

# Property Prices and Exposure to Multiple Noise Sources: Hedonic Regression with Road and Railway Noise \*

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**Abstract** This study examines the effect of road and railway noise on property prices. It uses the hedonic regression technique on a Swedish data set that contains information about both road and railway noise for each property, and finds that road noise has a larger negative impact on the property prices than railway noise. This is in line with the evidence from the acoustical literature which has shown that individuals are more disturbed by road than railway noise, but contradicts recent results from a hedonic study on data of the United Kingdom.

**Key words** Hedonic Pricing; Noise; Railway Traffic; Road Traffic

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## 1 Introduction

It has been suggested that more than 20 percent of the population of the European Union (EU) are exposed to higher noise levels than considered acceptable (European Commission, 1996). Noise is an environmental and health problem of major concern in many developed countries, and one of the major sources of noise exposure is the transport sector. Noise from this sector is problematic for, broadly speaking, two reasons: (i) increasing transportation of goods and people means higher noise levels, and (ii) since transport is related to human activity and needs, much of it occurs in areas where people live, work, go to school, etc. The latter means that today's urbanization will lead to noise being a bigger problem in the future unless efforts are made to mitigate the problem (Nijland et al., 2003).

Such efforts come at a cost, though, and policies and projects to reduce noise levels need to be evaluated to secure an efficient resource allocation. Benefit cost analysis (BCA) is a powerful tool to evaluate noise abatement, but it requires both benefits and costs to be measured in a common metric. Moreover, the EU has decided that infrastructure charges should be based on short-run marginal costs (European Commission, 1998), which has the potential of mitigating the negative effects of traffic. Such charges also require monetary values. To monetize the social value of changes in noise levels, analysts rely on non-marketed good evaluation techniques, and the technique that dominates is Rosen's hedonic regression method (Rosen, 1974).

Most studies monetizing noise have focused on road and air noise (Nelson, 1982, 2004; Bateman et al., 2001; Navrud, 2004). This study examines willingness to pay (WTP) to reduce road and railway noise. It is a well established fact in the acoustic literature that, for the same level of the noise indicator, individuals are more annoyed by road than by railway noise (Miedema and Oudshoorn, 2001).<sup>1</sup> However, in a recent study using the hedonic regression technique in the UK, Day et al. (2007) found that WTP among property owners to reduce railway noise was higher compared with road noise. This conflicting evidence is interesting since the evidence from the acoustic literature is based on individuals' stated annoyance from different noise sources, whereas the evidence in Day et al. is based on actual decisions by property owners.

This study examines how property prices are affected by multiple noise sources, in this case road and railway noise. The aims are: (i) to ascertain whether the findings in Day et al. (2007) are robust for the revealed preference literature or whether WTP is more in line with the findings in the acoustical literature, and (ii) to estimate WTP to reduce road and railway noise that could be considered in policy implementation. The first aim is of great interest from both a research and policy perspective since

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<sup>1</sup> The evidence also suggests that individuals are more annoyed by air than road noise (Miedema and Oudshoorn, 2001).

it examines how individuals' stated preferences (non-binding) agree with their actual behavior. The second aim is mainly of policy interest, since it examines the need for differentiated values in BCA or infrastructure charges (Andersson and Ögren, 2007a,b). We employ the hedonic regression technique on a municipality in the west of Sweden.

The article is organized as follows. Section 2 briefly describes the hedonic regression technique. Sections 3, 4, and 5 contain the data used, the econometric models, and the results. The final section discusses our findings and relates them to other results in the literature.

## 2 The hedonic regression technique

In his seminal paper, Sherwin Rosen (Rosen, 1974) showed that in an economy with utility and profit maximizing individuals and firms, marginal WTP for attributes of composite goods will equal their implicit prices.<sup>2</sup>

Considering the scenario of interest in this study, where our composite good is a property, let  $L$  and  $\mathbf{A} = [a_1, \dots, a_n]$  denote noise and a vector of other utility-bearing attributes. The hedonic price function ( $P$ ) may then be written as

$$P = P(L, \mathbf{A}). \quad (1)$$

Rosen showed that the consumer's WTP for the good will equal its market price. Since, in optimum, the consumer's marginal WTP equals his marginal rate of substitution between the price of the good and any of the attributes, the slope of the price function may be used to determine the consumer's marginal WTP. Focusing on noise, marginal WTP is, thus, estimated as

$$\text{MWTP} = \frac{\partial P(L, \mathbf{A})}{\partial L}. \quad (2)$$

The information about individuals' preferences from Eq. (2) only reveals marginal WTP in optimum; it does not reveal the underlying preference structure. To derive the price function and to estimate marginal WTP using the hedonic regression technique is sometimes referred to as the *first step* of the technique. In the *second step*, where the preference parameters are estimated, the results from the *first step*, together with information on property owners/households, are used. The *second step* enables the analyst to calculate "theoretically consistent" values for non-marginal changes, which was done in Day et al. (2007). In this study only the *first step* is conducted.

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<sup>2</sup> The hedonic regression technique has been discussed in several articles, books and book chapters (Bateman et al., 2001; Freeman, 2003; Haab and McDonnel, 2003; Ekeland et al., 2004; Palmquist, 2005; Andersson, 2008), and we therefore only give a brief introduction to the technique here. For a more comprehensive description of the technique, see references provided or the original source (Rosen, 1974).

### 3 Data

This study estimates the impact of traffic noise from both railway and roads on property prices in the municipality of Lerum close to Gothenburg in the west of Sweden. Lerum has about 36,000 inhabitants and a population density of 138 inhabitants per km<sup>2</sup>. Two major transport routes that connect Gothenburg and Stockholm, the railway line *Västra stambanan* and the motorway *E20*, cross the municipality. Figure 1 shows a sketch over the survey area with the two transport routes.

[Figure 1 about here.]

The data set used in this study originates from two sources. The data on the property prices and attributes (besides the noise levels) are from the *National Land Survey of Sweden* and are used for property taxation. The property attributes also contain the geographical coordinates, which are used here to derive geographical variables like neighborhood dummies and distance to nearest train station and highway entrance. The data set covers all the sales of single family houses in the municipality of Lerum from the autumn of 1996 to early 2006. Since the data covers a period of several years, the property prices have been adjusted to the property price index of the Gothenburg region and are shown at 2004 price levels. The sale closest to January 1st 2004 is used in the regressions for those properties that were sold several times during the period.

Information about noise levels is from a study on the health effects of traffic noise conducted in Lerum in 2004 (Öhrström et al., 2005). Separate noise calculations were made for railway and road noise for all the residential buildings in Lerum.

Descriptive statistics for the different variables are shown in Table 1. The following three sections describe the groups of variables used as explanatory variables in the price equations, followed by a section describing the exclusion criteria used in the regressions.

[Table 1 about here.]

#### 3.1 Structural variables

Structural variables define the character of the property, and those used in the regressions are property type, living space and a quality index that is based on a self-reported form that the house owner fills in for the tax assessment. The quality index is based on questions concerning the indoor-quality of the property, for instance the standard of the kitchen, the existence of an open fire place or a sauna, etc. The buildings are categorized as detached, linked by a garage or terraced.

### 3.2 Geographical attributes

The geographical variables included in the study are all derived from the coordinates of each property. All the properties are divided into 11 districts based on their distance to the five commuter train stations in the municipality. The commuter train stations are centrally situated in distinct neighborhoods and the district variables are constructed in a way that divides properties into two groups depending on whether they are 1 km or between 1 and 2 km from the nearest station. For properties more than 2 km from the nearest station a separate district is created, *Country side*. Moreover, a variable measuring the distance to the nearest commuter train station is included to further capture the accessibility to train and to other community services located close to the train stations. A dummy that equals one for the properties within 100 meters from the motorway *E20* is included to control for other disadvantages (or possibly advantages), apart from noise, of living close to a major road, like effects on air quality. To capture accessibility by car, the distance to the nearest entrance to the motorway *E20* is also included in the models.

### 3.3 Noise indicator

The most commonly used noise indicator is the A-weighted equivalent sound pressure level, which is an energy average over a certain time period, normally 24 hours and then denoted  $L_{Aeq,24h}$ . The A-weighting approximates the varying sensitivity of the human ear to different frequencies. The equivalent level is a good indicator of overall annoyance, but for sleep disturbance a better choice is the maximum level, which is normally defined as the maximum noise level occurring during a certain time period. The maximum level is more difficult to predict using calculation methods, and has a complex dependence on the traffic volume since a noisy vehicle may be present even in low traffic conditions (see Sandberg and Ejsmont, 2002). We will, therefore, focus on the equivalent level in this study.

In Öhrström et al. (2005) equivalent noise levels ( $L_{Aeq,24h}$ ) were calculated for each property separately for both rail and road noise using the “Nordic methods” (Jonasson and Nielsen, 1996; Nielsen, 1996). For each residential building the façade with the highest noise level was chosen to represent the property, which meant that the rail noise and the road noise for some properties occurred at different façades. The noise variables were calculated in 2003 and reflected the noise level for that particular year, but the effect of increasing traffic through the area is limited expressed as increased noise source strength.<sup>3</sup>

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<sup>3</sup> Approximately 1 dB for a 30% traffic increase over 10 years

The dB-scale used for all noise variables in this study does not have a natural zero point; instead, the zero of the scale is determined by convention (see Sandberg and Ejsmont, 2002). The sound pressure level 0 dB corresponds to a sound pressure of  $20 \mu\text{Pa}$ , which is roughly the lowest audible level for a tonal sound at a frequency of 1000 Hz. The total absence of sound is represented by a sound pressure of 0 Pa, corresponding to negative infinity on the dB scale ( $-\infty$  dB). For other environmental effects it makes sense to use valuations that vanish when the effect variable becomes zero (for instance, number of particles per  $\text{m}^3$  describing air pollution), but the same is not true for noise measured in dBs. The effect should be zero when no negative effect is observed from noise, and in our study we have chosen to use a lower limit of  $L_{\text{AEq},24\text{h}} = 45$  dB. The limit is somewhat arbitrarily determined, but the percentage of persons reporting that they are annoyed by traffic noise is very low below this level (Miedema and Oudshoorn, 2001). Therefore, the noise variables in our hedonic regressions are defined by the absolute noise level minus 45, with 0 for levels below 45 dB.

### 3.4 Included observations

As mentioned above, we assume that equivalent noise levels below 45 dB do not influence the property prices. However, to get a more homogeneous sample we include only properties with a total noise level that is assumed to be disturbing. As thresholds we use two levels, 50 and 55 dB. The first (50 dB) is the official Swedish threshold value, i.e. the official Swedish cost function from noise exposure is zero for noise levels below 50 dB (SIKA, 2005). The latter (55 dB) is often used by authorities as a limit value below which no measures are taken to mitigate the noise (Nijland and Van Wee, 2005). By using two threshold levels, we also examine how sensitive our regression results are to the chosen level. The threshold level is based on the total equivalent noise level, which is calculated as

$$L_{\text{tot}}(L_1, L_2) = 10 \log(10^{\frac{L_1}{10}} + 10^{\frac{L_2}{10}}). \quad (3)$$

where  $L_j$ ,  $j \in \{1, 2\}$ , represent the equivalent noise level in dB from road (1) and rail (2) traffic noise, respectively. When  $L_1$  and  $L_2$  are equal the total level becomes  $L_1 + 3$  ( $= L_2 + 3$ ). If one source is dominant, the other source will have very little influence on the total level ( $L_1 + L_2 \approx L_1$  if  $L_1 \gg L_2$ ).

As shown in Table 1, restricting the observations to include only properties with a total noise level of at least 55 dB leads to a reduction of the data set by two thirds compared to using all the observations with a total noise level of at least 50 dB.

## 4 Econometric model

### 4.1 Spatial dependence

The first law of geography states “Everything is related to everything else, but near things are more related than distant things” (Tobler, 1970, p. 236). This statement has a bearing on hedonic regressions on property prices as the geographical location of a house is an important element of the good. The concept of near things being more related than distant things is named spatial dependence.

Spatial dependence, or spatial autocorrelation, implies that the assumption of independence between observations is violated. Spatial dependence is often handled through either a spatial lag or error model (Anselin, 1999). The different models can be hard to distinguish empirically, but they are based on different theoretical grounds. The spatial lag and error models are defined by,

$$P = \rho WP + A\beta + \varepsilon, \quad (4)$$

$$P = A\beta + u \text{ where } u = \lambda Wu + \varepsilon, \quad (5)$$

where  $W$  is the spatial weight matrix that describes the correlation structure between observations. The spatial lag model in Eq. (4) assumes that the property price (the dependent variable), in addition to its attributes, is affected by the prices of neighboring houses. A spatial lag model is therefore appropriate when the interest lies in either estimating this spatial relationship or measuring the “true” or direct effect of the property’s own characteristics after removing the influence of nearby properties.

A spatial error model is, on the other hand, appropriate when properties share common amenities that have a spatial pattern and these amenities cannot be controlled for, as shown in Eq. (5). The spatial pattern in omitted variables leads to spatially autocorrelated error terms in a hedonic equation, which affects the inference even if ordinary least square (OLS) remains unbiased (Anselin, 1999). The spatial error model is an appropriate choice when the aim is to obtain efficient estimators and unbiased inference and not model the spatial relationship *per se*. If  $\rho$  and  $\lambda$  are 0 the spatial lag and error models are reduced to the OLS model.

What kind of model best describes the spatial pattern for our study is hard to tell beforehand. That prices of neighboring properties influence the price of a property is conceivable as a prospective buyer might look at the prices of neighboring properties to form an opinion of a reasonable price. This kind of pattern is best described by a spatial lag model. On the other hand, the emphasis of this study lies in obtaining unbiased estimates of the effect of noise on the property prices, not in describing the spatial pattern *per se*, which suggests that a spatial error model may be appropriate.

#### 4.2 Hedonic price functions

The noise profiles of road noise and railway noise differ (Miedema and Oudshoorn, 2001), and it is therefore reasonable that the influence of road and railway noise on the property price varies. Since our data set contains information about noise levels from both road and railway noise for the properties, it enables us to estimate separately how the different noise sources affect the property prices. Thus, our regressions include separate variables for road and railway noise.

In estimating a relationship between noise and property prices, the choice of functional form is not self-evident. Economic theory leaves us without much guidance (Rosen, 1974) and a variety of forms is used in the empirical literature. The semi-logarithmic functional form, where the natural logarithm of the price is assumed to be a linear function of the noise level, is a common choice, but other functional forms such as piecewise linear regressions are also present in the literature (Theebe, 2004). We estimate: (i) a semi-logarithmic price function, since it is the model that dominates in the hedonic noise literature, and (ii) a function that is designed to have an increasing WTP to reduce the noise level.

The semi-logarithmic model is given by,

$$\ln(P_i) = \beta_0 + \sum_{j=1}^2 \beta_j L'_{ij} + \sum_{h=1}^H \beta_{h+2} a_{ih} + \varepsilon_i \quad (6)$$

where  $L'_{ij}$  denotes the noise variables, which are defined as the noise level above 45 dB, subscript  $i$  denotes single properties,  $j$  denotes road (1) and rail (2) as above, and  $a_{ih}$  other property attributes besides the noise variables. The semi-logarithmic model implies a convex relationship between the price of a property and the noise level (when  $\beta_j \neq 0$ ,  $j \in \{1, 2\}$ ), i.e. marginal WTP based on the price function is higher for low noise levels compared to the marginal WTP for high noise levels. However, if the marginal disutility of noise increases with the level, marginal WTP should increase with the noise level. We, therefore, want to relax the assumption of a convex relationship and estimate a functional form that allows for a concave relationship between the property price and the noise level, i.e. a function where the marginal price discount is increasing with the noise level.

A function that attempts to capture a concave relationship between the property price and the noise level is

$$P_i = \gamma_0 \prod_{j=1}^2 f(L'_{ij}) \prod_{h=1}^H a_{ih}^{\gamma_h} + \varepsilon_i, \quad (7)$$

where  $\gamma_h$  are parameters to be estimated, and where

$$f(L'_{ij}) = 1 + \frac{1 - b_j - (1 - b_j) e^{k_j L'_{ij}}}{e^{30k_j} - 1}. \quad (8)$$

The parameter  $b$  corresponds to the maximum effect at the highest allowable noise level 75 dB and  $k$  describes the concavity of the function. Figure 2 (a) and (b) shows the functional form for different values

of  $b$  and  $k$ , holding the other parameter constant. The parameter  $k$ , restricted to be between 0 and 1, is estimated as,

$$k_j = \frac{e^{c_j}}{1 + e^{c_j}}, \quad (9)$$

thus,  $k$  is allowed to differ between road and rail noise. Hence, Eq. (7) makes it possible to assume not only different maximum effects from railway and road noise, but also different degrees of concavity for the two noise sources.

[Figure 2 about here.]

## 5 Results

### 5.1 Spatial Dependence

The semi-logarithmic model has been tested for spatial dependency using a row-standardized distance-based spatial weight matrix. The reason for not testing the concave function for spatial dependence is that methods for incorporating spatial dependence in non-linear regressions have not been developed. Test results after estimation on the data set including properties with a total noise level of at least 55 dB are shown in Table 2. There are no signs of spatial dependence, either in the form of a spatial error model or a spatial lag model.<sup>4</sup> Therefore, the models are estimated without considering the spatial dimension.

[Table 2 about here]

### 5.2 Hedonic price regressions

The regression results from the semi-logarithmic model and the concave function for the two subsets (total noise levels of at least 50 or 55 dB based on Eq. (3)) are shown in Table 3.<sup>5</sup> We first focus on the semi-logarithmic model, in which the structural variables are statistically significant and with the expected signs, with one exception, *Linked*, which is not statistically significant in the regression with only properties exposed to  $L_{\text{tot}} \geq 55$  dB. Some of the neighborhood dummies are also significant compared to the reference group (*Floda 2*). The prices of properties situated within 100 meters from the motorway *E20* are not significantly affected by the motorway, given that the noise level is controlled for. Neither does the distance to the nearest train station nor entrance to the motorway significantly affect the price. The coefficients for the noise variables are our main interest and for both subsets the discount for road noise is higher than for railway noise.

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<sup>4</sup> The same tests have been executed on the data set including properties with a total noise level of at least 50 dB with the same result, i.e. we cannot reject the hypothesis of spatial independence.

<sup>5</sup> Note that the estimated parameters are not directly comparable since the functional forms differ. Signs and statistical significance can be compared for the structural and geographical variables, though.

Using the observations with a total noise level equal to or above 50 dB, the road noise coefficient is highly significant, whereas the railway noise coefficient is significant only on the 10% level. The coefficients imply that a 1 dB increase in road and railway noise is associated with approximately a 1.3% and a 0.4% decrease in property price. Using only the properties with a total noise level equal to or above 55 dB reveals a slightly higher influence of both road and railway noise on the price, 1.7% for road noise and 0.7% for railway noise per dB, both highly significant. The coefficients for road and railway noise are statistically significantly different in both regressions. The fit is slightly better using the data set with only properties with a total noise level equal to or above 55 dB with a  $R^2$  at 0.56, compared to using properties where the threshold is set to 50 dB with a  $R^2$  at 0.51.

The concave price function is estimated using nonlinear least-square estimation. This functional form reveals similar results to the semi-logarithmic functional form in terms of signs and statistical significance of the coefficient estimates. Regarding the noise variables, the relevant hypothesis testing for  $b_j$  is whether the coefficient is equal to one, since  $b_j = 1$  suggests that the price is not influenced by the noise level. For both data sets  $b_1$  (road noise) is significantly different from 1 while  $b_2$  (rail noise) is not significantly different from 1 at the 10% level. The  $k$ -parameter is calculated using the estimates of  $c_j$  (see Eq. (9)), and is restricted to being between 0 and 1 where a higher value implies a more concave function and a value close to zero implies an almost linear relationship between the noise level and the property price.

[Table 3 about here.]

The results show that the relationship between property value and rail noise is more concave than the relationship between property value and road noise, which is illustrated in Figure 3 (a), where the factors  $f(L'_{ij})$  from Eq. (7) are plotted with the estimated parameters. If only properties with a combined equivalent noise level greater than or equal to 55 dB are included in the analysis, the functions become less concave and predict a stronger negative influence on the price for both road and rail traffic noise. Comparing the  $b_j$  and  $c_j$  coefficients; the only statistically significant difference is found for  $c_1$  and  $c_2$  in the regression on a total noise level of at least 55 dB.

Figure 3 (b) displays the factors  $e^{\beta_j L'_{ij}}$  and  $f(L'_{ij})$  from the semi-logarithmic (Eq. (6)) and concave model (Eq. (7)), respectively. The semi-logarithmic model estimates a stronger negative effect on the price at low noise levels compared to the concave model, and the effect is reversed at high noise levels.

[Figure 3 about here.]

The *Noise Sensitivity Depreciation Index* (NSDI) is often used to compare results from SP and RP noise studies (Bateman et al., 2001; Navrud, 2004). It gives the percentage change in property value due

to a 1 dB decrease in noise exposure,

$$\text{NSDI} = \left| \frac{\partial P}{\partial L} \frac{100}{P} \right|. \quad (10)$$

The semi-logarithmic functional form has the advantage of giving an easily interpretable noise coefficient that can be approximately interpreted directly as the NSDI. This means that the NSDI is constant for all noise levels.

For the concave price function the NSDI is given by,

$$\text{NSDI}(L'_{i,j}) = 100 \cdot \frac{f'(L'_{i,j})}{f(L'_{i,j})} = 100 \cdot \frac{k_j(1-b_j)e^{k_j L'_{i,j}}}{e^{30k_j} - b_j - (1-b_j)e^{k_j L'_{i,j}}} \quad (11)$$

which, since other attributes cancel, only depends on the noise level.<sup>6</sup> Thus, the NSDI of the concave model increases with the noise level as a consequence of the functional form.

Table 4 shows NSDI estimates for the semi-logarithmic model and for different noise levels for the concave model. The higher degree of concavity for rail noise leads to lower NSDI values from rail noise than road noise for low noise levels but higher values for very high noise levels. The effect of rail noise on the property prices is lower than the effect of road noise for all noise levels except the highest (70 dB). There are few properties with noise levels above 70 dB, only three properties with road noise at 70 dB or above and three properties with railway noise above 70 dB. This means that the calculated NSDI are based on very few observations for the highest noise levels. Comparing the NSDI for road noise from the semi-logarithmic model with that from the concave model shows that it is lower for all noise levels for the semi-logarithmic model compared with the concave model. The NSDI for railway noise shows more mixed results where the concave model gives lower price discounts for railway noise at low noise levels, but higher discounts at higher noise levels compared to the semi-logarithmic model.

[Table 4 about here.]

## 6 Discussion

This study estimates the effect of exposure to road and railway noise on property prices. We have also examined the effect of different functional forms and of the assumption of when noise has an effect on the property price (50 or 55 dB). In contrast to the findings in Day et al. (2007) we show that road noise has a larger impact on property prices than railway noise.<sup>7</sup> Our results are in line with the evidence from the acoustical literature that individuals are more disturbed by road than railway noise (Miedema and Oudshoorn, 2001).

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<sup>6</sup>  $f'(L'_{i,j}) = \frac{k(1-b)e^{kL'_{i,j}}}{e^{30k}-1}$

<sup>7</sup> Except at the highest noise levels ( $\geq 74$  dB) using the concave price function. Note that the estimated price functions at these high noise levels are based on a small number of observations.

We have not been able to reject the hypothesis of no spatial dependency. The reason why we have not detected spatial dependency may be explained by the relatively homogeneous sample, since the study area was constrained to one municipality. Spatial dependency is, therefore, ignored in our estimated regressions, which are based on a semi-logarithmic and a concave price function. The findings between price functions and subsamples are robust with expected signs of statistically significant coefficient estimates. Moreover, we show that the chosen threshold level (50 or 55 dB) has an impact on the results. In the semi-logarithmic function the influence of the noise is higher for the 55 dB threshold level for both noise sources. In the concave function, the same result is found for lower levels, but the opposite for higher levels.

Our estimates of NSDI for road noise in the semi-logarithmic price function are within the range of previous estimates, e.g. Bateman et al. (2004) reported a range of 0.08-2.22 with a mean value of 0.55. The estimates from the concave function are within the range for noise levels 55, 60, and 65 dB, but above the range for 70 dB when it comes to railway noise. The estimates for road noise are above 2.22 also for medium high noise levels. Overall, we conclude that our NSDI estimates are higher than most of the values reported in Bateman et al. (2004). For railway noise the number of empirical estimates of NSDI is limited; however, Day et al. (2007) report a NSDI of 0.67. Our estimate from the semi-logarithmic model and a total noise level above or equal to 55 dB is close to this estimate, 0.69, whereas the estimate from the other subsample is lower and the estimates from the concave function varies between 0.09 – 4.48.

A question not addressed in this study is what noise indicator to use. We use the equivalent level for a full 24-hour period,  $L_{Aeq,24h}$ , which is the most commonly used noise indicator. An example of another indicator that better reflects both general annoyance and sleep disturbance is the  $L_{den}$  (level day evening night), which has been chosen as the noise indicator in the *Environmental Noise Directive* (European Commission, 2002). Baranzini and Ramirez (2005) examined the effect of different noise indicators in hedonic studies and found that the impact was “fundamentally the same, whatever the noise measure used” (p. 643). The above mentioned and examined noise indicators are all scientific indicators. Individuals are, however, assumed to base their decisions on subjective beliefs. Thus, hedonic studies should then be based on subjective and not scientific noise indicators. Baranzini et al. (2008) studied how estimates differed between using a subjective and a scientific noise indicator and found that for moderate and high noise levels (55 to 75 dB) the scientific noise measure approximated the subjective measure, and that the subjective measure did not improve the hedonic estimation.

A theoretically consistent measure of welfare estimates for non-marginal changes of the noise levels requires the estimation of the second step of Rosen’s hedonic regression technique (Rosen, 1974; Freeman, 1974). Only the first step is estimated in this study, which means that theoretically consistent estimates

cannot be obtained from our results. However, if the price function does not shift as a result of changes in the noise level, e.g. if the number of properties with a change is small relative to the total market, the price function may be used to calculate the welfare measure (Freeman, 2003, p. 379). The official Swedish policy values for noise abatement (SIKA, 2005) are based on estimates from a hedonic study on road traffic noise using this approach (Wilhelmsson, 2000). The values show a highly convex relationship between the social cost of noise exposure and the noise level, which is a result of the functional form of the price equation in Wilhelmsson (2000). Our study reveals a less convex relationship for road noise, which is in line with Day et al. (2007), who estimated the second step, and thus, a theoretically consistent welfare estimate.

Our findings, which contrast with Day et al. (2007) but are in line with the evidence from the acoustical literature (Miedema and Oudshoorn, 2001), are especially interesting since respondents from the study on which the data set is based stated that they were more annoyed by railway than road noise (Öhrström et al., 2005). Öhrström et al. (2005) assumed that this was an effect of strategic answers by the respondents, since a new railway track through Lerum was being planned at the time of the survey. The conflicting evidence of stated and revealed preferences for road and railway noise is interesting and highlights the importance of further research.

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Figure 1 Sketched map over the research area

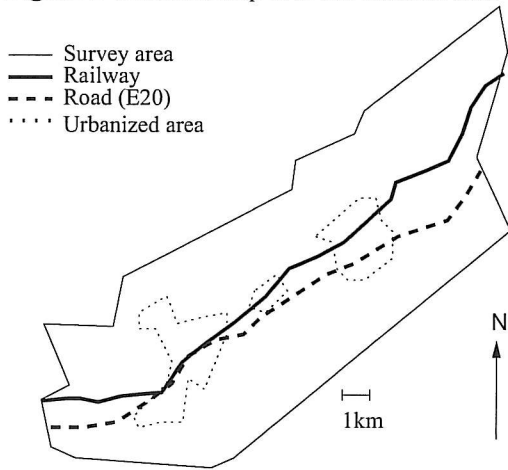


Figure 2 Influence of the parameters  $b$  and  $k$  on the price function (8)

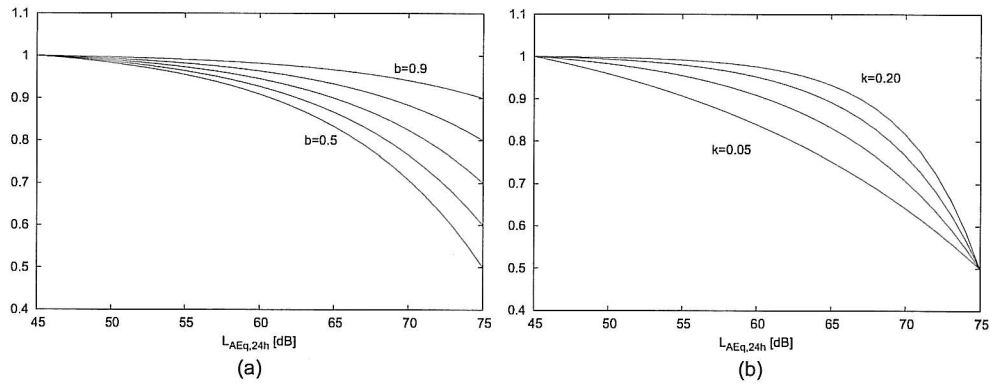
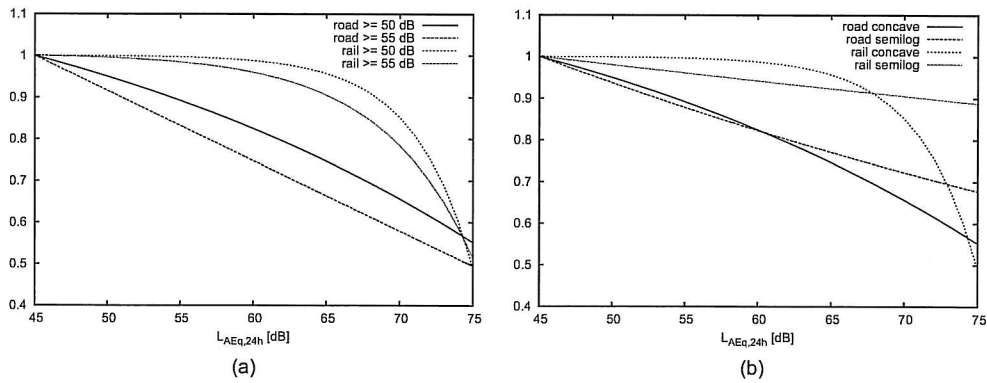


Figure 3 Estimated price functions: (a) Concave price functions for road and railway noise and threshold levels, (b) Semi-logarithmic and concave functions for road and railway noise ( $\text{dB} \geq 50$ )



**Table 1** Descriptive Statistics

Variable	Description	Mean value		
		All	$L_{tot} \geq 50$ dB	$L_{tot} \geq 55$ dB
Price	Property price in thousand SEK and 2004 price level	1887.215 (655.354)	1917.913 (675.549)	1812.621 (738.747)
Living space	Living space in square meters	128.709 (48.099)	130.144 (47.606)	132.350 (61.515)
Quality Index	Index of indoor-quality	28.934 (5.359)	29.016 (5.517)	28.299 (5.444)
Dist. station	Distance to nearest railway station in km	1.296 (1.018)	1.191 (1.061)	1.117 (1.260)
Dist. entrance	Distance to nearest motorway entrance in km	1.527 (0.772)	1.427 (0.743)	1.317 (0.693)
Road noise	Road noise in dB exceeding 45 dB	5.065 (4.535)	7.566 (4.17)	11.415 (4.895)
Rail noise	Rail noise in dB exceeding 45 dB	1.837 (4.040)	3.005 (4.888)	6.680 (6.597)
Terraced	Dummy equals one if terraced house	0.056	0.063	0.081
Linked	- " - if house linked by a garage	0.100	0.093	0.051
Detached	- " - if detached house	0.843	0.844	0.868
Aspen 1	- " - if <1 km from nearest stn Aspen	0.017	0.026	0.048
Aspen 2	- " - if 1-2 km from nearest stn Aspen	0.054	0.043	0.015
Aspedalen1	- " - if <1 km from nearest stn Aspedalen	0.033	0.049	0.102
Aspedalen2	- " - if 1-2 km from nearest stn Aspedalen	0.096	0.088	0.039
Lerum1	- " - if <1 km from nearest stn Lerum	0.040	0.063	0.117
Lerum2	- " - if 1-2 km from nearest stn Lerum	0.230	0.252	0.177
Floda1	- " - if <1 km from nearest stn Floda	0.023	0.035	0.042
Floda2	- " - if 1-2 km from nearest stn Floda	0.299	0.246	0.180
Stenkullen1	- " - if <1 km from nearest stn Stenkullen	0.013	0.019	0.045
Stenkullen2	- " - if 1-2 km from nearest stn Stenkullen	0.047	0.067	0.153
Countryside	- " - if >2 km from nearest station	0.149	0.112	0.084
E20 100m	- " - if within 100 m from motorway	0.047	0.079	0.228
N		1738	1034	334

Standard deviations in brackets. For dummies,  $\text{std.dev.}(x) = \sqrt{\bar{x}(1 - \bar{x})}$ .  
 EUR 1 = SEK 9.13, [www.riksbank.se](http://www.riksbank.se), 9/16/2008

**Table 2** Diagnostic tests for spatial dependency in OLS regression

Test	Statistic	df	p-value
<i>Spatial error:</i>			
Moran's I	0.900	1	0.368
Lagrange multiplier	0.586	1	0.444
Robust Lagrange multiplier	0.851	1	0.356
<i>Spatial lag:</i>			
Lagrange multiplier	0.022	1	0.882
Robust Lagrange multiplier	0.287	1	0.592

**Table 3** Regression Results Semi-logarithmic and Concave function

Variable	Semi-logarithmic model		Concave model	
	$L_{tot} \geq 50$ dB	$L_{tot} \geq 55$ dB	$L_{tot} \geq 50$ dB	$L_{tot} \geq 55$ dB
Living space	0.003*** (0.00)	0.003** (0.00)	0.486*** (0.02)	0.553*** (0.04)
Quality Index	0.014*** (0.00)	0.018*** (0.00)	0.313*** (0.04)	0.433*** (0.08)
Terraced	-0.270*** (0.02)	-0.244*** (0.04)	-0.307*** (0.05)	-0.267*** (0.07)
Linked	-0.162*** (0.02)	-0.004 (0.06)	-0.175*** (0.03)	0.014 (0.06)
Aspen1	0.264*** (0.05)	0.266*** (0.09)	0.258*** (0.05)	0.187*** (0.06)
Aspen2	0.178*** (0.04)	0.162 (0.14)	0.212*** (0.04)	0.084 (0.10)
Aspedalen1	0.246*** (0.05)	0.230*** (0.08)	0.187*** (0.04)	0.096 (0.07)
Aspedalen2	0.327*** (0.03)	0.403*** (0.06)	0.308*** (0.03)	0.305*** (0.06)
Lerum1	0.231*** (0.04)	0.304*** (0.07)	0.158*** (0.04)	0.161** (0.06)
Lerum2	0.183*** (0.02)	0.188*** (0.05)	0.154*** (0.02)	0.101** (0.05)
Country Side	0.056 (0.06)	-0.240 (0.15)	0.097** (0.04)	-0.109 (0.09)
Stenkullen1	0.004 (0.08)	0.088 (0.11)	0.047 (0.06)	0.033 (0.08)
Stenkullen2	-0.042 (0.05)	-0.136** (0.06)	-0.009 (0.04)	-0.211*** (0.06)
Floda1	0.056 (0.05)	0.154 (0.10)	0.053 (0.05)	0.141* (0.08)
E20 100m	-0.011 (0.04)	-0.004 (0.05)	0.002 (0.04)	-0.014 (0.04)
Dist. Station	-0.020 (0.02)	0.028 (0.04)	-0.027 (0.02)	0.004 (0.04)
Dist. Entrance	0.028 (0.02)	0.011 (0.04)	0.035** (0.02)	0.020 (0.03)
Road Noise	-0.013*** (0.00)	-0.017*** (0.00)		
Rail Noise	-0.004* (0.00)	-0.007*** (0.00)		
$b_1$			0.552*** (0.13)	0.495*** (0.01)
$c_1$			-3.497*** (1.22)	-25.930*** (0.43)
$b_2$			0.492 (0.54)	0.515 (0.32)
$c_2$			-1.121 (1.04)	-1.660** (0.73)
Constant	6.715*** (0.09)	6.705*** (0.14)	62.670*** (10.10)	35.648*** (10.03)
$k_1$			0.029	$5 \cdot 10^{-12}$
$k_2$			0.246	0.160
N	1034	334	1034	334
$R^2$	0.507	0.556	0.949	0.950

Standard errors in brackets, robust for semi-log model.

Significance levels: \* 10%, \*\* 5%, \*\*\* 1%

$k_j = e^{c_j} / (1 + e^{c_j})$

Subscript  $j = \{1, 2\}$  denotes road (1) and rail (2).

**Table 4** Noise sensitivity depreciation index (NSDI)

Regression model	$L_{\text{tot}} \geq 50$ dB		$L_{\text{tot}} \geq 55$ dB	
	Road	Rail	Road	Rail
<i>Semi-log</i>				
All levels	1.32	0.36	1.73	0.69
<i>Concave</i>				
55 dB	1.40	0.09	2.02	0.33
60 dB	1.76	0.32	2.25	0.74
65 dB	2.25	1.12	2.53	1.75
70 dB	2.96	4.29	2.91	4.48

NSDI =  $|(\partial P / \partial L)(100/P)|$