficient values for the use of nodal sections

Time range of node's use (p)	Use coefficient $(\varphi_{\bullet p})$
1	***0.8***
2	***1.3***
3	***1***

In case of stop on the five main identified stations, the coefficient would it be 4.

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[31] M 43T/2000, Technical Annex 15 .

[32] DM 43T/2000, Technical Annex 16

For all the others cases, the coefficient would it be 1[33].

3.3 Energy Consumption charge

The Energy consumption charge is calculated as the cost per kilometre of the electric traction, established at € 0,3320, multiply for the number of kilometres covered by the train on trunk, complementary lines and nodal sections.

The charge is calculated by the following formula:

$$\left(\sum_{j=1}^{n} \mathrm{km}^{FE}{}_{j} + \mathrm{km}^{CE} + \sum_{r=1}^{t} \mathrm{km}^{NE}{}_{r}\right) * \mathrm{Pbasekm}^{E}$$

where:

j= the trunk line net as identified and codified by the Decree.

n= the quantity of trunk lines out of the 78 identified.

KmNEj= path kilometres on the truck line (J) on the time frame concerned (w) and made using electricity traction

KmCE= path kilometres on the complementary line on the time frame concerned and made using electricity traction

r= means the nodes as identified and codified.

t= means the quantity of nodes out of the 8 identified by the Decree.

KmNEr: path kilometres inside the node r and made by using electricity traction

PbasekmE= traction electricity cost. The traction per electricity cost is established at € 0,3320.[34]

The cost for electricity traction might be subjected to changes depending upon the price to which the Infrastructure Manager is subjected.

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33 DM 43T/2000, Technical Annex 17

[34] 34 DM 43T/2000, Economic Annex 7 , as updated by Ministry Transport Decree of the 18th August 2006.

4. Charges variability by type of trunk line and speed

The following tables show the price variation (€/km) of the km charge on the trunk line net on the basis of the values attributed to the three parameters considered: speed, density and tear and wear.

The variation ranges from the minimum of € 0,67 per km in case of low density and minimum tear and wear and speed to the maximum of € 3,17 for the case of high peak hours, maximum speed and tear and wear.

Table 12: Charge per kilometres in case of low density

P3=Tear and Wear / P1=Speed	P2=Low Density (< 50%)			
	0% - 80%	**80% - 120%**	**120% - 200%**	**200% and above**
0% - 20%	0,67	0,77	1,02	1,60
20% - 50%	0,75	0,85	1,10	1,68
50% -100%	1,33	1,43	1,68	2,27
100% - and above	2,00	2,10	2,35	2,93

Table 13: Charge per kilometres in case of medium density

P3=Tear and Wear / P1=Speed	P2=Medium Density (50%- 75%)			
	0% - 80%	**80% - 120%**	**120% - 200%**	**200% and above**
0% - 20%	0,90	**1,03**	1,25	1,83
20% - 50%	0,98	1,08	1,33	1,92
50% -100%	1,57	1,67	1,92	2,50
100% - above	2,23	2,33	2,58	3,17

Basic Price Value

Table 14: Charge per kilometres in case of high density

P3=Tear and Wear P1=Speed	P2=High Density (above 75%)			
	0% - 80%	**80% - 120%**	**120% - 200%**	**200% - and above**
0% - 20%	1,07	1,17	1,42	2,00
20% - 50%	1,15	1,25	1,50	2,08
50% -100%	1,73	1,83	2,08	2,67
100% - and above	2,40	2,50	2,75	3,33

The charge variability per minute spent on the nodal sections depends on the time period and the use of the main station.

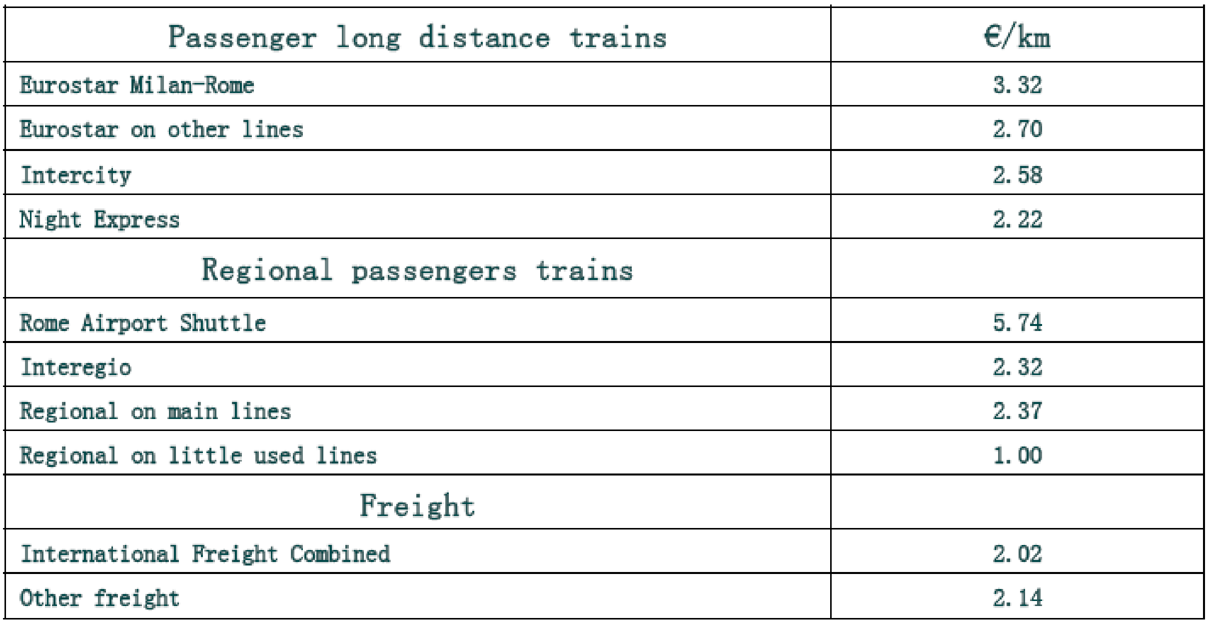
Table 15: Charge per minutes spent at the nodes

	Use of Main Station	
Time Period	**no**	**Yes**
6.00 - 9.00 (peak hour)	1,30	5,20
9.00 - 22.00 (semi-peak hour)	**1,03**	4,00
22.00 - 6.00 (night)	0,80	3,20

Basic Price value

On the basis of the specific characteristics of the trains, the average charge €/km can be summarised as follows:

Table 16: Average charge



Passenger long distance trains	€/km
Eurostar Milan-Rome	3.32
Eurostar on other lines	2.70
Intercity	2.58
Night Express	2.22
Regional passengers trains	
Rome Airport Shuttle	5.74
Interegio	2.32
Regional on main lines	2.37
Regional on little used lines	1.00
Freight	
International Freight Combined	2.02
Other freight	2.14

5. CONCLUSION

The RFI approach for supporting the efficient use of rail infrastructure arises from the combination of three main parameters, influencing the order of magnitude of the variable part of the rail charge:

d) density (a proxy of the congestion);
e) speed (measured as the difference between the speed of the train in question and the speed deemed optimal for the route in question)
f) wear and tear.

Scarcity is addressed through the imposition of higher charges to the extent that the route is more congested and the average speed of the train higher than the optimal speed of the line (distinguished by night time – 22.00-6.00; semi-peak hour – 9.00-22-00; and peak hour – 6.00-9.00).

A similar approach is assumed for supporting the efficient use of the most congested nodes, charging higher the time (in minutes) spent in congested nodes and in particular when the train is using the node during the peak hour.

Compared to the other approaches addressing scarcity, the RFI tries to derive charges considering speed deviation from an optimal speed/time deviation defined for every section and time period.

The other approaches derive charges basically according to two factors: 1) the different type of services and 2) time period, either through the combination of the two factors or considering them separately.

ANNEX : the optimum speed on the rail network

ALLOWED SPEED (Km/h) IN THE RAIL NETWORK BY PERIOD OF TIME: 22.00-6.00/6.00-9.00/9.00-22.00