Noise cost in different residential environments[1]

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Abstract

In this paper, we estimate the noise cost in different residential environments. In particular, we compare noise cost of apartments and single-family houses for both road traffic and rail traffic. The results, based on both linear and non-linear functional forms, show that in general there is a price discount of all residences when noise exposure is relatively high. Additionally, the tendency is towards higher marginal willingness to pay for noise abatements among buyers of single-family houses compared to apartment buyers. Our results could be used to estimate the indoor noise cost as a share of the total noise cost. These results might be useful for cost-benefit analysis of noise-abatement measures where only indoor noise is affected, i.e. façade insulation measures.

Keywords: Noise cost, Hedonic model, Residential environment, apartment, single-family house Indoor noise, Outdoor noise, Semiparametric

JEL Codes: C14, D62, Q53, R41

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1. Introduction

Transport-related noise is an external cost that needs to be monetized for implementation in a cost-benefit analysis (CBA) of measures in the transport sector. To include noise costs in CBA we need estimates of individuals' willingness to pay (WTP) for noise abatement. Noise is not characterized as a good sold in a market with an easily observed price, instead the common strategy to valuate non-market goods, such as noise, is to use individuals' actual choices of another market. Studies of noise valuation is mostly based on the hedonic model (Rosen, 1974) applied on the market for single-family houses to estimate the implicit price of noise.

One important question that is barely studied is the importance of different residential environments for the noise impact on the residential price. One such important difference should exist between single-family houses that has a residency garden and apartments that does not have a residency garden.

Different implicit prices of noise across owned apartments and single-family houses may be policy-relevant, interpreted as the cost of noise in the single-family house's property yard, which enables us to identify different cost of indoor noise and outdoor noise. The cost of noise in an owned apartment will then be the cost of noise indoor whilst the noise cost in single-family houses is the sum of the noise cost indoor and outdoor. As an example of the policy relevance, façade-insulation measures impact indoor noise but not outdoor noise.

To base such a comparison across different residential environments on between-study estimates of the noise depreciation index[2] (NDI) would be hazardous, however. As noted by Trojanek et al. (2017), difficulties arise when results are compared across studies since different noise indicators, threshold levels, types of properties, and sources of data are used across these studies. This clearly highlights the importance of intra-study comparisons to analyze the different noise cost between different residential environments. There are a few hedonic pricing studies that value noise separately for single-family houses and apartments. Lavandier et al. (2016) presents higher NDI in average for apartments than for single-family houses. They estimate a non-linear relationship by using indicator variables and especially for relative low noise levels (below 60 dB) the price discount is higher for apartments than for single-family houses. Ahlfeldt and Maennig (2013) estimate the air noise discount for single-family houses, multifamily houses, and commercial properties in Berlin using both parametric models and a difference-based semiparametric model. For Tegel Airport the discount is clearly higher for single-family houses than for multi-family houses, while the results for Tempelhof

[2] This index states by how many percentages the housing price is decreased when the noise level is increased one decibel.

Airport is unexpected for multi-family houses with a positive relation between price and noise level. Trojanek et al. (2017) estimated the impact of aircraft noise on housing prices in Poznan, Poland, for both apartments and single-family houses. They present estimated (NDI) of 0.87 percent for single-family houses and 0.57 percent for apartments.

Trojanek et al. (2017) touches the interpretation of different noise sensitivity for individuals living in apartments compared to individuals living in single-family houses. Inspired from that, our interpretation is that the NDI for apartments reveal the cost for indoor noise exposure. Thus, the relation between these NDI estimates might result in an estimate of the distribution of the total noise cost into indoor noise cost and outdoor noise cost. Based on Trojanek et al. (2017), this distribution would be 66 percent (0.57/0.87) indoor noise cost, and from that follows automatically 34 percent outdoor noise cost. In addition, Brandt and Maennig (2011) note that their relatively low-price discount of road-noise exposed condominiums in Hamburg depends on the fact that almost all estimates in the literature is based on single-family homes.

In the literature of noise valuation, there are meta studies (e.g. Nelson, 2004; Bristow et al., 2015; Kopsch, 2016), as well as literature reviews of hedonic studies (e.g. Navrud, 2002; Bateman et al., 2001). Nevertheless, none of these meta studies nor literature reviews distinguish between hedonic valuation based on single-family houses and apartments, meaning that no guidance to a broad literature of differences across residential environments are existent.

Previous Swedish studies have, for example, estimated the willingness to pay (WTP) for reduced noise levels based on differences in housing prices of single-family houses (Andersson et al., 2010; Andersson et al., 2013; Swärdh et al., 2012). These studies have been guiding the Swedish Transport Administration's appraisal of railway noise and road noise (Swedish Transport Administration, 2018). Furthermore, these guidelines states that the distribution of total cost of noise is equally distributed into indoor costs and outdoor costs, hence, 50 percent each (Swedish Transport Administration, 2018). However, this distribution is not empirically validated through willingness-to-pay estimates. In addition, this distribution is policy important as some noise-reducing measures influence only indoor noise while other measures influence both indoor noise and outdoor noise.

Thus, an important contribution to the literature, both in an international perspective and in a Swedish policy perspective, would be a study with the aim to intra-compare noise costs for households living in apartments with noise costs for those households living in single-family houses, to overcome the shortcomings of using estimates from different housing markets. This is achieved through intra-city comparisons for a more valid approach. To this end, the purpose of our study is to estimate and compare the noise cost of apartments and single-family houses in several Swedish small regions to cover specific housing market characteristics that might occur in one single study area.

Furthermore, our study contributes to the literature in a number of distinct ways. This is, as far as the authors knows, the first study to compare noise cost of single-family houses and apartments in the context of road noise and rail noise. In addition, we use a rich data material with, at least for road noise, a large number of residential sales in different small regions in Sweden. Finally, the analysis in a Swedish setting is interesting as the traffic noise level in a relatively sparsely populated country as Sweden is generally lower compared to the noise level in large parts of the continental Europe.

The paper is disposed as follows. In the next section we present the methodology including the hedonic modelling framework, estimation specifications, and how to calculate marginal willingness to pay and the distribution of indoor noise cost and outdoor noise cost. In Section 3, we present data and descriptive statistics. Our estimated results including possible implementation of our estimates is presented in Section 4. The paper is concluded in Section 5.

2. Methodology

In this paper, we estimate the effect of noise differentials on housing prices using a traditional hedonic model framework. Different types of model specifications are used to end up with our estimates of noise costs of different residential environments.

2.1. Hedonic model

The hedonic model is suitable for analysis of the pricing of different heterogenous attributes of a commodity where different objects are close but not perfect substitutes. One of such commodities are residences, which also is one of the most studied commodities in the hedonic literature.

Empirically, the hedonic regression model goes back around 100 years as G.A. Hass estimated a farmland price model in 1922 (Colwell and Dilmore, 1999). Most of the theoretical development of the hedonic model is contributed to Rosen (1974).

In our study, we use hedonic pricing modeling to estimate the implicit price of noise exposure. In other words, the price of a residence is the dependent variable, while the noise level along with other control variables will be the explanatory variables. The hedonic pricing model has empirically been used in numerous studies to monetize individual’s preferences for non-market goods such as noise. This type of estimation is, as mentioned above, appropriate for estimating different kinds of markets or goods that are closely related, however, not perfect substitutes, for example owned apartments and single-family houses that will be used in this study.

In hedonic regressions, one important challenge is to control for as many value-influencing attributes as possible to overcome problems with omitted variable bias. Thus, we will control for other attributes such as housing attributes, spatial variables and other geographical variables.

More specifically, the model framework in our study is formulated as:

$$P_i = f(L_i, \mathbf{X}_i) \quad (1)$$

where P_i is the price of the residence *i*, L_i is the noise level of residence *i*, and $\mathbf{X}_i$ is a vector of other price-influencing characteristics of residence *i*.

In our application of the hedonic model we will use both a semiparametric specification and (parametric) OLS with different functional forms. The basic parametric model formulation is given as:

$$P_i = \alpha + \beta L_i + \boldsymbol{\gamma}\mathbf{X}_i + \epsilon_i\ , \quad (2)$$

where ϵ_i is the error term, and $\alpha, \beta, \boldsymbol{\gamma}$ are a set of parameters to be estimated. Especially of interest is β, which in this setting is interpreted as the implicit (or marginal) price of noise. Note that in our semiparametric specification, βL_i is substituted by $f(L_i)$.

Nelson (2008) discusses important features to consider when applying hedonic methods in the context of transportation noise valuation. First, the threshold value of noise exposure is important and difficult to easy determine. This point is also highlighted in Trojanek et al. (2017) where their short literature review is showing threshold levels ranging from 30 dB to 62 dB. In an economic setting, the threshold should be set where the willingness to pay for noise abatement starts. However, to find this level is difficult and can be extremely locally dependent.

Locally conditioned heterogeneity leads us to the second important feature that is market segmentation. The housing market is characterized by different types of residences that are to a strong degree, substitutes. On the other hand, there are clear market segments that need to be considered, e.g. geographical markets and different types of residences in the way of apartments and single-family houses.

Third, spatial considerations need to be considered when applying hedonic models. Either by spatially dependent errors or by carefully including high-resolution indicator variables of city districts.

Finally, the functional form of the hedonic model is not theoretically given. As pointed out by Dekkers and van der Straaten (2009), the semilogarithmic functional form is widely used in the hedonic literature. The semilog functional form implies that the housing price is transformed to its natural logarithm.

2.2. Different estimation models

We estimate several different hedonic models to analyze the differences across residential environments and how sensitive the estimates are to different specifications. We also, use different specifications to analyze other potential sources for different noise-level estimates. All models are estimated separately for each market and each residential environment.

The effect of noise level on residential price is not necessarily – or in fact unlikely to be – constant in the noise level. One reason is that the dB scale itself is not linear, which implies that there is no reason for why the willingness to pay for a one-dB noise reduction should be equal regardless of the noise level. The intuition is that this relationship would be an increasing willingness to pay in percentage terms when the noise level increases. In addition, this relationship may be different for apartments compared to single-family houses. Such a nonlinear relationship suggest that more flexible functional forms may be relevant for our hedonic model.

First, we thus estimate a semiparametric partial linear model. The nonparametric part of this model is estimated for the noise variable which impose a flexible functional form without parametric assumptions. This model is estimated by the plreg command in Stata (Lokshin, 2006). In addition, this model specification was also estimated by Ahlfeldt and Maennig (2013). In the semiparametric model we analyze the effect of different noise levels on the housing price using smoothed relations between the noise level and the housing price. These figures could also provide a guideline of at which noise levels the housing prices are negatively influenced. In the semiparametric specifications we include all housing transactions with a noise level of 45 dB and higher.

Second, we also estimate a traditional semi-logarithmic hedonic model using OLS for two different thresholds of noise namely 45 dB and 50 dB. We also test alternative specifications by the way of interacting the noise level with the existence of a balcony for apartments and an interaction between noise level and age of dwelling for both apartments and single-family houses. The reason is that a balcony may increase the willingness to pay for noise abatement as it simply is an outdoor residential place that belong to the apartment. Unfortunately, we have access to a complete balcony data for only a small part of our apartment transactions. Considering the covariance between noise and age of dwelling on the transaction price, the argument is that the façade insulation is different for different generations of dwellings.

For rail noise, the number of observations in each market is relatively small and thus we test to merge the different markets to one single regression model. Here we need to be careful about violating the market-segmentation recommendation, but on the other hand we can achieve a higher degree of efficiency with a larger estimation sample.

We will also test two parametric models that are more flexible by estimating the influence of noise on residential price through a polynomial function of degree three, i.e. include noise variables in the way of a linear term, a quadratic term, and a cubic term, or through dummy variables given in one-dB grids. These functional forms could impose different non-linear relationship but is not completely flexible.

2.3. Marginal willingness to pay

Based on our estimated hedonic models we can derive the estimated marginal willingness to pay (MWTP) for noise abatement. Here, we describe how these estimates are derived in our different model specifications. Note that all MWTP estimates are normalized to be given per individual and per year. Here we use region-specific average number of individuals in a household, which is specific for apartments and single-family houses respectively. Also, we use the discount rate of 3.5% as is the practice in Swedish guidelines of CBA of transportation measures (Swedish Transport Administration, 2018).

In the semiparametric partial linear model, we estimate MWTP by defining the local slope of the price with respect to the noise level in different noise intervals. If we denote this local slope as *S*, the formula is given by:

$$MWTP = -S * 0.035/\overline{HH}. \quad (3)$$

In the OLS models with a semilogarithmic functional form we estimate the MWTP evaluated at noise level, *L*, by the formula:

$$MWTP = -(\beta_L + 2\beta_{L2}L + 3\beta_{L3}L^2) * 0.035 * \bar{P}/\overline{HH}. \quad (4)$$

In Eq. (4), the formula is valid for the both the specification with a constant noise effect on housing price and for the polynomial specification of degree three. In the latter case all estimated beta parameters are included in the MWTP estimate. For the specification where *L* enters linearly, on the other hand, the expression within parenthesis in Eq. (4) collapses to β_L, i.e. the MWTP is not dependent on the noise level but constant for all noise-exposed housings.

2.4. Distribution of indoor noise cost and outdoor noise cost

One underlying purpose of our study is to estimate the distribution of total noise cost into indoor cost and outdoor cost. This estimate is assumed to be identified through a comparison of the MWTP for apartments and single-family houses. The argumentation is that noise exposure at a single-family house is capitalized in the price for both indoor residency and outdoor residency as these properties consist of both a dwelling and a garden. Regarding owned apartments, the price of the residence is only for the right to dispose the apartment for residency and it is assumed to not consist of any willingness to pay for outdoor residency.

Furthermore, the relation between the MWTP for apartments and single-family houses may be different at different noise levels. One such hypothesis is that the willingness to pay for outdoor residence starts at lower noise levels than the willingness to pay for indoor residence. In such cases, the share of total noise cost that is indoor noise cost will be lowest for relatively low noise levels. In addition, there might also be a difference between rail noise and road noise. The façade insulation for rail noise is higher than for road noise (see e.g. Swedish Transport Administration, 2018), which may imply that the implicit price for rail noise in apartments is low or even non-existing at relatively low noise-exposure levels.

The formula for the share of MWTP that is indoor cost, denoted as ρ, can be written as:

$$\rho = \frac{MWTP_a}{MWTP_h}, \qquad (4)$$

where a denotes the market segment of owned apartments, and h denotes the market segment of single-family houses.

3. Data

We study five separate small regions in Sweden, two considering railway noise and three considering road noise. The regions are chosen based on the availability of noise data and a region population that is sufficiently large to achieve a relatively large number of noise-exposed housing transactions.

Multiple data sources will be combined in our study. First, we collect data of owned apartments and single-family houses from a database of residential transactions in Sweden. Here, we also collect information about the apartments and single-family houses, including price, residential area, and housing standard. Second, calculated residence-specific noise levels including their coordinates are provided by the Swedish Transport Administration or by municipalities responsible for noise mapping. Third, coordinates of residences, to be able to match residences with noise levels, are produced by a geocoding program. Finally, network data of roads and railways are collected from open sources provided by the Swedish Transport Administration. Here below, we in more detail present the different data used in our study.

3.1. Noise calculations

The noise calculations are provided from various existing mappings of rail noise and road noise in Sweden. Table 1 shows the different sources for each of our studied small regions.

Table 1 – Noise sources for the different small regions studied

Small region	Traffic noise studied	Source of noise calculations
Linkoping	Rail noise	Swedish Transport Administration
Lund	Rail noise	Swedish Transport Administration
Gothenburg	Road noise	Municipality of Gothenburg
Orebro	Road noise	Municipality of Orebro
Umea	Road noise	Municipality of Umea

The municipality authorities in large cities are responsible for noise mapping of road noise. These data are provided by the municipalities of Gothenburg, Orebro and Umea, which are the second, sixth and twelfth largest cities of Sweden, respectively. These data are calculated at different height levels which we use to combine the noise calculation with apartments of different floors.

The Swedish Transport Administration are administering the railway lines in Sweden. For several of the main lines they have available noise mappings with calculated noise levels of different metrics for exposed buildings. Such noise-calculation data for railway noise are provided for Linkoping and Lund, which are the seventh and eleventh largest cities of Sweden, respectively.

The different types of sources of the noise calculations may raise questions whether the estimates are comparable across the small regions. Note, however, that the main purpose of our study is intra-region comparisons of noise preferences of different residential environments, in our application defined as apartments and single-family houses.

Note also that the noise indicator we use is the 24-hour equivalent level, conventionally denoted as L_{Aeq24h}. Furthermore, we have no yearly time variation in the noise data. However, the changes in the equivalent noise level is relatively small when the traffic volume is increasing (see e.g. Andersson & Ögren, 2011).

In Figures 1 and 2, maps of the noise calculation in Gothenburg (road) and Linköping (rail) is presented to illustrate the difference between road-noise and rail-noise data. These figures show that road noise calculation is covering almost the entire urban areas, where the railway noise is covering only a relatively narrow strip around the railway. From these figures follow the challenge of estimating MWTP for rail-noise abatement as the number of transactions will be relatively small.

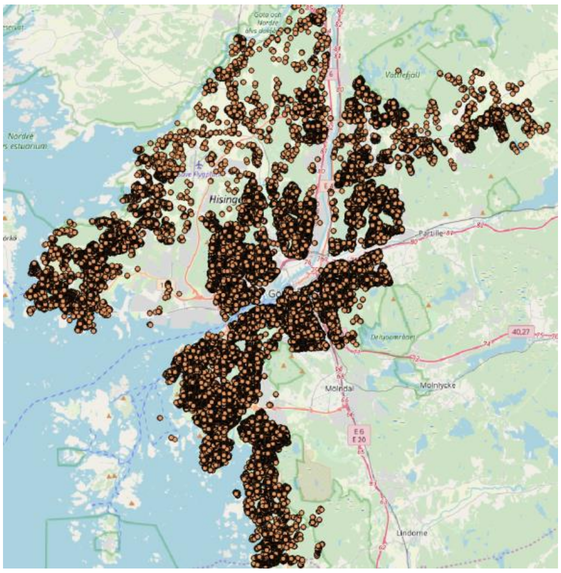


Figure 1: Road-noise calculations in Gothenburg

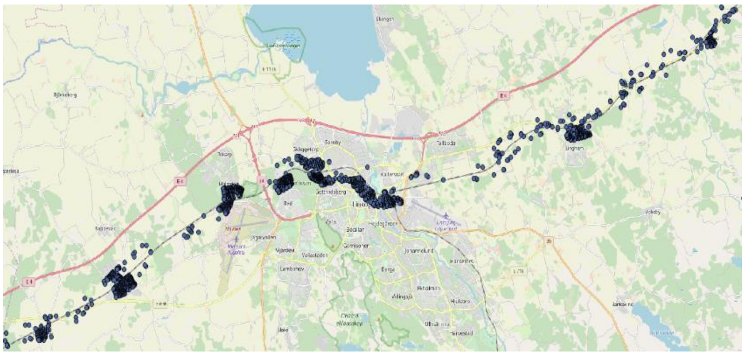


Figure 2: Railway-noise calculations in Linkoping

3.2. Property-sales data

Property-sales data are collected through a database provided by a Swedish company. We collect data for two distinct types of residences in Sweden, both sold in unregulated markets. First, we have single-family houses which are privately owned properties mostly with detached dwellings. Second, we also collect data for owned apartments, where the right to dispose the apartment is sold in the market. These apartments are located in multi-family houses without private access to a garden area.

These two different types of residence also have different characteristics that we are able to record. For single-family houses we observe an index determining the standard level of the house, which is taken from the property taxation register. For apartments, we do not observe any standard and instead we need to model the price as a function of a fixed fee (that is paid to the housing cooperative that are legally administering the house and its property), floor and residential area.

Furthermore, transactions of single-family houses are taken from the property register of Sweden in the years 2000 to 2018, where the date given is when the transfer of ownership has taken place. This date is not the same as when the contract has been signed and as the latter is the time when the price is determined it will not be meaningful to include monthly dummies in our estimations. However, we still use yearly dummies, which are capturing long-term trends that are not captured by the price-index deflation with indices defined on a higher regional level.

For apartments, on the other hand, the data are from registers completed by real estate agents from the year 2005 to 2018. Here the date of the contract signing is recorded in the transaction register, thus we can use monthly dummies in our estimation models.

Note also that the transaction needs to have been taken place between sellers and buyers on a private market to be included in our estimated models. This means that transactions involving legal personalities as municipality authorities are excluded.

Since the data consist of transactions that has taken place over a relatively large time span, the property prices are adjusted to the same price year by using price indices from Statistics Sweden. We use regionally specified price indices of single-family houses and owned apartments respectively. The prices are given in price year 2009.

More description of all our estimation variables can be found in Table 2 in Section 3.5.

3.3. Geographical data

The data used to obtain the coordinates is the address of the residences that are included in the database of residential transactions in Sweden. The coordinates of the residences are produced by the geocoding program OpenCage that turns a geographic reference such as an address into a geographic coordinate (latitude and longitude). An example of residential coordinates is shown in Figure 3, in this example for single-family houses in Orebro.

The geographical variables such as distance to road and distance to railway track is derived from network data of road and railway collected from an open source provided by the Swedish Transport Administration. The data of the networks and the coordinates of the residences were managed in the GIS-program QGIS. First, small neighborhood roads[3] are excluded. Then the distance between the coordinates of the residences and the closest road of those roads with a classification 5 or below (lower number implies a higher road classification) is calculated by QGIS.

[3] In this case roads above classification 5 according to the definition by the Swedish Transport Administration.

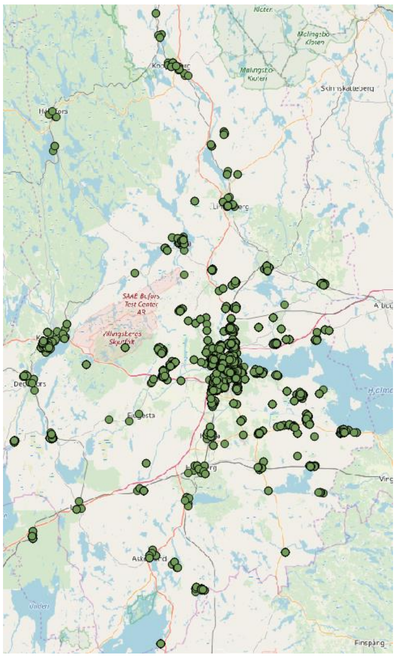


Figure 3: Coordinates of single-family houses in Orebro

To control for the accessibility of the residences we acquire variables such as distance to city center, distance to railway station and distance to the closest motorway entrance. By obtaining the coordinates of where these are located, we could measure the distance from the residence to each of these coordinates by using QGIS and the statistics software STATA.

3.4. Data combination

To combine and merge the multiple data sets, we use the GIS-program QGIS and the statistics software STATA. To begin with, the coordinates of the residences are matched with the calculated house-specific noise level point located the closest to the coordinate of the residence, together with the distance to the noise point from the coordinate of the residence by using QGIS. To make sure that no residence without noise exposure are matched with a noise-calculation point far away, we set an upper limit of 50 meters from the residence coordinate to the noise-calculation point.

The data sets including geographical variables that are created in QGIS, such as distance to the city center or distance to railway station are merged with the rest of the residence data in STATA.

3.5. Variables and descriptive statistics

In Table 2, a description of all variables used in the estimations is presented. The variables are classified as variables exclusively for apartments and single-family houses, respectively, and as those variables that are common for both residential environments.

Table 2 – Description of all estimation variables

Common variables	**Description**
Price	Transaction price of the apartment or the single-family house, given in SEK (1 EUR ≈ 11 SEK) and deflated to 2009 years prices
Noise	Calculated noise level at façade, given in the 24-hour equivalent metric L_{Aeq24h}
Residential area	Area of the dwelling given in square meters
Age of dwelling	Number of years since the dwelling was constructed
Distance to railway	Distance in meters as the crow flies from the dwelling to the nearest railway line
Distance to train station	Distance in meters as the crow flies from the dwelling to the nearest train station
Distance to road	Distance in meters as the crow flies from the dwelling to the nearest road classified as 5 or below
Distance to city center	Distance in meters as the crow flies from the dwelling to the city center
Distance to motorway entrance	Distance in meters as the crow flies from the dwelling to the nearest motorway entrance
Year	Year of the transaction, can be from 2000 to 2018 for single-family houses and from 2005 to 2018 for apartments.
Apartment variables	
Housing cooperative fee	The monthly fee in SEK that the owner of an apartment has to pay to the housing cooperative that administer the common properties of the dwelling
Floor	The floor of the apartment, can be given in halves
Zip Code	The highest resolution of zip code of a residential address.
Month	The month of the contract signing of the apartment transaction
Single-family house variables	
Supplementary residential area	Areas in the house that are not fulfilling the criteria to be housing area. Examples are basements and parts of an attic that has a low ceiling height
Housing standard index	Index from the property taxation that measures the overall standard of the property. Examples of included attributes are number of bathrooms, garage, municipal fresh water and sewer, and standard level of bathroom and kitchen
Property area	Area of the total property given in square meters
Beside river/lake/sea	Indicator for a property within 150 meters to the closest river/lake/sea
Housing type	Indicators for detached (reference), linked or terraced house
Leased property	Indicator for properties that are leased from the municipality by the house-owners who pay a yearly leasing fee to the municipality
Property taxation area	Indicators for the homogeneous property taxation area used by taxation authorities to prescribe the taxation value of a property

In Table 3, we present descriptive statistics for the variables per small region and residential type. We can see that all our small region are relatively heterogenous residential markets as the price of the residences differ substantially. In fact, the price, for both single-family houses and apartments, is roughly twice as large in Gothenburg and Lund compared to in Orebro. Regarding our controlling variables, they are relatively similar across all small regions, but as expected an average single-family house has a much larger residential area than the average apartment.

Table 3 – Descriptive statistics for each city and form of housing. Mean value and standard deviation

	Road			Rail	
	Gothenburg	**Orebro**	**Umea**	**Linkoping**	**Lund**
Single-family houses					
Price of property	3 180 737 (1 520 177)	1 790 254 (1 1073 72)	2 134 157 (791 307)	2 128 538 (75 2729)	3 360 487 (1 546 917)
Noise level, if ≥ 45 dB	50.133 (4.063)	50.104 (3.717)	49.359 (4.112)	50.756 (4.419)	55.048 (5.403)
Noise level, if ≥ 50 dB	53.995 (3.144)	53.460 (2.964)	54.208 (3.098)	54.357 (3.716)	56.122 (4.794)
Residential area	125.456 (41.542)	121.614 (35.763)	128.285 (34.339)	116.918 (30.504)	131.358 (37.581)
Supplementary residential area	40.550 (38.709)	45.496 (47.756)	46.254 (42.233)	76.539 (41.775)	36.564 (47.796)
Housing standard index	28.370 (4.758)	29.751 (4.861)	29.738 (4.314)	30.289 (4.831)	29.600 (4.338)
Property area	588.982 (470.259)	813.177 (728.737)	745.327 (659.150)	852.807 (504.930)	630.298 (632.648)
Age of dwelling	45.936 (23.593)	45.007 (21.823)	37.473 (20.064)	45.444 (18.697)	38.885 (31.092)
Distance to railway (meters)	2 435.463 (2 379.014)	1 633.147 (2574.343)	2329.163 (3660.078)	280.870 (133.279)	228.780 (145.571)
Distance to train station (meters)	-	-	6330.331 (6715.368)	7991.841 (4728.898)	2841.889 (1865.956)
Distance to road (meters)	167.204 (155.057)	251.543 (220.408)	249.695 (217.577)	181.600 (106.972)	2983.434 (870.461)
Distance to city center (meters)	6 199.516 (3 322.119)	-	-	-	-
Distance to motorway entrance (meters)	-	3 205.564 (5 272.961)	-	5 581.553 (3654.28)	2 983.434 (870.461)
Beside river/lake/sea (dummy)	0.119	0.126	0.215	0.188	0.1275
Linked (dummy)	0.117	0.288	0.171	0.222	0.143
Terraced (dummy)	0.326	0.054	0.246	0.054	0.150
Leased property (dummy)	0.236	0.141	0	0.016	0
Number of observations	12 303	6 235	4 714	958	698
Apartments					
Price of property	1 875 277 (951 215)	998 899 (515 843)	1 006 987 (421 408)	1 217 260	1 784 157 (813 299)
Noise level, if > 45 dB	54.753 (5.661)	53.621 (5.355)	52.209 (5.615)	50.925 (3.561)	52.191 (5.853)
Noise level, if > 50 dB	56.930 (4.569)	56.192 (4.396)	56.273 (4.193)	53.353 (3.174)	55.489 (5.124)
Housing area	65.150 (24.827)	72.652 (22.447)	68.184 (21.162)	66.777 (26.819)	68.528 (28.183)
Age of dwelling	60.463 (29.849)	44.299 (25.794)	34.850 (18.848)	48.962 (27.553)	60.709 (33.153)
Housing cooperative fee	3 506.316 (1 194.401)	4097.166 (1289.893)	3 788.667 (1 343.942)	3499.502 (1420.028)	3 590.292 (1 322.115)
Floor	2.845 (1.906)	2.0656 (1.266)	2.410 (1.659)	2.592 (1.716)	2.385 (1.591)
Distance to Railway (meter)	1 383.504 (1228.345)	782.163 (792.422)	1 470.880 (1 564.634)	312.911 (132.572)	238.430 (123.390)
Distance to Road (meter)	108.497 (96.949)	202.885 (220.328)	250.990 (288.589)	111.155 (95.764)	98.150 (85.083)
Distance to motorway entrance (meters)	-	2051.913 (1140.222)	-	2924.253 (892.873)	2372.168 (403.097)
Distance to railway station (meters)	-	2208.006 (1639.322)	2 448.295 (1 991.312)	312.910 (132.572)	791.6564 (676.497)
Distance to city center (meter)	2 955.606 (1 963.947)	-	-	-	-
Number of observations	51 396	6 104	5 019	1 851	1 572

When investigating the distribution of our noise variable, we present mean values both for all observations equal to and above 45 dB and all observations equal to and above 50 dB, i.e. the two different threshold levels we will use in our estimations. Here we can notice some interesting differences. First, the noise average is very different across the small regions. Also, regarding road noise the noise level on average is much higher for apartments compared to single-family houses. For rail noise, on the other hand, the noise level is relatively similar for apartments and single-family houses. In fact, if any difference could be detected, the noise level is slightly higher for single-family houses.

The different average noise levels are making us interested in the complete distributions. In Appendix A, figures of these noise distributions are presented. Here, we clearly can see the heterogeneous distribution of noise exposure across our small regions, noise sources and housing types. These different distributions are one argument for estimating flexible functional forms where the noise effect on price is different for different noise levels.

4. Empirical Results

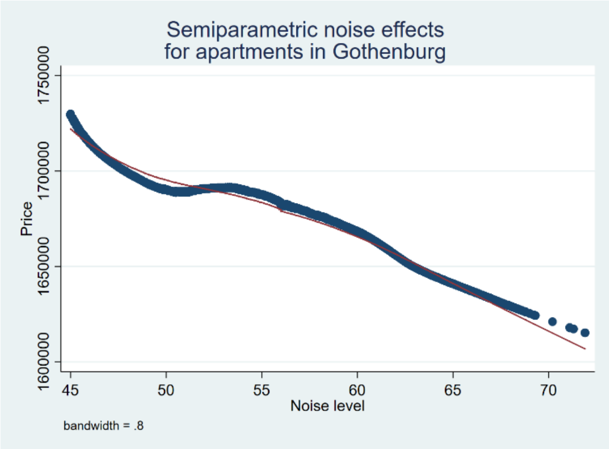
In the following subsections we present the estimated results of our hedonic models, first visual presentation of the semiparametric models followed by parametric estimations.

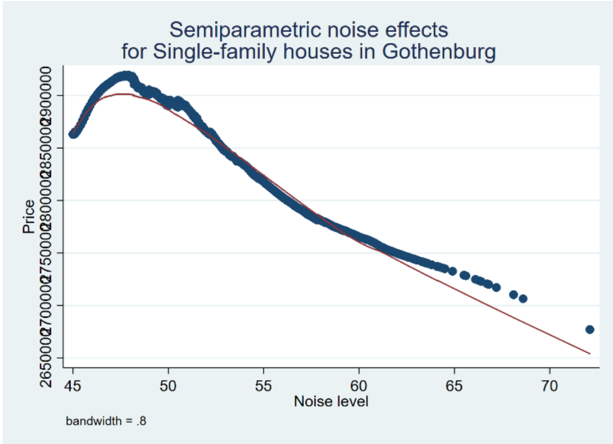
4.1. Semiparametric models

We start by exploiting the result of the estimated hedonic model by using a semiparametric functional form where the effect on the price from the noise level is the nonparametric part of the model. The semiparametric model we use is a partial linear model estimated by the Stata command plreg (Lokshin, 2006).

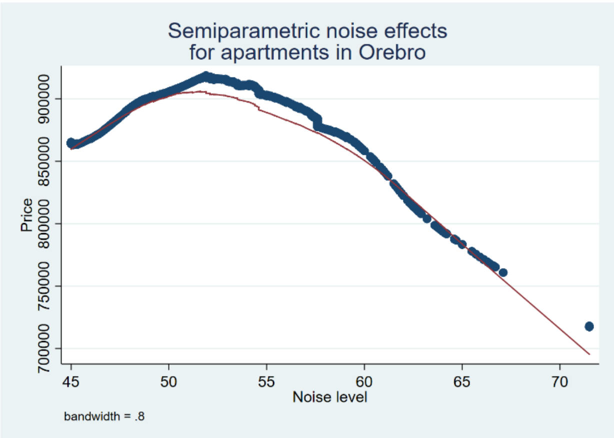
The results of our estimated semiparametric noise effects are found in Figures 4-13. Here we can see the local marginal effect of noise-level changes on housing price. Our expectation is that the slope at some noise levels starts to be negative and then with a higher negative slope the higher the noise level is.

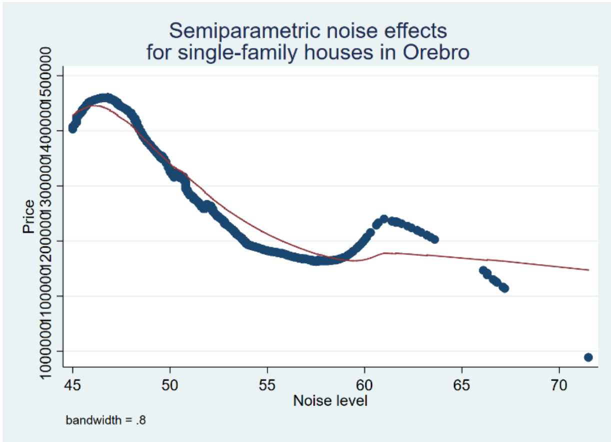
Exploring the smoothed red-colored lines, such *clear* pattern is not found in any of the figures. Single-family houses in Linköping has a noise effect that is close to the expected pattern. Also, the noise effects for Gothenburg (both markets), apartments in Lund, and apartments in Orebro show a relatively expected pattern.



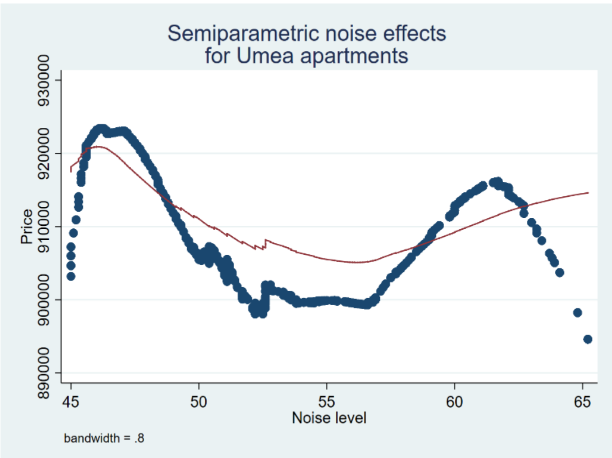


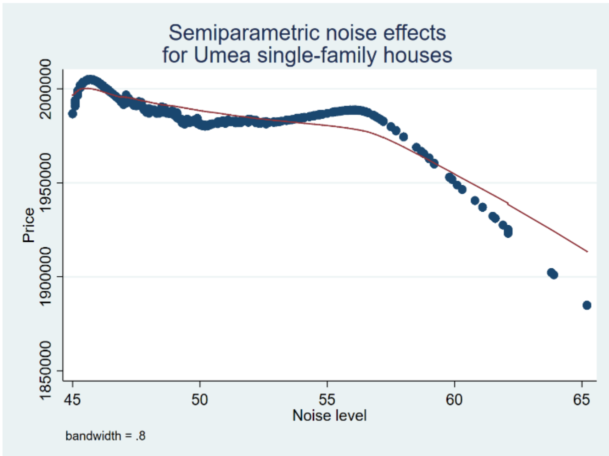
Figures 4 and 5 – Semiparametric noise effects on housing price in Gothenburg



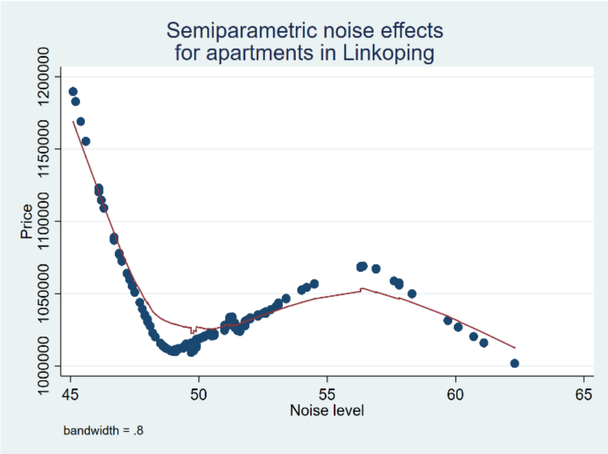


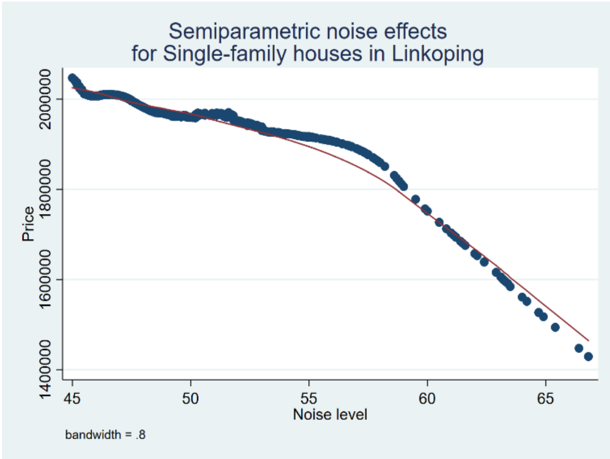
Figures 6 and 7 – Semiparametric noise effects on housing price in Orebro



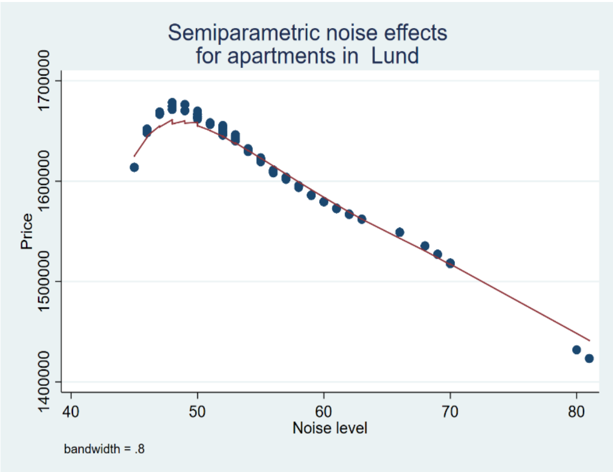


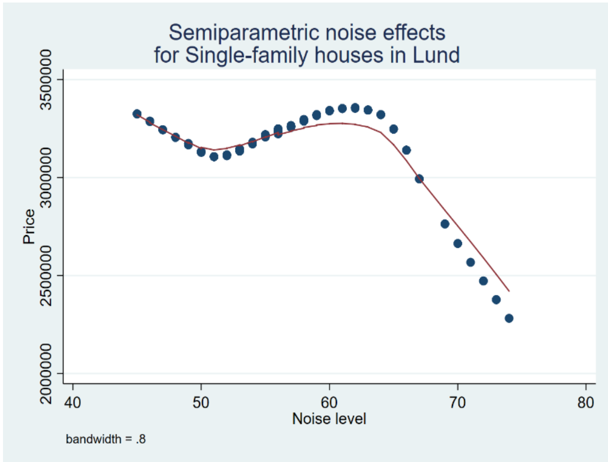
Figures 8 and 9 – Semiparametric noise effects on housing price in Umea





Figures 10 and 11 – Semiparametric noise effects on housing price in Linkoping





Figures 12 and 13 – Semiparametric noise effects on housing price in Lund

However, based on these figures we could observe a number of interesting features that we will use for the ongoing analysis.

In the figures, we can observe the approximate noise level where the price discount starts, i.e. where the noise effect starts to slope downwards without a further upward slope. This effect occurs at noise level of about 52 dB for apartment exposed to road noise (except Umea), at 47-48 dB for single-family houses exposed to road noise (except for a small hump at 62 dB in Orebro). For the two rail-noise exposed markets, the result here is mixed with 50 or 57 dB for apartments and 45 or 61 dB for single-family houses. Summarizing results for the intervals where the noise effects are negative is found in Table 4. These intervals will be used when the marginal willingness to pay is derived.

Table 4 – Intervals of noise levels where noise has a negative influence of the housing price

	Road			Rail	
	Gothenburg	**Orebro**	**Umea**	**Linkoping**	**Lund**
Noise intervals apartments	>45 dB	>52 dB	47-57 dB	45-49 dB >57 dB	>49 dB
Noise interval single-family houses	>48 dB	47-59 dB	>46 dB	>47 dB	45-51 dB >61 dB
Common intervals	>48 dB	52-59 dB	47-57 dB	47-49 dB >57 dB	49-51 dB >61 dB

4.2. Parametric models

In this section we present the estimated hedonic models of the parametric, i.e. OLS, specifications. First, we analyze the results when the noise threshold is set to 45 dB, followed by models where the threshold is set to 50 dB.

In Table 5, we present the parametric model results for apartments, that is the model where the noise level threshold to be included in the estimation sample is set to 45 dB. First one can see that most of the controlling variables are significant with the expected signs. A higher cooperation fee is decreasing the price, while a higher floor and a larger residential area is increasing the price. For age of dwelling and the geographical distance variables, the estimated parameters show more mixed result. Note that, e.g., distance to road could capture different effects, both negative effects as traffic safety and air pollution, as well as positive effects as accessibility.

Considering the variable of interest in our study, namely the noise level, the result is also mixed, which is expected with the patterns of Figures 4-13 in mind. In Gothenburg, the road noise is strongly statistically significant with the expected negative sign. Gothenburg is also the only market with this expected result for the noise effect on price. In fact, Orebro provides an unexpected positive effect on price of noise.

Finally, notice that we also control for zip code indicators, monthly indicators and yearly indicators – which are not presented with their coefficients in the table – and that the R^2-adjusted is relatively high for all of our hedonic models on apartments.

Table 5 – Estimated result of the hedonic regressions, basic model for Apartments

	Road			Rail	
	Gothenburg	**Orebro**	**Umea**	**Linkoping**	**Lund**
Noise	-0.0019***	0.0030***	-0.0015	0.0001	-0.0016
Residential area	0.0122***	0.0201***	0.0115***	0.0162***	0.0124***
Age of dwelling	0.0001***	-0.0008***	-0.0006**	-0.0001	-0.0003*
Housing cooperation fee	-0.0001***	-0.0002***	-0.0001***	-0.0001***	-0.0001***
Floor	0.0140***	0.0046*	0.0246***	0.0506***	0.0122***
Distance to railway	0.0001***	-0.0000	-0.0002	-0.0002*	-0.0002*
Distance to road	-0.0001***	-0.0001***	-0.0002***	0.0002*	0.0001
Distance to train station (meters)	-	-0.0000	-0.0002***	0.000	-0.0001**
Distance to motorway entrance (meters)	-	-0.0000	-	-0.0001	0.0002
Distance to city center (meters)	-0.0001***	-	-	-	-
Zip code indicators	Yes, 126	Yes, 39	Yes, 61	Yes, 19	Yes, 9
Monthly indicators	Yes	Yes	Yes	Yes	Yes
Yearly indicators	Yes	Yes	Yes	Yes	Yes
No of observations	51 396	6 539	5 019	1 851	1 572
R2-adjusted	0.877	0.765	0.772	0.845	0.855

Note: ***, **, and * denotes statistically significance from 0 at the 1-percent-level, 5-percent level, and 10-percent level, respectively.

In Table 6, we present the result of the corresponding hedonic regression on single-family houses. Also here, the controlling variables have in general expected signs. Residential area and housing standard have strongly significant positive effects on price. Supplementary residential area, property area, linked house and terraced house have the expected effect on price in most of the markets. As for apartments, the result for geographical-distance variables are mixed. Age of dwelling, on the other hand, is here mostly negative. Leased property has an extremely odd parameter estimate for both Orebro and Linkoping. The only interpretation of this large positive effect that we can come up with is that the leased properties are exclusively located in one or a few town areas that have high residential prices in general.

Considering the estimated noise parameter, we could notice that for single-family houses all of them are negative and statistically significant at, at least, the 10-percent level. Also here, the significance is strongest in Gothenburg.

We have also controlled for town areas, here in the way of taxation value area indicators, as well as yearly indicators. The explanation rate R^2-adjusted, is consistently lower for single-family houses than for apartments, although still relatively high with a rate ranging from 0.48 to 0.76.

Table 6 – Estimated result of the hedonic regressions, basic model for single-family houses

	Road			**Rail**	
	Gothenburg	**Orebro**	**Umea**	**Linkoping**	**Lund**
Noise	-0.0033***	-0.0051*	-0.0024*	-0.0118**	-0.0064**
Residential area	0.0027***	0.0055***	0.0032***	0.0031***	0.0038***
Supplementary residential area	0.0003***	0.0001	0.0001	0.0010***	0.0003
Housing standard	0.0106***	0.0122***	0.0158***	0.0153***	0.0126***
Property area	0.0001***	0.0000	0.0001***	0.0001***	0.0000
Age of dwelling	-0.0016***	-0.0002	-0.0024***	-0.0012	-0.0016***
Distance to railway (meters)	-0.0001**	0.0000	0.0000	-0.0003	-0.0000
Distance to train station (meters)	-	-0.0001***	-0.0000	0.0000	0.0000
Distance to road (meters)	0.0001**	-0.0004***	-0.0000	0.0001	0.0001
Distance to city center (meters)	-0.0000	-	-	-	-
Distance to motorway entrance (meters)	-	0.0001***	-	-0.0000	-0.0002*
Beside river/lake/sea (dummy)	0.0331**	0.0610	0.0400***	0.0293	-0.2847***
Linked (dummy)	-0.0568***	-0.3306***	-0.0856***	-0.0394	-0.0474*
Terraced (dummy)	-0.0994***	-0.2362***	-0.1321***	-0.0161*	-0.1453***
Leased property (dummy)	-0.0390***	0.9681***	-	0.6412***	-
Taxation value area indicators	Yes, 126	Yes, 85	Yes, 59	Yes, 14	Yes, 10
Yearly indicators	Yes	Yes	Yes	Yes	Yes
No of observations	12 303	6 235	4 714	958	698
R2-adjusted	0.737	0.540	0.727	0.483	0.764

Note: ***, **, and * denotes statistically significance from 0 at the 1-percent-level, 5-percent level, and 10-percent level, respectively.

One reason for the mixed result regarding the influence of noise on the residential price might be the high influence of residences with a relatively low noise level. This suspicion could also be detected, although not completely clear, by the pattern of semiparametric estimates found in Figures 4-13. Recall also that the noise distributions presented in Section 3.6. show that in most of the studied small regions, the noise level is very frequent at the lower levels, in particular between 45 dB and 50 dB. Furthermore, a possible reason for the difference across apartments and single-family houses might be that the price discount starts at lower noise levels for single-family houses, a statement that is consistent with the hypothesis that single-family house buyers also pay a price for lower noise in their residency garden.

Therefore, we estimate exactly the same model as before with the only exception that the noise threshold is changed to 50 dB from 45 dB. From this sample exclusion follows that the estimated sample sizes decrease substantially. These results are briefly presented in Tables 7 and 8, where we only present the most relevant estimation results that is the noise estimates and some summary of statistics.

We can see in Tables 7 and 8 that the noise effect on transaction price is slightly changed, but still not all the coefficients are statistically significant. Here, opposite to the models with threshold level 45 dB, all points estimates are negative. Changed statistical significance occurs for single-family houses in Umea, where the statistically significance surprisingly is ceased in the 50 dB-threshold model; and for apartments in Orebro, where the change is substantial in the way of moving from a strongly statistically significant *positive* effect to a strongly statistically significant *negative* effect.

The number of observations decreases a lot compared to the basic models, illustrating the relatively large share of observation between noise levels 45 dB and 50 dB. In addition, the explanation rate, R^2-adjusted, is relatively unaffected with some markets showing a small increase while other markets are showing a small decrease.

Table 7 – Estimated result of the hedonic regressions for Apartments with noise threshold at 50 dB

	Road			**Rail**	
	Gothenburg	**Orebro**	**Umea**	**Linkoping**	**Lund**
Noise	-0.0029***	-0.0055***	-0.0025	-0.0019	-0.0019
No of observations	39 372	4 555	2 808	978	968
R2-adjusted	0.877	0.782	0.779	0.846	0.866

Note: ***, **, and * denotes statistically significance from 0 at the 1-percent-level, 5-percent level, and 10-percent level, respectively.

Table 8 – Estimated result of the hedonic regressions for single-family houses with noise threshold at 50 dB

	Road			**Rail**	
	Gothenburg	**Orebro**	**Umea**	**Linkoping**	**Lund**
Noise	-0.0038***	-0.0095*	-0.0024	-0.0159**	-0.0066**
No of observations	5 265	2 756	1 630	459	616
R2-adjusted	0.755	0.540	0.736	0.404	0.761

Note: ***, **, and * denotes statistically significance from 0 at the 1-percent-level, 5-percent level, and 10-percent level, respectively.

4.2.1. Other model specifications

Here we briefly describe the other model specifications that we have tested but not presented in Tables.

First, the estimated polynomial models for apartments and single-family houses show that it is difficult to parametrically estimate effects of noise on housing prices that are specific for different noise levels. At some noise levels, the noise effect on prices are negative but at some other noise levels positive. This finding is not surprising referring to the patterns in Figure 4-13.

The models where we analyze the effect of noise on the housing price for apartments with a balcony and apartments with respect to different construction years show some unexpected results, e.g. a positive co-effect of balcony and noise level on the housing price. The general observation is that it is not possible to identify any distribution of indoor noise cost and outdoor noise cost from these models. Thus, we have decided to not present them in the paper.

We have also tested to estimate the noise effects by using dummy variables in one-decibel grids following the modeling framework in Lavandier et al. (2016). These models show unreliable results with a mixture of positive and negative coefficients. We can refer to the pattern in Figures 4-13 to conclude that such results would probably occur.

The models for the rail-noise markets with noise threshold 50 dB consist of a relatively small number of observations. Thus, we test to relax the market-segmentation recommendation in favor of more observations by merging the markets of Linkoping and Lund. These models show that the separate-market results broadly speaking remains.

4.3. Marginal willingness-to-pay (MWTP) estimates and comparison across residential environments

The MWTP estimates for different intervals of the semiparametric models and for the OLS models with threshold level of 50 dB are presented in Table 9. To be included here, most of the noise interval should be above 50 dB.

The results in Table 9 reveals a few interesting observations. First, MWTP seems to increase with the noise level, which is according to empirical evidence of the literature. Second, there is a tendency towards higher MWTP for rail noise than for road noise in the single-family house’s markets, which contradicts the common findings in the literature. Finally, MWTP seems to be higher for buyers of single-family houses than for apartment buyers.

Table 9– Estimated MWTP in different models, given in SEK in 2009 years prices

Model and noise level	Road			Rail	
Apartments					
	Gothenburg	**Orebro**	**Umea**	**Linkoping**	**Lund**
OLS, threshold 50 dB	111	116	53	52	66
Semiparametric model:					
>45 dB	79				
47-57 dB			37.5		
>49 dB					142
>52 dB		216			
>57 dB				226	
Single-family houses					
	Gothenburg	**Orebro**	**Umea**	**Linkoping**	**Lund**
OLS, threshold 50 dB	144	214	58	418	263
Semiparametric model:					
>46 dB			38.5		
47-59 dB		321			
>47 dB				314	
>48 dB	131				
>61 dB					723

We also estimate the relationship between the MWTP of apartments and the MWTP of single-family houses. The ratio between the apartment estimate and the single-family-house estimate is interpreted as the share of total noise cost for a given noise level that is indoor noise cost. These indoor estimates are presented in Table 10. We also note if the estimate falls outside the valid range between 0 and 1.

For the OLS models, estimates outside the interval 0 to 1 is only for Orebro and Linkoping when the noise threshold is 45 dB. This is not a problem if that has a clear reason, for example if façade insulation makes the willingness to pay for apartments to start at higher noise level compared to the willingness to pay in the market for single-family houses. In both these cases, the non-negative sign of the apartment models indeed is the reason.

Furthermore, we can see that the OLS model with threshold 50 dB, all point estimates are in the valid range between 0 and 1. Here, the tendency of a higher indoor share for road noise than for rail noise is noticeable. This might have been expected as façade reduction is larger for rail noise than for road noise.

Table 10 – estimated indoor noise cost as the share of total noise cost

	Road			Rail	
Model and noise level	**Gothenburg**	**Orebro**	**Umea**	**Linkoping**	**Lund**
OLS, threshold 45 dB	0.57 [0.33– 0.81]	Negative	0.48 [-0.37-1.34]	Negative	0.20 [-0.12-0.53]
OLS, threshold 50 dB	0.77 [0.23-1.32]	0.55 [-0.10- 1.19]	0.92 [-1.57- 3.41]	0.13 [-0.33-0.58]	0.25 [-0.18-0.68]
Semiparametric model:					
>48 dB	0.51				
47-49 dB				>1	
49-51 dB					0.34
47-57 dB			>1		
52-59 dB		0.88			
>57 dB				0.39	
>61 dB					0.16

When the indoor noise cost shares are estimated for different noise intervals based on the semiparametric models, most of the shares are in the interval 0 to 1. To summarize these shares, they are between 0.48 and 0.92 for road noise and between 0.13 and 0.39 for rail noise.

4.4. Discussion of the results

Our estimated results of noise exposure effects on housing prices are mixed and somewhat non-stable. This conclusion especially holds for the model specifications aiming for an estimated noise cost that differ across the noise level. Thus, we need to discuss potential sources for these mixed results and different kinds of limitations with our study, mostly regarding data and methodology. Especially the more flexible functional forms show that it is based on our method and data difficult to estimate effects on housing prices from locally defined noise levels.

The noise calculation, and in particular its connection to housing addresses via geocoding, may include coding errors. We have handled the observed errors such as low geocoding quality by exclusion of the samples, but potential error sources may remain. In addition, we cannot observe the exact apartment location in a multi-family house, nor the location of bedrooms.

The number of observations can be another feature of the difficulties to find stable negative impact of noise at all different noise levels on the housing price. A feature speaking for this reason is that Gothenburg, with the clearly largest number of transactions, show the most stable results. Gothenburg has for both residential environments always a negative slope of the noise impact on the housing price.

Another possible reason is that a lot of buyers do not care about noise exposure and that there might be different preferences against noise regarding apartment buyers and buyers of single-family houses.

The inconsistency of the results may be due to omitted variable bias, meaning that we cannot control for all effects that are correlated with the noise level. Although, we include numerous different control variables and have access to a calculated noise level with a high resolution, there might be some noise levels that are associated with other certain housing attributes that we do not observe.

4.5. Implementation

The empirical results may be implemented in cost-benefit analysis of measures to mitigate transportation noise emissions.

In the current principles of CBA in the Swedish transport sector, the total noise cost in living environments are divided into 50 percent indoor and 50 percent outdoor, a main principle that is the same for rail noise and road noise (Swedish Transport Administration, 2018). There is, however, an exception regarding rail noise from 50 dB to 58 dB, where a larger share is treated as outdoor noise cost. In fact, the indoor noise cost is 0 for 50 dB to 53 dB and about 31 percent of total noise cost for 57 dB.

Furthermore, the principle of dividing the total noise cost into indoor noise and outdoor noise have been changed in the Swedish guidelines regarding rail noise. Previously, the distribution changed to 60 percent indoor and 40 percent outdoor, and that principle was for both rail noise and road noise, and before that the guidelines for rail noise was to divide the total noise into 90 percent indoor and 10 percent outdoor (Swedish Transport Administration, 2012). In the current version of CBA recommendations of Swedish Transport Administration (2018), the guidelines are a 50-50 distribution.

The most apparent empirical result is that the indoor noise share is larger for road noise than for rail noise. This is consistent with the façade reduction being generally larger for rail noise than for road noise.

Regarding road noise, there is a weak support for a higher share of indoor noise cost than today, a recommendation is to at least reconsider the previous guidelines of an indoor noise cost that is 60 percent of the total noise cost. There is also weak support for no road noise effect on apartment prices up to approximately 52 dB.

For rail noise, the results seem to support a lower share than 50 percent. However, no clear pattern is existing for a different indoor share for different noise levels.

As suitable for implementation in guidelines for evaluations of noise measure, our results may be one of several bases for decisions. However, other complementary material is recommended to point in the same direction to provide stronger evidence.

5. Conclusions

In this paper, we estimate the noise cost of different living environments. In particular, we compare noise cost of both road traffic and rail traffic for apartments and single-family houses. The results, based on both linear and non-linear functional forms, show that in general there is a price discount of the residences when noise exposure is relatively high. Of our five studied small regions, the estimated models of residential sales in Gothenburg consistently are most in line with expected price effects of noise. The flexible semiparametric estimation of the noise effect reveals an unexpected positive slope for relatively high noise levels in a few markets.

The relationship between noise cost for apartments and noise cost for single-family houses is suggested to reveal the distribution of total noise cost into cost for indoor noise and cost for outdoor noise.

These estimated relationships show no clear evidence of the indoor noise cost share. However, some indications may be suggested based on our results. First, there is a weak tendency for the share of indoor noise cost being above 50 percent for road noise. For rail noise, on the other hand, the results seem to support a lower share than 50 percent. Both these indications can be summed up into a suggestion of a larger indoor share of road-noise costs compared to rail-noise costs. In addition, the price discount of noise exposure seems to start at lower noise levels for single-family houses than for apartments.

Our empirical hedonic application also shows the high importance of the threshold level when noise cost is estimated. Our estimated noise effect on residential price differs substantially when the threshold is changed from 45 dB to 50 dB. This opens up for a more flexible functional form, and the partial linear model also shows a pattern where the price effect of noise starts at different levels for different markets. Further, the threshold level for when the willingness to pay for noise abatement starts is important, especially as most of the noise-exposed individuals are exposed to relatively low noise levels. The high number of individuals in this group will make them influential in a cost-benefit analysis of noise measures.

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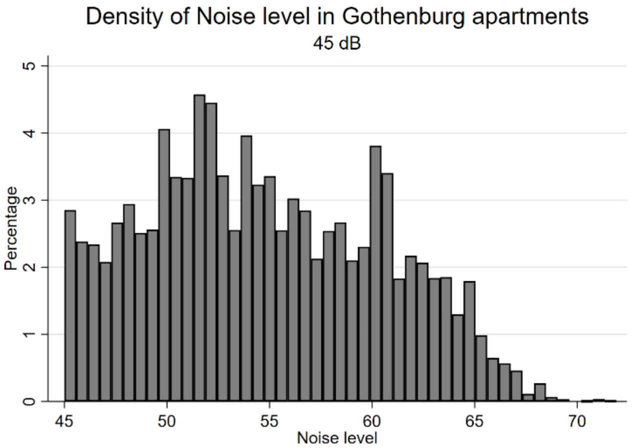
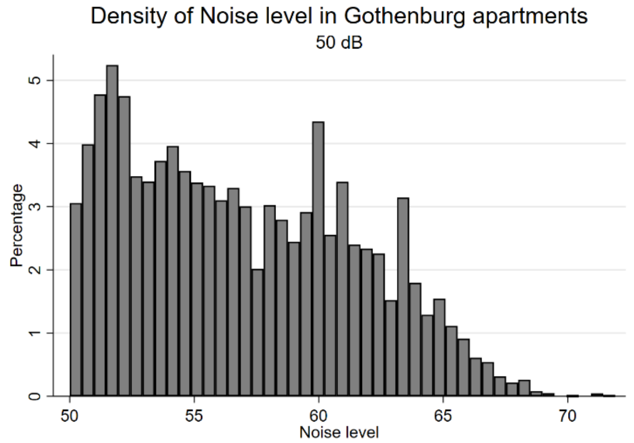
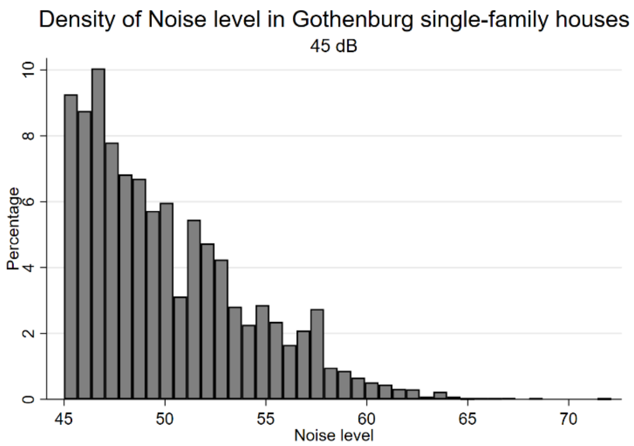
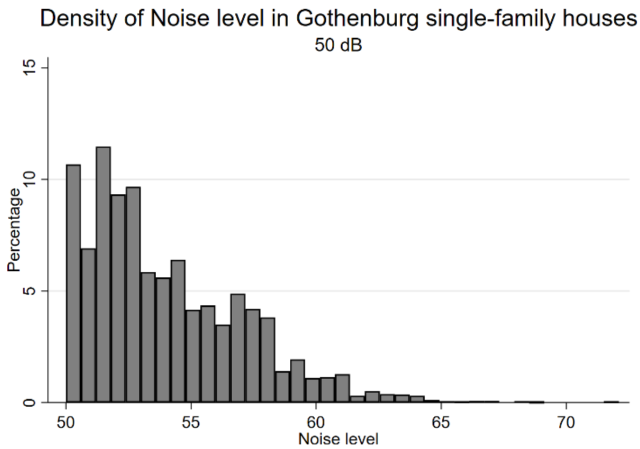
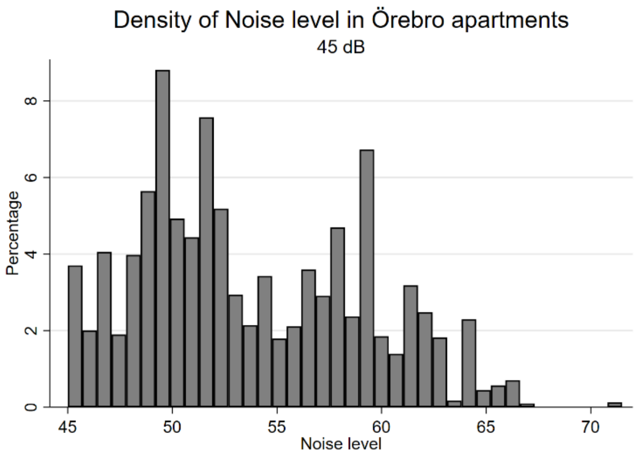
APPENDIX A

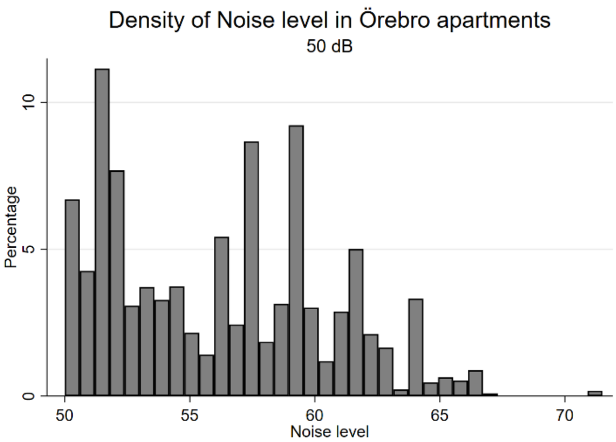

Density of Noise level in Gothenburg apartments
45 dB
Percentage
0
1
2
3
4
5
45
50
55
60
65
70
Noise level

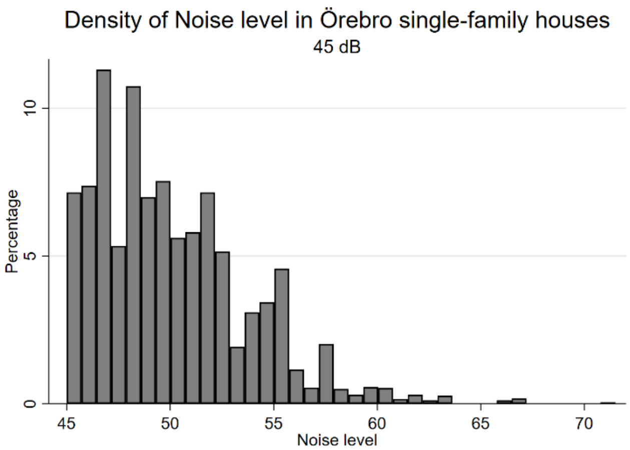

Density of Noise level in Gothenburg apartments
50 dB
Percentage
0
1
2
3
4
5
50
55
60
65
70
Noise level

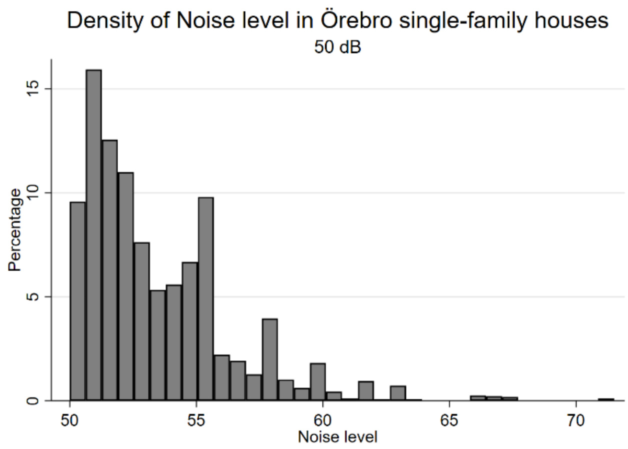

Density of Noise level in Gothenburg single-family houses
45 dB
Percentage
0
2
4
6
8
10
45
50
55
60
65
70
Noise level

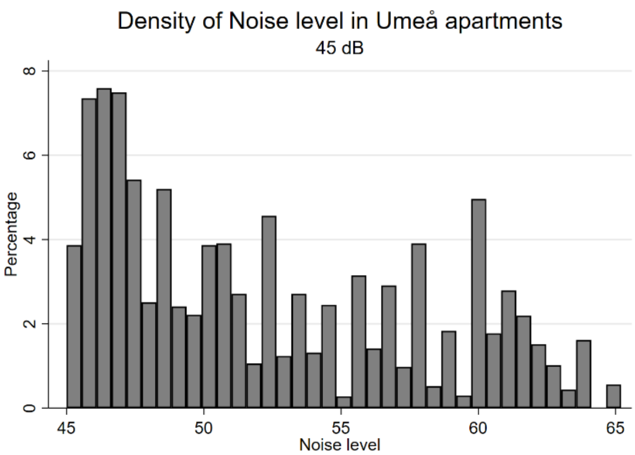

Density of Noise level in Gothenburg single-family houses
50 dB
Percentage
0
5
10
15
50
55
60
65
70
Noise level

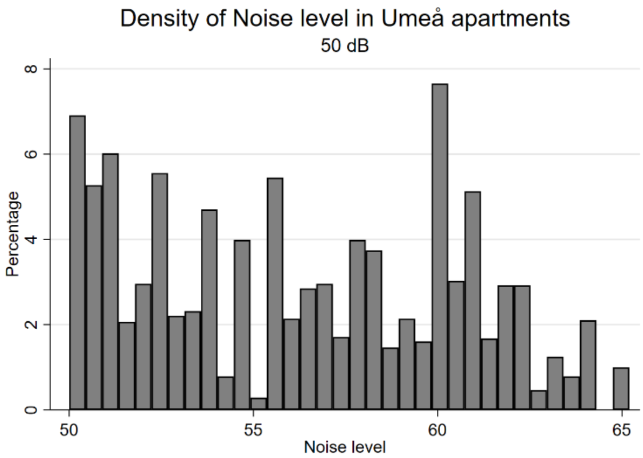

Density of Noise level in Örebro apartments
45 dB
Percentage
0
2
4
6
8
45
50
55
60
65
70
Noise level

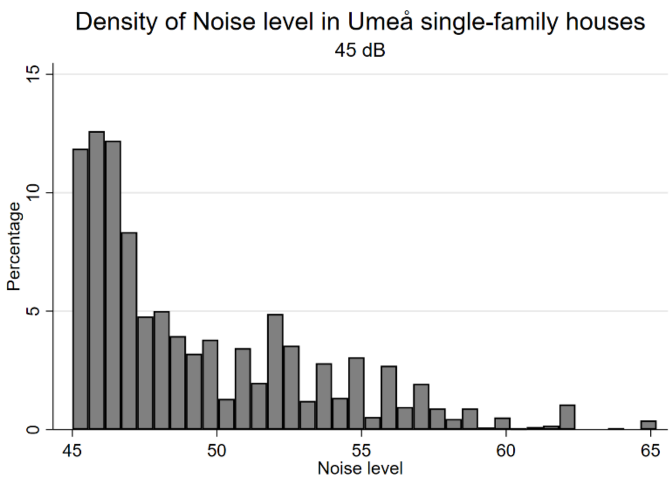

Density of Noise level in Örebro apartments
50 dB
Percentage
0
5
10
50
55
60
65
70
Noise level

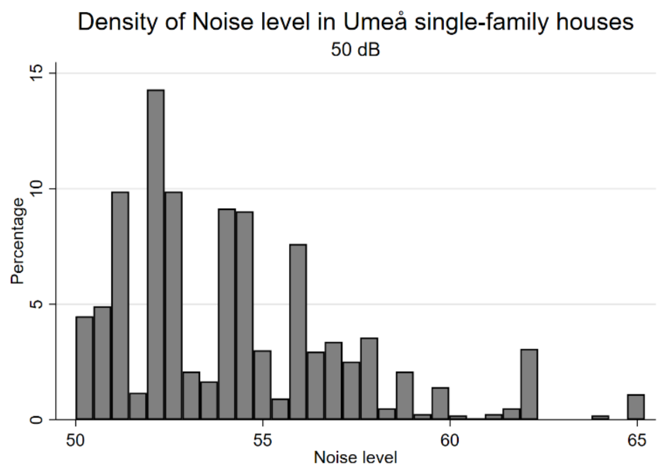

Density of Noise level in Örebro single-family houses
45 dB
Percentage
Noise level

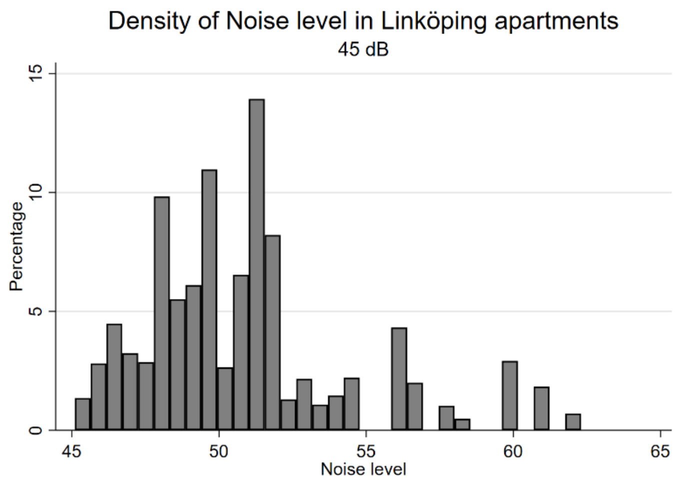

Density of Noise level in Örebro single-family houses
50 dB
Percentage
Noise level

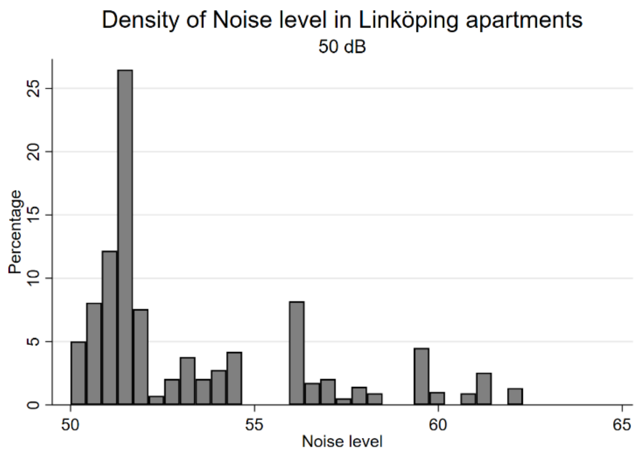

Density of Noise level in Umeå apartments
45 dB
Percentage
Noise level

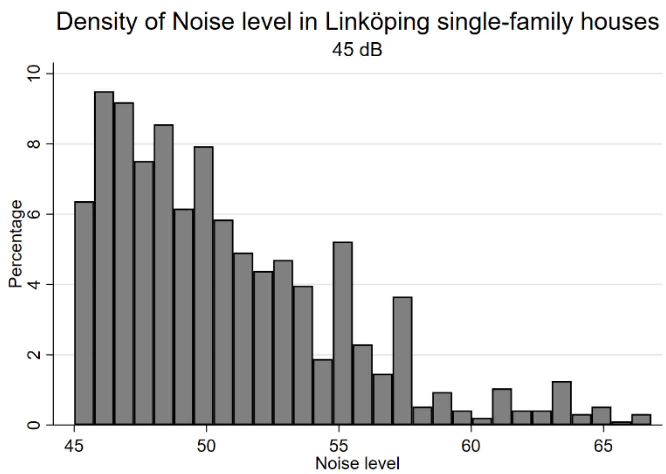

Density of Noise level in Umeå apartments
50 dB
Percentage
Noise level

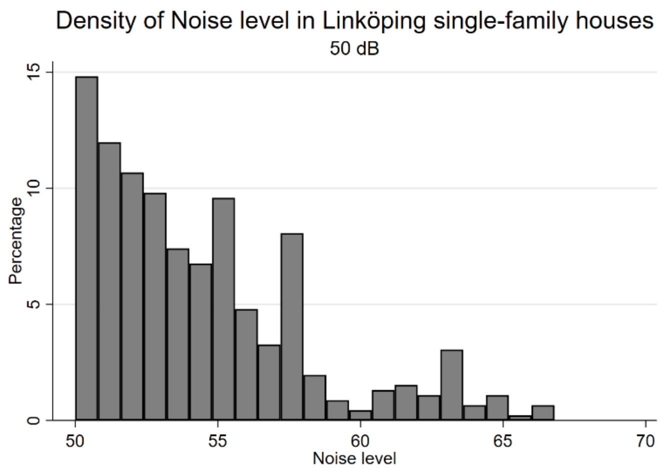

Density of Noise level in Umeå single-family houses
45 dB
Percentage
Noise level

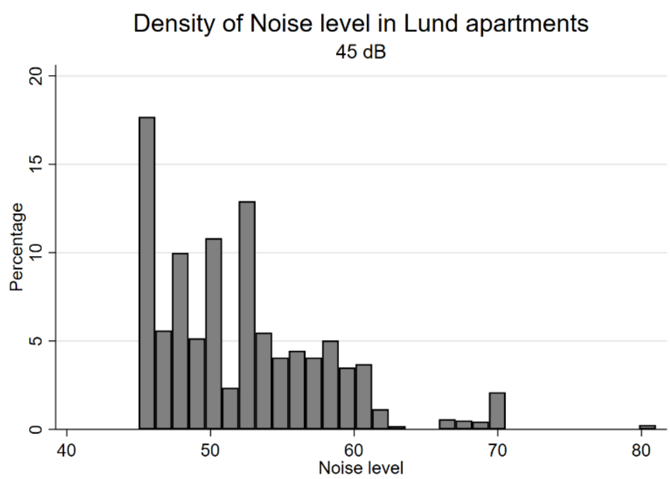

Density of Noise level in Umeå single-family houses
50 dB
Percentage
Noise level


Density of Noise level in Linköping apartments
45 dB
Percentage
0
5
10
15
45
50
55
60
65
Noise level


Density of Noise level in Linköping apartments
50 dB
Percentage
0
5
10
15
20
25
50
55
60
65
Noise level


Density of Noise level in Linköping single-family houses
45 dB
Percentage
0
2
4
6
8
10
45
50
55
60
65
Noise level


Density of Noise level in Linköping single-family houses
50 dB
Percentage
0
5
10
15
50
55
60
65
70
Noise level


Density of Noise level in Lund apartments
45 dB
Percentage
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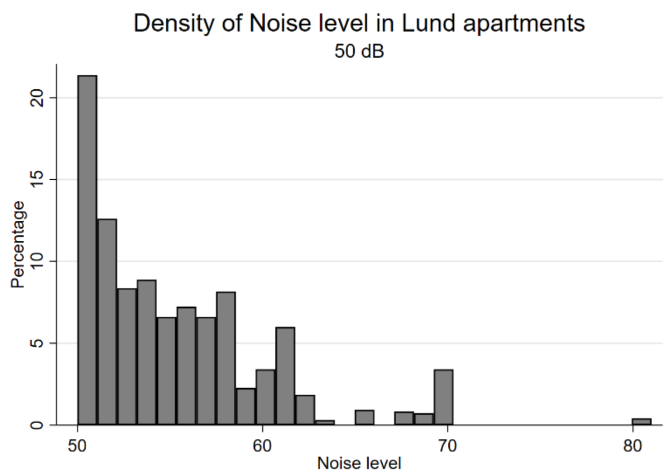
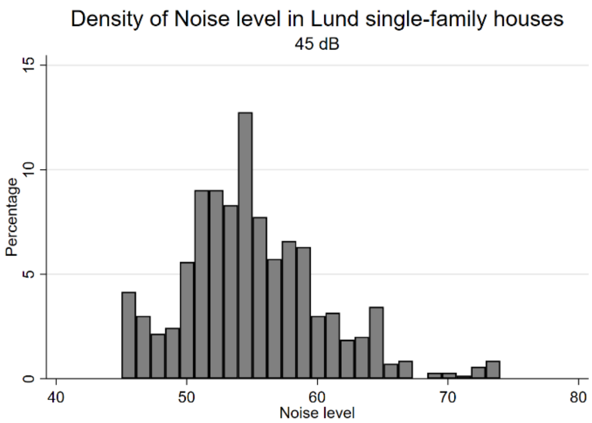
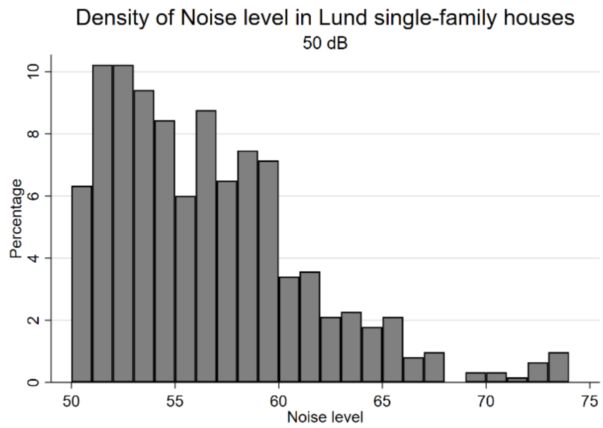
5
10
15
20
40
50
60
70
80
Noise level


Density of Noise level in Lund apartments
50 dB
Percentage
0
5
10
15
20
50
60
70
80
Noise level


Density of Noise level in Lund single-family houses
45 dB
Percentage
0
5
10
15
40
50
60
70
80
Noise level


Density of Noise level in Lund single-family houses
50 dB
Percentage
0
2
4
6
8
10
50
55
60
65
70
75
Noise level