# Estimating non-marginal willingness to pay for railway noise abatement: Application of the two-step hedonic regression technique*

Jan-Erik Swärdh†
Department of Transport Economics, VTI, Sweden

Henrik Andersson
Toulouse School of Economics (UT1, CNRS, LERNA), France

Lina Jonsson
Department of Transport Economics, VTI, Sweden

Mikael Ögren
Department of Environment and Traffic Analysis, VTI, Sweden

November 15, 2012

**Abstract**

In this study we estimate the demand for peace and quiet, and thus also the willingness to pay for railway noise abatement, based on both steps of the hedonic model regression on property prices. The estimated demand relationship suggests welfare gains for a 1 dB reduction of railway noise as; USD 162 per individual per year at the baseline noise level of 71 dB, and USD 86 at the baseline noise level of 61 dB. Below a noise level of 49.1 dB, individuals have no willingness to pay for railway noise abatement. Our results also show the risk of using benefit transfer, i.e. we show empirically that the estimated implicit price for peace and quiet differs substantially across the housing markets. From a policy perspective our results are useful, not only for benefit-cost analysis, but also as the monetary component on infrastructure use charges that internalize the noise externality.

**Keywords:** Benefits transfer; Hedonic regression; Railway noise; Willingness to pay

**JEL Codes:** C21; C26; Q51; Q53

*This study was funded by Banverket, and the financial support is gratefully acknowledged. Comments and suggestions by Mats Wilhelmsson and other conference/seminar participants at Korea University, Chungnam National University, Canadian Resource and Environmental Economics Study Group Annual Conference, and VTI are greatly appreciated. The authors are solely responsible for the results and views expressed in this paper.

†To whom correspondence should be addressed: VTI, Box 55685, SE-102 15 Stockholm, Sweden. E-mail: jan-erik.swardh@vti.se

# 1 Introduction

Noise in general, but transport related noise in particular, is a pollutant of major concern in many developed countries that not only causes disturbance but also negative health effects. For instance, in the European Union (EU) estimates suggest that more than 20 percent of the population are exposed to higher noise levels than are considered acceptable (European Commission, 1996). Road traffic is the major source, but other modes such as air and railway traffic also contribute substantially (Kalivoda et al., 2003; Lundström et al., 2003; SOU, 1993). Due to an increase in traffic volume and urbanization more people will be exposed, and to higher noise levels, unless measures are taken to mitigate either the amount of pollution or the levels to which individuals are exposed (Nijland et al., 2003).

When addressing the problems related to transport noise emissions, policy makers have, broadly speaking, two alternatives: (i) protecting individuals from the emissions, or (ii) reducing the emissions. Examples of the former are physical investments such as noise barriers or façade insulation, whereas examples of the latter are legislation on maximum emission levels, reduced speed limits, or when and where motor vehicles can be used. However these measures are not without cost, which means that there is a trade-off between accepting the noise exposure and using valuable resources to reduce it. Benefit-cost analysis (BCA) is a powerful tool to guide resource allocation, but its use requires that both costs and benefits are measured in a common metric. Money is usually used as this common metric and since no easily observable market prices exist for noise abatement, to employ BCA the benefits of reducing noise levels need to be monetized. An alternative approach to addressing the noise problem is to use the price mechanism, where those that pollute pay. For instance, it has been decided in the EU that infrastructure use charges should be based on the short run marginal cost principle. This also includes a noise component, but again for its estimation, it is necessary that noise is monetized (Andersson and Ögren, 2007, 2011).

The method used by economists to monetize environmental and health benefits (and costs) is the willingness to pay (WTP) approach. It measures the maximum amount individuals are prepared to pay (forgo other consumption) to receive a good or to avoid something undesired.[1] The empirical methods to monetize individual preferences can broadly

[1]Individual preferences can also be monetized using willingness to accept (WTA) which is the minimum amount required as compensation to give up a good or to accept something undesirable.

speaking be classified as revealed-preference (RP) or stated-preference (SP) methods. Whereas the RP methods use information about individuals' actual decision to estimate the WTP, SP methods are based instead on decisions in hypothetical markets.

In the evaluation of noise abatement, several SP studies have been conducted (e.g., Sælensminde, 1999; Parumog et al., 2006), but the field is dominated by RP studies (Nelson, 2008). The RP studies have in general elicited individuals' preferences for quieter living by examining the effect of noise levels on property prices, using the hedonic regression technique (Rosen, 1974). Most of the studies have estimated individuals' WTP to reduce road or aircraft noise, only a few studies have estimated WTP to reduce railway noise (McMillen, 2004; Theebe, 2004; Nelson, 2008; Bateman et al., 2001; Brandt and Maennig, 2011). The evidence that noise has a negative effect on property prices is strong. The empirical evidence also suggests, though, that the effect is market specific, i.e. individuals' WTP varies between markets. Moreover, the empirical evidence also suggests that individual WTP varies between noise sources (Day et al., 2007; Dekkers and van der Straaten, 2009; Andersson et al., 2010), which is in line with the evidence from the acoustical literature that the annoyance experienced from road, railway, and air noise differs (Miedema and Oudshoorn, 2001).

Examining the effect on the property prices from different attributes, here noise, is usually referred to as the first step of the hedonic regression technique. In the first step, individual WTP is estimated as the slope of the price function, and estimated WTP is therefore only a true preference measure of a marginal change in the noise level. The hedonic regression technique can also be used to derive the underlying preference structure, which is usually referred to as the second step of the technique. With few exceptions, studies using the hedonic regression technique have only conducted the first step, i.e. estimated the marginal WTP. For transport noise Day et al. (2007) extended the analysis and also conducted the second step with the aim of "recovering theoretically consistent and transferable values" (Day et al., 2007). Since the preference parameters and the demand function are recovered in the second step, it enables the analyst to estimate theoretically correct WTP estimates for non-marginal changes and to use the demand relationship for benefits transfer exercises.

The aim of this study is to elicit individual WTP to reduce railway noise using Swedish data. A recent Swedish study estimated WTP to reduce road and railway noise based on property prices, but it only conducted the first step of the hedonic regression technique

(Andersson et al., 2010). We follow Day et al. (2007) and also estimate the second step of the technique. Day et al. (2007) conducted their study using data from Birmingham, UK, and they estimated WTP for road, aircraft, and railway noise. We focus only on railway noise but we improve the analysis of Day et al. in three different aspects: (i) we use data from six geographically distinct markets, (ii) we perform the second stage of the hedonic regression technique by including socioeconomic characteristics on an individual level, and (iii) we have access to a larger data set of properties exposed to railway noise. Our objectives with the study are to: (i) derive monetary values that can be used for policy purposes, e.g. BCA and/or pricing of noise externalities as mentioned above, (ii) examine the effect of household characteristics on WTP, and (iii) examine how stable WTP is between markets. The third objective is a test of the use of benefit transfers and is of interest from both a policy and research perspective.

The paper is outlined as follows. In the next section we briefly describe the first and second step of the hedonic regression technique. In Section 3 we describe our data and show descriptive statistics. Then follows the modeling frameworks in Section 4, and results in Section 5. We discuss our findings in Section 6 and conclude our paper in Section 7.

## 2 The hedonic regression technique

We use the hedonic regression technique to derive a property price function and to estimate a demand function for peace and quiet. This technique was formalized by Rosen (1974) and has been used in several studies to monetize individuals' preferences for non-market goods. Since it is already well described in the literature (see, e.g., Rosen, 1974; Haab and McConnell, 2003; Palmquist, 2005) we only provide a brief description of the technique and how we apply it.

The hedonic regression technique assumes that a property's price is a function of its utility bearing attributes. Let $P$ denote the property price and the price function can be written as

$$P = P(Q, \mathbf{A}, \mathbf{G}), \quad (1)$$

where $Q$, $\mathbf{A}$, and $\mathbf{G}$ denote the level of peace and quiet, a vector of property characteristics, and a vector of geographical variables, respectively. Rosen (1974) showed that in optimum the marginal WTP for a specific attribute of the good revealed by the market, equals the marginal rate of substitution between the price of the good and the attribute. When the market is in optimum the marginal WTP is estimated by the slope of the price function. Thus, the implicit price of peace and quiet, $\pi$, is defined by

$$\pi = \frac{\partial P}{\partial Q}, \tag{2}$$

and since we expect $Q$ to have a positive effect on the price of the property, $\pi > 0$. Equations (1) and (2) are usually referred to as the *first step* of the hedonic regression technique, and they provide the marginal WTP in optimum. That is, they do not reveal the underlying preference structure.

To estimate the preference parameters, Rosen (1974) suggested to using the results from the first step, together with information on the household of the property-owner ($\mathbf{S}$), to derive a marginal WTP function. This is often referred to as the *second step* and has been considerably debated due to the problem of identifying the marginal WTP function (see, e.g., Ekeland et al., 2004). One proposed solution has been to use data from different property markets where the hedonic price functions differ but where the preference structure is the same across markets.[2] We follow this approach but in accordance with Day et al. (2007), we specify the equation in the second step as demand for peace and quiet and not the WTP-function as suggested by Rosen (1974). Hence, in our application, the second step model is specified as

$$Q = Q(\pi, \mathbf{S}, \mathbf{A}, \mathbf{G}), \tag{3}$$

which results in the estimated (Marshallian) demand for peace and quiet. From this demand function we can calculate the theoretically consistent WTP for non-marginal changes of peace and quiet. The main reason for following Day et al. (2007), and to estimate the second step as the demand for peace and quiet instead of the WTP function, relates to the access to instruments. With an implicit price on peace and quiet that varies depending on the noise level, the buyer of a property will simultaneously choose the implicit price and quantity of peace and quiet. Endogeneity problems will therefore arise in both specifications, but the instrumented variable will differ. To find instruments for the quantity of peace and quiet, which are not correlated with the implicit price of peace and quiet through the property price, would be very difficult. Thus, it is easier to

[2]Other possible estimation approaches to go beyond the optimum function of the first step analysis are to use a quasi-experimental approach to valuate noise abatement (e.g. Boes and Nüesch, 2011) or to assume a specific utility function and derive non-marginal WTP from estimations of the expenditure rates (see e.g. Wilhelmsson, 2002).

instrument the implicit price of peace and quiet compared to the quantity of peace and quiet.

## 3 Data and market segmentation

We use data from seven Swedish municipalities. Our selection of municipalities is mainly driven by: (i) a requirement to have a sufficient number of properties exposed to different levels of railway noise, (ii) no large roads close to the railway, and (iii) municipalities geographically located in different parts of Sweden. The municipalities we use are Töreboda, Sollentuna, Falköping, Hässleholm, Kungsbacka, Alingsås and Gävle. The locations of these municipalities are shown in Figure 1, and characteristics of the municipalities are presented in Table 1.

[Figure 1 about here.]

The municipalities vary regarding population size and location with respect to the closest urban areas. Töreboda is a very small municipality located in a rural area. Sollentuna, Kungsbacka and Alingsås can be categorized as suburban municipalities located close to Stockholm and Gothenburg respectively. Gävle is the largest municipality and also the center of its region, whereas Falköping and Hässleholm are mid-sized municipalities located too far away from an urban area to be considered as suburban municipalities.

[Table 1 about here.]

### 3.1 Data sources

The data set used, originates from four sources. The data on prices and attributes of the properties is from the *National Land Survey of Sweden*, which is used for property taxation by the Swedish authorities. The property attributes also contain the geographical coordinates, which are used to derive geographical variables. The data set covers all sales of single family houses from the autumn of 1996 to September 2009 in each municipality. We deflate the property prices to the value of 2009 by regional property price indices for the county to which the municipality belongs.[3]

Traffic data was obtained from the *Swedish Transport Administration*, and the general map data, such as terrain heights, was obtained from *Lantmäteriet*, the Swedish

[3] These indices are used instead of the consumer price index because the price increase of properties in Sweden between 1996 and 2009 was much larger than the increase of consumer prices; for properties this increase was 171 percent whereas the increase was only 17 percent for consumer prices.

mapping, cadastral and land registration authority. The areas were inspected on site to determine the presence and height of sound barriers. Based on this data, railway noise levels were estimated following the standardized "Nordic methods" (Jonasson and Nielsen, 1996; Ringheim, 1996).

Individual socioeconomic characteristics are provided as register data by *Statistics Sweden*.[4] This data provides us with information on all individuals who are registered as living in a given property at the end of the purchase year of that property. The variables we utilize are income (available up to year 2008), age, household size and education level.

The following four subsections describe the groups of variables used as explanatory variables in the property price equations and in the demand equation.

#### 3.1.1 Structural variables

Structural variables define property characteristics. We use property type, living space, subsidiary space, property area, quality index, age of the dwelling, and an indicator variable for properties bordering the sea or a lake. Property types are distinguished as detached, linked by a garage or terraced. The quality index is based on a self-reported form completed by the house owners for the tax assessment concerning the indoor-quality of the property, for instance the standard of the kitchen, number of bathrooms, the existence of an open fire place or a sauna, etc. Age of dwelling is missing in a total of 437 cases in step 1. We impute the missing values by using the predicted values from a housing market-specific regression on age of dwelling, with the other structural variables and the geographical variables described below as covariates.[5]

#### 3.1.2 Geographical variables

The geographical variables are derived from the coordinates of each property and are supposed to capture accessibility differences and environmental disutility sources, other than noise exposure, within each municipality. As geographical variables, when applicable, we use the distance to nearest train station, an indicator for countryside[6], the distance

[4]For reasons of integrity, Statistics Sweden merged the socioeconomic data with our property data only under the condition that it should not be possible to trace individual properties. This means that Statistics Sweden had deleted all geographical coordinates when we received the merged data set, which potentially can be a limit to our analysis since we cannot use coordinates in the second step of the hedonic model.

[5]Note that, as described above, we no longer have the connection between the data sets of our two steps, which means that in step 2 the age of the dwelling is imputed by the observations in step 2.

[6]In Sollentuna there is no clear countryside. Instead we divide Sollentuna into five different geographical areas.

to nearest large main road, and the distance to nearest motorway entrance. Distance is throughout our study defined as the crow flies.

#### 3.1.3 Noise indicator

The railway noise is calculated using the "Nordic method" for railway traffic noise (Ringheim, 1996). The noise exposure is calculated at the height of two meters above ground at the center of the property area. The effect of screening by the terrain or noise barriers is taken into account but not the screening effect of buildings. The height profile is determined in a grid with a spatial resolution of 25 meters. Our noise indicator is measured in decibels (dB) and is the 24-hour, A-weighted equivalent sound pressure level, which is an energy average over a certain time period, denoted as $L_{\text{AEq,24h}}$. This is the standard noise indicator used by Swedish authorities, and the A-weighting approximates the varying sensitivity of the human ear to different frequencies.

In contrast to many other environmental effects it does not make sense to use the zero point of noise as the point when the pollution vanishes. Instead the effect should be zero when no negative effects are experienced from noise. We follow Andersson et al. (2010) and choose 45 dB for $L_{\text{AEq,24h}}$ as the lower limit for our noise variable. As discussed by Andersson et al. (2010) this limit is somewhat arbitrarily determined, but the percentage of people reporting that they are annoyed by traffic noise is very low below this level (Miedema and Oudshoorn, 2001).[7] Moreover, in accordance with Day et al. (2007), we transform the "bad" noise exposure to the "good" peace and quiet ($Q$) as $Q = 75 - L_{\text{AEq,24h}}$. This means that peace and quiet is equal to 0 when the equivalent railway noise level is 75 dB.[8]

For Sollentuna, information on road traffic noise from a major road is available and used in the estimation as a control variable. The road traffic noise indicator used is the "level day, evening, night" (European Commission, 2000), $L_{\text{DEN}}$, which is approximately 3 dB higher than the equivalent level $L_{\text{AEq,24h}}$ for typical road traffic noise. The calculated road noise values are taken from the official Swedish calculations according to the Environmental Noise Directive (END) (European Commission, 2002). The values are in 10 dB intervals starting from $L_{\text{DEN}}$ 55 dB, so they are just a rough indication of the

[7] See, e.g., Andersson et al. (2010) for a brief description of the "zero point" of noise.

[8] The maximum level in our sample is 71.1 dB. Hence our definition of $Q$ ensures positive values that can be transformed into their natural logarithm without resulting in extreme values.

presence of road traffic noise.[9]

#### 3.1.4 Socioeconomic variables

For all individuals who are registered as living in a given property we have data on registered income, age and education level. We translate this data into household variables as described below.

Our household income variable includes labor income, capital income and transfer payments for all household members. In accordance with the property prices, we deflate the income to the year of 2009. Labor income and capital income cannot be separated in our data and since we expect labor income to be larger than capital income for most of the households, we use the labor income index to deflate the sum of labor income and capital income. The Swedish transfer payment system uses a price-adjusted base amount to adjust transfer payments over time, and this base amount is used to deflate the transfer payments to the value of year 2009. The decision to buy a property may be heavily dependent on expectations of future income and not only on the income of the purchasing year of the property. To account for this effect we use the income of the purchasing year as well as the income the year after as covariates.

Education level is categorized on four different levels. We use indicator variables for the two oldest household members, which are assumed to be the adults. In some households there is only one adult, i.e. for single households and when the second oldest household member is the child of the oldest household member. We use the same indicator variable for education level of the second oldest household member in both these cases. However, we cannot observe with certainty when the second oldest household member is the child of the oldest household member, so we assume that this is the case when the second oldest household member is more than 18 years younger than the oldest household member. Furthermore, we include the number of children in a household defined in different age groups. The groups are 0-3, 4-6, 7-11, and 12-17 years of age. Finally, we also include an indicator variable for single households.

[9] In Alingsås and Kungsbacka there are some areas, which due to the properties of the ground, are known to be sensitive to building vibrations mainly from freight traffic. Such vibrations increase the annoyance from noise reported in social surveys (Öhrström et al., 2010), and may influence the WTP in these areas. There is no standardized calculation method for such vibrations, and apart from the properties of the ground and the track and embankment, the details of the buildings have a large influence on the vibrations. Therefore no effort has been made to include vibrations in our model.

### 3.2 Market segmentation

To be able to identify the different structures of the implicit prices of peace and quiet, the first step of the hedonic regression technique will be performed on several distinct housing markets. Substantial frictions in moving between markets cause the segmentation of the market into different submarkets. The different submarkets will have different implicit prices and a possibility to move easily between markets will distort the identification strategy in the second step estimation. A natural basis for the housing market segmentation is geography. Since our data covers several municipalities in different parts of Sweden we base our segmentation on municipalities.

However, some of the municipalities belong to the same local labor market region and thus one might question whether they are separate housing markets.[10] This holds for Kungsbacka and Alingsås, and Töreboda and Falköping, which belong to the local labor market region of Gothenburg and Skövde, respectively. To determine if these municipalities should be treated as belonging to the same housing market a first-step hedonic OLS regression for each of the local labor markets was estimated. These regressions included an indicator variable for one of the municipalities and an interaction variable between the municipality indicator and peace and quiet, to determine if the implicit price of peace and quiet varied between the municipalities. Test results showed that Töreboda and Falköping should be treated as separate housing markets while Kungsbacka and Alingsås belong to the same housing market. Hence, our hedonic analysis is based on six distinct housing markets, since the data from Kungsbacka and Alingsås is pooled into one market.

Furthermore, we do not want to use socioeconomic characteristics as the basis for housing market segmentation (as in Day et al., 2007) since these characteristics are used in the second step to identify shifts in the demand curve for peace and quiet. Thus we avoid the circularity in the estimation strategy caveated by Day et al. (2007, p. 230).

This leaves us with property characteristics as a potential source of further housing market segmentation. Living space, for example, might serve as a good basis for housing market segmentation since most property demanders have predetermined their demand for a house of a specific size, at least to within a relatively narrow margin. In other words, most property demanders have decided if they want to purchase a small house or a large house. As will be described in subsection 4.2, we are using living space as an instrument

[10] Local labor market regions are defined by Statistics Sweden based on commuting flows between municipalities.

variable and thus also using housing attributes to segment the housing market is not adequate.

### 3.3 Estimation sample

To create a more homogenous sample and to mitigate the effect of influential outliers, the sample was restricted in several ways. For instance, to be included in the sample, the equivalent railway noise level had to be above 45 dB, which is assumed to be the minimum noise level that can be experienced as disturbing and therefore influence the property price. However, for Gävle only properties with equivalent railway noise level above 50 dB are included. The complex structure of different motorways and railway lines in Gävle implies that including properties exposed to equivalent railway noise below 50 dB, may include properties exposed both to railway and road traffic noise, and thus distort the estimated model.

We also restrict the sample with respect to living space and property area. For living space we exclude observations of 30 square meters or less and 506 square meters or more. Regarding property area, we exclude areas above 10 000 square meters which we believe might be properties used for business activities and not for private housing. In addition, the railway noise is calculated at the center of the property area and if the property area is large, this point of calculation may be misleading since we do not observe where the dwelling is located. Only a few observations are excluded by these property size restrictions, however.

Our last registered income is for year 2009 and since we use a lead variable of income, only data up to year 2007 is used in the estimation of the second step. In the first step estimation we still use data up to year 2009 to increase the number of observations and thus utilize the maximum available information. Also, for some households there is no available income, which means that the sample size of the second step will be even smaller than the sample size of the first step. However, these drop-outs are not in any way systematic with respect to the different housing markets.

### 3.4 Descriptive statistics

Descriptive statistics are shown in Table 2. The mean estimates of property prices reveal a large variation in prices between the markets. The Stockholm suburb, Sollentuna, has the highest average property price followed by the Gothenburg suburbs Kungsbacka and

Alingsås. The property prices are lowest in the rural housing market Töreboda. Also, household income follows the same pattern, although the relative difference in income levels between the housing markets is much lower than the relative difference in property prices. The structural variables are fairly similar across the housing markets with the exception that linked and terraced properties are more common in suburban housing markets and in the regional center Gävle, and that the property area generally is smaller in suburban housing markets.

[Table 2 about here.]

The average equivalent railway noise exposure is highest in Gävle, which mostly depends on the exclusion of properties exposed to less than 50 dB in Gävle in contrast to 45 dB in the other housing markets. However, the average noise exposure is only slightly lower in Töreboda than in Gävle. Kungsbacka and Alingsås has the lowest average noise exposure.

The number of children of different ages differs substantially across the housing markets. Generally, Sollentuna seems to have the highest average, which probably depends on the high average property price leading to a selection effect. In urban areas, the high property price implies that only households with a very strong preference for owned property actually buy a property. One indicator for such a strong preference is likely to be a household with many children. Also, single households are most frequent in Töreboda followed by Hässleholm, which are the housing markets with the lowest average property price. With a relatively low property price, single households have a better opportunity to afford buying a property.

# 4 Modeling framework

## 4.1 The hedonic price regression - first step

When the relationship between noise and property prices is estimated, the choice of functional form is not self-evident and not much guidance is provided by economic theory (Rosen, 1974). In general, implicit prices of attributes are not linear in property prices. The semi-logarithmic form where the property price is transformed to its natural logarithm is widely used in the literature (Dekkers and van der Straaten, 2009). However, based on explanatory power, we alternatively propose a log-linear specification where both the property price, and peace and quiet, are included in their natural logarithmic forms. Our log-linear model is formulated as

$$\ln P_i = \beta_0 + \beta_1 \ln Q_i + \sum_{n=1}^{N} \gamma_n f(a_{ni}) + \sum_{h=1}^{H} \lambda_h f(g_{hi}) + \varepsilon_i, \quad (4)$$

where subscript $i$ denotes individual properties. The variables $a$ and $g$ denote structural and geographical variables, respectively, where those that are not indicator variables are transformed to their natural logarithm. Based on our functional from in Eq. (4) the implicit price of peace and quiet is given by

$$\pi_i = \frac{\beta_1 P_i}{Q_i}. \quad (5)$$

A common problem in hedonic regressions on property prices is spatial dependence. This is often handled either through a spatial error or a spatial lag model (Anselin, 1999, 2003). With the spatial error model the OLS estimator is unbiased but not efficient (Anselin, 1999), whereas the marginal implicit price of a spatial lag model depends on both the direct effect and a spatial indirect effect (Kim et al., 2003). We test for spatial dependence based on the criteria taken from Anselin (2005, p. 196-200). We use inverse distance-based spatial weight matrices and test different distance bands ranging from two kilometers up to the maximum distance. For each market, we choose the spatial weight matrix that implies the highest log-likelihood. For two of our markets, the spatial error model is preferred, whereas the spatial lag model is preferred for the other four markets. We choose, however, to use the spatial error model for all markets due to lack of clarity on how to interpret the indirect effect of the spatial lag model.[11]

Small and Steimetz (2012) showed that whether the indirect effect in the lag-model should be part of the implicit price, depends on the mechanism behind the influence of neighboring properties. With a technological externality, individuals obtain utility from living close to higher-priced houses, and the indirect effect should then be included. A pecuniary effect arises, for instance, when buyers use the prices of surrounding properties as a guide to the value of their property of interest. Here the indirect effect is a welfare neutral transfer and should therefore not be included. Thus, referring to the different results of the spatial model diagnostics and the lack of clarity on how to interpret the indirect effect of the spatial lag model, we use the spatial error model for all markets.

The implicit price of peace and quiet is estimated according to Eq. (5). Since our dependent variable is the price of the property, the implicit price represents the present

[11] Results from the diagnostics tests for spatial dependence are omitted but available from the authors upon request.

value of a marginal change in the noise level. For policy purposes it is more convenient to have an annual benefit measurement and we therefore convert our present value to an annual WTP. Firstly, if the expected lifetime of the properties is assumed to be infinite, the annual WTP can simply be estimated by multiplying the implicit price with the discount rate ($r$). We use a real interest rate equal to 3.11 percent, which is based on the weighting average ten-year nominal interest rate in 2009 equal to 5.11 percent[12] minus the 2 percent inflation objective of the Central Bank of Sweden, which we assumed is the expected inflation rate. Secondly, we also need to take into account any property tax ($\tau$), since failing to do so would underestimate the welfare effects (Niskanen and Hanke, 1977). The property tax is not based on the full value of the property, however, but on a taxation value ($T_i$) which is a proportion of its full value. The yearly property taxation for the years 1996 to 2007 was 1 percent of the taxation value of the property, and since only a proportion of the property is taxed we multiply this tax rate with the property taxation value divided by the property price.[13] Thus, the annualized implicit price, $\pi_i'$, is calculated as

$$\pi_i' = \left(r + \tau \frac{T_i}{P_i}\right) \pi_i = \left(0.0311 + 0.01 \frac{T_i}{P_i}\right) \beta \frac{P_i}{Q_i}. \tag{6}$$

### 4.2 The hedonic price regression - second step

In the second step we use the property specific implicit price of peace and quiet along with the socioeconomic variables as regressors for the chosen level of peace and quiet in a linear specification.[14] Variables from the first step are included to account for characteristics that are either substitutes or complements to peace and quiet. A positive and a negative parameter implies that the characteristic is a complement and substitute to peace and quiet, respectively. Note, however, that we do not include distance to road since it is not

[12]Holds for Swedbank, which is one of the largest providers of housing loans in Sweden and also provides data of historic interest rates on their web page, see http://hypotek.swedbank.se/rantor/historiska-rantor/historik-bostadsrantor-2008-2009.

[13]The center-right government that was elected in Sweden 2006 had as one of their electoral promises to decrease the property taxation for most properties by imposing a ceiling for the taxation, which was subsequently implemented from 2008. This proposal might have affected the property prices before 2008 through individuals' expectations. However, we only consider the property taxation according to the former legislation. Moreover, for Gävle we do not have access to the property taxation value and therefore we use 0.75 percent as the taxation part of the discount rate, which originates from the objective of the legislation stating that the property taxation value should correspond to 75 percent of the property value.

[14]This demand relation may not be linear as described in Day et al. (2007), which is further discussed in Section 6.

defined for Töreboda. Our demand equation is formulated as

$$Q_{ij} = \alpha_0 + \alpha_1\pi_{ij} + \sum_{m=1}^{M} \delta_m s_{mij} + \sum_{n=1}^{N} \kappa_n a_{nij} + \sum_{h=1}^{H} \theta_h g_{hij} + \epsilon_{ij}, \tag{7}$$

where subscripts $i$ and $j$ denote individual properties and markets respectively. Note also that no variables in Eq. (7) are given in the natural logarithmic form, which differs from the first step equation, further improving the identification of the demand relationship.

The second step of the hedonic regression analysis based on Eq. (7) suffers from endogeneity problems as the implicit price is dependent on the level of peace and quiet. Therefore we use the instrumental variable (IV) method and estimate Eq. (7) by two stage least squares (2SLS). To produce unbiased parameter estimates, the instruments must be strong and valid (Cameron and Trivedi, 2005). In our application, strong means that the instruments should explain a sufficient amount of the implicit price for peace and quiet, whereas valid means that the instruments have to be uncorrelated with the error term in Eq. (7). To test whether the instruments are strong and valid we rely on the minimum eigenvalue statistic of the instruments in the first-stage regression of the 2SLS, and Sargan's test for overidentifying restrictions, respectively.

As the implicit price of peace and quiet depends on property price, property characteristics that are strongly correlated with the property price will also be strongly correlated with the implicit price of peace and quiet and therefore serve as strong instruments. We propose living space as such a property characteristic. In addition, we use year indicator variables that significantly influence the implicit price of peace and quiet as instruments. These years are 2005, 2006 and 2007. Variation over time in the implicit price of peace and quiet may occur as a result of a different supply of properties in general, and in particular of quiet properties over time, so some of the year indicators are potentially correlated with the implicit price of peace and quiet.

To be valid instruments, the instruments need to be uncorrelated with the decision process behind the choice of peace and quiet. We argue that there is no specific relation between our instruments and the preferences against noise exposure. Regarding our first instrument, living space, we argue that preferences concerning noise are uncorrelated with the decision on optimal living space, i.e. buying a large or a small house does not depend on the property buyer's preferences for peace and quiet. Moreover, by controlling for socioeconomic characteristics, which may vary over time, in the second step the influence of year indicators on demand for peace and quiet is presumed to be small. What we recover in Eq. (7) is the underlying preference structure, and by assuming that the preferences for peace and quiet are stable over time the year indicators are valid instruments. Thus we can identify the demand for peace and quiet by using these instruments for the implicit price of peace and quiet.

## 5 Results

### 5.1 The hedonic price regression - first step

The results of the first step hedonic price regressions for the different housing markets are shown in Table 3. The model fit is strong for most of the housing markets with the squared correlation, corresponding to the conventional $R^2$-measure, in the interval 0.332-0.661. The model fit is considerably lower for Sollentuna and Gävle compared to the other housing markets, which indicates that for these markets there are probably some variations in the property prices that are of local knowledge type, which we cannot control for in our models. We also find that the spatial parameter $\rho$ is strongly significant in all markets, which shows the importance of taking the spatial structure into account.

The results reveal that our variable of main interest, *Peace and quiet*, is strongly significant in all housing markets except Gävle where it still is significant at the five-percent level. Its parameter estimates also reveal a substantial difference between markets, the elasticities range from 0.104 to 0.477. In general, the results show significant structural variables in all housing markets. Living space and quality index are positive and strongly significant for all markets. Age of the dwelling is significant for all markets except Gävle. Property area, subsidiary space, linked properties and terraced properties are all significant in about half of our markets. Bordering a sea/lake often has no effect on the property price with the exception of Sollentuna, where it has a positive effect on the price.

[Table 3 about here.]

Among the geographical variables, distance to railway station is significant for all markets, whereas distance to road is positively significant for Sollentuna, and for Kungsbacka and Alingsås. Distance to road captures both positive accessibility effects and negative pollution, noise and barrier effects, so its expected sign is ambiguous. In Sollentuna however, we control for the accessibility through the distance to motorway entrance, so here the positive effect of living further away from a major road is expected. For Sollentuna, we also control for road noise, so this negative effect of living close to the major road probably captures pollution and barrier effects. Countryside is mostly negative but does not affect the property price in Hässleholm. It should also be emphasized that none of our parameter estimates are significant with an unexpected sign.

In Table 4, the market-specific distributions of the estimated implicit prices are presented. For all presented percentiles Sollentuna has the highest implicit price while Hässleholm has the lowest. Further, the average estimated implicit price is 3.12 times higher in Sollentuna compared to Hässleholm. The quite substantial differences in implicit prices between the housing markets highlight the risk of transferring the values taken from the first step of the hedonic regression technique to other housing markets. A generalized value for railway noise abatement will therefore differ substantially depending on which housing market it is based on.

[Table 4 about here.]

At the bottom of Table 4 we also report estimates of the *Noise Sensitivity Depreciation Index* (NSDI), which has evolved as the standard measure of the WTP in the hedonic noise literature (Nelson, 1980). It measures the percentage reduction in property value due to a 1 dB increase in noise exposure and is estimated as

$$\text{NSDI} = \left| \frac{\partial P}{\partial Q} \frac{100}{P} \right| = \beta_1 \frac{100}{Q}, \tag{8}$$

where $Q = 75 - L$ and $P$ and $L$ denote property prices and noise level, respectively. The estimates reported in Table 4 are based on the mean noise level in each market, and they again show a large variation between markets from the effect of noise on the property prices.

### 5.2 The hedonic price regression - second step

The second step estimates are shown in Table 5. We present the results of both the OLS estimation, which are assumed to be suffering from endogeneity problems, and the consistent 2SLS estimation with the endogenous implicit price of peace and quiet instrumented by living space and year indicators for 2005, 2006 and 2007.

[Table 5 about here.]

The diagnostic tests of our instruments reveal that we can reject the hypothesis that our instruments are weak, and that we cannot reject the hypothesis that our instruments are valid. Since the test of weak instruments has a critical value of 16.85 for significance at the five-percent level and our test statistic is about 47, we strongly reject the null hypothesis of weak instruments. The Sargan's test of valid instruments has a $p$-value of 0.271, which means that we cannot reject the null hypothesis of valid instruments. Since our instruments satisfy the diagnostic tests we conclude that they are adequate for our application.

Furthermore, the results show that the relationship between the implicit price and peace and quiet is negative, as expected, and strongly significant.[15] Among the socioeconomic variables, we include both current and future income. To include future income is a way to control for the influence of expected income on the chosen level of peace and quiet when households decide to purchase a property. Expected income is found to have a strongly significant influence on the choice of peace and quiet while current income is in fact non-significant. This means that when we have controlled for expected income, including the current income is not adding any more explanation for the demand of peace and quiet. The findings on income is robust in the sense that we get the same result if we omit current or future income, i.e. if we only include one income variable, in the regressions. Moreover, the number of children 0-3 years of age positively influences the demand for peace and quiet. However, there is no significant effect for the number of children in the other age groups and for single households.

The results of the included first-step variables, reveal whether they are substitutes or complements to peace and quiet. For distance to railway station, the only geographical variable included, the effect is assumed to be driven by geographical constraints and should not be interpreted as a substitute to peace and quiet. For the structural variables; property area, subsidiary space, quality index and bordering a sea/lake, are complements to peace and quiet, whereas age of the dwelling is a substitute. Generally, we can say that if you choose more of an attractive attribute you also choose more peace and quiet. Finally, linked properties are complements to peace and quiet whereas terraced properties are substitutes for peace and quiet, both in comparison to detached properties, which is the reference.

[15] Note that, as in Day et al. (2007), we do not consider the uncertainty of the implicit price estimates when these are used in the second step.

### 5.3 Welfare estimates

The result of the second step is the estimated demand for peace and quiet, i.e. based on preferences only and not affected by the supply side of the housing markets. This means that we can calculate welfare estimates for non-marginal changes of railway noise exposure. The estimated demand relationship, expressed in the conventional price-quantity space where all other covariates are evaluated at their respective sample means, is given as

$$\pi = 1500 - 57.87Q, \tag{9}$$

where $\pi$ is the price and $Q$ is peace and quiet. A change in peace and quiet will lead to a change in consumer surplus which reflects the welfare effect of the change in noise level.

Household size is taken into account by dividing the welfare estimates by 3.02; the average number of household members in the estimation sample, i.e. the demand function to estimate the monetary welfare measures is defined per individual. We have also transformed the demand to account for income differences between Sweden in general and the seven municipalities of this study, weighted with respect to the number of included observations per housing market. This transformation implies multiplying by a factor of 0.914, which means that the average income in Sweden is approximately nine percent lower than in the municipalities included in our sample. As described earlier, $Q$ is defined so that 0 corresponds to an equivalent railway noise level of 75 dB. The maximum level of equivalent railway noise in our estimation sample is 71.1 dB. The estimated demand reveals that individuals have no WTP for reducing railway noise below an equivalent railway noise level of 49.1 dB.

In Table 6, the welfare estimates for a 1 dB decrease in railway noise with different baseline noise exposure are shown. These estimates are based on the demand equation above. As we can see, for a reduction of the equivalent railway noise level from 71 dB to 70 dB the average Swedish citizen is willing to pay SEK 1239 per year and for a reduction of the equivalent railway noise level from 61 dB to 60 dB the WTP is SEK 661. We also report welfare estimates for the elimination of railway noise at different baseline levels of noise. For instance, the WTP for eliminating railway noise of 71 dB is approximately SEK 13 898 per individual per year.

[Table 6 about here.]

## 6 Discussion

We have in this study estimated the first and second step of Rosen's hedonic regression technique. Using data from seven Swedish regions we show that noise has a negative impact on property prices, which is in line with our expectations. We also find, which is of importance for the objective of the study, that there is a significant difference in the marginal WTP between markets. This result has important policy implications and motivates the use of the second step to recover the underlying preference structure.

From our estimated demand we derive the welfare effects for railway noise changes. Our results show a welfare gain for a 1 dB reduction of railway noise equivalent to SEK 1239 (USD 162 and EUR 117) per individual per year at the baseline noise level of 71 dB. At a baseline noise of 61 dB, the welfare gain is estimated to be equivalent to SEK 661 (USD 86 and EUR 62). These estimates are more or less in line with the literature. Furthermore, below a noise level of 49.1 dB, there are no welfare gains from railway noise abatement.

Comparing our results to other findings in the literature we focus on the two studies that we consider most relevant; Andersson et al. (2010), a recent Swedish study, and Day et al. (2007) which also conducted both steps of the hedonic regression technique. Andersson et al. (2010) found a marginal WTP between SEK 24 and SEK 3027, depending on the noise level. Andersson et al. (2010) however only estimated the first step of the hedonic regression technique. Their findings reveal a more progressive relationship between marginal WTP and the results shown in Table 4 in this study, but it should be kept in mind that the functional forms differ.

When comparing to Day et al. (2007), the only application of the hedonic second step for railway noise valuation that the authors are aware of, we found a weaker influence on demanded peace and quiet from changes in the implicit price. This means that our welfare estimates are higher for high baseline levels of railway noise and lower for low baseline levels of railway noise compared to Day et al. (2007). To reduce the equivalent railway noise level from 71 dB to 70 dB, the average Swedish resident is willing to pay SEK 1239. Day et al. (2007) estimate the same WTP to be equivalent to SEK 754.[16] For a baseline noise level of 56, on the other hand, we estimate the WTP to be SEK 371

[16]It is not straight-forward to convert the estimates of Day et al. (2007), which are given per property and in 1997 year's prices. We have assumed 2.36 individuals per household (see Nellthorp et al., 2007), 46.6 percent increase in real income in the UK between 1997 and 2009, and GBP 1 = SEK 11.93 (www.riksbank.se, 6/13/2012).

whereas Day et al. (2007) estimate this WTP to be equivalent to SEK 536. The welfare estimates of Day et al. (2007) are thus decreasing slowly as the baseline railway noise is decreasing, which means that the WTP does not reach zero for a noise level where individuals are assumed not to be disturbed by traffic, which they assume is the case below the background urban noise level of 55 dB. Here we believe that our estimated demand, where the WTP is zero below a noise level of 49.1 dB and that WTP increases continuously above this noise level, is more consistent.

Our first-step hedonic estimates reveal the NSDI for the different housing markets to be between 0.47 and 2.41. Compared to the literature, our NSDI estimates seem plausible with a tendency towards high values. Recent estimated NSDI for railway noise is 0.67 (Dekkers and van der Straaten, 2009), 0.34-0.72 for traditional functional forms (Andersson et al., 2010), and 0.67 on average (Day et al., 2007). Also when looking at other type of traffic noise, 28 previous studies of road noise have resulted in an NSDI interval from 0.08 up to 2.22 with a mean NSDI of about 0.55 (Bateman et al., 2001). Finally, 20 air noise studies in the USA and Canada resulted in estimated NSDI of 0.28 up to 1.49 with an average of 0.6 (Nelson, 2004).

Having access to a very rich data set we were able to include household characteristics in the second step regression. In addition, to be able to derive the underlying demand function for peace and quiet, our finding of main interest from the second step is the results on household income and the marginal WTP for peace and quiet. A standard validity test of the preference estimates in both RP and SP studies is whether income has a positive effect on individual WTP. In these tests analysts usually use current income as a measure of wealth. In our study we had information on current and future income, and whereas we found that current income had no statistically significant effect on the property owners' WTP, their future income had a strong statistically significant effect. Hence, with only information about current income we would not have been able to reject the premise that income has no effect on individual WTP for peace and quiet.

Regarding our demand function in the second step we estimated a linear function, which not for certain is the most adequate functional form.[17] To relax the linearity assumption we could have chosen another functional form in the second step. Poudyal et al. (2009) used a log-linear function in the second step when they estimated the demand for

[17] Note however that the linearity in the second step should not be confused with a linear estimate in the first step of the hedonic model. Since we estimate the second step of the hedonic model, this linear demand still means that the WTP for a 1 dB noise reduction rises with the baseline noise level.

urban recreation parks. However, the log-linear model states a non-linear demand relationship by definition, which can also be seen as an inflexibility of the model. Moreover, we have already used a log-linear specification in the first step. Including a squared term of the implicit price would be another possible approach to relax the linearity assumption. When testing this approach in the IV regression, that is instrumenting the implicit price and then calculating the square term of the instrumented implicit price, the linear term is still negative and strongly significant whereas the squared term is not significant at conventional significance levels with a $p$-value of 0.369. Thus we cannot reject the linear specification of the demand for peace and quiet.

As described earlier, the functional form of the first step model is not self-evident either. We proposed a log-linear formulation whereas the semi-logarithmic function is widely used in the hedonic literature. Therefore, we have also tested a semi-logarithmic specification estimated by OLS in the first step with the same variable specification followed by the IV-approach in the second step. The results are very similar with slightly lower welfare estimates for noise abatement but still within the 95 percent confidence interval of our log-linear model. This result provides support for the consistency of our model.

## 7 Conclusions

In this study we estimate the demand for peace and quiet, and thus also the WTP for railway noise abatement, based on hedonic regressions on property prices. Both steps of the hedonic model are estimated and our estimated demand for peace and quiet is therefore theoretically consistent for non-marginal changes in noise exposure. Since we use different municipalities around Sweden as different housing markets, and generalize the results to account for average household size, in our estimation sample and income in Sweden in general, we believe that our welfare estimates for noise exposure can be generally applicable in Sweden. From a policy perspective our results are useful, not only for BCA, but also as the monetary component on infrastructure use charges that internalize the noise externality (Andersson and Ögren, 2007, 2011).

Our results also show the risk of using benefit transfer, i.e. we show empirically that the estimated implicit price for peace and quiet differs substantially across the housing markets. Monetary estimates for the social value of noise abatement are often based on a single or scant number of studies and the values are then used either unadjusted or adjusted based on, e.g. income differences between the study and policy cite, on a national level. Therefore, even a benefit transfer approach with adjustments may not be sufficient to obtain values on a national level that reflect the individuals' preferences.

Even if we have recovered "theoretically consistent and transferable values" (Day et al., 2007) in this study there is still room for further analysis. The WTP for noise abatement as estimated in this paper only takes into account the effect that is capitalized into the property market, and there may be other effects that are not included here. First, we can consider that individuals do not spend all their time in their own homes but also at work, in school and in different public areas. Unless preferences for peace and quiet are the same in these environments as they are in people's homes, using the monetary estimates from our study will either over or underestimate the social cost related to being exposed to noise in places other than people's homes.

Furthermore, there is a possibility that all negative effects, both disturbances and health effects, caused by transport-related noise are not capitalized into the property market. In welfare economics we usually assume that individuals know their own best and that their preference-based choices are utility maximizing. We also assume that there is no asymmetric information in the market, e.g. buyers are assumed to be perfectly informed about the characteristics of the purchased good. Pope (2008) however, in a study of airport noise, suggests that information asymmetry may be substantial. Regarding health effects, on the other hand, even if buyers are well-informed, if medical service and labor related insurances are to a great extent subsidized, as in Sweden; there is a further external cost of noise if individuals do not take the complete health effect of noise into account. This is also the case if individuals are not aware of the negative health effects caused by noise exposure.

While unconsidered health effects might lead to an underestimation of the true noise cost, other factors might lead to an overestimation. One such factor is that our study is based on only single family houses and not apartments, and since a buyer of a house with a garden can be assumed to place more emphasis on quiet surroundings than a buyer of an apartment without direct access to an outdoor area, our estimated WTP might reflect preferences that are not valid for apartment buyers.[18]

Although some caveats are presented above, our study is an important contribution

[18] Also, individuals that are living in rented apartments tend to have a lower income in general compared to property-owners. In Nellthorp et al. (2007), this latter effect for the UK is calculated to a 17.5 percent decrease of the welfare estimates.

to the literature as it is based on the two-step hedonic regression technique and uses combined data of geographically different housing markets and individual socioeconomic characteristics.

## References


Andersson, H., L. Jonsson, and M. Ögren: 2010, 'Property Prices and Exposure to Multiple Noise Sources: Hedonic Regression with Road and Railway Noise'. *Environmental and Resource Economics* **45**, 73–89.

Andersson, H. and M. Ögren: 2007, 'Noise Charges in Rail Infrastructure: A Pricing Schedule Based on the Marginal Cost Principle'. *Transport Policy* **14**(3), 204–213.

Andersson, H. and M. Ögren: 2011, 'Noise Charges in Road Infrastructure: A Pricing Schedule Based on the Marginal Cost Principle'. *Journal of Transportation Engineering* **137**(12), 926–933.

Anselin, L.: 1999, 'Spatial Econometrics'. Mimeo, University of Texas at Dallas, USA.

Anselin, L.: 2003, 'Spatial externalities, spatial multipliers, and spatial econometrics'. *International Regional Science Review* **26**(2), 153–166.

Anselin, L.: 2005, 'Exploring Spatial Data with GeoDaTM : A Workbook'. Technical report, Spatial Analysis Laboratory, Department of Geography, University of Illinois, Urbana-Champaign.

Bateman, I., B. Day, I. Lake, and A. Lovett: 2001, 'The effect of road traffic on residential property values: A literature review and hedonic pricing study'.

Boes, S. and S. Nüesch: 2011, 'Quasi-experimental evidence on the effect of aircraft noise on apartment rents'. *Journal of Urban Economics* **69**(2), 196 – 204.

Brandt, S. and W. Maennig: 2011, 'Road noise exposure and residential property prices: Evidence from Hamburg'. *Transportation Research Part D: Transport and Environment* **16**(1), 23–30. Cited By (since 1996): 4.

Cameron, A. C. and P. K. Trivedi: 2005, *Microeconometrics: Methods and Applications*. New York: Cambridge University Press.

Day, B., I. Bateman, and I. Lake: 2007, 'Beyond implicit prices: Recovering theoretically consistent and transferable values for noise avoidance from a hedonic property price model'. *Environmental and Resource Economics* **37**(1), 211–232.

Dekkers, J. and J. W. van der Straaten: 2009, 'Monetary valuation of aircraft noise: A hedonic analysis around Amsterdam airport'. *Ecological Economics* **68**(11), 2850–2858.

Ekeland, I., J. J. Heckman, and L. Nesheim: 2004, 'Identification and estimation of hedonic models'. *Journal of Political Economy* **112**(1), S60–S109.

European Commission: 1996, 'Future Noise Policy - European Commission Green Paper'. Report COM(96) 540 final, European Commission, Brussels, Belgium.

European Commission: 2000, 'Proposal for a Directive of the European Parliament and of the Council relating to the Assessment and Management of Environmental Noise'. Technical Report COM(2000) 468 final, 2000/0194(COD), Commission of the European Communities.

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

Haab, T. C. and K. E. McConnell: 2003, *Valuing Environmental and Natural Resources: The Econometrics of Non-Market Valuation*. Cheltenham, UK: Edward Elgar.

Jonasson, H. and H. Nielsen: 1996, 'Road traffic noise – Nordic prediction method'. TemaNord 1996:525, Nordic Council of Ministers.

Kalivoda, M., U. Danneskiold-Samso, F. Krüger, and B. Bariskow: 2003, 'EURailNoise: a study of European priorities and strategies for railway noise abatement'. *Journal of Sound and Vibration* **267**, 387–396.

Kim, C. W., T. T. Phipps, and L. Anselin: 2003, 'Measuring the benefits of air quality improvement: A spatial hedonic approach'. *Journal of Environmental Economics and Management* **45**(1), 24–39.

Lundström, A., M. Jäckers-Cüppers, and P. Hübner: 2003, 'The new policy of the European Comission for the abatement of railway noise'. *Journal of Sound and Vibration* **267**, 397–405.

McMillen, D. P.: 2004, 'Airport expansions and property values: the case of Chicago O'Hare Airport'. *Journal of Urban Economics* **55**(3), 627 – 640.

Miedema, H. M. E. and C. G. M. Oudshoorn: 2001, 'Annoyance from transportation noise: Relationships with exposure metrics DNL and DENL and their confidence intervals'. *Environmental health perspectives* **109**(4), 409–416.

Nellthorp, J., A. L. Bristow, and B. Day: 2007, 'Introducing willingness-to-pay for noise changes into transport appraisal: An application of benefit transfer'. *Transport Reviews* **27**(3), 327–353.

Nelson, J. P.: 1980, 'Airports and Property Values. A Survey of Recent Evidence'. *Journal of Transport, Economics and Policy* **14**(1), 37–52.

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.

Nelson, J. P.: 2008, *Hedonic Methods in Housing Markets: Pricing Environmental Amenities and Segregation*, Chapt. Hedonic Property Value Studies of Transportation Noise: Aircraft and Road Traffic, pp. 57–82. New York: Springer.

Nijland, H. A., E. E. M. M. Van Kempen, G. P. Van Wee, and J. Jabben: 2003, 'Costs and benefits of noise abatement measures'. *Transport Policy* **10**(2), 131–140.

Niskanen, W. A. and S. H. Hanke: 1977, 'Land prices substantially underestimate the value of environmental quality'. *Review of Economics and Statistics* **59**(3), 375–377.

Öhrström, E., A. Gidlöf-Gunnarsson, M. Ögren, and T. Jerson: 2010, 'Effekter av buller och vibrationer från tågtrafik'. Rapport 4:2010, Occupational and Environmental Medicine, University of Gothenburg.

Palmquist, R. B.: 2005. *Handbook of Environmental Economics: Valuing Environmental Changes, Vol.2 of Handbooks in Economics 20, Chapter Property Value Models* pp. 763–819.

Parumog, M., S. Mizokami, and R. Kakimoto: 2006, 'Value of traffic externalities from attribute-based stated choice: Route choice experiment'. *Transportation Research Record* **1954**, 52–60.

Pope, J. C.: 2008, 'Buyer information and the hedonic: The impact of a seller disclosure on the implicit price for airport noise'. *Journal of Urban Economics* **63**(2), 498 – 516.

Poudyal, N. C., D. G. Hodges, and C. D. Merrett: 2009, 'A hedonic analysis of the demand for and benefits of urban recreation parks'. *Land Use Policy* **26**(4), 975–983.

Ringheim, M.: 1996, 'Railway Traffic Noise – Nordic Prediction Method'. TemaNord 1996:524, Nordic Council of Ministers, Copenhagen, Denmark. ISBN 92-9120-837-X.

Rosen, S.: 1974, 'Hedonic prices and implicit markets: Product differentiation in pure competition'. *Journal of Political Economy* **82**(1), 34–55.

Sælensminde, K.: 1999, 'Stated choice valuation of urban traffic air pollution and noise'. *Transportation Research Part D: Transport and Environment* **4**(1), 13–27.

Small, K. A. and S. S. Steimetz: 2012, 'Spatial Hedonics and the Willingness to Pay for Residential Amenities'. *Journal of Regional Science* **In press**.

SOU: 1993, 'Handlingsplan mot buller: Betänkande av Utredningen för en handlingsplan mot buller'. SOU 1993:65, Statens offentliga utredningar, Miljö- och naturresursdepartementet, Stockholm, Sweden.

Theebe, M. A. J.: 2004, 'Planes, trains, and automobiles: The impact of traffic noise on house prices'. *Journal of Real Estate Finance and Economics* **28**(2-3), 209–234.

Wilhelmsson, M.: 2002, 'Household expenditure patterns for housing attributes: A linear expenditure system with hedonic prices'. *Journal of Housing Economics* **11**(1), 75–93.

Table 1: Description of the municipalities

| **Municipality** | **Population** | **Local labor market** | **Railway lines** | **Motorways** | **Closest urban area center** | **Regional center (yes/no)** |
|---|---|---|---|---|---|---|
| Töreboda | 9238 | Skövde | Västra Stambanan | - | Gothenburg (170 km) | No |
| Sollentuna | 63 174 | Stockholm | Ostkustbanan | E4 | Stockholm (13 km) | No |
| Falköping | 31 419 | Skövde | Västra Stambanan<br>Jönköpingsbanan | - | Gothenburg (108 km) | No |
| Hässleholm | 50 036 | Kristianstad | Södra Stambanan<br>Skånebanan<br>Markarydsbanan | - | Malmö (78 km) | No |
| Kungsbacka | 73 763 | Gothenburg | Västkustbanan | E20/E6 | Gothenburg (24 km) | No |
| Alingsås | 37 465 | Gothenburg | Västra Stambanan | E20 | Gothenburg (42 km) | No |
| Gävle | 94 255 | Gävle | Ostkustbanan<br>Norra Stambanan<br>Bergslagsbanan | E4<br>R80 | Stockholm (158 km) | Yes |

*Notes*: Local labor markets are defined by Statistics Sweden based on commuting flows between municipalities. Population data is from November 1st of 2009.

Table 2: Descriptive statistics: Mean values and standard deviations (in parenthesis)

| Variable | Housing market | | | | | | Expected sign |
|---|---|---|---|---|---|---|---|
| | **Töreboda** | **Sollentuna** | **Falköping** | **Hässleholm** | **Kungsbacka and Alingsås** | **Gävle** | |
| *First-step variables* | | | | | | | |
| Property price[a] | 685 918 | 3 749 929 | 1 332 310 | 1 354 171 | 2 482 976 | 1 613 278 | |
| | (383 601) | (1 337 199) | (550 053) | (578 497) | (833 141) | (765 374) | |
| Railway noise | 55.18 | 52.99 | 54.08 | 53.39 | 52.65 | 55.23 | + (Peace and quiet) |
| | (5.50) | (4.84) | (4.89) | (5.59) | (5.63) | (3.93) | |
| Property area | 1496.142 | 785.790 | 933.523 | 1087.971 | 861.137 | 1003.778 | + |
| | (1376.625) | (524.085) | (802.403) | (640.221) | (751.435) | (649.384) | |
| Living space | 118.114 | 127.059 | 130.908 | 123.385 | 132.638 | 121.886 | + |
| | (45.573) | (34.579) | (43.801) | (40.107) | (44.280) | (39.777) | |
| Subsidiary space | 47.743 | 42.261 | 60.884 | 60.310 | 46.085 | n.a. | + |
| | (43.928) | (42.012) | (45.774) | (44.989) | (42.797) | | |
| Age of dwelling | 51.750 | 39.260 | 45.828 | 43.323 | 44.767 | 52.395 | - |
| | (27.504) | (21.153) | (26.303) | (22.317) | (25.283) | (31.638) | |
| Quality index | 27.486 | 28.777 | 28.992 | 28.738 | 28.331 | 28.953 | + |
| | (5.351) | (5.050) | (5.331) | (5.258) | (5.189) | (5.678) | |
| Detached | 0.947 | 0.620 | 0.900 | 0.936 | 0.704 | 0.818 | Reference |
| Linked | 0.035 | 0.169 | 0.060 | 0.032 | 0.169 | 0.125 | - |
| Terraced | 0.018 | 0.211 | 0.040 | 0.032 | 0.127 | 0.057 | - |
| Bordering the sea/lake | 0.018 | 0.004 | 0 | 0.002 | 0.005 | 0.013 | + |
| Road noise | n.a. | 53.676 | n.a. | n.a | n.a. | n.a. | - |
| | | (7.084) | | | | | |
| Distance road | n.a. | 746.403 | 1356.331 | 1722.247 | 1231.138 | 2010.857 | Ambiguous[b] |
| | | (446.973) | (539.440) | (690.284) | (1080.810) | (1647.249) | |
| Distance railway station | 5088.834 | 830.219 | 1698.122 | 2178.928 | 1114.530 | 4089.863 | - |
| | (5568.373) | (284.858) | (1899.324) | (1774.186) | (844.891) | (2570.625) | |
| Distance motorway entrance road | n.a. | 1172.854 | n.a. | n.a. | n.a. | n.a. | - |
| | | (403.721) | | | | | |
| Countryside | n.a. | n.a. | 0.167 | 0.339 | 0.143 | 0.592 | - |
| No of observations | 720 | 3594 | 947 | 1459 | 1454 | 1092 | |
| *Second-step variables* | | | | | | | |
| Household income | 425 537 | 903 024 | 620 810 | 550 075 | 681 208 | 660 800 | + |
| | (267 636) | (607 286) | (545 597) | (496 675) | (405 040) | (409 325) | |
| Single household | 0.248 | 0.132 | 0.134 | 0.191 | 0.135 | 0.120 | - |
| No of children 0-3 years of age | 0.297 | 0.456 | 0.395 | 0.305 | 0.377 | 0.378 | + |
| | (0.550) | (0.655) | (0.599) | (0.550) | (0.618) | (0.591) | |
| No of children 4-6 years of age | 0.137 | 0.202 | 0.234 | 0.145 | 0.191 | 0.186 | + |
| | (0.351) | (0.449) | (0.496) | (0.400) | (0.435) | (0.425) | |
| No of children 7-11 years of age | 0.186 | 0.273 | 0.222 | 0.226 | 0.251 | 0.198 | + |
| | (0.468) | (0.596) | (0.538) | (0.556) | (0.548) | (0.495) | |
| No of children 12-17 years of age | 0.175 | 0.201 | 0.199 | 0.192 | 0.257 | 0.195 | + |
| | (0.474) | (0.524) | (0.586) | (0.519) | (0.599) | (0.497) | |
| No of observations | 451 | 2270 | 688 | 952 | 981 | 842 | |

*Notes*: Standard deviations of indicator variables are not shown since they are determined by the mean, $\mu$, according to $\sqrt{\mu(1-\mu)}$.
n.a. stands for not available.
*a*: In Swedish kronor (SEK) and 2009 price level. USD 1 = SEK 7.65 and EUR 1 = SEK 10.62 (www.riksbank.se, 6/13/2012)
*b*: In Sollentuna the expected sign for distance to road is negative since we control for accessibility through distance to motorway entrance road.

Table 3: Hedonic first step estimates

| **Variable** | **Housing market** | | | | | |
|---|---|---|---|---|---|---|
| | **Töreboda** | **Sollentuna** | **Falköping** | **Hässleholm** | **Kungsbacka and Alingsås** | **Gävle** |
| ln Peace and quiet | 0.477*** | 0.205*** | 0.282*** | 0.165*** | 0.104*** | 0.190** |
| | (0.112) | (0.038) | (0.051) | (0.031) | (0.033) | (0.084) |
| ln Property area | 0.161*** | 0.168*** | 0.013 | 0.050* | 0.143*** | 0.049 |
| | (0.039) | (0.018) | (0.029) | (0.028) | (0.044) | (0.038) |
| ln Living space | 0.454*** | 0.357*** | 0.508*** | 0.616*** | 0.491*** | 0.551*** |
| | (0.073) | (0.023) | (0.039) | (0.042) | (0.035) | (0.054) |
| ln Subsidiary space | 0.020* | 0.012*** | 0.014** | 0.004 | 0.010* | n.a. |
| | (0.011) | (0.003) | (0.007) | (0.005) | (0.005) | |
| ln Age of dwelling | -0.272*** | -0.069*** | -0.122*** | -0.201*** | -0.117*** | -0.015 |
| | (0.039) | (0.009) | (0.019) | (0.017) | (0.018) | (0.033) |
| ln Quality index | 1.042*** | 0.246*** | 0.804*** | 0.642*** | 0.348*** | 0.520*** |
| | (0.155) | (0.033) | (0.066) | (0.061) | (0.051) | (0.085) |
| Linked | -0.038 | -0.027 | -0.136*** | -0.104*** | -0.011 | -0.122* |
| | (0.059) | (0.030) | (0.044) | (0.035) | (0.033) | (0.063) |
| Terraced | -0.178** | 0.026 | -0.288*** | -0.088** | 0.060 | -0.014 |
| | (0.088) | (0.032) | (0.046) | (0.041) | (0.069) | (0.083) |
| Bordering the sea/lake | 0.134 | 0.209*** | n.a. | 0.245 | 0.070 | 0.089 |
| | (0.092) | (0.059) | | (0.163) | (0.158) | (0.078) |
| ln Road noise | n.a. | 0.102 | n.a. | n.a. | n.a. | n.a. |
| | | (0.070) | | | | |
| ln Distance road | n.a. | 0.146*** | 0.040 | -0.001 | 0.072*** | -0.004 |
| | | (0.024) | (0.028) | (0.022) | (0.013) | (0.019) |
| ln Distance railway station | -0.153*** | -0.092*** | -0.090*** | -0.173*** | -0.054*** | -0.187*** |
| | (0.022) | (0.023) | (0.028) | (0.034) | (0.020) | (0.059) |
| ln Distance motorway entrance | n.a. | -0.015 | n.a. | n.a. | n.a. | n.a. |
| | | (0.028) | | | | |
| Countryside | n.a. | n.a. | -0.152** | -0.046 ´ | -0.118*** | -0.424*** |
| | | | (0.064) | (0.038) | (0.040) | (0.132) |
| $\rho$ | 0.411*** | 0.993*** | 0.755*** | 0.596*** | 0.449*** | 0.426*** |
| | (0.105) | (0.006) | (0.105) | (0.070) | (0.088) | (0.086) |
| Distance band (kilometers) | 3 | 2 | 10 | 2 | 2 | 3 |
| No of observations | 720 | 3594 | 947 | 1459 | 1454 | 1092 |
| Squared correlation | 0.581 | 0.332 | 0.660 | 0.630 | 0.523 | 0.348 |

*Notes*: Dependent variable is the natural logarithm of the property price.
***, ** and * denote difference from zero at the one, five and ten percent significance level respectively.
The models include yearly dummy variables but for simplicity these coefficients are not shown in the table.
Robust standard errors are given in parenthesis.
The models also include an intercept.
n.a. stands for not available.
The model for Sollentuna includes four indicator variables of geographical areas instead of countryside.

Table 4: Market-specific distribution of implicit price of peace and quiet

| | **Housing market** | | | | | |
|---|---|---|---|---|---|---|
| | **Töreboda** | **Sollentuna** | **Falköping** | **Hässleholm** | **Kungsbacka and Alingsås** | **Gävle** |
| Implicit price - 10th percentile | 289 | 766 | 357 | 204 | 241 | 294 |
| Implicit price - 25th percentile | 406 | 964 | 470 | 272 | 314 | 428 |
| Implicit price - median | 578 | 1231 | 640 | 361 | 402 | 579 |
| Implicit price - mean | 643 | 1332 | 701 | 414 | 456 | 615 |
| Implicit price - 75th percentile | 808 | 1607 | 854 | 496 | 543 | 769 |
| Implicit price - 90th percentile | 1090 | 2018 | 1117 | 662 | 718 | 988 |
| NSDI$^a$ | 2.41 | 0.93 | 1.35 | 0.76 | 0.47 | 0.96 |

*Note*: Implicit price is given in SEK per property and year in 2009 prices.

$a$: NSDI $= \frac{\partial P}{\partial Q}\frac{100}{P} = \beta_1 \frac{100}{Q}, \quad Q = 75 - L$, where $L$ is noise level. Evaluated at the mean values of $L$ in Table 2.

Table 5: Hedonic second step estimates

| **Variable** | **OLS** | **2SLS** |
|---|---|---|
| Implicit price | -0.004*** | -0.005*** |
| | (0.000) | (0.001) |
| ln Household income | -0.004 | 0.002 |
| | (0.035) | (0.035) |
| ln Household income year t+1 | 1.558*** | 1.795*** |
| | (0.155) | (0.265) |
| Single household | 0.149 | 0.311 |
| | (0.422) | (0.442) |
| No of children 0-3 years of age | 0.254** | 0.316** |
| | (0.115) | (0.124) |
| No of children 4-6 years of age | -0.100 | -0.070 |
| | (0.142) | (0.144) |
| No of children 7-11 years of age | 0.150 | 0.202 |
| | (0.117) | (0.125) |
| No of children 12-17 years of age | -0.077 | -0.061 |
| | (0.121) | (0.123) |
| Property area | 0.030*** | 0.039*** |
| | (0.011) | (0.012) |
| Subsidiary space | 0.003* | 0.003** |
| | (0.001) | (0.001) |
| Age of dwelling | -0.026*** | -0.027*** |
| | (0.003) | (0.003) |
| Quality index | 0.067*** | 0.081*** |
| | (0.012) | (0.016) |
| Linked | -0.782*** | -0.660*** |
| | (0.213) | (0.228) |
| Terraced | 0.609*** | 0.552*** |
| | (0.176) | (0.184) |
| Bordering the sea/lake | 2.384*** | 2.463*** |
| | (0.679) | (0.721) |
| Distance railway station | -0.529*** | -0.576*** |
| | (0.027) | (0.044) |
| No of observations | 6184 | 6184 |
| $R^2$ | 0.238 | 0.230 |

*Notes*: Dependent variable is peace and quiet.
***, ** and * denote difference from zero at the one, five and ten percent significance level respectively.
The models include education dummy variables, which for simplicity are not shown here.
Robust standard errors are given in parenthesis.
Distance to railway station is defined in kilometers.
Property area is defined in hundreds square meters.
The models also include an intercept.

Table 6: Welfare estimates in SEK of changes in noise exposure

| Noise level change | Welfare estimate | 95 percent CI |
|---|---|---|
| 1 dB change | | |
| 71 ⇔ 70 | 1239 | [977 ; 1502] |
| 66 ⇔ 65 | 950 | [764 ; 1136] |
| 61 ⇔ 60 | 661 | [552 ; 769] |
| 56 ⇔ 55 | 371 | [339 ; 403] |
| 51 ⇔ 50 | 82 | [36 ; 128] |
| Elimination of noise | | |
| 71 ⇔ 49.1 | 13 898 | [10 936 ; 16 860] |
| 66 ⇔ 49.1 | 8280 | [6645 ; 9915] |
| 61 ⇔ 49.1 | 4109 | [3415 ; 4802] |
| 56 ⇔ 49.1 | 1384 | [1247 ; 1521] |
| 51 ⇔ 49.1 | 106 | [69 ; 143] |

*Notes*: Noise is given in equivalent dB.
The welfare estimates are given in SEK per individual and year in 2009 prices. (USD 1 = SEK 7.65 and EUR 1 = SEK 10.62)
The 95 percent confidence interval is based on standard errors calculated by the delta method.

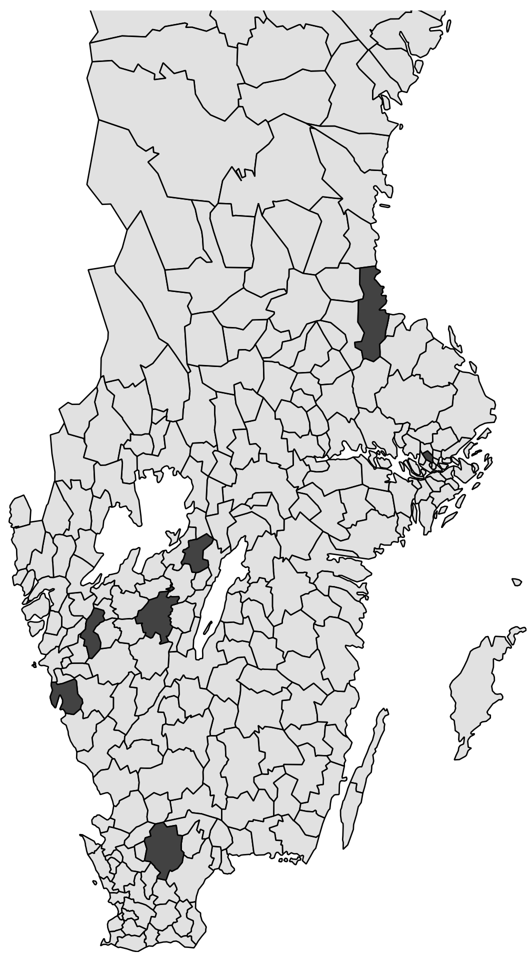

Figure 1: Map over the seven municipalities