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Marginal Infrastructure Costs and Pricing in Road and Rail Transport

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Licentiate thesis


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Abstract

This licentiate thesis examines marginal cost estimation and pricing in transport infrastructure, with empirical applications to Swedish roads and railways. The thesis consists of three papers addressing how infrastructure charges can be aligned with short-run marginal social costs.

The first paper estimates marginal road renewal costs per heavy vehicle kilometre using panel data on approximately 1.3 million 100-meter road segments (1999–2022). A two-part discrete–continuous framework is applied, combining models of renewal timing (probit and Weibull survival specifications) with renewal expenditures (a log–log function). The results show substantial heterogeneity in marginal renewal costs across road types, with heavy vehicles generating higher costs on low-standard roads than on motorways or other high-standard roads.

The second paper estimates short-run marginal road maintenance costs per heavy vehicle kilometre using administrative maintenance data at the Maintenance District Unit (MDU) level (2015–2024). A log–log cost function relates annual maintenance expenditure to heavy-vehicle traffic intensity by road type, controlling for network scale and weather conditions. The results indicate that the marginal maintenance cost per heavy vehicle kilometre is about 50 percent higher on low-standard roads than on high-standard roads. Combined with the renewal estimates from Paper 1, total marginal infrastructure costs range from 0.03 €/heavy-vkm on motorways to 0.51 €/heavy-vkm on low-standard roads, indicating that the marginal infrastructure cost imposed by heavy vehicles varies greatly across the road network

The third paper analyses optimal rail access charges in a vertically separated railway market, where marginal capacity costs reflect track congestion. A calibrated demand and supply model for the Stockholm–Gothenburg corridor is used to simulate how track charges affect fares, frequencies, welfare, and modal competition. The results show that increases in track charges to reflect the marginal cost of congestion primarily reduce service frequency rather than

substantially increasing fares, with welfare-optimal charges depending critically on congestion externalities.

Together, the papers show that marginal infrastructure pricing requires both disaggregated cost estimates and an understanding of how transport operators respond to infrastructure charges.

Keywords: Marginal cost; Road renewals; Road maintenance; Rail access charges; Optimal pricing

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List of papers

- I. Rushid, A.R. & Börjesson, M., Estimating the Marginal Costs of Road Renewals by Road Type
In manuscript
- II. Rushid, A.R. & Börjesson, M., Marginal Maintenance Costs by Road type
In manuscript
- III. Börjesson M., Ragipi Rushid A., Liu, C., The impact of optimal rail access charges on frequencies and fares, *Economics of Transportation*, Volumes 26–27, 2021.
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Contributions

Paper I. and II.

The first and second studies are co-authored with Maria Börjesson. The thesis author is responsible for data collection and preparation, methodology, software implementation, formal analysis, and writing.

Paper III.

The third study is co-authored with Maria Börjesson and Chengxi Liu. The thesis author is responsible for input data collection, software model implementation, formal analysis, and writing.

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Introduction

Road and rail infrastructure represent one of the largest and most costly public assets in modern economies. Maintaining and renewing these networks requires substantial and sustained expenditure – total public spending on road and rail maintenance and renewals in Sweden alone amounted to €3.1 billion in 2024 (Table 1). Ensuring that these costs are covered efficiently and fairly is therefore a central challenge for many governments.

In Europe, this challenge is partly addressed through the principle that infrastructure users should face charges reflecting the marginal social costs generated by their use. In road freight transport, this principle is implemented through Directive 1999/62/EC and its later amendments, which allow Member States to recover infrastructure costs and selected external costs through fuel taxes, distance-based charges, or time-based user charges. In practice, most European countries have moved towards kilometre-based charging for heavy goods vehicles, as such systems allow charges to vary with actual road use, vehicle characteristics, and environmental performance, providing a more efficient pricing instrument than fixed time-based charges. This shift is set to become increasingly important as road freight electrifies and fuel-tax revenues decline, making distance-based infrastructure charges more central to cost recovery.

Infrastructure costs are central to such pricing because heavy vehicles generate a disproportionate share of road wear (Transport Analysis, 2025). Road deterioration increases non-linearly with axle load, implying that infrastructure charges must rely on robust estimates of the marginal costs generated by additional traffic. Yet an important empirical question remains unresolved: are marginal infrastructure costs higher on heavily trafficked high-standard roads, where traffic intensity is greatest, or on lower-standard roads, where deterioration may be more sensitive to additional loads? Existing evidence on how marginal road infrastructure costs vary across road types is limited, and this thesis provides the first estimates combining

both maintenance and renewal components at a disaggregated level for the same road network.

Table 1. Swedish public expenditure on maintenance and renewal of roads and railways in 2024 (million €)

Mode	Renewals	Maintenance and operation	Total expenditures
Road infrastructure	316	1 233	1 549
Rail infrastructure	473	1 080	1 553

Source: Own calculations based on Swedish Transport Administration (2024), using an exchange rate of 1 EUR = 10.9 SEK.

Rail transport follows the same principle of cost internalisation under a different institutional framework. In vertically separated railway systems, train operators pay access charges intended to reflect the marginal costs generated by infrastructure use, including wear, congestion, noise, and accident costs. In Sweden, rail access charges have long been used as an instrument for fair and efficient pricing. As in road transport, such charges influence operator behaviour, although in rail they also directly affect service supply because operators adjust fares, frequencies, and train configurations under capacity constraints.

Against this background, this thesis examines marginal infrastructure costs and marginal-cost-based pricing in both road and rail transport. Two papers estimate road infrastructure costs through separate cost components, renewals and maintenance. The third paper analyses rail access charges and their effects on passenger rail market outcomes. Together, Papers 1 and 2 provide estimates of total marginal infrastructure wear costs for roads, while Paper 3 shows that the policy implications of marginal-cost-based pricing depend on market responses.

Literature review

Estimating marginal infrastructure costs for roads

Estimating marginal infrastructure costs requires consideration of how maintenance and renewal expenditures reflect distinct cost-generation processes and therefore require different empirical approaches. Maintenance covers recurrent interventions such as surface repairs, winter service, and drainage that preserve functionality during the asset's operating life. Traffic affects maintenance directly, increasing the intensity or frequency of interventions needed, although costs also depend on network size and infrastructure standards (Haraldsson, 2007a). Renewals are large, infrequent interventions that restore the asset to near-original condition. Rather than responding continuously to wear, renewals occur when accumulated deterioration crosses a threshold. Traffic therefore affects renewals primarily through timing, as heavier use accelerates deterioration and shortens asset life.

These differences shape the empirical approaches required. Maintenance expenditures vary continuously and are well suited to linear cost-function estimation, where annual costs are explained by traffic, network characteristics, and environmental conditions (Bak et al., 2006; Haraldsson, 2007a; Link, 2009, 2014; Schreyer et al., 2002; Yarmukhamedov & Swärdh, 2016). Renewal costs, by contrast, involve a corner-solution structure: in most periods, no renewal occurs, while renewal years generate strictly positive costs. This requires modelling both the probability or timing of renewal and the cost conditional on renewal (Andersson et al., 2012; Odolinski et al., 2020).

Despite a substantial literature on marginal infrastructure cost estimation, robust road-specific estimates remain scarce. On the maintenance side, methodological advances have largely occurred in the railway sector, and existing road studies either suffer from data limitations or fail to find a statistically significant traffic effect for paved roads (Haraldsson, 2007a; Yarmukhamedov & Swärdh, 2016).

No study disaggregates beyond paved versus gravel roads, leaving costs on high- and low-standard paved roads, where most expenditure occurs. On the renewal side, no study has estimated road-type-specific marginal costs directly from microdata. The dominant approach links deterioration elasticities to assumed average renewal costs, ignoring systematic variation in realised expenditures across regions and road categories, a practice that can bias estimates (Haraldsson, 2007b; Murray & Link, 2023; Nilsson et al., 2020). While a two-part model addressing this has been applied in rail, it has not been extended to roads.

This thesis addresses both gaps. Paper 2 estimates marginal maintenance costs by road type using a cost function approach on administrative MDU-level data, while Paper 1 models both renewal timing and realised expenditures directly, comparing two first-stage specifications. Together, they produce the road-type-specific total marginal cost estimates in Table 2.

Rail access charges and operator responses

Since the introduction of vertical separation in European railway markets, rail access charges have become a central instrument for implementing marginal cost pricing in the rail sector. In vertically separated systems, infrastructure managers set access charges intended to reflect marginal infrastructure costs and selected external costs, while train operators determine fares and service supply. In practice, however, charges are often set below estimated marginal social costs and vary substantially across countries. A large part of the literature has therefore focused on how track charges should be designed to reflect wear, congestion, and cost recovery under high fixed infrastructure costs (A. Nash, 2003; C. Nash et al., 2018; Smith & Nash, 2018).

Existing studies on optimal pricing and service supply have mainly examined urban or subsidised public transport systems, where pricing and frequency are determined jointly under welfare-maximising assumptions (Basso & Silva, 2014; Parry & Small, 2009; Tirachini et al., 2014). Much less attention has been given to

commercial long-distance rail markets, where operators face monopoly or limited competition and respond strategically to track charges. Previous studies analysing rail access charges often assume that higher charges are fully passed through to fares or focus on competition between rail operators (Ljungberg, 2013; Sánchez-Borràs et al., 2010). Less is known about how track charges affect fares and frequencies when rail competes with other transport modes and when track congestion is explicitly considered. The third paper in this thesis contributes to this literature by analysing how profit-maximising fare and frequency decisions respond to marginal-cost-based access charges in a vertically separated intercity corridor with intermodal competition.

Summary of papers

Paper 1

Paper 1 examines how marginal renewal costs per heavy vehicle kilometre vary across road categories by combining information on road renewal timing and realised renewal expenditures for Swedish state roads. Previous studies have typically estimated renewal marginal costs by using a survival model to estimate how traffic affects road lifetime, and then combining the estimated deterioration effect with an assumed average renewal cost (Haraldsson, 2007b; Murray & Link, 2023; Nilsson et al., 2020). A limitation of this approach is that actual renewal expenditures may vary substantially across road types, pavement types and regions.

To address this, the first stage estimates renewal timing using either a discrete-time probit or a Weibull survival model, and the second stage models realised renewal expenditures conditional on renewal, controlling for heavy-vehicle traffic volumes, road age, pavement (asphalt-mix) type, and region and year effects. The analysis draws on panel data for 100-metre road segments over 1999–2022, where renewal timing, realised costs, and traffic are all observed at the segment level.

Marginal renewal costs are derived by multiplying the traffic cost elasticity from the two-part model (with either probit or survival Weibull in the first stage) by the average cost per vehicle-kilometre. Although both models yield similar first-stage elasticities, the survival model is preferred because it better captures cumulative pavement deterioration. The results show clear variation in marginal renewal cost per heavy vehicle kilometre across road types: it is lowest on motorways and highest on low-standard roads (Table 2). This reflects the stronger pavement structures on high-standard roads, which limit marginal wear per additional heavy vehicle despite higher traffic volumes.

Paper 2

Paper 2 estimates marginal maintenance costs using annual expenditure data for Swedish maintenance delivery units (MDUs), where the largest MDU covers roughly 1,873 km of road. The dataset covers 2015–2024 and is aggregated at the MDU level, combining maintenance cost records with traffic data differentiated by road type, network characteristics, and climatic conditions. A log-log Cobb-Douglas cost function is estimated, in which maintenance cost is the dependent variable and heavy vehicle volume, along with other explanatory variables, are included as regressors. More flexible specifications were also tested. Random effects are preferred over fixed effects because traffic variation is predominantly cross-sectional, with nearly all variation occurring between MDUs rather than within MDUs over time. Differencing out this cross-sectional variation would remove most of the information needed to identify road-type-specific cost responses. To address the concern that traffic may correlate with time-invariant MDU characteristics, a correlated random effects (CRE) specification is estimated as a robustness check (Mundlak, 1978).

The results confirm traffic as a statistically significant determinant of maintenance costs. The marginal cost of maintenance is higher for low-standard roads than for high-standard roads, reflecting greater sensitivity to traffic loads on less robust infrastructure. Winter severity, measured by annual snowfall, emerges as a major determinant of expenditure. Road network size has a positive and statistically significant effect for both road types, indicating a substantial scale effect independent of traffic volumes. The implied marginal costs are reported in Table 2, showing higher costs per vehicle-kilometre on low-standard roads than on high-standard roads.

Table 2. Marginal infrastructure costs by road type (€ per heavy-vehicle km)

Road type	Renewal MC	Maintenance MC	Total infrastructure MC
Motorway	0.023	0.007	0.030
High-standard roads	0.188	0.007	0.195
Low-standard roads	0.492	0.013	0.505

Paper 3

Paper 3 analyses how rail access charges designed to internalize congestion on the tracks affect fares and service frequency in a vertically separated railway market. While marginal-cost-based rail charging reflecting the deterioration of the track has long been established in Europe, less is known about how commercial train operators adjust fares and service supply in response to charges designed to internalise track congestion.

The paper develops a calibrated supply-demand model for the Stockholm–Gothenburg corridor in which a profit-maximising rail operator competes with air, bus, and car transport. The model incorporates heterogeneous travellers (business and private), intermodal competition, congestion on the tracks, and crowding in trains. This allows track charges to influence both prices and frequencies through operator optimisation.

The results show that increases in access charges do not translate into proportionally higher fares. Instead, as charges increase, frequencies and producer surplus decline while fares remain relatively unchanged, particularly when operators can extend train length. The degree to which operators adjust fares versus frequencies depends on the strength of intermodal competition and the degree of track congestion. Overall, congestion-based access charges emerge as

an efficient instrument for allocating scarce track capacity, generating limited fare increases for passengers while encouraging operators to utilise their vehicles more efficiently.

Conclusion

The results reveal substantial variation in marginal infrastructure costs across road types, ranging from 0.03 €/vkm on motorways to 0.51 €/vkm on low-standard roads. This implies that marginal costs are nearly 17 times higher on low-standard roads, suggesting that uniform kilometre charges would systematically undercharge heavy vehicles where pavement is most sensitive to additional loads. With road freight electrification set to reduce fuel-tax revenues, such robust marginal cost estimates will become increasingly important for designing distance-based infrastructure charges.

Paper 3 adds an important qualification about how infrastructure charges translate into market outcomes. A common assumption is that higher track charges are passed through to passengers as higher fares. The results show this is incorrect: as access charges increase, operators instead reduce frequencies while keeping fares relatively stable, driven by intermodal competition that discourages raising generalised travel costs. This illustrates a broader point relevant to infrastructure pricing across modes: the welfare effects of cost-reflective charges depend critically on market structure and operator behaviour, not just on the level of the charge itself.

Together, the papers highlight that efficient infrastructure pricing requires both disaggregated marginal cost estimates and an understanding of how charges translate into market outcomes.

References

- Andersson, M., Smith, A., Wikberg, Å., & Wheat, P. (2012). Estimating the marginal cost of railway track renewals using corner solution models. *Transportation Research Part A: Policy and Practice*, 46(6).
<https://doi.org/10.1016/j.tra.2012.02.016>
- Bak, M., Borkowski, P., Musiatowicz-Podbial, G., & Link, H. (2006). *Road infrastructure cost in Poland (Annex 1.2C to Deliverable D3, Marginal cost case studies for road and rail transport)*, GRACE. ITS, University of Leeds.
- Haraldsson, M. (2007a). Marginal costs for road maintenance and operation—A cost function approach. In 'Essays on Transport Economics'. [Doctoral dissertation, Uppsala University].
- Haraldsson, M. (2007b). *The marginal cost for pavement renewal: A duration analysis approach*. Working paper. VTI, Swedish National Road and Transport Research Institute.
<https://urn.kb.se/resolve?urn=urn:nbn:se:vti:diva-680>
- Link, H. (2009). *Marginal costs of road maintenance in Germany. Annex 3 to Deliverable D6, Road Cost Allocation for Europe: Recommendations and open questions, CATRIN (Cost Allocation of Transport Infrastructure)*. VTI, Swedish National Road and Transport Research Institute.
- Link, H. (2014). A cost function approach for measuring the marginal cost of road maintenance. *Journal of Transport Economics and Policy*, 48(1), 15–33.
- Murray, N., & Link, H. (2023). Estimating the Marginal Costs of Road Renewals: Evidence from a Duration Approach. *Journal of Transport Economics and Policy (JTEP)*, 57(2), 104–130.
- Nilsson, J.-E., Svensson, K., & Haraldsson, M. (2020). Estimating the marginal costs of road wear. *Transportation Research Part A: Policy and Practice*, 139, 455–471.
<https://doi.org/10.1016/j.tra.2020.07.013>
- Odolinski, K., Nilsson, J.-E., Yarmukhamedov, S., & Haraldsson, M. (2020). The marginal cost of track renewals in the Swedish railway network: Using data to compare methods. *Economics*

- of Transportation*, 22, 100170.
<https://doi.org/10.1016/j.ecotra.2020.100170>
- Schreyer, C., Schmidt, N., & Maibach, M. (2002). *(UN)ification of accounts and marginal costs for Transport Efficiency) Deliverable 10 Road econometrics – Case study motorways Switzerland*. ITS, University of Leeds.
- Swedish Transport Administration. (2024). *Trafikverkets årsredovisning 2024*. Swedish Transport Administration.
- Transport Analysis. (2025). *Transportsektorns samhällsekonomiska kostnader 2024* (2025:1). Transport Analysis.
- Yarmukhamedov, S., & Swärdh, J.-E. (2016). *Marginal cost of road maintenance and operation. Swedish estimates based on data from 2004 to 2014* (VTI Notat 15A-2016). VTI, Swedish National Road and Transport Research Institute.

Papers

The papers associated with this thesis have been removed for copyright reasons. For more details about these see:

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