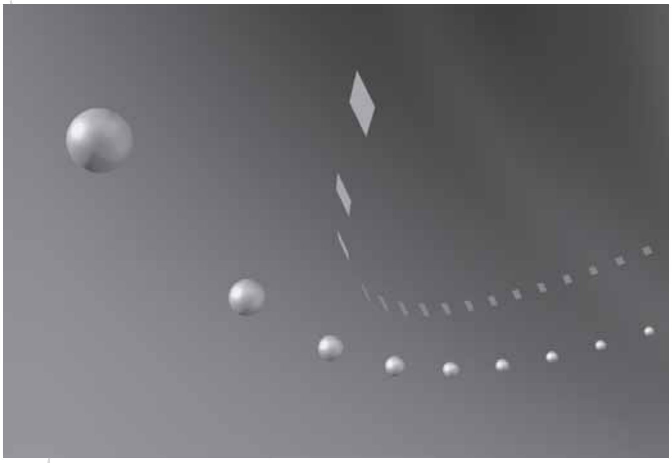
VTI notat 26A-2006
Published 2006

www.vti.se/publications



Noise charges in railway infrastructure

A pricing schedule based on the marginal cost principle

Henrik Andersson
Mikael Ögren

FINDING A BETTER WAY

Preface

This report constitutes an account of the project *PINA Noise Charges*. The aim of the project has been to outline a model on how to estimate railway noise charges which reflect the short run marginal social cost of noise. The project is joint work between Henrik Andersson, Dept. of Transport Economics, and Mikael Ögren, Dept. of Environment and Traffic Analysis, both at VTI (Swedish National Road & Transport Research Institute).

The authors would like to thank Karin Blidberg, Gunnar Lindberg, Chris Nash, Rikard Nilsson, Kjell Strömmer, and seminar participants at VTI and Banverket, for valuable comments on earlier drafts of this paper. The authors would like to express their gratitude to Evy Öhrström, Helena Svensson and Annbritt Skånberg for support with data, and Rune Karlsson for the constrained least squares polynomial fit of the marginal cost function. Financial support from Banverket is gratefully acknowledged. The authors are solely responsible for the results presented and views expressed in this paper.

Stockholm June 2006

Henrik Andersson
Project manager

Quality review

Internal peer review was performed by Gunnar Lindberg, research leader, on April 19, 2006. Henrik Andersson, researcher, has made alterations to the final manuscript of the report. The research director of the project manager examined and approved the report for publication on June 26, 2006.

Kvalitetsgranskning

Intern peer review har genomförts av Gunnar Lindberg, forskningsledare, 19 april 2006. Henrik Andersson, forskare, har genomfört justeringar av slutligt rapportmanus. Projektledarens närmaste chef har därefter granskat och godkänt publikationen för publicering 26 juni 2006.

Contents

Noise charges in railway infrastructure: A pricing schedule based on the marginal cost principle

by Henrik Andersson
Dept. of Transport Economics
VTI (Swedish National Road & Transport Research Institute)
SE-171 06 Solna Sweden

and Mikael Ögren
Dept. of Environment and Traffic Analysis
VTI (Swedish National Road & Transport Research Institute)
SE-402 78 Gothenburg Sweden

Summary

In order to mitigate the negative effects of transportation and to achieve a competitive transport sector, infrastructure charges in the European Union shall be based on short-run marginal costs. This paper shows that railway-noise charges can be estimated using already obtained knowledge of monetary and acoustical noise evaluation. Most European countries have standardised calculation methods for total noise level, which can be used to estimate the marginal acoustical effect. Based on a Swedish case study (with a relatively high number of exposed individuals), railway-noise charges are estimated at 0.026, 0.099 and 0.89 €/km for commuter, high-speed and freight trains, respectively.

Bulleravgifter för järnväg: Prissättning enligt marginalkostnadsprincipen

av Henrik Andersson
Avdelningen för Transportekonomi
VTI
171 06 Solna

och Mikael Ögren
Enheten för Miljö och trafikanalys
VTI
402 78 Göteborg

Sammanfattning

För att mildra de negativa effekter som uppkommer till följd av transporter samt för att uppnå en konkurrenskraftig transportsektor, har det beslutats att avgifter för infrastrukturutnyttjande inom den Europeiska Unionen skall baseras på kortsiktiga marginalkostnader. Denna studie visar hur befintlig kunskap om skattning av individers värdering av en tystare miljö samt skattning av bullernivåer kan utnyttjas för att beräkna bulleravgifter för järnvägen. De flesta europeiska länderna har standardiserade beräkningsmodeller för total bullernivå som kan användas för att beräkna marginalbuller. Baserat på en svensk fallstudie (med ett relativt högt antal bullerexponerade individer) skattas bulleravgifter till 0,026, 0,099 och 0,89 €/km för respektive pendel-, höghastighets- och godståg.

1 Introduction

The transportation of goods and people is beneficial to society, but imposes negative external effects, e.g. air pollution, noise, destruction of wild life areas, etc. One negative effect of growing importance is noise from transportation. Compared with the situation in the early 1990s, noise is the only environmental problem "for which the public's complaints have increased" (Öhrström et al., 2005b, p. 1). One reason is that the overall noise level has increased as a result of an increase in traffic volume. Another reason is that urbanisation has led to more individuals being exposed to traffic noise. Hence, even if noise emissions from traffic would have been constant during the last couple of decades, urbanisation itself would have caused noise to be a bigger problem today than it was a couple of decades ago (ceteris paribus). Therefore, if efforts are not taken to reduce either noise emissions or people's reception of noise, the problem will probably increase as a result of more people being exposed to noise in the future.

In this study we are interested in one specific noise source, railway traffic. In order to reduce the railway noise levels people are exposed to, policy makers can choose between reducing either the emission or the exposure. Several studies have shown that the costs of reducing emission at the source are lower than the costs of reducing high noise levels through barriers, façade insulation, etc. (de Vos, 2003; Oertli, 2000). Reducing emissions at the source requires either legislation or that the train operators are given incentives to do so. Well known problems with legislation are that: (i) the noise level might be set at a non-optimal level if the legislators are not fully informed, and (ii) it does not give the operators incentives to reduce their emissions below the given level. Incentives can be given either by subsidies where, e.g., operators are given subsidies to install "quiet technology", or imposing charges based on short-run marginal costs (SRMC), by which those operators, who contribute more to the noise emissions, will have to pay more and be induced to run quieter trains.

In order to achieve both a competitive transport sector and to mitigate negative effects from traffic, it has been decided that infrastructure charges in the European Union (EU) shall be based on SRMC (European Commission, 1998). Infrastructure charges based on SRMC internalise not only the external effects on the rest of the society, but also externalities within the transport sector, e.g. congestion. Charges based on SRMC, thus, give operators incentives to contribute to a more efficient allocation of resources, and have the potential to result in an optimal traffic volume and use of technology.

The aim of this study is to describe how railway-noise charges based on the marginal cost principle can be estimated.[1] Using already obtained knowledge on monetary and acoustical noise evaluation, we first estimate railway-noise charges in a case study and then outline an estimation model. In an ideal infrastructure charging system, railway charges would be diversified according to their true marginal social costs. However, it is necessary to compromise between the variability of the true SRMC and what is an economically sound charging scheme. We discuss the compromises/simplifications and the kind of information that we believe are necessary to estimate railway-noise charges.

The paper is organised as follows. In section 2.1 we briefly describe the SRMC in terms of an increase in railway traffic. We do not estimate any monetary values for noise reductions, since the aim is not to evaluate noise, but to design a model for charging train operators for their noise emissions. In section 2.2 we describe the monetary values used

[1] Regarding the conflict between the marginal social cost principle and full cost recovery, we refer to other literature for discussions on charging principles or financing problems, e.g. Nash (2005), Rothengatter (2003), or Sansom et al. (2001).

and how they are calculated. Since we believe that most readers are familiar with the subject of evaluation of non-marketed amenities, we dispense with a discussion on non-market evaluation methods.[2] In section 3.1, we briefly discuss the bad of interest to this study, i.e. noise, and how it is measured, which is followed by a description of how marginal noise is estimated in section 3.2. The next section contains a case study from Sweden where railway-noise charges are estimated. Section 5 outlines a model on how to estimate railway noise charges. Finally, section 6 offers some conclusions regarding our model and the results.

[2]For information on the topic we recommend any text book in environmental or health economics, e.g. Freeman (2003).

2 The Social Cost of Railway Noise

2.1 The Marginal Social Cost and Railway-Noise Charges

The SRMC of being exposed to railway noise is the social cost of one extra train. Let $C(L(Q,r,X))$ denote the individual cost-function which is a function of the noise level L. The noise level is assumed to be determined by the traffic volume (Q), distance to the noise emission source (r), and a vector of other factors assumed to influence the noise level (X), e.g. barriers and ground properties. The total social noise cost of railway traffic ($S(Q)$) can then be estimated as

$$S(Q) = \int_0^\infty C(L(Q,r,X))n(r)\mathrm{d}r, \tag{2.1}$$

where $n(r)$ is the density of exposed individuals at different distances. The marginal social cost ($M(Q)$) is the change in total cost as a result of a change in traffic volume, i.e.

$$M(Q) = \frac{\partial S(Q)}{\partial Q} = \int_0^\infty \frac{\partial C(L(\cdot))}{\partial L}\frac{\partial L(\cdot)}{\partial Q}n(r)\mathrm{d}r. \tag{2.2}$$

However, data on distributions of individuals are often available in discrete and not continuous forms. The estimation of railway-noise charges is then carried out using discrete models, and in equation (2.3) the integral over distance is divided into i discrete sections,

$$M(Q) = \sum_i \int_{a(i)}^{b(i)} c(L(\cdot))\frac{\partial L(\cdot)}{\partial Q}n(r)\mathrm{d}r, \tag{2.3}$$

where $a(i)$ and $b(i)$ are distance boundaries for interval i and $c(L(\cdot)) = \partial C(L(\cdot))/\partial L$. Further, the estimation of the railway-noise charges in the case study in this paper uses data where the noise level is equal for the individuals within each i-interval. From a policy perspective it is reasonable to assume that the noise levels will also be available in discrete forms[1], and if so $M(Q)$ can be written as

$$M(Q) = \sum_i c(L(\cdot))n(r)\Delta r\frac{\partial L(\cdot)}{\partial Q}. \tag{2.4}$$

The marginal social cost in equation (2.4) is for a marginal change in traffic volume, but in order to estimate railway-noise charges for one train we need to multiply $M(Q)$ with the actual change in traffic volume, denoted by ΔQ. Thus, let $T(Q)$ denote the railway-noise charge, then $T(Q) = M(Q)\cdot\Delta Q$. Moreover, in this paper the estimated railway-noise charges are based on noise levels, not distance to emission source. The number of exposed to the noise level L is given by $N(L)$, corresponding to $n(r)\Delta r$ in equation (2.4). Let ΔL denote the change in noise level from the increase in traffic[2]; then equation (2.5) is the railway-noise charge estimated in this paper,

$$T(Q) = \sum_L c(L(\cdot))N(L)\Delta L. \tag{2.5}$$

[1] For instance, based on the *European Commission's Environmental Noise Directive* data will be collected on the number of persons exposed to noise levels in 5 dB intervals (European Commission, 2002).

[2] $\Delta L = \frac{\partial L(\cdot)}{\partial Q}\Delta Q$

2.2 The Monetary Values used in our Case Study

As a measure of the social cost of noise exposure we employ the official monetary noise values used in Sweden (SIKA, 2005). These values are based on the results of a Swedish hedonic property-value study (Wilhelmsson, 1997).[3] The cost to society from noise exposure can be divided into (Metroeconomica, 2001): (i) *Resource costs*, i.e. medical and health service costs, both costs covered by insurances (public and private) and out-of-pocket payments, (ii) *Opportunity costs*, i.e. lost productivity and the opportunity cost of leisure, and (iii) *Dis-utility*, i.e. other social and economic costs, e.g. discomfort or inconvenience, and anxiety and concern about the future for oneself, family members and others.

Components (i)-(iii) are not completely separable, but may overlap, and simply adding the components would result in double counting. Components (i) and (ii) are often referred to as "cost of illness" (COI) in the evaluation literature and can be measured using market prices. Market prices usually do not exist for component (iii), the individuals' loss of utility, and, instead, different non-market valuation techniques are used to elicit the individuals' willingness to pay (WTP) to avoid, or willingness to accept (WTA), exposure to the noise. If the property owners in Wilhelmsson (1997) also considered the risk of financial losses, leisure time lost, etc., from the noise exposure, then the estimates include part of components (i) and (ii). We assume, however, that the full COI is not included in the estimates, and hence the monetary values used in this study should be interpreted as lower-bound estimates.[4]

Wilhelmsson (1997) estimated the relationship between property values and exposure to noise from road traffic in a suburb of Stockholm, Sweden. The price function was only estimated for sound levels above 55 dB and consisted of two linear segments; the function had a kink at 68 dB (dB is briefly explained in the following section) with a steeper slope for noise levels above 68 dB. The committee responsible for recommendations on cost-benefit analysis within the Swedish transport sector, ASEK[5], used the results from Wilhelmsson (1997), but decided that the annual individual cost function: (i) should be continuously progressively increasing, and (ii) have positive values also 51-55 dB as well (SIKA, 1999).[6]

The official cost estimates are only available in table format (SIKA, 2005), and in order to get a continuous marginal cost function we, therefore, calculate the marginal cost function by fitting a monotonic polynomial to the differences in table estimates.[7] The estimated monotonic polynomial used as our marginal cost function is given by

$$c(x) = 31.712 + 6.1563x + 0.88402x^2 + 0.032610x^3 - 0.0010994x^4, \qquad (2.6)$$

where $x = L_{\mathrm{AEq,24h}} - 62$, $L_{\mathrm{AEq,24h}} \in [50, 75]$.[8] $L_{\mathrm{AEq,24h}}$ refers to the equivalent A-

[3] The hedonic technique is one method to elicit the individuals' preferences. For studies on the evaluation of noise abatement, see e.g. Bateman et al. (2001), Navrud (2004) and Nelson (2004).

[4] The welfare measures from Wilhelmsson (1997) are based on the hedonic price function, not the hicksian demand functions. This simplified estimation procedure is possible for localised amenity changes when the price function is constant. Zero moving costs are assumed, however, which means that the benefit estimate is an upper bound (see e.g. Freeman, 2003).

[5] Arbetsgruppen för SamhällsEkonomiska Kalkyler, freely translated The Committee on Cost-Benefit Analysis.

[6] People are assumed not be disturbed at levels below 50 dB.

[7] We were in contact with representatives for ASEK, but they were not able to provide us with a cost function.

[8] Removing 62 from the argument keeps the coefficients of the polynomial at the same order of magnitude.

weighted noise level in dB. Monetary values are in Euros (€) in 2002 price level.[9] The lower bound is the bound set by ASEK and the upper bound does not apply in our analysis since no individuals in the case study area are exposed to noise levels above 75 dB.[10]

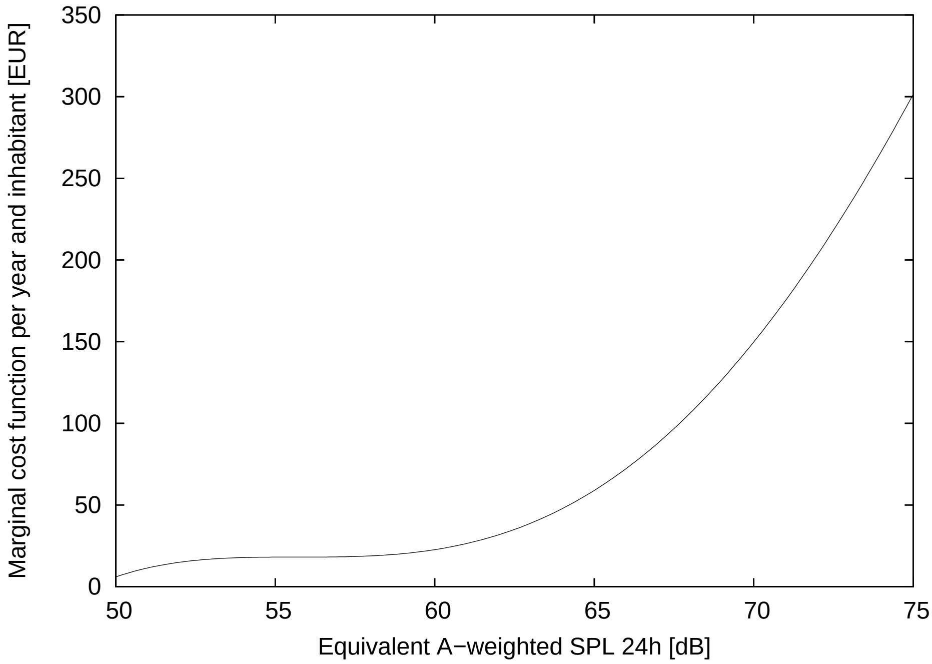


Figure 2.1 *Marginal cost as a function of* $L_{\mathrm{AEq,24h}}$.

[9]Values originally in Swedish kronor 2001 price level (SIKA, 2005). Adjusted to Euros (€) in 2002 price level using consumer price indices (www.scb.se, 02/03/06) and the average exchange rate for 2002, SEK 1 = € 9.16 (www.riksbanken.se, 02/03/06).

[10]ASEK developed a cost function for railway noise based on the results in Wilhelmsson (1997) (SIKA, 2002). This function includes the maximum noise level as one variable, but since the maximum level is not appropriate for estimation of marginal effects (see section 3.2), we do not use it.

3 Acoustical Parameters

3.1 Noise Indicator

The sound pressure level (SPL) determines the strength of the noise, and it is normally A-weighted. This weighting is different for different frequencies and is an approximation of the average sensitivity of the human ear. For railway-noise exposure two basic noise indicators are used, the equivalent and the maximum level. The equivalent level is an energy average over a certain time period, and the maximum level is the maximum level that occurs during a time period under certain restrictions, for details see, for instance, Sandberg and Ejsmont (2002).

The equivalent level is used as an indicator of general annoyance, and the maximum level as an indicator of sleep disturbance. The maximum level is more difficult to determine from noise measurements, since: (i) the longer the measurements the higher the maximum level, and (ii) it is easily influenced by sources other than the one examined. For railway noise the maximum level is simply determined by the loudest train passage, and all other train passages become irrelevant.[1] The equivalent level is more influenced by loud passages, but all trains contribute. No train passage can lower either the equivalent or the maximum level.

The equivalent level for a full 24-hour period is denoted $L_{\text{AEq,24h}}$. It is the most commonly used noise indicator, also used by Swedish authorities. However, in order to incorporate both the effects of general annoyance and sleep disturbance in one indicator, the L_{den} (level day evening night) has been proposed (Miedema and Oudshoorn, 2001) and chosen as the noise indicator for railway noise exposure in the *Environmental Noise Directive* (European Commission, 2002). This indicator is an equivalent level, but with a penalty for noise events in the evening and at night, effectively giving more weight to evening and night time traffic.[2]

3.2 Calculating the Acoustical Marginal Effect

The marginal effect in acoustical terms is the effect one extra train will have on the noise level. This effect is dependent not only on the acoustical parameters of the extra train, but also on the total traffic already present on the railway. For the maximum level the marginal effect is zero for all trains except for those louder than all trains already in traffic. For the equivalent level, the marginal effect is the increase in level that the marginal train will cause, which makes the equivalent level a more appropriate indicator than the maximum level when studying marginal effects.

In this study the standardised *Nordic method* (Jonasson and Nielsen, 1996), which is the method employed by Swedish authorities, is used to calculate both the equivalent levels of the current traffic and the marginal effects. This method utilises data on ground type, distance between rail and receiver, screening by buildings and terrain, train type and speed, and calculates the level at the receiver. The method assumes slightly unfavourable weather conditions, i.e. slightly higher sound levels than with a neutral atmosphere, and is stated to be accurate up to a distance of 300 m. This method will soon be replaced by a new more detailed and accurate Nordic method (Plovsing and Kragh, 2000a,b), which in turn will be replaced by a harmonised European method (de Vos et al., 2005).

[1] Strictly speaking, the maximum level will not only be determined by a single train passage, since there is a random effect involved. The maximum noise emission of a single train type is a distribution, and therefore different train types will contribute different probabilities to the maximum level. However, data on the distribution of the maximum emission levels are generally not available for a given train type.

[2] $L_{den} = 10 \log \left(\frac{12}{24} 10^{0.1 L_d} + \frac{4}{24} 10^{0.1 (L_e + 5)} + \frac{8}{24} 10^{0.1 (L_n + 10)} \right)$

4 Case Study Lerum

Lerum is a municipality located along the railway line (Västra stambanan) and the motorway (E20) between Gothenburg and Stockholm in Sweden. We employ data from a study conducted in order to examine health effects from noise exposure (Öhrström et al., 2005a,b). Öhrström et al. measured and calculated road and rail traffic noise levels for more than 24,000 inhabitants, and based on these calculations they chose a subset of the municipality around the railway and motorway for further investigation, see the sketch in Figure 4.1. In that area 3,120 dwellings had $L_{\mathrm{AEq,24h}}$ higher than 45 dB, and 2,751 questionnaires were distributed with a return rate of 71%, i.e. 1953 households answered the survey. The total number of exposed in our study is estimated based on the respondents' answers about household size and the total number of exposed dwellings.[1] A refined set of calculations of $L_{\mathrm{AEq,24h}}$ and L_{den} noise levels due to the railway traffic were carried out for those who answered the questionnaire, and it is these values that are used in our study. Non-responding households are excluded from our analysis since less information on noise exposure is available for them, and the number of exposed is, thus, underestimated.

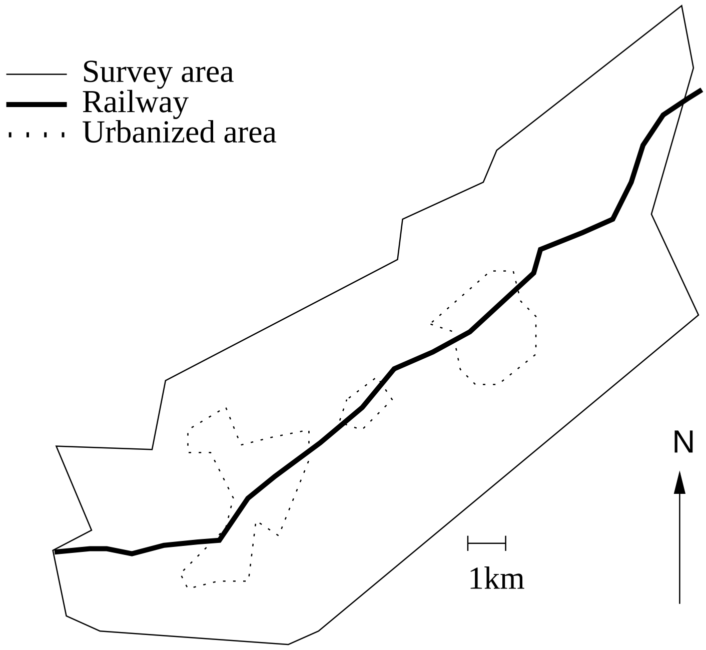


Figure 4.1 *Sketched map over the research area.*

4.1 Traffic Volume and Number of Exposed Individuals

The railway traffic through the survey area is 190 trains per day on two parallel tracks. The details are given in Table 4.1, where the acronyms *X10*, *X2* and *Rc* refer to commuter, high-speed and freight train, respectively. All trains are electrically powered and more details on the different train types can be found in Diehl and Nilsson (2003). The speed is relatively low, in other areas along the railway line speeds are up to 200 km/h (kilometres/hour) for high speed trains and up to 160 km/h for passenger trains. Note that freight traffic mainly occurs at night while the opposite is true for passenger traffic, and that the variation in train speed is relatively small.

[1] The average number of inhabitants per dwelling is 2.8.

Table 4.1 Railway traffic data

	Vehicle type			
	Commuter (X10)	**High speed (X2)**	**Freight (Rc)**	**Inter city (Rc)**
Length of train set [m]	50[a]	200	650[b]	125
Speed [km/h]	120	135	100	110
Number of trains				
day 07–19	51	19	9	27
evening 19–23	16	6	10	9
night 23–07	9	3	22	9

a: Some train sets are 100 m long in peak traffic.
b: Average length.
The acronyms X10, X2 and Rc are the Swedish acronyms for the train sets.

The track length is 21 km within the research area, and as illustrated in the upper diagram of Figure 4.2, where the number of inhabitants in each 25 m interval is plotted as a bar graph, the population is distributed relatively evenly as a function of distance to the railway. Only a few dwellings are located between 0 and 25 m, since this zone is either prohibited or occupied by infrastructure elements. Since high noise levels occur only in a relatively narrow zone close to the railway, fewer inhabitants are exposed to high compared with low noise levels. Summing up the number of inhabitants in each $L_{AEq,24h}$ 1 dB interval gives the distribution in the lower diagram of Figure 4.2. Note that the number of inhabitants in each interval below 50 dB seems constant instead of increasing, which is an artifact of the limited size of the research area.

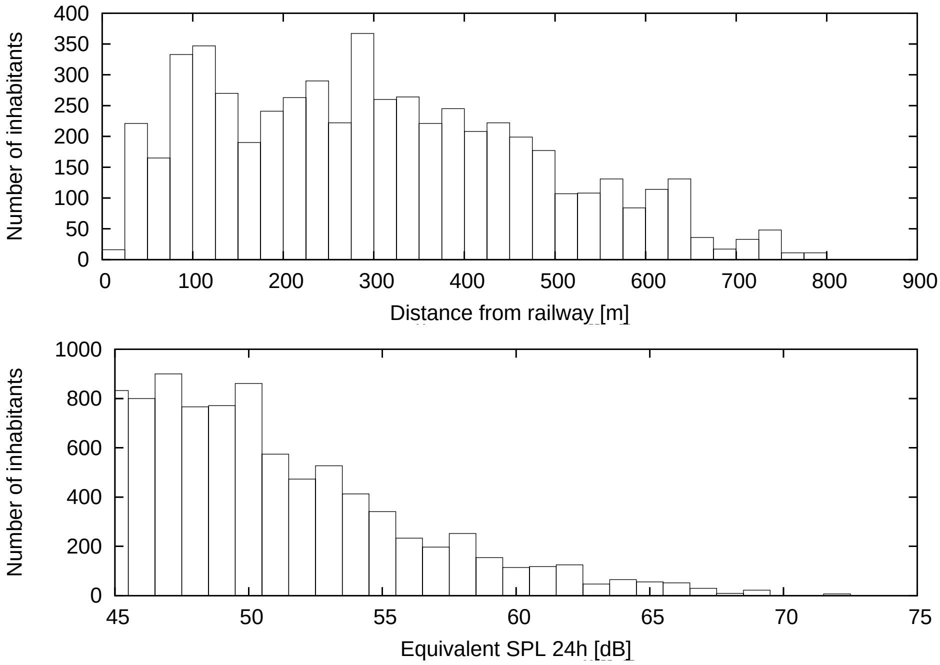


Figure 4.2 *Histogram of number of inhabitants in 25 m intervals of distance from railway (upper), and in 1 dB intervals of the equivalent sound level $L_{AEq,24h}$ (lower).*

In Figure 4.3 the equivalent noise level calculated at each respondent's dwelling is marked in a scatter plot against the corresponding distance from the railway. The horizontal lines are formed since the noise levels are rounded to integers. If only the distance to the railway was important for the noise level, the points would form a line, but for dwellings that are screened behind terrain or other buildings the level is lower than what can be expected from the distance only. Instead, the upper bound can be interpreted as the level at an openly exposed position and the spread as the varying degrees of shielding. The extreme outliers are dwellings where the position has been misinterpreted either when determining the distance to the railway (based on GIS data) or when calculating the sound level.

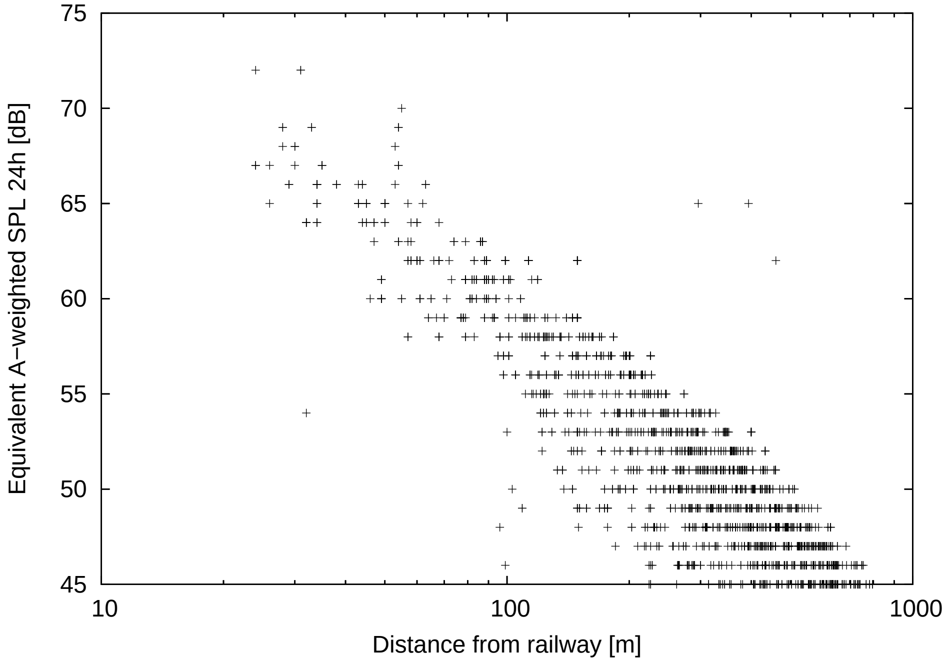


Figure 4.3 *Scatter plot of equivalent SPL $L_{\mathrm{AEq,24h}}$ versus distance from railway.*

4.2 Estimation of Railway-Noise Charges for Lerum

By combining information about the marginal cost function and the number of individuals exposed at different noise levels, the social cost associated with a marginal increase in the noise level can be estimated. Based on the railway-traffic data in Table 4.1 and using the *Nordic method* we calculate the marginal change in sound level from a single extra train passage per day for the three train types above. Using the marginal change in sound level, the annual marginal cost (T) in the survey area is calculated by multiplying the number of inhabitants in a 1 dB interval with the cost function and the acoustical change,

$$T = \sum_{L=50}^{75} c(x)\, N(L)\, \Delta L, \qquad (4.1)$$

where L defines $L_{\mathrm{AEq,24h}}$, and $N(L)$, $c(x)$ and ΔL are the number of inhabitants exposed in the 1 dB interval centred around L, the annual cost function from equation (2.6) and the change in sound level due to the marginal train, respectively.[2]

Figure 4.4 shows how the contribution to the marginal cost for one extra train passage varies with $L_{\mathrm{AEq,24h}}$. Levels below 50 dB do not contribute at all since the cost function in Figure 2.1 is not defined below 50 dB. It is interesting to note that even though the marginal cost per inhabitant is substantially lower for the inhabitants at the lower noise levels, their contribution is substantial since there are many more exposed inhabitants at lower levels. For instance, inhabitants exposed to levels below 55 dB (a level often considered to be tolerable) account for 32% of the total marginal cost.

[2]Note, from equation (2.6), $x = L_{\mathrm{AEq,24h}} - 62$.

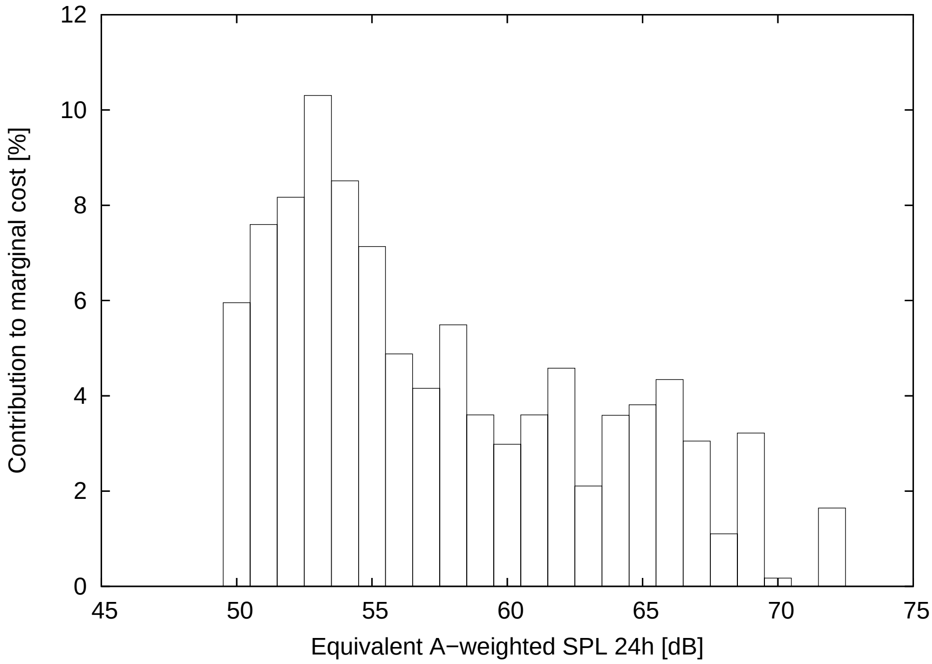


Figure 4.4 *Contribution to the marginal cost of inhabitants in each 1 dB interval.*

Rail access charges are often given per km. To get the calculated total marginal cost for the survey area in €/km it must be adjusted by the number of days per year and the length of the track within the survey area (21 km). The marginal cost estimates per km for the three train types are shown in Table 4.2. The marginal cost for the freight train is approximately ten times higher than the cost for the high speed train due to its length and higher source strength.

Table 4.2 *Marginal cost in €/km*

	Vehicle type		
	Commuter (X10)	**High speed (X2)**	**Freight (Rc)**
$L_{AEq,24h}$			
24h	0.026	0.099	0.89
L_{den}			
day	0.016	0.060	0.54
evening	0.050	0.19	1.7
night	0.16	0.60	5.3
	Charges based on 5 dB railway noise bonus[a]		
$L_{AEq,24h}$			
24h	0.0088	0.033	0.30
L_{den}			
day	0.0076	0.029	0.26
evening	0.024	0.091	0.81
night	0.076	0.29	2.5

a: The level is reduced by 5 dB before calculating the cost, assuming that railway noise is 5 dB less disturbing than road traffic noise.

When using $L_{AEq,24h}$ it does not matter when the train passage occurs. Using the L_{den} as the noise indicator means that the cost is different, depending on the time of day for the train passage. The marginal cost of a nighttime passage is about ten times as high as the daytime passage for all trains, corresponding to the 10 dB penalty for passages during the night when calculating the L_{den} indicator. Since the total level is slightly higher when using L_{den}, the acoustical marginal effect is lower for daytime passages compared to the equivalent level, which in turn gives a lower marginal cost. On the other hand the nighttime train passages have a substantially higher marginal cost when L_{den} is used compared with $L_{\text{AEq,24h}}$. However, it should be noted that the cost function in equation (2.6) was determined in a study based on equivalent levels, which introduces errors when estimating the effect for L_{den}.

Railway noise is believed to be less disturbing (in terms of general annoyance) than road traffic noise of the equivalent level (Miedema and Vos, 1998). In Sweden railway noise is considered to be 5 dB lower than the measured equivalent level when comparing to noise limits. This 5 dB deduction is called the railway noise bonus. Our marginal cost function is based on road traffic. In the lower part of Table 4.2 the effect on the charges from deducting the railway noise bonus is shown. As can be seen, the charges would be considerably lower if the railway noise bonus was taken into consideration.

4.3 Sensitivity to Total Traffic Volume

The marginal effect is not only dependent on the acoustical properties of the marginal train set, but also on the total traffic already present on the railway. For a low traffic volume the marginal acoustical effect might be substantial, but the total level the inhabitants are exposed to is relatively low. For a situation with a high total traffic the reverse is true; the marginal effect is small but the total level is high. Since the marginal cost depends on both the total level and the marginal effect, an interesting numerical experiment is to vary the total traffic and see how the marginal cost is affected.[3]

When the traffic volume is increased, the total noise level is also increased, which leads to more inhabitants being exposed to higher levels. On the other hand, the marginal effect of a single train passage is decreased, since it contributes less to the total noise level. In Figure 4.5 the marginal cost, which is the product of the two effects, for the freight train in the example above is calculated as a function of total traffic volume under the assumption that the proportions between different train types are not changed. As can be seen, the marginal cost is not very sensitive to the total traffic volume. Doubling the total traffic from 100% to 200% only changes the marginal cost by 10%.[4]

---

[3]Let $f(z)$ and $g(z)$ denote the marginal cost function and the marginal noise function at different noise levels (z). The marginal cost at a given noise level (z) is given by $MC(z) = f(z)g(z)$. Reasonable assumptions are that $f(z) \geq 0$, $f'(z) > 0$, $f''(z) > 0$, $g(z) \geq 0$, $g'(z) < 0$, and $g''(z) > 0$, where primes denote differentiation. Without further assumptions, the effect on $MC(z)$ from an increase in the noise level is ambiguous,

$$MC'(z) = f'(z)g(z) + f(z)g'(z) \gtreqless 0.$$

[4]Total traffic, 100%, corresponds to the traffic used in the previous examples (190 trains per day).

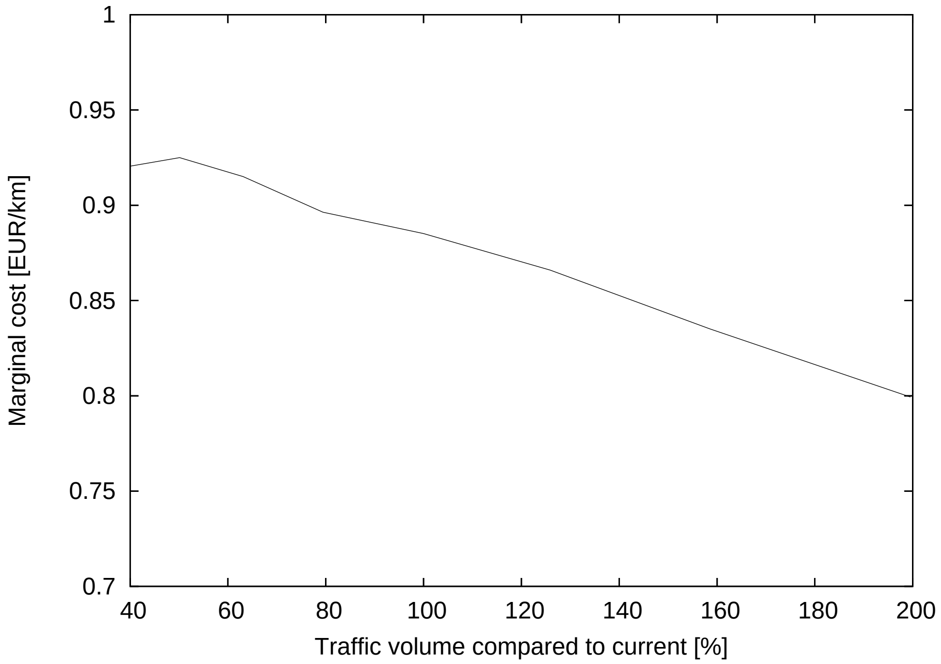


Figure 4.5 *Marginal cost for a freight train as a function of the traffic volume, where 100% corresponds to the traffic given in Table 4.1.*

5 Discussion of Estimation of Railway-Noise Charges

The estimations in section 4 illustrate how railway-noise charges can be estimated. In this section we make our recommendations on how to proceed in the development of estimation models for railway-noise charges.

5.1 The Monetary Estimate of Noise Abatement

It is desirable that all three social cost components from section 2.2 are included in the charges. The impact pathway approach (IPA) includes all three cost components and is intuitively appealing (Bickel et al., 2002; Metroeconomica, 2001; Navrud, 2004; Schmid and Friedrich, 2002).[1] IPA rests on assumptions for which there is a lot of uncertainty, however, and we believe that more research is needed before the IPA can be used to estimate the social cost of noise. Instead, we recommend that the social cost of noise is estimated as the sum of *Resource costs* and WTP estimates from stated- or revealed-preference studies. Since WTP estimates might reflect both opportunity and dis-utility costs, this approach mitigates double counting.

Today most cost estimates are based on noise from road traffic in living environments (Navrud, 2004). The characteristics of road traffic noise are quite different from those of rail traffic noise, and several studies have showed that individuals perceive noise from road traffic as more disturbing than from rail traffic (Miedema and Vos, 1998). This means that it is reasonable to expect that preferences for noise abatement differ between rail and road traffic. It is well known that the estimates are context-related and depend on the evaluation technique and quality of the evaluation study, which is a problem for “benefit transfers” (Bateman et al., 2001; Day, 2001; Navrud, 2004). We, therefore, recommend that monetary values for rail traffic are estimated when non-existing.

It would be desirable to have diversified estimates according to where (housing, business, recreation areas, etc.) and when the rail traffic occurs.[2] However, based on the state of the art of noise evaluation and on the costs associated with eliciting different values, we do not believe that a perfect differentiation is economically sound. Instead, we recommend that values from housing areas based on L_{den} are used for other areas as well. L_{den} is the indicator recommended by the European Commission (European Commission, 2002), and since it depends on when the traffic occurs, it punishes evening and night traffic.

5.2 Estimation of the Acoustical Marginal Effect

Calculating the total noise level is rather straightforward. Most European countries have standardised calculation methods and there is also a common European method (de Vos et al., 2005) that can be used. The input data needed (apart from traffic volume data) is typically information on terrain heights, noise emission of the train types in traffic, the ground properties (acoustic impedance), screening objects such as buildings, distance between railway and receiver, and meteorological conditions. The marginal acoustical effect can be calculated with these standardised methods by taking the difference of the noise level before and after the marginal train is added. Care has to be taken so that the calculated values are not rounded off before the difference is taken (commercially available software often outputs integer values).

Noise emission data is normally available for existing train types and the noise predic-

[1] For a description of the method see ExternE (2005).

[2] Carlsson et al. (2004) showed, for airport noise, that the individual WTP varies depending on when the disturbance occurs.

tion methods include procedures for adding new train types based on field measurements. There is also an *EN ISO* standard for determining noise emission from railway vehicles (ISO, 2005). Thus, train types can be diversified with standardised calculation methods and available information, which is important if we want the railway-noise charges to reflect the train types' SRMC.

5.3 Number of Individuals Exposed to Noise

As shown in section 4.3 the marginal cost is not very sensitive to changes in traffic volume. The number of exposed individuals has a large influence on the estimates, however. As illustrated in Figure 4.5, increasing the traffic volume by 100% reduces the marginal cost by approximately 10%, whereas a doubling of the number of exposed doubles the marginal cost. For instance, Lerum is relatively densely populated, and by combining the distribution of people exposed in Lerum with the population density of 8 other municipalities along the same train route, the SRMC for freight traffic is reduced from € 0.89/km to € 0.42/km.[3]

In order to estimate the number of exposed at different noise levels, information on the distribution of individuals in relation to the railway is needed. If the location of each individual is known, the noise level at that location can be calculated. However, data on the exact location of each exposed individual along a certain railway line is difficult to obtain. Perhaps the most efficient way is to make detailed calculations for a number of areas and then extrapolate to different regions via smart rules of thumb based on inhabitant density, urban/rural area, terrain type, etc, as illustrated in Figure 5.1. For instance, the *Swedish National Road Administration* uses a 4 level classification system (rural, urban sparse, urban medium and urban dense) when estimating the social cost of road noise.

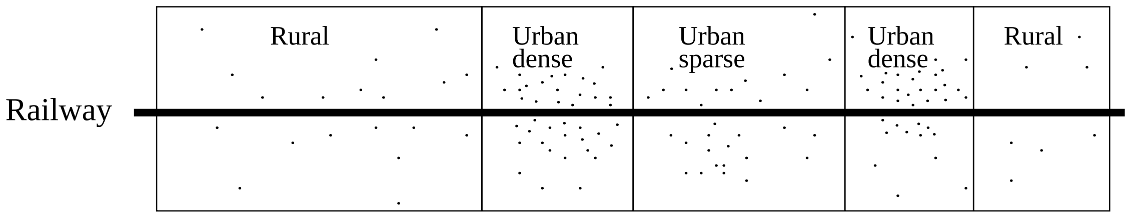


Figure 5.1 *Sketch of classification system of number of exposed inhabitants.*

In Europe an alternative and effective approach for determining the number of exposed individuals will soon be available. As part of the noise-mapping required by the European Commission's Environmental Noise Directive, the number of exposed persons along railway lines with relatively heavy traffic will be surveyed and published by infrastructure managers starting in 2007 (European Commission, 2002). These data will be available as the number of persons exposed to noise levels in 5 dB intervals, both for $L_{\mathrm{AEq,24h}}$ and L_{den}, and can be used directly to calculate the noise charge for the railway lines surveyed. Railway lines with less traffic will not be included in the survey, and must be dealt with using other methods, for example by rules of thumb and a classification as described above.

Since the data from the case study in section 4 is given in 1 dB intervals, the error of grouping exposed persons together in 5 dB intervals can easily be investigated. In Figure 5.2 the effect of grouping is demonstrated by plotting the 5 dB interval data together with the original data from Figure 4.2. When using the centre of each 5 dB interval

[3] See appendix for how this lower SRMC was calculated.

to calculate the cost function in equation (2.6), the marginal cost for running a train through the area is 18% higher. This increase is caused by inhabitants being shifted to and assumed exposed to the level at the centre of the interval, when in reality there are more exposed inhabitants in the lower end of the interval than in the high end. If the distribution of individuals is known, either from theory or from detailed surveys, this error can be compensated for. Preliminary tests on our case study indicate that the error can be reduced to a few percent only.

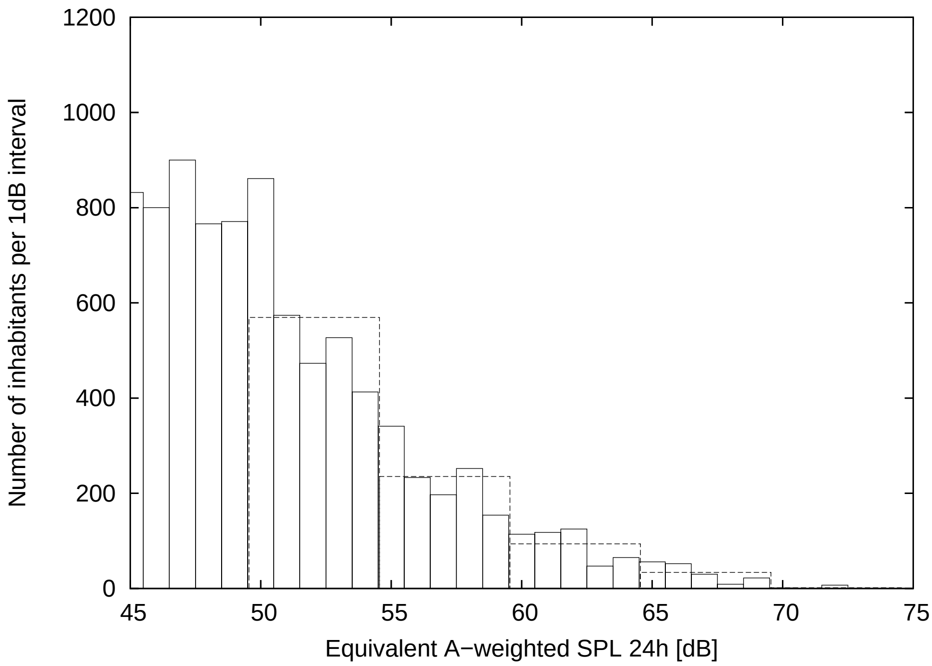


Figure 5.2 *Histogram of number of inhabitants in 1 dB and 5 dB intervals of the equivalent sound level* $L_{AEq,24h}$.

Even though the 5 dB intervals from the European surveys result in errors, it would be unnecessary duplication of work to redo them to get more detailed descriptions of the number of exposed individuals. Uncertainties in the monetary values are likely to be at least of the same order. Instead, the focus should be on how to use the results as effectively as possible for the calculation of noise charges, and on dealing with railway lines that are not included in the surveys.

6 Conclusions

The calculated railway-noise charges in this study are of limited value since they are based on a single case study.[1] However, from our case study we have learned that: (i) the effect of changes in total traffic (within reasonable limits) for a certain railway line on the SRMC is negligible, (ii) the estimated SRMC is sensitive to the number of individuals exposed, and (iii) standardised methods can be used to get diversified charges. Thus, there is often no need to update the marginal cost calculations based on changes in traffic volume, but it is important that the estimated number of exposed individuals reflect actual numbers exposed, especially for lower noise levels, since most individuals belong to this group. The estimated charges in Table 4.2 show not only that diversification is possible, but also that the estimates are in line with what we expect, i.e. considerably higher for freight and night traffic.

One problem with charges that differ between countries is that a diversity of rail infrastructure charges poses a problem for international rail freight (Nash, 2005, p. 259). However, it is important that charges are context-dependent and that the noise part of any charges is not too simple in its construction. A charge which is the same for all train types is an obvious problem, since it might destroy the incentive for operators to utilise technology that reduces the noise emission. For instance, changing brake pads on freight waggons from cast iron to commercially available composite pads typically lowers the equivalent noise level by 8 dB according to the *International Union of Railways* (UIC).[2] Lowering the level for the freight train in our example by 8 dB lowers the marginal cost from € 0.89/km to € 0.14/km, a strong incentive for operators if it is available within the rail access charge system.[3]

We have shown that, with information on the number of people exposed, it is possible to calculate the SRMC for railway noise by using standardised calculation methods and estimates of monetary values already in use by national authorities. The railway noise prediction methods will be harmonised within the European Union in the future, and noise maps will be available for all major railways as required by the Environmental Noise Directive of the European Commission (European Commission, 2002). The missing piece in the puzzle, from both a European and a global perspective, is that monetary noise values based on rail-traffic are often missing.

[1] Based on a 10% increase in traffic, Sansom et al. (2001) estimated, for Great Britain, SRMC for passenger and rail traffic in the ranges 0.13-0.42 and 0.28-0.94 €/km. (Values originally in GBP 1998 price level. Values adjusted using consumer price indices and exchange rates (www.econstats.com, 06/07/06).

[2] For calculations see http://www.uic.asso.fr/environnement/Railways-Noise.html (04/13/06).

[3] For overviews of rail infrastructure charges in Europe, see CEMT (2005) or Hylén (2005).

References

Bateman, I., B. Day, I. Lake, and A. Lovett: 2001, 'The Effects of Road Traffic on Residential Property Values: A Literature Review and Hedonic Pricing Study'. Technical report, University of East Anglia, Economic & Social Research Council, and Univeristy College London.

Bickel, P., S. Schmid, and R. Friedrich: 2002, 'Estimation of Environmental Costs of the Traffic Sector in Sweden'. Mimeo, Institut für Energiewirtschaft und Rationelle Energieanwendung (IER), Universitä Stuttgart.

Carlsson, F., E. Lampi, and P. Martinsson: 2004, 'Measuring Marginal Values of Noise Disturbance from Air Traffic: Does the Time of Day Matter?'. *Transportation Research Part D* **9**(5), 373–385.

CEMT: 2005, 'Railway Reform and Charges for the Use of Infrastructure'. CEMT/CS (2005)8, European Conference of Ministers of Transport (CEMT).

Day, B.: 2001, 'The Theory of Hedonic Markets: Obtaining Welfare Measures for Changes in Environmental Quality using Hedonic Market Data'. Economics for the Environment Consultancy, Mimeo.

de Vos, P., M. Beuving, and E. Verheijen: 2005, 'Harmonised Accurate and Reliable Methods for the EU Directive on the Assessment and Management of Environmental Noise – Final technical report'. Technical report. http://www.harmonoise.org.

de Vos, P.: 2003, 'How the Money Machine May Help to Reduce Railway Noise in Europe'. *Journal of Sound and Vibration* **267**(3), 439–445.

Diehl, U. and L. Nilsson: 2003, *Svenska lok och motorvagnar*. Gothenburg, Sweden: Svenska Järnvägsklubbens förlag. ISBN 91-85098-98-1.

European Commission: 1998, 'White Paper on Fair Pricing for Transport Infrastructure Use'.

European Commission: 2002, 'European noise directive 2002/49/EG'.

ExternE: 2005, 'ExternE: Externalities of Energy. A Reserach Project of the European Union'. Internet, www.externe.info, 10/7/05.

Freeman, A. M.: 2003, *The Measurement of Environmental and Resource Values*. Washington, D.C., US: Resources for the Future, 2 edition.

Hylén, B.: 2005, 'Banavgifter i Europa - rapport till Banverket'. Mimeo VTI dnr 2005/0495-21, VTI, Solna, Sweden.

ISO: 2005, 'Railway applications – Acoustics – Measurement of noise emitted by railbound vehicles'. EN ISO 3095:2005, International Organization of Standardization (ISO) and European Comittee for Standardization (CEN).

Jonasson, H. and H. Nielsen: 1996, 'Road Traffic Noise – Nordic Prediction Method'. TemaNord 1996:525, Nordic Council of Ministers, Copenhagen, Denmark. ISBN 92-9120-836-1.

Metroeconomica: 2001, 'Monetary Valuation of Noise Effects: Final Draft Report'. Mimeo, May, Preparde for The EC UNITE Project.

Miedema, H. and C. Oudshoorn: 2001, ‘Annoyance from Transportation Noise: Relationships with Exposure Metrics DNL and DENL and Their Confidence Intervals’. *Environmental Health Perspectives* **109**(4), 409–416.

Miedema, H. and H. Vos: 1998, ‘Exposure-response relations for transportation noise’. *Journal of the Acoustical Society of America* **106**(6), 3432–3445.

Nash, C.: 2005, ‘Rail Infrastructure Charges in Europe’. *Journal of Transport Economics and Policy* **39**(3), 259–278.

Navrud, S.: 2004, ‘The Economic Value of Noise Within the European Union - A Review and Analysis of Studies’. Mimeo.

Nelson, J. P.: 2004, ‘Meta-Analysis of Airport Noise and Hedonic Property Values: Problems and Prospects’. *Journal of Transport Economics and Policy* **38**(1), 1–28.

Oertli, J.: 2000, ‘Cost-Benefit Analysis in Railway Noise Control’. *Journal of Sound and Vibration* **231**(3), 505–509.

Öhrström, E., L. Barregård, A. Skånberg, H. Svensson, P. Ängerheim, M. Holmes, and E. Bonde: 2005a, ‘Undersökning av hälsoeffekter av buller från vägtrafik, tåg och flyg i Lerums kommun’. Technical report, Environmental Medicine, Sahlgrenska, Gothenburg, Sweden. ISSN 1400-5808.

Öhrström, E., A. Skånberg, L. Barregård, H. Svensson, and P. Ängerheim: 2005b, ‘Effects of Simultaneous Exposure to Noise from Road and Railway Traffic’. Inter-Noise.

Plovsing, B. and J. Kragh: 2000a, ‘Comprehensive Outdoor Sound Propagation Model. Part 1: Propagation in an Atmosphere without Significant Refraction’. Delta report AV 1849/00, Delta, Lyngy, Denmark.

Plovsing, B. and J. Kragh: 2000b, ‘Comprehensive Outdoor Sound Propagation Model. Part 2: Propagation in an Atmosphere with Refraction’. Delta report AV 1851/00, Delta, Lyngy, Denmark.

Rothengatter, W.: 2003, ‘How good is first best? Marginal cost and other pricing principles for user charging in transport’. *Transport Policy* **10**(2), 121–130.

Sandberg, U. and J. A. Ejsmont: 2002, *Tyre/Road Noise Reference Book*. Kisa, Sweden: Informex. ISBN 91-631-2610-9.

Sansom, T., C. A. Nash, P. J. Mackie, J. Shires, and P. Watkiss: 2001, ‘Surface Transport Costs and Charges: Great Britain 1998’. Final report, Institute for Transport Studies, University of Leeds, UK.

Schmid, S. A. and R. Friedrich: 2002, ‘External costs of transport noise. a bottom-up appraoch’. Inter-noise 2002.

SIKA: 1999, ‘Översyn av samhällsekonomiska kalkylprinciper och kalkylvärden på transportområdet’. SIKA Report 1999:6, SIKA (Swedish Institute for Transport and Communications Analysis), Stockholm, Sweden.

SIKA: 2002, ‘Översyn av samhällsekonomiska kalkylprinciper och kalkylvärden på transportområdet’. SIKA Report 2002:4, SIKA (Swedish Institute for Transport and Communications Analysis), Stockholm, Sweden.

SIKA: 2005, ‘Kalkylvärden och kalkylmetoder - En sammanfattning av Verksgruppens rekommendationer 2005’. Pm 2005:16, SIKA (Swedish Institute for Transport and Communications Analysis), Stockholm, Sweden.

Wilhelmsson, M.: 1997, ‘Trafikbuller och fastighetsvärden - en hedonisk prisstudie’. Meddelande 5:45, Division of Building and Real Estate Economics, Royal Institute of Technology, Stockholm, Sweden.

Appendix A Extending the Lerum data: Västra Götaland

In section 4.3 it is demonstrated that the marginal cost is not very sensitive to the total traffic volume. The marginal cost is sensitive to the number of exposed individuals, however. Therefore, in order to demonstrate this sensitivity, the calculation of the marginal cost of a freight train is extended to the eight neighbouring municipalities within the region *Västra Götaland* in Figure 1.

Figure 1 *Railway route map Västra Götaland*

When calculating the marginal costs presented in Table 1, it is assumed that the distribution of exposed individuals as a function of distance to the railway is identical to the distribution in Lerum in section 4 (i.e. the shape of the function in Figure 4.2) and the same for all municipalities. Given this assumption, and that the traffic volume is the same as in Lerum[4], the marginal costs of the other municipality are estimated by scaling the ratios of the population densities and the lengths of the railway tracks based on the data from Lerum. These factors are given as percentages in the table. This is a crude approximation, since it assumes that the distribution of inhabitants follows the same pattern as in Lerum, and that the shielding effect of terrain and buildings follows a similar pattern. However, the municipalities show some significant similarities, for instance that a majority of population centres are located along the railway line.

Table 1 *Marginal cost calculation for one freight train passage through nine municipalities based on the data from Lerum*

Municipality	Inhabitants per km^2	Track length [km]	Factor	€	€/km
Partille	580	6	117%	6.42	1.04
Lerum	138	22	100%	19.89	0.89
Alingsås	75	18	44%	7.23	0.40
Vårgårda	25	18	15%	2.37	0.13
Herrljunga	19	22	14%	2.69	0.12
Falköping	29	42	40%	14.85	0.35
Skövde	74	35	85%	26.62	0.75
Töreboda	17	30	17%	4.47	0.15
Gullspång	18	9	5%	0.43	0.05
Total		204			0.42

The result in Table 1 shows that if the lower population density of the region as a whole (compared with Lerum) is taken into account, the marginal cost of one freight train passage is lowered from € 0.89/km to € 0.42/km.[5]

[4]This assumption is unproblematic, since the SRMC is not very sensitive to the traffic volume.

[5]Note that the city of Gothenburg is not included, since it is unreasonable to expect that it can be modelled in the same way as the municipality Lerum. Including Gothenburg would increase the marginal cost.

www.vti.se
vti@vti.se

VTI är ett oberoende och internationellt framstående forskningsinstitut som arbetar med forskning och utveckling inom transportsektorn. Vi arbetar med samtliga trafikslag och kärnkompetensen finns inom områdena säkerhet, ekonomi, miljö, trafik- och transportanalys, beteende och samspel mellan människa-fordon-transportsystem samt inom vägkonstruktion, drift och underhåll. VTI är världsledande inom ett flertal områden, till exempel simulatorteknik. VTI har tjänster som sträcker sig från förstudier, oberoende kvalificerade utredningar och expertutlåtanden till projektledning samt forskning och utveckling. Vår tekniska utrustning består bland annat av körsimulatorer för väg- och järnvägstrafik, väglaboratorium, däckprovningsanläggning, krockbanor och mycket mer. Vi kan även erbjuda ett brett utbud av kurser och seminarier inom transportområdet.

VTI is an independent, internationally outstanding research institute which is engaged on research and development in the transport sector. Our work covers all modes, and our core competence is in the fields of safety, economy, environment, traffic and transport analysis, behaviour and the man-vehicle-transport system interaction, and in road design, operation and maintenance. VTI is a world leader in several areas, for instance in simulator technology. VTI provides services ranging from preliminary studies, highlevel independent investigations and expert statements to project management, research and development. Our technical equipment includes driving simulators for road and rail traffic, a road laboratory, a tyre testing facility, crash tracks and a lot more. We can also offer a broad selection of courses and seminars in the field of transport.

vti

HUVUDKONTOR/HEAD OFFICE
LINKÖPING
POST/MAIL SE-581 95 LINKÖPING
TEL +46(0)13 20 40 00
www.vti.se

BORLÄNGE
POST/MAIL BOX 760
SE-781 27 BORLÄNGE
TEL +46 (0)243 446 860

STOCKHOLM
POST/MAIL BOX 6056
SE-171 06 SOLNA
TEL +46 (0)8 555 77 020

GÖTEBORG
POST/MAIL BOX 8077
SE-402 78 GÖTEBORG
TEL +46 (0)31 750 26 00