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Kathrine von Graevenitz

ZEW

Zentrum für Europäische
Wirtschaftsforschung GmbH

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†Centre for European Economic Research (ZEW), L7,1, 68161 Mannheim, Germany. Email: vongraevenitz@zew.de. Tel.: +49 (0)621 1235 340, Fax.: +49 (0)621 1235 226.

Abstract

This article reports a complete two stage hedonic analysis for road noise. For the estimation of the hedonic price function I develop a spatial research design which simultaneously reduces the risk of omitted variable bias and the risk of measurement error in the noise measure. The preference parameters are identified following the approach developed in Bajari and Benkard (2005) by using a simple functional form for utility. Preferences are very heterogeneous and observable demographic characteristics explain 30 percent of the variation in taste for quiet. Results are used to discuss willingness to pay for noise reductions from two policy measures.

KEYWORDS: Hedonic method, traffic noise, preferences, measurement error.

JEL: Q51, Q53, R23, R41, D12

1 Introduction

Noise pollution is defined as unwanted noise caused by human activity. The primary source of noise pollution is transportation and most importantly road traffic, which is found throughout the urban environment. Noise pollution interferes with recreation, conversation, interrupts sleep and can be detrimental to productivity and health. The European Environment Agency estimates that more than 100 million Europeans are exposed to noticeable levels of traffic noise. The World Health Organization's European division estimates that traffic noise is harmful to the health of every third European citizen and that every fifth European is exposed to traffic noise levels at night which seriously impact their health. These health effects include hypertension and cardiovascular disease after long term exposure to traffic noise (WHO (2011)).

In the last decade noise pollution has received increased political attention in the European Union where the EU noise directive was put into place in 2002 (Commission (2011)). In Denmark construction of new residential areas is recommended to avoid locations with daytime noise in excess of 58 dB. However, approximately 1/3 of all existing Danish homes are exposed to traffic noise above this noise limit. Furthermore, traffic volumes are generally increasing all over Europe, and have increased by 10 percent in Denmark over the last 10 years. For these reasons, noise pollution is a salient issue in many urban municipalities and for infrastructure authorities. Several measures are undertaken to reduce noise at the emitter or the receiver through e.g. noise-reducing asphalt, sound barriers and noise insulation of homes. Additionally, municipalities in Denmark actively use urban planning in terms of zoning and traffic management to reduce noise exposure of residential areas, see Jensen (2010). Such measures are costly and beg the question what noise reductions are worth to households. Fortunately, it is possible to address this question by considering the housing market, where noise exposure is frequently traded as part of the composite housing good.

The use of revealed preference methods for noise valuation is extensive. The hedonic method as proposed by Rosen (1974) lends itself naturally to recovering the welfare loss resulting from noise pollution. The literature on valuation of noise annoyance has been surveyed by Navrud (2002) and Nelson (2008). Almost all contributions focus on calculating the Noise Depreciation Index (NDI). This index describes the depreciation in housing prices associated with a 1 dB increase in noise levels. The NDI can be calculated from the results of a first stage hedonic analysis and is used to calculate "implicit prices" of noise pollution. The implicit prices from the first stage of Rosen's two stage method can only be used to valuate marginal changes in noise exposure and are specific to the area under study. For welfare effects of non-marginal changes it is necessary to recover the preference parameters of the household in the second stage of the hedonic analysis. The revealed preference literature on the estimation of household preference parameters for quiet is scarce (Wilhelmsson (2002), Day et al. (2007)). As a result, little is known about what characterizes the households that are sensitive to noise pollution as well as how much of the variation in taste for quiet is due to observables.

The aim of the present analysis is to recover and characterize the preference parameters and willingness to pay (WTP) for quiet for the population in the Greater Copenhagen area. The dataset collected for this analysis is relatively large comprising almost 100,000 transactions over a period of 9 years. It is more detailed than most data used in hedonic analyses as it contains data on both housing and household characteristics at the individual level. Additionally, the measure of traffic noise used in the analysis has a very fine spatial resolution allowing the robust recovery of the effect of traffic noise on housing prices.

The analysis consists of two steps. In the first step the hedonic price function is estimated with a spatial research design based on border zones near large roads. This research design reduces the risk of omitted variable bias and measurement error invalidating the parameter estimates. The parameters from the first stage analysis are used to calculate "implicit prices" for each product attribute, which enter the second step of the analysis. Day et al. (2007) is the most recent of the few attempts to recover preference parameters for quiet. They estimate pseudo-demand functions using spatially lagged implicit prices to instrument for endogeneous prices in the second stage of the hedonic. Their instrumental variable strategy relies on the assumption that the source of endogeneity in the second stage is not correlated across space. This is a strong assumption considering the spatial nature of the housing market. The second stage estimation in the current analysis achieves identification through the use of a simple functional form to approximate the utility function. This approach was first used in Bajari and Benkard (2005) and applied to the housing market in Bajari and Kahn (2005) to study preferences for racial segregation. The approach is transparent, and does not require the use of instrumental variables. Due to sorting in the housing market valid instrumental variables are extremely hard to come by in the absence of multiple markets in time or space.[1] Another advantage of the Bajari-Benkard approach is that it does not require assuming a distribution for the unobservable idiosyncratic preference parameters. The household preference parameters are recovered based on the implicit prices and analyzed to gain a deeper understanding of welfare effects of noise pollution and the substantial preference heterogeneity in the population.

The findings indicate large variation across the population in the marginal willingness to pay recovered from the first stage of the hedonic model. The observed pattern in WTP is consistent with the location choices of households in terms of noise exposure in that households with a high marginal WTP tend to consume less noise. The analysis further shows that the WTP for non-marginal noise reductions is generally higher for households exposed to higher noise levels. Observable demographic characteristics explain some 30 percent of the variation in preferences for quiet. In particular, the presence of children is associated with a stronger preference for quiet. The remaining idiosyncratic preference heterogeneity is very close to being normally distributed.

The details of the theoretical framework are given in section 2 followed by a description of the data in section 3. Section 4 explains the econometric strategy with an emphasis on the road border research design. Section 5 discusses the estimated hedonic price function and the impact of the road border research design compared to a more standard fixed effects approach. Preference parameters are recovered and analyzed in section 6, followed by the concluding discussion.

2 Theoretical framework

The household maximizes (current) utility subject to its budget constraint, which contains an annualized house price:

$$\max_{x,c} U\left(h(x,z),c\right)\ s.t.\, y = \pi_t P\left(x,z\right) + c \tag{1}$$

where $h(x,z)$ is the housing good, c is a (numeraire) Hicksian composite consumption good, y is annual income, π_t is the user cost of housing, and $P(x,z)$ is the house price.[2] The price of a house given its attributes is the outcome of the sorting of households on available homes. The first stage of a hedonic analysis estimates this hedonic price function to characterize the price of a home, P as a function of its attributes:

$$P_{ij} = f\left(X_i, z_i, \xi_j, e_{ij}; \Omega\right) \tag{2}$$

Here, X_i is a vector of observable housing and neighbourhood characteristics, z_i is road noise exposure, ξ_j is a vector of unobserved neighborhood characteristics, and e_{ij} is an unobserved idiosyncratic component. Ω is a vector of parameters in the hedonic price function.

The first order condition from the household's maximization problem provides the theoretical basis for the interpretation of the derivative of the hedonic price function as a welfare measure. Simultaneously, this is the foundation for the second stage estimation as it relates the household's marginal rate of susbtitution to the price paid for an attribute. The second step of the analysis originally refers to the estimation of the household bid functions to recover the preference parameters. However, it is in this step of the analysis, that endogeneity of quantities and prices resulting from unobservable taste makes recovery of preference parameters difficult due to the lack of good instrumental variables, see e.g. McConnell and Phipps (1987), Epple (1987).

Following Bajari and Kahn (2005) preferences are modeled using a simple utility structure that can deliver estimates of the preference parameters without the need for instruments. Specifically, Bajari and Kahn impose separability of the housing attributes and logarithmic utility that is quasilinear in income. This utility structure is quite restrictive and it is useful to think of it as a local approximation of a household's utility that depends on the level of income. The utility structure for household i is then approximated by:[3]

$$u_i(h(x_i, z_i), c_i) = \sum_k \beta_{ki} log(x_{ki}) + \beta_{zi} log(N - z_i) + c_i \tag{3}$$

Here, N is 1 unit larger than the maximum noise observed in the data to ensure that quiet contributes positively to utility. The preference parameters vary by household:

$$\beta_{li} = exp\left(\theta_{li} + \alpha_{l0} + \sum_d \alpha_{ld} S_{di}\right), l = k, z \tag{4}$$

With this specification, the household has an idiosyncratic taste component for each attribute, θ, and preferences depend on the household's observable characteristics in S_d. The vector S_d is a vector of sociodemographic variables like age, presence and age of children, education level of household, and indicators for whether the household contains retirees, students, etc.

The parameters of the utility function can be estimated non-parametrically as in Bajari and Kahn (2005). Solving for the first order condition of the household's utility maximization:

$$\beta_{zi}/(N-z) = -\pi_t \left(\partial P/\partial z\right)_i \Rightarrow \beta_{zi} = -\pi_t \left(\partial P/\partial z\right)_i (N - z_i) \tag{5}$$

The random parameter β_z can then be decomposed to recover the determinants of taste for quiet including the unobservable taste parameter θ_{zi} as the residual from the regression in equation 4. Based on this simple utility model it is possible to ask how much of the estimated willingness to pay for quiet is due to variations in observable characteristics such as age and education levels, and how much is due to idiosyncratic taste heterogeneity. It is also possible to examine correlations between preferences for different attributes.

3 The data

The dataset collected for this analysis consists of the population of residential properties sold in single household transactions in the period from 2000 to 2008 in the Greater Copenhagen area.[4] In total, there are 99,768 arms length transactions over the 9 year period. The Greater Copenhagen area covers a total of 16 municipalities. Of these the largest is the municipality of Copenhagen, which contains approximately half of the transactions in the full data set. The study area was chosen due to the availability of noise measures at residential properties for this area.

Housing market transactions and housing characteristics

Data describing the structural characteristics of the housing unit is available from the Danish Building Registry. This data covers e.g. the size of the living area, year of construction, roof material, number of bathrooms etc. The Danish Building Registry is updated regularly and the information contained in it therefore reflects the characteristics of the individual dwellings at the time at which data was extracted (June 2010). The registry also contains information on the date of the latest large renovation. Here "large" refers to a renovation which required a permit from the municipality. This would be the case for e.g. house enlargement, construction of garages, or significant changes in outward appearance. This information is primarily used to control for large renovations taking place after the transaction occurred. The registry also contains spatial coordinates describing the exact location of each housing unit. Based on these coordinates, different measures have been calculated using Geographical Information Systems describing accessibility and other locational attributes of the dwelling, e.g. distance to the center of Copenhagen, to the coastline, nearest train station, etc. Data on the transaction describes the actual selling price and date of sale. A complete list of the variables included in the analysis can be found in appendix A.2.

Household data

The data on the households inhabiting the transacted properties is provided by Statistics Denmark. This data set describes the composition of households in terms of the number and age of children in the household, the age and number of adults, the education level of each of the adults, their place of birth, and whether they work full-time, part time or have retired from the labour market. Information on the household income after taxes and transfers is also available. The dataset on the households is merged with the data on transacted properties using the address. This process is carried out first for the year following the sale. If no inhabitants are found, inhabitants in the year of the sale are used, and finally, if no-one is registered at the address in that year either, the year before the sale is used. A match to household was achieved for approximately 97 percent of the transacted properties. For those properties that are matched, 93 percent are matched to households registered to the address in the year following a sale. Finally, households with extreme incomes after taxes and transfers were discarded from the sample used for analysis of preference heterogeneity. However, they were included in the estimation of the hedonic price function.[5]

Measures of traffic noise exposure

Noise is measured in decibels (dB) on a logarithmic scale. An increase of 1 dB is just perceivable and a 10 dB increase corresponds to a doubling of the perceived noise level. To give an idea of the noise levels common in everyday life, 40 dB corresponds to the sound of a whisper at 30 cm distance and 100 dB is the sound of a propeller airplane at 30 meters distance. In an urban environment it will rarely be completely silent due to the ambient noise created by the presence of many people in a single place.

Due to the EU Directive on Noise the mapping of noise in larger urban conglomerations across the EU member states was required for the first time in 2007. In Denmark, only the Greater Copenhagen Area qualified for this mapping. Three different measures of the traffic noise exposure of each housing unit were utilized. The measures of noise are of varying quality both depending on the type of noise (rail, airport or road) and between municipalities. All three noise measures are model-based calculations of L_{den} (Day-Evening-Night). L_{den} is a measure of average noise in a 24 hour period over the course of a year, where different weights are assigned to noise exposure depending on the time of day.[6] The measures of road and rail noise used in this paper are calculated using the Nord2000 noise model, whereas the measure of airport noise has been calculated using DANSIM. In both cases, input for the calculations consists of various data on the type, frequency and speed of traffic as well as data on weather conditions. In the Nord2000 model information on the density of buildings and type of asphalt are also included, see Kragh et al. (2006).

Road noise

For 14 of the municipalities included in the analysis, the road noise exposure was calculated in two heights at the face of the buildings: 1,5 m and 4 m from the ground. For the municipality of Copenhagen, which contains almost 2/3 of the transactions for apartments, noise has been calculated at a finer level so that individual noise measures exist for each individual floor of a building.[7] All the calculations were carried out using data on traffic in 2005/6. Noise measures are reported to be reliable from around 45 dB upwards according to the engineers responsible for the mappings.

The calculation of the traffic noise measures is designed to describe the amount of noise deriving specifically from nearby roads at the individual housing unit. They do not take account of the general level of background noise present in the neighborhood, e.g. noise from industry, or from neighbors etc. The actual level of background noise present depends on the level of urban activity in the neighborhood and is an empirical question.

Baranzini et al. (2010) discuss the relationship between perceived traffic noise and scientific measures of traffic noise in their study of the Geneva housing market. They find that the perceived noise curve is flatter than the actual noise curve implying that people are less annoyed at a marginal increase in noise than indicated by scientific measures. For road noise above 55 dB they find that adding perceived noise levels to a hedonic regression already containing scientific noise measures does not improve the fit of their model.

Railway and airport noise

Railway and airport noise are included as controls in the study. In most of the study area, calculated rail noise measures exist from 2011 for the railways. However, one stretch between North-Western Copenhagen and Copenhagen Airport was not included in this mapping. Data from 2007 was available in 5 dB intervals and has been used to proxy for the noise from this stretch of railways in the relevant areas.[8] The level of detail in the mapping differs from the detail in the road noise mapping. As a result, railway noise is mainly included as a control variable and the estimates should be interpreted with caution.

Airport noise differs considerable from the other two sources of traffic noise. Airport noise is calculated for grids of 50 square meters using the DANSIM model which satisfies the requirements for the EU noise mapping (Plovsing (2009)). Since the source of noise is placed above the dwellings, the presence of other buildings does not dampen that noise as it is the case with the rail and road noise. In consequence, the spatial variation in airport noise is much smaller. The lower variability across space makes the effect of this type of noise hard to distinguish from other neighborhood effects in the absence of exogenous temporal variation as in Boes and Nüesch (2011) and Almer et al. (2013).

4 Econometric strategy

There are a number of major concerns in estimating the first stage of the hedonic model. The hedonic relationship describes an equilibrium outcome in a market. In the 2000s, the Danish housing market evolved as most housing markets in Europe and the US: with dramatic housing price increases following liberalizations in the financing of real estate purchases. In Denmark, the most important changes were the introduction of payment free loans with varying interest rates in 2003 and a change in taxation of real estate which fixed taxes in nominal terms at the 2001 tax payment. These changes contributed to the dramatic increase in housing prices, which peaked in 2006. The changing market conditions make it likely that the hedonic equilibrium changed during the period suggesting that the data should not be pooled across all years. Three periods were identified in the data during which the regulatory environment remained stable. The first period (2000-2002) is before the liberalizations in the financial sector took place, the second period (2004-2005) is the beginning of the housing bubble and the final period (2007-2008) is after the burst of the housing bubble. The years 2003 and 2006 are left out of the estimations to concentrate on periods with stable market conditions. Once a market has been identified in time and space, the remaining challenges for estimating the hedonic price function concern mismeasurement of attributes or transaction prices, omitted variables, and choice of functional form.

Road border research design

The research design employed here is based on analyzing homes in the area bordering a large road and is referred to as the "road border research design". The design addresses specific problems concerning measurement error and omitted variables. The construction of the design is described in further detail below.

Measurement error

Most variables in the data set derive from Danish administrative data and are accurately measured characteristics of actual transactions. The main concern regarding measurement error is the variable of primary interest: road noise. Unfortunately, the measure of road noise used in the analysis is based on traffic counts for the short period covering the years 2005/2006. These measures have been used for housing transactions in the whole sample period (2000-2008). To reduce the risk that actual noise levels have changed substantially from the observed measures over the time period, a reduced sample based on homes within 200 meters of a *large road* is constructed. A large road is defined as a road wider than 6 meters and covers e.g. arterial roads and motorways. For many of the homes near large roads, these roads are the major source of noise pollution. This can be seen in figure 1, where there is a clear pattern in noise and distance to the large road for homes within a 200 m distance.

[Figure 1 about here.]

The large roads have relatively high traffic flows. The relationship between noise and amount of traffic is such, that doubling the traffic flow increases noise levels by 3 dB. On large, busy roads therefore, changes in traffic volume over the course of 3-5 years on either side of 2005 would have to be large to affect noise levels noticeably.[9] Limiting the analysis to homes within 200 m of a large road reduces the data set by 60 percent. This reduction of the sample size enhances internal validity at the expense of external validity, but the remaining sample still includes a variety of homes with different characteristics.

A map of the area under study with the large roads and their 200 m borders is shown in figure 2. The dots in the figure are transactions in the full data set. It is clear, that some residential areas fall completely outside the sample with this approach. In particular, there are fewer single family houses in the reduced data set (26-27 %) than in the full data set (35 %). Table 1 displays a comparison of the most important characteristics of the homes in the reduced and full samples. The homes near large roads are a little smaller, a little cheaper and exposed to a little more noise on average than homes in the full sample. The density of road noise for the transactions in the full and reduced data set can be seen in figure 3. As might be expected, the whole distribution shifts slightly to the right when the sample is limited to homes near a large road. There is a smaller share of observations with road noise at 45 dB or less (only 3.6 percent of the reduced data set as compared to 9 percent of the full data set) and a higher proportion with high noise levels.

[Figure 2 about here.]

[Figure 3 about here.]

Five types of households were defined for the data depending on the age, composition of the household and the primary occupation of the adult household members. These 5 groups are retirees, families with children, couples without children, singles and students.[10] The large proportion of students in newly transacted properties is in part explained by the common practice of parents purchasing housing for their student children. This practice has become quite popular in Denmark due to difficulties in finding rental housing in the university cities and the low interest rates, which characterize the period under study. Most of these students are not the actual owners of the property in which they live, which is evidenced by them not paying real estate taxes. Reducing the sample to the transactions within 200 m of a large road slightly changes the composition of the household types as shown in table 2. There are fewer retirees and families with children and slightly more singles and students.

[Table 1 about here.]

[Table 2 about here.]

Omitted variables

While the data set contains a lot of information, a threat remains that omitted variables could bias the analysis. Not all neighborhood characteristics that affect the desirability of a location are observable to the econometrician. In the current setting, one specific concern is air pollution where data on a sufficiently fine scale was unfortunately not available for the analysis. Another concern is the unobservable background noise level. Reducing the sample to homes near a large road makes it less likely that the impact of road noise on prices is confounded by comparing generally very quiet residential neighborhoods to noisier neighborhoods where unobersvable characteristics may differ in several dimensions. Spatial fixed effects have become standard in the hedonic literature to control for omitted spatially varying covariates, ξ_j, cf. Kuminoff et al. (2010). In this research, spatial fixed effects are employed to account for spatially varying unobservable characteristics at a fine spatial scale. By using transactions data from several years, the data is more spatially dense and smaller neighborhoods can be defined for the fixed effect. Here, the fixed effects build on the road border research design and capture an area on one side of a stretch of road. Examples are shown in figure 4, where the highlighted area is a single road border zone. They are constructed such that a border zone is limited to one side of the road as large roads can act as barriers in the urban landscape. The character of a neighborhood may therefore vary substantially from one side of the road to the other. Likewise, air pollution can differ on different sides of the same road depending on the wind.

Descriptive statistics for the road border zones are given in table 3 including percentiles of the size of each road border zone and the number of observations. The average size of these road border zones is 0.54 square kilometers, with the largest zone covering an area of 0.95 square kilometers. There are a total of 215 road border zones in the data, however several of these contain very few observations. Border zones, which contained less than 20 transactions in a period (2-3 years), were discarded. The remaining data set within 200 m of a large road covers a total of 30,309 transactions divided between 160, 127 and 96 road border zones in the three periods.

[Figure 4 about here.]

Despite the small spatial scale of the fixed effect, substantial variation in road noise remains within road zones in a given year as illustrated in the images in figure 5. Road noise varies at a fine spatial scale due to e.g. buildings acting as sound barriers. It is therefore possible to identify effects on house prices of road noise exposure in these small areas despite the use of fixed effects. Unfortunately, without data on air pollution it is hard to assess the extent to which the fixed effects are adequate to control for air pollution in the study area. Remaining bias depends on the correlation between road noise and air pollution. In Copenhagen a substantial part of air pollution does not derive from traffic, but from other local and regional sources (Jensen et al., 2013).[11] Furthermore, air pollution from traffic is diffuse and may affect a wider area than noise. Although the source is the same, the propagation mechanism differs as noise is transmitted through pressure waves. It is therefore unlikely that the two are perfectly correlated. As hedonic analyses containing both pollutants are rare, it is not possible to say anything about the magnitude of such remaining bias.

[Table 3 about here.]

[Figure 5 about here.]

Functional form

The shape of the hedonic price function is the outcome of sorting on both sides of the market. This makes it difficult to make clear predictions about the appropriate functional form for the different variables, although it is established, that the function is likely to be non-linear (Ekeland et al., 2004). Bajari and Kahn (2005) estimate a hedonic model using local linear regression, however the estimation of such models is costly in terms of computing time and requires them to sample from their data set rather than use the full set of transactions. They are also limited to including only a small number of housing characteristics and no fixed effects in their model.

In this paper, the hedonic surface is approximated using a semi-logarithmic function as is standard in previous hedonic analyses of traffic noise. To allow for non-constant marginal effects over the range of noise exposure a piece-wise linear specification of road noise is used with three intervals: $\{[45-55], (55-65], (65-max]\}\, dB$. The effect of road noise on price is further allowed to vary by housing type (apartment or house). For each period, the estimated equation is given by:

$$ln\, P_{ij} = \alpha + \sum_m \delta_m z_{mi} + \sum_m \delta_{mH} z_{mi} D_{House\, i} + \sum_k \gamma_k X_{ki} + \eta_j + \epsilon_{ij} \tag{6}$$

where $m = \{1, 2, 3\}$ indicates the road noise interval:

$$\begin{aligned} z_{1i} &= z_i \leq 55\, dB \\ z_{2i} &= z_i \in (55 - 65\, dB] \\ z_{3i} &= z_i > 65\, dB \end{aligned} \tag{7}$$

Other characteristics of the home are contained in X. These include additional noise measures for railway and airplane noise which enter as linear terms in the model. There are fewer homes exposed to railway and airplane noise and the measures are generally of poorer quality than the road noise measure, which makes it difficult to draw strong independent conclusions about their impact on house prices.[12] Several housing characteristics are included as control variables, e.g., the log of the living area, log of the lot size as well as accessibility measures in the shape of distance to the centre of Copenhagen, to the nearest train/metro station, to the nearest industrial site and to the coast line. A large number of covariates are included as factor variables: Number of toilets and bathrooms, number of stories in the building, the story for apartments, construction period, type of roof and building materials, etc. Municipality dummies and road border zone fixed effects, η_j, are included to account for variations in municipal taxes and public goods as well as to control for potential omitted neighborhood variables. For comparison, models with the full data set using school attendance zone fixed effects are also estimated for each period. Standard errors are clustered at the level of the fixed effect to account for remaining spatial correlation.

5 First stage results

The hedonic price function is estimated separately for each period using the transaction price in 2000-levels.[13] The full estimation contains a total of 24 housing attributes in addition to the fixed effects and commenting on each parameter estimate would take up too much space here. The full estimates can be found in appendix A.3. In general, the estimates conform to expectations, e.g. additional rooms, living space and lot size are all associated with higher housing prices while proximity to e.g. industrial areas is associated with lower housing prices.

As regards the impact of road noise on housing prices an initial concern is determination of the level of background noise in the study area. Changes in noise exposure below the background noise level are not perceived as such by the households.[14] While the measures of road noise are reported from 45 dB upwards, the level of background noise in an urban environment has often been assessed to be around 55 dB. This is also usually the threshold used in hedonic analyses (see e.g. Day et al. (2007)), however in many cases 55 dB is also the minimum level for regulatory purposes and therefore the minimum level available in the data for researchers. Here, the piece-wise linear modeling of the road noise variable allows for a background noise level below 55 dB. The estimates for each period and each segment of the piece-wise linear function are shown in table 4 for the road border design (1), (2) as well as for the full data set (3) and (4) with and without fixed effects.

[Table 4 about here.]

With the road border research design including fixed effects the estimated coefficients follow a similar pattern across all periods. No significant impact on housing prices can be found for noise levels below 55 dB suggesting that the background noise level is also near 55 dB in the data at least for the sample within 200 m of a large road. As the level of noise increases, so too does the size of the effect on the housing price. The effect of noise exposure is significantly larger for houses than for apartments supporting the decision to distinguish between the two types of dwellings in the model. While the individual estimates for the intermediary level of noise are mostly insignificant, a joint test of the coefficients including the interaction term for houses is significant for each of the periods, though only at the 10 percent level for the second period (see appendix A.3). In the semi-logarithmic model the coefficient for noise in the hedonic price function, referred to in the literature as the "noise depreciation index", captures the percentage change in price for a 1 dB change in noise levels. The range is between -0.1 to -1.5 percent of the transactions price for a 1 dB increase in noise above 55 dB. These results are within the range reported by Nelson (2008) and similar to findings in Day et al. (2007). Most previous studies of traffic noise assume a constant slope over the range of road noise above the background noise level. Such an assumption is clearly not supported in the current data set.

Second order conditions

The first derivative of the hedonic can be interpreted as a marginal WTP measure based on the assumptions that households optimize and that all attributes are continuous. The second order conditions for utility maximization depend on the relative curvature of the utility function and the hedonic price function. Here, the piece-wise linear functional form ensures that the second order conditions are satisfied locally, but given the estimated coefficients for road noise it is clear that globally, the hedonic curve is concave for road noise. This suggests that a smoother modelling could lead to violations of the second order conditions where the curvature increases dramatically around 65 dB. Violation of the second order conditions suggest that the identifying assumptions on utility may be too restrictive. It should be kept in mind that the current analysis views this specification as a local approximation. No claim is made that preferences have been globally identified.

Implicit prices

The shape of the hedonic with respect to noise is quite similar for the first two periods, but seems somewhat steeper for intermediate noise levels for the third period after the housing market decline. There is little change in the distribution of noise levels across the three periods, see figure 6. The implicit price for each household, $\left(\partial P/\partial z\right)_i$, is calculated as

$$\left(\partial P/\partial z\right)_i = \left[\left(\exp\left(\widehat{\delta_m}\right) - 1\right) + \left(\exp\left(\widehat{\delta_{mH}}\right) - 1\right) D_{House\,i}\right] P_i \tag{8}$$

where $m = \{1, 2, 3\}$ indicates the relevant interval of road noise for the household and $D_{House\,i}$ is a dummy that takes the value 1 if the home is a single family or terraced house. The implicit prices are summarized in table 5 for the road border zone model and table 6 for the full data model. To facilitate comparison the tables show implicit prices only for households within 200 m of a large road that are exposed to more than 55 dB of road noise. For households exposed to less noise than the background noise level, the estimated coefficient is unlikely to be an accurate estimate of their marginal willingness to pay. The median implicit price is larger in absolute terms in the second and third period, than in the first period for the road border research design with fixed effects. However, the distribution of the implicit prices in the second period seems more concentrated than in the other two periods. For the third period, after the housing market decline set in, the implicit prices are much larger in absolute terms than in the other two periods in the 75th and 90th percentile.

[Table 5 about here.]

[Table 6 about here.]

[Figure 6 about here.]

The impact of fixed effects and road border research design

The road border research design reduces the sample to mitigate the risk of measurement error affecting the estimates and includes fixed effects to account for unobservable neighborhood characteristics. The first three rows of table 5 and table 6 show results with fixed effects and the last three rows show results without fixed effects for the same model. To facilitate comparison of the models with the full and reduced sample, implicit prices shown in both tables are for the homes in the 200 m sample only. The estimated implicit prices are rather similar across models although they tend to be a little smaller for the 200 m sample. In both cases, the use of fixed effects reduces the implicit prices for changes in noise exposure, although the impact of the fixed effect varies across the distribution of implicit prices. The estimates with fixed effects are hard to compare across models as the full sample uses school attendance zones which are generally larger than the road border zones used for fixed effects in the reduced sample. The road border zones would be expected to capture the same omitted neighborhood characteristics as the school attendance zones and more. Thus it is less likely that omitted variable bias affects estimated parameters in the reduced sample. This observation is supported by the fact that the estimated coefficients exhibit a clearer pattern increasing in magnitude as noise levels increase in the road border research design than for the full sample with school district fixed effects (e.g. period 3).

The effectiveness of the sample reduction in dealing with measurement error is hard to assess. The potential measurement error is likely to be larger for homes with low noise levels in 2005/2006 as these homes are generally near less busy streets and therefore at a lower level on the curve depicted on the right in figure 1. However, it is hard to say whether the error will yield an over- or an underestimation of the noise level at the time of sale. While traffic has in general increased by an estimated 10 percent nationally over the whole sample period, the distribution of this additional volume of traffic on smaller roads in the Copenhagen area is not available for this analysis. Moreover the reduction in the sample to focus on homes near large roads is likely to have an additional effect in terms of reducing the overall heterogeneity in the types of homes available in the market. Similarly, the spatial scale of the fixed effects is smaller in the reduced sample, which helps to ensure that the variation in prices with traffic noise exposure is accurately captured. Differences in the estimated implicit prices between the full sample and the reduced sample reflect all of these aspects.

6 Recovering preference parameters

Within the theoretical framework described in section 2 preference parameters for each household can be recovered based on the first order condition of utility maximization. However, with a background noise level at 55 dB 22 percent of the sample have chosen the minimum noise level available, i.e. the corner solution. For this part of the sample, preferences are not identified as the first order condition used to recover their preference parameters is not necessarily satisfied with equality. Based on revealed preferences however, and the fact that noise exposure is generally associated with lower housing prices, the households who have chosen to consume large amounts of quiet have revealed that their total willingness to pay exceeds that of the majority of households in the market. To analyze the preferences of these quiet-loving households an assumption would need to be made about the distribution of the unobserved taste parameters. Since one aim of the analysis is to learn more about the unobserved taste parameter, imposing a distributional assumption would defeat the purpose. Instead, focus is on those households, who have located at noise levels above 55 dB in what follows.

While the hedonic price function has been estimated for each of the three periods separately, there is little indication based on observable characteristics, that households have sorted across time (i.e. into a period) according to preferences for quiet. Comparing the demographics by period, the share of student households has risen substantially between period 1 and 2 at the expense of households classified as singles or families without children. There is hardly any change in the composition of households between period 2 and 3. The analysis of preferences below is therefore based on the pooled sample of households over the three periods for which the hedonic function was estimated.

The implicit prices are converted to annual costs using the user cost of housing at the time of purchase as calculated by the Danish central bank with an average user cost of 3.7 percent over the period (see appendix A.1 for more detail). With these annualized measures in hand, the preference parameters can be estimated nonparametrically based on equation 5, repeated here for convenience.

$$\beta_{zi} = -\pi_t \left({}^{\partial P}\!/\!{}_{\partial z} \right)_i (N - z_i)$$

The maximum level of quiet is set to be one unit larger than the maximum observed noise above the threshold of 45 dB in the sample: $N = max(z) + 1 = 36.5\, dB$. As the hedonic model estimated has a very large number of covariates and the main focus of this paper is traffic noise, the following section concentrates on the recovered preference parameters for quiet, living space, and distance to the central business district.[15] Table 7 shows the annual implicit prices and preference parameters for quiet, living space and proximity to the center of Copenhagen. There is substantial variation in preference parameters and for all three attributes shown, the distribution is highly skewed with a long right tail.

[Table 7 about here.]

The preference parameters for different housing attributes are correlated as shown in table 8. Preferences for quiet and size of living area are very highly correlated. Preferences for a large living area and for proximity to the central business district are also correlated to a significant degree as are preferences for quiet and for a central housing location. While it seems intuitive that preferences for housing attributes are correlated, the extent is sensitive to the functional form approximating preferences.

[Table 8 about here.]

Preference parameters would be expected to vary across demographic groups as these have different needs over the life cycle and because of life style sorting. Overall, couples with children seem to live in quieter areas, along with some retirees, see figure 7. The density of retirees seems bimodal however with substantial probability mass at higher noise levels. Students, singles and couples without children are more likely to live in noisier locations than families with children. There is also considerable variation in income across demographic groups with double-income households earning significantly more than the other types of households. The variation in preferences and income gives rise to variations in willingness to pay for noise reductions.

[Figure 7 about here.]

Willingness to pay for noise reductions

Willingness to pay for marginal changes from the consumed bundle are given by the estimated implicit prices. Based on the preference parameters, willingness to pay for non-marginal changes in noise exposure from z^0 to z^1 can be calculated as the change in the Hicksian composite good required to equate utility levels before and after the change in noise exposure (i.e. compensating variation):

$$WTP_i^{01} = \beta_{z,i}(log(N - z^1) - log(N - z^0)) \tag{9}$$

As described in section 2, the analysis of preferences is based on a local approximation of the utility function that depends on the income level of the household. For large changes in noise exposure the assumed logarithmic functional form would play a decisive role in scaling the household's willingness to pay. As a result, WTP measures are likely to be more accurate for moderate changes in the consumed bundle of goods.

Several policy instruments are currently in use in the study area to limit the impact of road noise pollution. These span from technical solutions such as noise reducing asphalt or emission standards for tyres and vehicles, to traffic management, and subsidies for noise insulation. The current section discusses the welfare changes associated with two of these instruments: Regulation at the source in the shape of technical requirements (standards) for tyres, and traffic management with the closure of a busy road in central Copenhagen for private motor vehicles. The former is an example of regulation at the EU level whereas the latter is a policy available at the municipal level.

Standards for noise emission of tyres

The friction between road and tyres is of increasing importance in generating road noise for vehicles travelling at more than 35 km per hour. The noise emission of tyres has been subject to regulation at the EU level since 2001 and was tightened in 2009 ((EC) No 661/2009) with effect from November 2011. The noise limits for tyres were reduced by 3-4 dB, but as the existing fleet was to a large extent already equipped with tyres below the limit for noise the expected effect on noise pollution has been assessed to be closer to 1-2 dB than 3-4 dB (Jensen (2010)). The distribution of annual WTP for such a change is shown in table 9 by demographic groups as well as the sum for the given group under the assumption that all households in the sample experience the same reduction of 1 dB. The WTP for a 1 dB change is based on the implicit price directly recovered from the hedonic price schedule and therefore does not rely on the assumed preference structure.

[Table 9 about here.]

The median WTP for a 1 dB reduction of road noise is generally higher for families with children under the age of 18. Families without children and retiree households have very similar WTP somewhat lower than families with children. Students and singles have the lowest WTP. This distribution of welfare estimates is consistent with the noise exposures of the different types of households depicted in figure 7. Those groups with lower WTP have more probability mass at higher noise levels consistent with a sorting equilibrium in which those willing to pay the least for quiet are settled in the least quiet locations. The total WTP for a 1 dB reduction across the households sums to DKK 3.7 million annually in 2000-prices for the 23,000 households in the 200 m sample with noise above 55 dB. Although families with children only account for 23 % of the sample, 37 % of the benefits from the 1 dB reduction accrue to them. In contrast, singles make up 28 % of the sample and receive only 15 % of the benefits. If these WTP estimates are representative of the population of the whole EU area the total willingness to pay for the reduction in road noise is substantially larger. Overall, the benefits are likely to exceed the cost of the policy. Low noise tyres were already on the market prior to 2011 and were not generally more expensive than other tyres nor did they have worse properties according to FEHRL (2006).[16]

Traffic management: The case of Nørrebrograde

A preferred strategy for noise reduction in the municipality of Copenhagen is to concentrate traffic on the network of major roads (Center for Miljø, 2013). In late 2008 an experiment was conducted in the district of Nørrebro in central Copenhagen. The municipality of Copenhagen decided to re-route traffic out of Nørrebrogade, a main route into the center of Copenhagen. Parts of the street were closed for car traffic temporarily for 3 months starting in October 2008.[17] In the fall of 2009 it was decided to make the closure permanent with minor changes and to reduce the speed limit from 50 to 40 km/h. An evaluation of the effects of the project has shown a reduction in noise levels of up to 3 dB for homes located in the affected part of Nørrebrogade, where noise levels were estimated at 68 dB before the project (Center for Trafik, 2013).[18]

It is not possible to calculate WTP for households located in the exact street as all information on location at a finer scale than the district level was removed from the data once socio-demographic information was merged to the individual transactions.[19] Instead table 10 shows the distribution of WTP for a 3 dB reduction for five groups in the road border sample: The whole sample; households in the Nørrebro district; households with at least 68 dB road noise; households in Nørrebro with at least 68 dB road noise; and finally, households in a wealthier neighboring district, Østerbro, with at least 68 dB road noise. The WTP for a 3 dB reduction is very heterogeneous in the sample as a whole. In Nørrebro the heterogeneity is lower and WTP is generally lower with a median WTP half the size of the median WTP for the sample as a whole. For households in the whole research area exposed to at least 68 dB of road noise, the distribution of WTP for a 3 dB reduction shifts to the right and is less dispersed though still with a long right tail. The WTP for households in Nørrebro with more than 68 dB of road noise is similar but more symmetric with an annual median WTP of 386 DKK not far from the mean of 417 DKK. In the wealthier district of Østerbro, the distribution of WTP shifts to the right with a median WTP of 467 DKK and a mean WTP of 606 DKK indicating that individual households there would gain more from a similar reduction. However, Østerbro is characterised by larger apartments compared to Nørrebro, which has more than twice the population density of Østerbro. The aggregate WTP for such a change may therefore still be higher in the Nørrebro area.

It should be kept in mind that these WTP estimates are for owner-occupier households whose preferences may or may not be similar to tenants in rental properties. Increases in property value accrue to the owners and they can not be made worse off by a policy that lowers noise levels. For tenants it is likely that the change in noise levels will lead to more costly housing and re-sorting may occur in the longer run as households with higher WTP replace those whose WTP is lower than the increase in rents. It is not possible to say on the basis of the current analysis by how much rents would increase, but it is not clear that tenants in the area have been made better off. In the sorting literature where house price responses can be predicted welfare losses for some households have been found for improvements in environmental attributes such as air quality due to increased costs of housing (Sieg et al., 2004). Other effects of such a policy should also be considered in a full cost benefit analysis. In particular, travel time considerations are likely to be the dominant concern in terms of cost of traffic management policies. In the case of Nørrebrogade the cost of (small) delays for cars would need to be weighed against the value of faster travel times for bicyclists, and improved reliability for bus passengers.

[Table 10 about here.]

Preference heterogeneity

To get a deeper understanding of the heterogeneity in preferences, regression analysis has been carried out to decompose the parameter β_{zi} into the demography-dependant components and the unexplained taste for quiet following the expression in equation 4. The estimated preference parameter is a function of the hedonic equations, the level of background noise modeled, and housing characteristics as well as the assumed utility structure. As shown in table 7, the distribution of β_z is highly skewed. As a result, β_z

is modelled as being log-linear in socio-demographics (equation 4) rather than the linear structure used in Bajari and Kahn (2005). The extent to which preference heterogeneity can be modelled as a function of observable characteristics has implications for the use of such estimates for benefit transfer, i.e., predicting WTP for areas outside the study area.

The results can be found in table 11. Household income net of housing expenditure is associated with a stronger taste for quiet as might be expected. Taste for quiet can also be seen to increase with age at a declining rate. For the demographic groups, families with children have a stronger preference for quiet, whereas singles and retirees have a significantly weaker taste for quiet than a double-income household without children. These findings are consistent with the policy scenario discussed above and the observed noise exposure for these groups. The highest level of education completed within the household is also associated with taste for quiet. Households who have completed a Master's degree have a stronger preference for quiet than all other groups, while PhDs have the weakest taste for quiet all else equal. Working part time or being a tenant (i.e. not paying property tax) does not contribute significantly to explaining variation in taste for quiet. In total, the observable characteristics of the household explain no more than 30 percent of the variation in taste for quiet.

[Table 11 about here.]

Based on these results, a large part of preference heterogeneity is due to variation in unobservable taste. The distribution of the residuals from the decomposition of the preference parameter is shown in figure 8 together with a normal distribution. Unobservable taste heterogeneity is not quite symmetric but otherwise very close to being normally distributed. Often economists model unobserved heterogeneity using a normal distribution, e.g., in several random parameter models or in probit selection models. This assumption would seem to be a fair approximation in the case of taste for quiet. It should be kept in mind however, that the estimates of unobserved taste heterogeneity are conditional on the simple utility structure in the model, and that the current analysis does not deal with the 22 per cent of households that have chosen to locate in areas with minimum noise available.

[Figure 8 about here.]

The fact that observable characteristics account for so little of the variation in preferences suggests that one might worry about using the model to predict WTP for quiet outside the area under study. The relative error in WTP gives some idea of how wrong an estimate of WTP based solely on demographics and the current model might be. In order to examine the potential error in benefit transfer a regression similar to that in table 11 was carried out with the log of the household's WTP for a 3 dB reduction as the dependent variable.[20] Estimated coefficients are all quantitatively similar to those in table 11 and can be found in appendix A.4. WTP was then predicted based on the observable characteristics with Duan smearing to account for the log transformation. The relative prediction error shown in table 12 was calculated as:

$$Relative\ error_i = {}^{\left(WTP_{3dB,i} - \widehat{WTP}_{3dB,i}\right)}\!/_{WTP_{3dB,i}}$$

[Table 12 about here.]

The first row in table 12 is repeated from table 10 for convenience and shows the actual WTP for the whole 200 m sample. The second row shows the predicted WTP for the same group excepting those households for which no sociodemographic information was available. Although the predicted mean WTP for a 3 dB reduction is equal to the actual mean WTP, there are large prediction errors for individual households. The median relative deviation from actual WTP is an overestimation of WTP by 40 %. The model performs especially poorly in capturing the WTP for households exposed to intermediate noise levels where the median prediction error indicates an overestimation by 130 %.

7 Concluding discussion

The current analysis introduces the Bajari and Benkard (2005)-approach into the literature on the welfare effects of traffic noise. The analysis sheds new light on the relationship between household demographics and preferences for quiet. Moreover, it adds to the existing literature by introducing a new way to use single year noise mappings in combination with multiple year transactions data. The analysis recovers robust estimates of the negative effect of traffic noise on housing prices. The detailed quality of the road noise measures and the road border research design reduce the potential impact of omitted variables bias and measurement error allowing the use of a single mapping of road noise for 9 years of transactions. The road border research design slightly lowers willingness to pay estimates compared to the full sample with school district fixed effects. The identified effect of noise on property values is larger for single family and terraced houses than for apartments. The findings in terms of percentage change in house prices for a 1 dB increase in noise levels are comparable to findings in previous studies, though there is considerable variation across levels of noise due to the non-linear nature of the hedonic price function.

There is large variation across the population in the marginal willingness to pay recovered from the first stage of the hedonic model. Using a simple quasi-linear function to approximate utility, preference parameters are calculated from the estimates to shed light on the willingness to pay for changes in noise levels associated with implemented policies to reduce noise, and to explore the heterogeneity in preferences further. The preference parameters for living area, proximity to the center of Copenhagen and for quiet are all correlated with each other. The correlation of preference parameters for different housing attributes hints at the difficulty of finding valid instruments for use in a second stage estimation, since it is hard to think of any variable relevant to household choice of housing, which would reasonably be uncorrelated with the household's unobserved taste for housing attributes.

Policies that address noise at the emitter level such as the emission standards for tyres have the potential to generate substantial gains for households, though the extent to which households are willing to pay for an improvement varies for different demographic groups. The observed pattern in WTP is consistent with the location choices of households in terms of noise exposure in that households with a high WTP tend to consume less noise. Traffic management also has potential to generate welfare gains for affected households. The analysis shows that the WTP for noise reductions is generally higher for households exposed to higher noise levels. It should be kept in mind however, that large changes in noise levels are likely to lead to resorting of households and welfare effects may not be positive for tenants whose rent may increase beyond their WTP for the reduction in noise. A more specific modeling of the sorting behaviour of households in a discrete choice model or an equilibrium sorting model would be an interesting extension to the current study.

Observable demographic characteristics explain some 30 percent of the variation in preferences for quiet. Some of the more important factors are income and household type. In particular, the presence of children is associated with a stronger preference for quiet. A large part of preference heterogeneity is left unexplained, which may be a problem for use of the current estimates in benefit transfer. While it is possible to adjust for observable differences between areas in terms of e.g. household composition, selection into different areas based on unobserved taste cannot be controlled for in such a setting. The analysis shows, that unobserved taste heterogeneity is close to being normally distributed consistent with assumptions often made in the economic literature in the absence of better information. However, predicting WTP within sample suggests that although the mean of predicted WTP is close to the mean of the actual WTP, the model tends to overestimate WTP especially for those households exposed to low or intermediate noise levels.

While the present analysis adds to the existing knowledge about preferences for quiet, there are important caveats. Obtaining data on air pollution at a fine spatial scale would be desirable to ensure that the identified effect on prices of road noise is not confounded by other pollution sources. Data on air pollution from traffic would also allow a more complete analysis of the WTP for reducing environmental externalities of road traffic. Further, as in all revealed preference analyses only the perceived benefits associated with the use of the home are captured in the willingness to pay measures here. As such these estimates are subject to asymmetric information (see Pope (2008) for an analysis of airport noise and information revelation), although road noise is likely to be more easily discovered by households than other more intermittent sources of noise. If households are unaware of the health risks associated with traffic noise, their actual willingness to pay may also be higher than this study suggests. Additionally, costs associated with noise exposure at the work place or in schools and public parks is not captured here and would require a study of e.g. commercial properties and their traffic noise exposure. These costs may be non-negligible. For example, the evaluation of the rerouting of traffic in Nørrebrogade mentions that recreational use of the affected area has increased substantially and the increase is attributed in part to the reduction in noise levels.

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Notes

[1]Even with multiple markets the identifying assumption is that preferences across markets are identical, i.e. no sorting across markets due to unobservable preference heterogeneity.

[2]The user cost of housing,π_t, converts the purchase price into annual costs and takes account of taxes, depreciation and the mortgage interest rate. See appendix A.1 for more details.

[3]The subscript i is used for both homes and households. There is a 1:1 correspondence between homes and households in the data and so the same index is used to keep notation simple.

[4]The data set consisted of the population of transactions taking place in the period of single family houses, terraced houses and apartments. The data was cleaned by eliminating transactions where the buyer was not a household (e.g. companies, organizations etc.). Furthermore, foreclosures and transactions between relatives were discarded. Transactions in which whole apartment buildings were sold to private households were also eliminated. Finally, homes smaller than 35 sqm were eliminated as were outliers in terms of the price per square meter. The aim of the study is to quantify tradeoffs for private households in their housing consumption decision. Therefore the sample used for the analysis should reflect the open market faced by private households. The data cleaning of the household data is described in footnote 5 and affects only the data used in the analysis of preference parameters.

[5]Extremely low income was defined as less income than their annual cost of housing determined by the user cost of owning a home, plus a minimum amount per person set at 40,000 DKK (2000-levels) for the first person and 20,000 DKK for each additional adult. This reduces the data set used in the final estimations by 1,816 observations, the majority of which are students. In some of these cases, the parents are the likely owners of the property. Additionally, 27 observations with extremely high incomes (higher than 1,500,000 DKK after housing costs) were removed. Unfortunately, data on wealth was not available for this analysis. The data cleaning of the household data only affects the data used for the analysis of the preference parameters as no transactions were barred from fitting the hedonic surface based on the demographic data.

[6]The formula used to calculate L_{den} is: $L_{den} = 10 \cdot log\frac{1}{24} \cdot \left(12 \cdot 10^{\frac{L_{day}}{10}} + 4 \cdot 10^{\frac{L_{eve}+5}{10}} + 8 \cdot 10^{\frac{L_{nig}+10}{10}}\right)$, so a penalty of 5 and 10 are added to noise levels in the evening and night where households are presumably more sensitive to noise. L_{day}, L_{eve} and L_{nig} are the A-weighted equivalent sound pressure levels for the corresponding 12, 4 and 8 hour periods: 7 AM to 7 PM, 7 PM to 11 PM and 11 PM to 7 AM.

[7]One municipality (Dragør) was not a part of the noise mapping and road noise measures do not exist for the transactions in this municipality. The municipality does not have any large roads and complaints of road noise are uncommon there. As a precaution however, all dwellings within 200 meters of a large road (6 meters wide) have been dropped from the analysis.

[8]The noise calculation model used for railway noise is constructed for calculation of road noise and has been adapted to calculate noise from railways. The accuracy with which this noise measure captures the

perceived railway noise exposure is not known as railway noise is quite different in terms of duration and frequency. A measure of maximum railway noise exposure was also provided and comparison between this measure and the average 24 hour measure L_{den} revealed that only homes that experienced large maximum noise levels have positive 24 hour average railway noise in the mappings. Further, the mapping of railway noise was only required to cover homes exposed to railway noise above 55 dB and this limit was imposed by selecting buffers around the railways for which noise measures were calculated. In contrast to road noise therefore, rail noise has only been calculated for those housing units within a certain distance to the railroad.

[9]Traffic counts from roads entering the municipality of Copenhagen and key intersections in the center of Copenhagen in the period show that changes in traffic flows lie between -33 pct. and + 33 pct. of the 2005 count used to compute the noise measure. 7 out of 45 counting stations experienced more than 20 pct. variation in traffic flows corresponding to 1-2 dB changes in noise levels in the years 2000 or 2008 relative to 2005. Of these only 3 are in the data set. 2 of them are relatively new freeways (1997/8), which experienced (expected) rapid growth in traffic flows in the early 2000s. The remaining road was subject to a temporary closure in 2008 explaining the reduction in traffic in that year relative to 2005. The measurement error induced by the use of a single cross section thus seems to be of minor concern on these large roads.

[10]Retirees are defined as: Average age of adults $>$ 55 years and no children. Families w/ children: Households containing children under the age of 18 years. Students: If at least one adult member of the household is a student and the average age is less than 35 years and no children. Singles consist of one adult household member, who is not a student, not retired and has no children. Families without children are the remaining households.

[11]Regional sources dominate for $PM_{2.5}$ and PM_{10}, whereas local sources (mainly traffic) dominate for NO_x.

[12]Aggregating the noise measures into a single measure of total traffic related noise was considered following guidelines from the Danish Environmental Protection Agency. These are based on an energy equivalence principle and require that assumptions be made about the dosis response relationship between dB measured and annoyance from each source to transform the dB to a comparable scale. If one source of noise dominates, the addition of further noise sources will not change the total noise level by much. As the relative annoyance from different measures of noise is an empirical question, no attempt was made to calculate an aggregate.

[13]All models are estimated using xtreg with the cluster option in Stata 13, SE.

[14]In an urban environment, background noise levels vary by neighborhood depending on the density of development and the activities in the neighborhood. While background noise levels are often set at the same level for a whole city, this is not likely to be an accurate description of how households perceive

their noise exposure, as selection into quieter neighborhoods is likely correlated with overall preferences for quiet.

[15]The formula for recovering preferences for living area (la) is: $\beta_{la,i} = \pi_t {}^{\partial P}/_{\partial x_{la}}(x_{la,i})$, for proximity to the CBD a maximum proximity of $C = max(x_{CBD}) + 0.1 = 20.4\ km$ was used and the formula is: $\beta_{CBD,i} = -\pi_t {}^{\partial P}/_{\partial x_{CBD}}(C - x_{CBD,i})$

[16]The EU regulation also imposes requirements for wet grip and fuel efficiency which should be included for a complete cost benefit analysis of the policy.

[17]At the outset it was not clear that the experiment would result in a permanent closure of the street. The effect in terms of the relocation of traffic, noise reduction, improved accessibility for busses etc. were hard to forecast which was the reason for the temporary closure.

[18]Traffic counts show that traffic has increased by about 10 per cent on alternative large roads into Copenhagen (Cowi, 2008). Such an increase is not large enough to generate noticeable increases in road noise.

[19]Group IDs for school districts and road border zones were de-identified by Statistics Denmark so it is not possible to pinpoint the exact location of any of these in the final data set.

[20]One potentially important omitted variable in this regression is the level of background noise. Clearly WTP for a noise reduction depends on how much ambient noise there is in a neighborhood.

List of Figures

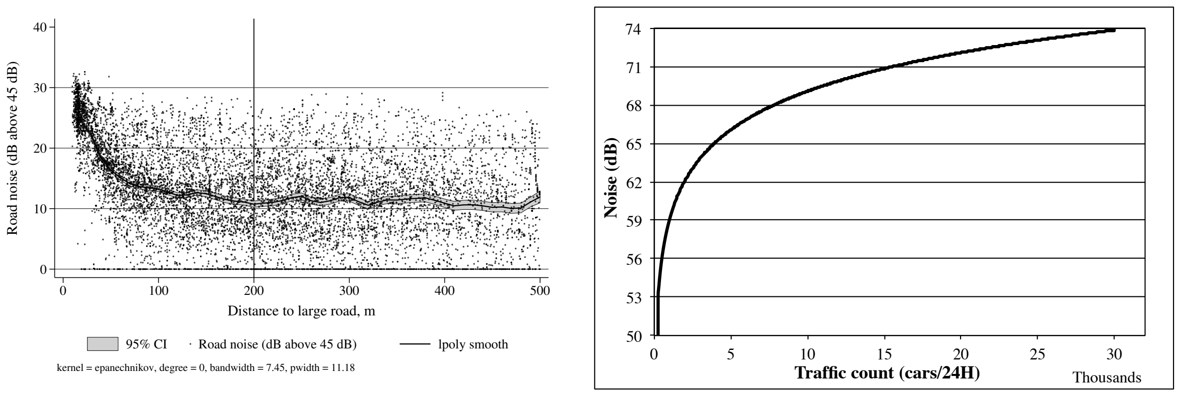


Figure 1: Noise variation, distance to a large road and traffic count, example
Noise variation and distance to large road for observations from 2005 only. The relationship depicted between noise and traffic count is an example. The exact level of noise generated depends on the speed and asphalt as well as the composition of vehicles (e.g. share of heavy vehicles).

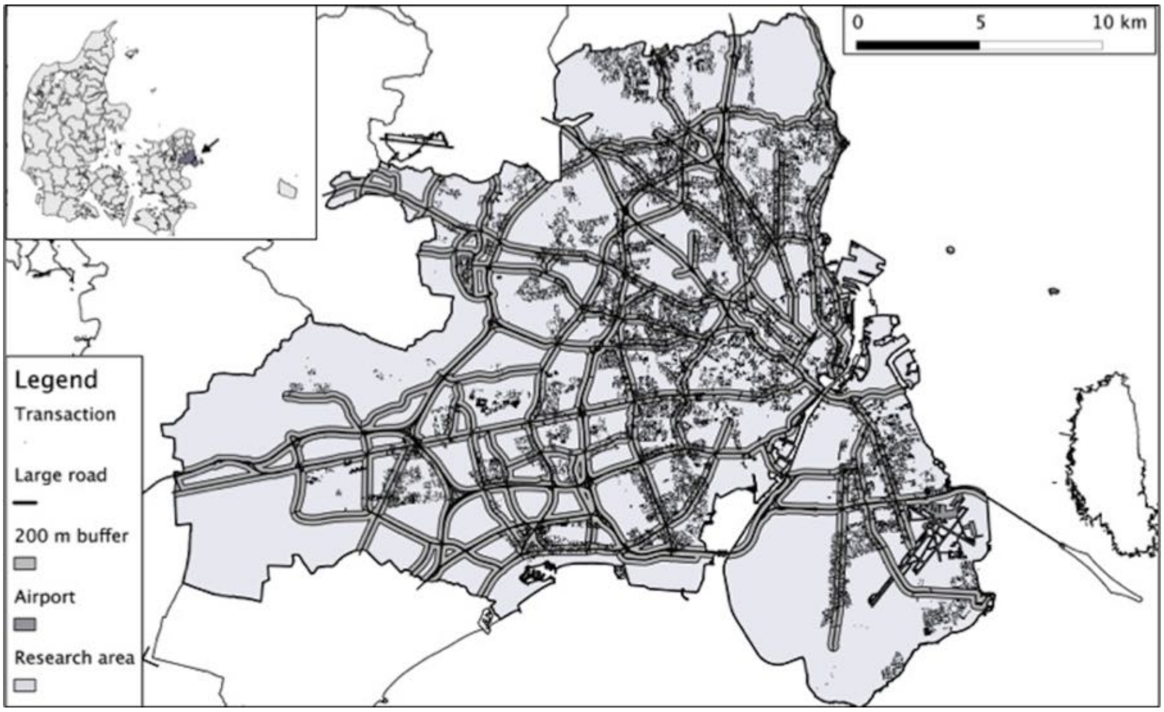
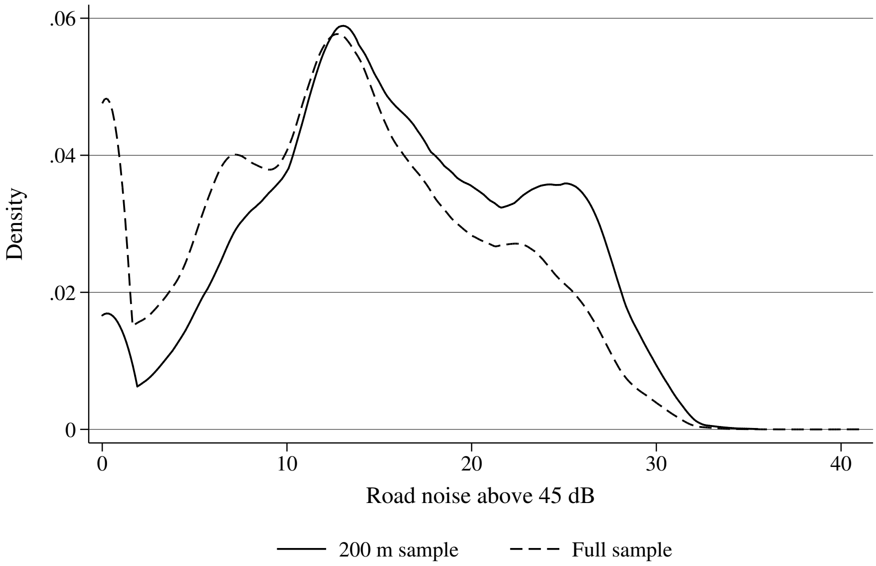


Figure 2: Survey area: Large roads and borders with transactions

Figure 3: Density for road noise, full and reduced samples



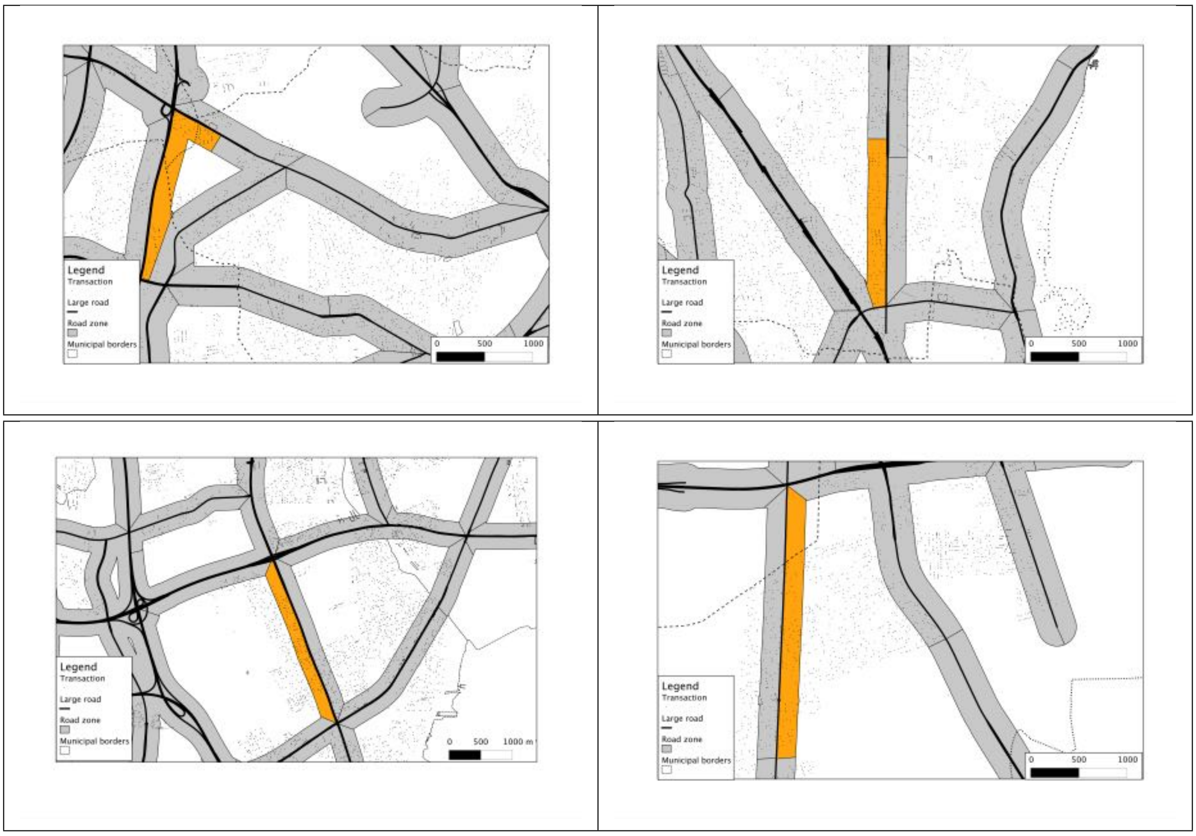


Figure 4: Examples, 200 m road border zone used for fixed effects

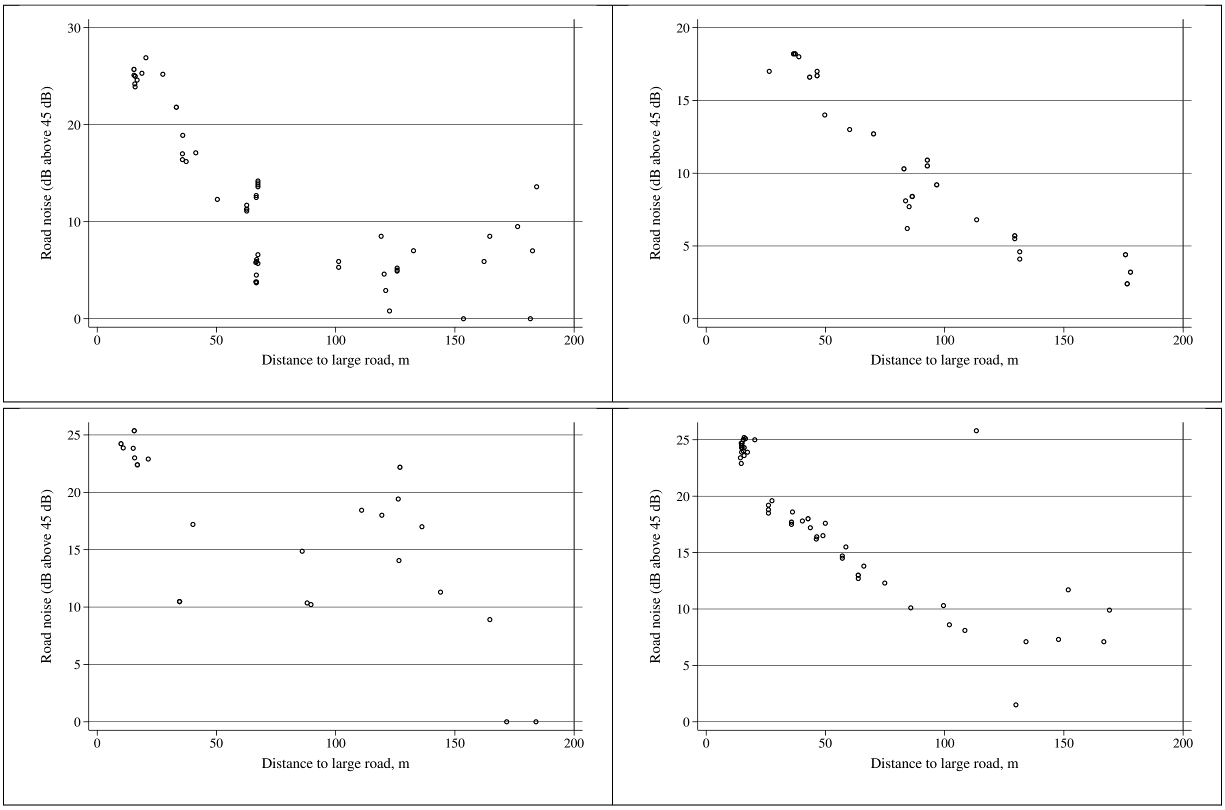
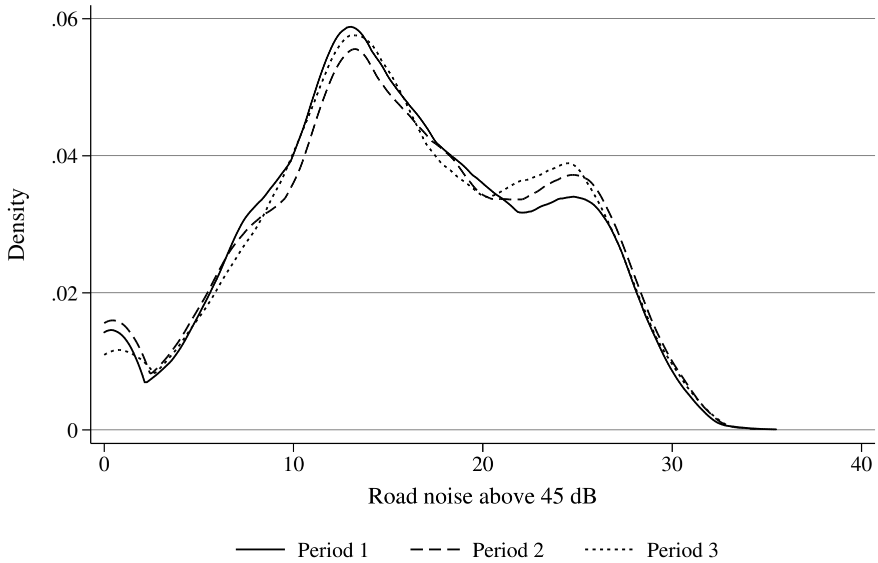


Figure 5: Examples, within road zone road noise variation
Road zones number 49, 52, 102 and 244. Observations from 2005 only.

Figure 6: Distribution of road noise by period



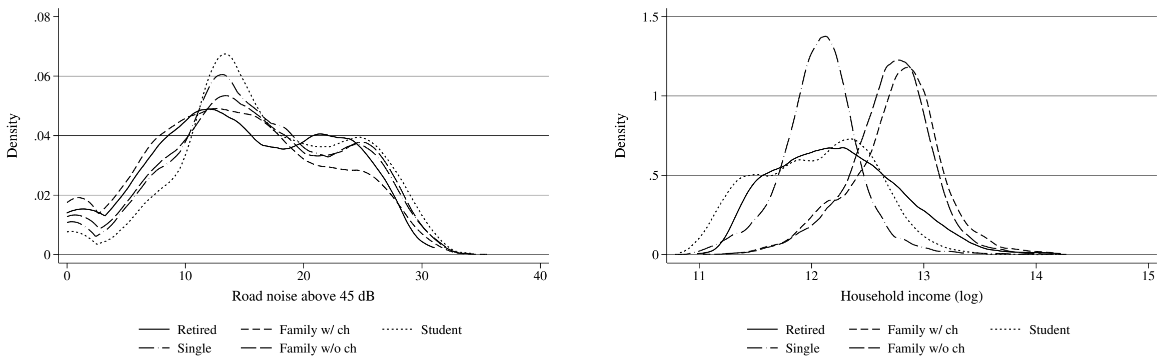
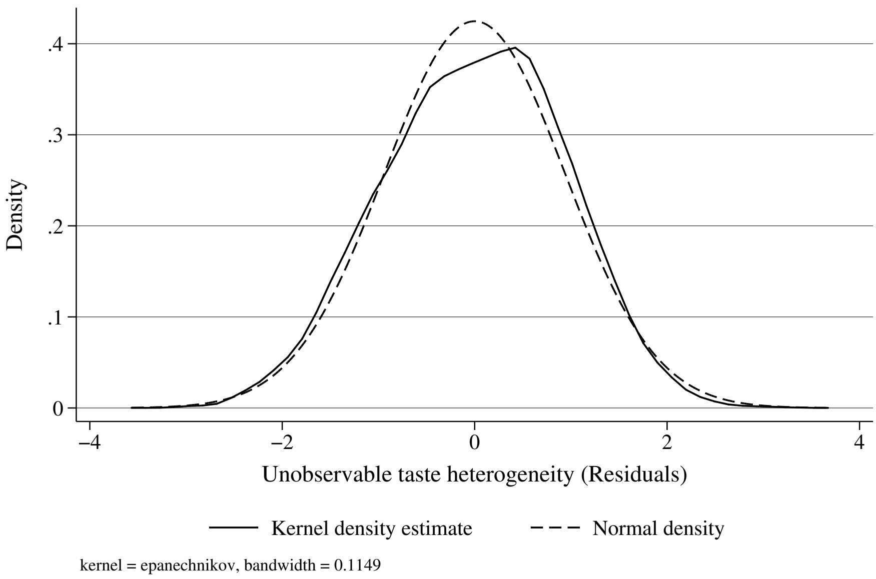


Figure 7: Demographic groups: noise levels and log income, 200 m sample

Figure 8: Unobservable taste heterogeneity



List of Tables

Table 1: Selected descriptive statistics of the housing transactions

	Within 200 m			Full sample		
Variable	10th P	90th P	mean	10th P	90th P	mean
Road noise > 45 dB	6.2	25.9	15.7	0.9	23.4	12.7
Train noise > 55 dB	0.0	0.0	0.2	0.0	0.0	0.1
Airport noise > 45 dB	0.0	0.0	0.1	0.0	0.0	0.2
Living space (sqm)	49.0	140.0	85.6	51.0	149.0	92.4
Price (2000-DKK, thousands)	540.7	1,705.9	1,036.4	581.8	1,893.2	1,163.9
Distance to CBD (km)	1.6	11.9	5.7	1.6	12.2	6.1

Note: P stands for percentile of the distribution.

Table 2: Demographic groups

	200 m sample		Full sample	
Retirees	2,393	8.6	6,962	9.7
Families w/ children	6,462	23.3	20,615	28.6
Families, no children	5,356	19.3	14,198	19.7
Singles	7,851	28.3	17,932	24.9
Students	5,723	20.6	12,429	17.2
	27,785	100	72,136	100

Note: Extreme income households excluded, all 3 periods pooled.

Table 3: Descriptive statistics, road zones

Period	2000-2002		2004-2005		2007-2008	
Transactions	15,073		9,889		5,347	
Road border zones	160		127		96	
Border zone stats	5th P	50th P	95th P	mean	min	max
Area (km^2) - 200 m	0.30	0.52	0.88	0.54	0.17	0.95
Obs./period - 200 m	27	115	482	163	20	552

Note: P stands for percentile of the distribution.

Table 4: Coefficient estimates, road noise

		(1)	(2)	(3)	(4)
Period 1	Noise ≤ 55 dB	0.316	0.282*	−0.037	−0.129*
		(1.66)	(2.50)	(−0.32)	(−2.11)
	Noise (55-65 dB]	−0.079	−0.128	−0.102	−0.160***
		(−0.94)	(−1.95)	(−1.30)	(−3.65)
	Noise >65 dB	−0.430***	−0.560***	−0.500***	−0.595***
		(−3.53)	(−6.62)	(−4.58)	(−8.62)
	Noise ≤ 55 dB (house)	−0.388	−0.613***	−0.051	−0.006
		(−1.59)	(−3.44)	(−0.35)	(−0.07)
	Noise (55 -65 dB] (house)	−0.491***	−0.434***	−0.406**	−0.354***
		(−3.32)	(−3.35)	(−3.15)	(−4.28)
	Noise >65 dB (house)	−0.848***	−0.948***	−1.058***	−1.097***
		(−3.64)	(−4.49)	(−4.58)	(−5.66)
Period 2	Noise ≤ 55 dB	−0.073	−0.084	−0.155	−0.160*
		(−0.34)	(−0.63)	(−1.21)	(−2.24)
	Noise (55-65 dB]	−0.068	−0.041	−0.114	−0.192***
		(−0.73)	(−0.46)	(−1.32)	(−3.43)
	Noise >65 dB	−0.550***	−0.634***	−0.527***	−0.558***
		(−4.09)	(−5.72)	(−4.02)	(−6.32)
	Noise ≤ 55 dB (house)	−0.083	−0.257	−0.073	−0.137
		(−0.23)	(−1.05)	(−0.38)	(−1.29)
	Noise (55 -65 dB](house)	−0.364	−0.362	−0.509***	−0.373**
		(−1.64)	(−1.85)	(−3.46)	(−3.22)
	Noise >65 dB (house)	−0.801**	−0.769*	−0.853**	−1.021***
		(−2.68)	(−2.51)	(−2.94)	(−4.25)
Period 3	Noise ≤ 55 dB	−0.139	−0.229	−0.417***	−0.488***
		(−0.60)	(−1.12)	(−3.41)	(−5.07)
	Noise (55-65 dB]	−0.296**	−0.293**	−0.161*	−0.250***
		(−3.12)	(−2.82)	(−2.11)	(−3.85)
	Noise >65 dB	−0.428*	−0.562***	−0.540***	−0.612***
		(−2.50)	(−4.17)	(−3.65)	(−5.81)
	Noise ≤ 55 dB (house)	−0.075	−0.016	0.329	0.272*
		(−0.19)	(−0.05)	(1.66)	(2.08)
	Noise (55 -65 dB] (house)	−0.452	−0.433	−0.662***	−0.474***
		(−1.75)	(−1.75)	(−4.09)	(−3.58)
	Noise >65 dB (house)	−1.032*	−0.862*	−0.811*	−0.931**
		(−2.20)	(−2.22)	(−2.42)	(−2.87)
	Fixed effects	Yes	No	Yes	No
	Observations	30,309	30,309	78,771	78,771

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: t statistics in parentheses, standard errors clustered at the FE level for the FE models. Road noise has been divided by 100 so estimates show the approx. percentage change in the price associated with a 1 dB increase in noise and (house) indicates the interaction term.

Table 5: Implicit prices in DKK (2000-levels), 200 m road border zones

With F.E.	10th P	25th P	Median	75th P	90th P	Mean
Period 1	-10,012	-5,739	-2,351	-588	-468	-4,044
Period 2	-8,539	-5,376	-2,999	-540	-421	-3,919
Period 3	-11,987	-5,350	-2,962	-2,079	-1,658	-5,146
No F.E.	10th P	25th P	Median	75th P	90th P	Mean
Period 1	-10,546	-6,508	-3,067	-949	-755	-4,774
Period 2	-9,437	-5,688	-3,408	-326	-255	-4,066
Period 3	-12,006	-6,489	-3,531	-2,127	-1,662	-5,493

Abbreviations: F.E. is fixed effect and P denotes percentile.

Table 6: Implicit prices in DKK (2000-levels), Full sample model

With F.E.	10th P	25th P	Median	75th P	90th P	Mean
Period 1	-9,528	-5,846	-2,731	-756	-601	-4,416
Period 2	-9,942	-6,212	-2,894	-908	-709	-4,442
Period 3	-13,129	-6,107	-2,912	-1,184	-915	-5,054
No F.E.	10th P	25th P	Median	75th P	90th P	Mean
Period 1	-10,229	-6,328	-3,315	-1,183	-941	-5,031
Period 2	-9,666	-6,155	-3,298	-1,530	-1,195	-4,879
Period 3	-12,403	-6,850	-3,534	-1,833	-1,419	-5,563

Abbreviations: F.E. is fixed effect and P denotes percentile.

Note: All implicit prices are calculated for the 200m-sample with noise above 55 dB.

Table 7: Annual implicit price estimates and preference parameters, pooled sample

Annual price	10th P	25th P	Median	75th P	90th P	Mean
Noise per dB	-391	-186	-94	-26	-15	-158
Living area per sqm	274	346	453	565	669	465
CBD per km	-3,409	-2,282	-1,470	-562	-266	-1,680

Note: All prices in DKK (2000-levels).

β_{ki}	10th P	25th P	Median	75th P	90th P	Mean
Quiet	323	555	1,277	2,684	7,149	2,549
Living space	18,491	24,129	33,016	46,014	64,319	38,046
Proximity to CBD	220	420	1,349	2,847	5,225	2,220

Table 8: Preference parameter correlations

	Quiet	Prox. to CBD	Living area
Quiet	1.00		
Prox. CBD	0.67	1.00	
Living area	0.84	0.65	1.00

Note: All correlations are significantly different from zero.

Table 9: WTP per year for a 1 dB reduction in noise exposure

	10th P	25th P	Median	75th P	90th P	mean	Total WTP
Retired	18	38	126	257	444	191	349,351
Family w/ ch	27	102	220	419	673	301	1,393,808
Students	14	22	61	122	184	89	503,855
Singles	13	21	54	114	172	84	564,311
Family w/o ch	18	33	125	250	445	189	805,237

Note: All values in DKK (2000-levels). Total WTP is calculated for 200 m sample above 55 dB only.

Table 10: WTP for a noise reduction from 68 to 65 dB

	10th P	25th P	Median	75th P	90th P	mean
Whole sample (200 m)	42	73	251	501	1,081	429
Nørrebro	39	58	105	310	496	204
Over 68 dB	221	278	376	591	1,221	576
Nørrebro over 68 dB	230	295	386	516	647	417
Østerbro over 68 dB	277	333	467	681	927	606

Note: All values in DKK (2000-levels).

Table 11: Taste for quiet explained by demographics

	Coefficient	t-statistic
Income net of housing exp. (log)	0.360***	20.04
Average age, adults	0.0395***	13.66
Average age, sq.	−0.0002***	−6.35
Female	−0.239***	−10.41
Male	−0.233***	−10.30
Part time employed	−0.033	−1.77
HH foreign born	−0.239***	−9.67
Some foreign born	−0.0805**	−3.15
More than 2 adults	0.378***	10.49
Possible tenant	0.0007	0.03
Retired	−0.278***	−5.05
Student	−0.148***	−6.21
Single	−0.264***	−10.36
Youngest child - under 2 yrs	0.478***	17.62
- 3-5 yrs	0.645***	17.61
- 6-9 yrs	0.580***	10.54
- 10-14 yrs	0.510***	10.60
- 15-17 yrs	0.363***	5.60
Highest completed education - Primary school	−0.088***	−3.36
- Highschool or equivalent	0.089***	4.28
- Academy profession	0.085**	2.96
- Bachelor	0.048*	2.33
- Master	0.099***	4.68
- PhD	−0.141***	−4.35
Constant	1.913***	8.63
R^2	0.302	
Observations	21,606	

Note: Omitted: Families w/o children; Education: Vocational training. SEs are Huber/White.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 12: Relative prediction error, WTP for a 3 dB reduction

	10th P	25th P	Median	75th P	90th P	mean
WTP: Whole sample (200 m)	42	73	251	501	1,081	429
Predicted WTP	167	220	334	558	843	429
Error: Whole sample (200 m)	-5.97	-2.67	-0.40	0.27	0.54	-1.84
Error: Over 68 dB	-0.64	-0.14	0.21	0.45	0.62	0.07
Error: Under 68 dB	-7.04	-3.77	-1.30	0.10	0.48	-2.52

A Appendix

Contents

A.1 Changing housing market 2000-2008 and the user cost of housing

The Danish housing market was characterized by sharply rising prices peaking around 2006 at which point the market slowed down significantly (see fig. 1). These developments mirror events in other countries in the same period, and have similar causes. In the early 2000s a number of policy changes affected both the taxation of real estate and the financial instruments available for financing real estate purchases. For the last two hundred years, almost all property in Denmark has been financed through mortgage loans issued by mortgage credit institutions. Previously, mortgage lending was heavily regulated which made it difficult for credit institutions to create new financial products. However, following liberalizations in the late 1990s, mortgage credit institutions and banks were quick to launch new types of financing with variable interest rates and flexible payment schemes. Prior to 2000 almost all Danish mortgage loans were fixed-rate annuity loans. Since early 2000 the proportion of households using variable-rate financing has increased while interest rates were falling. In October 2003, the "payment free loan" was introduced as a 30 year loan with fixed or variable interest rate, but with a 10 year period of no payment on the principal. These loans quickly became very popular and constituted 19 percent (2004), 31 percent (2005) and 39 percent (2006) of the value of all loans. In addition to the introduction of these new instruments, the tax on real estate was fixed in nominal terms in 2001. Coupling these developments with high economic growth the outcome was a housing market bubble which burst in 2007 followed by declining prices and increasing times to sale, Dam et al. [2011]. The number of sales in the period varies by year reflecting the drying up of the market in the later years (see fig. 2).

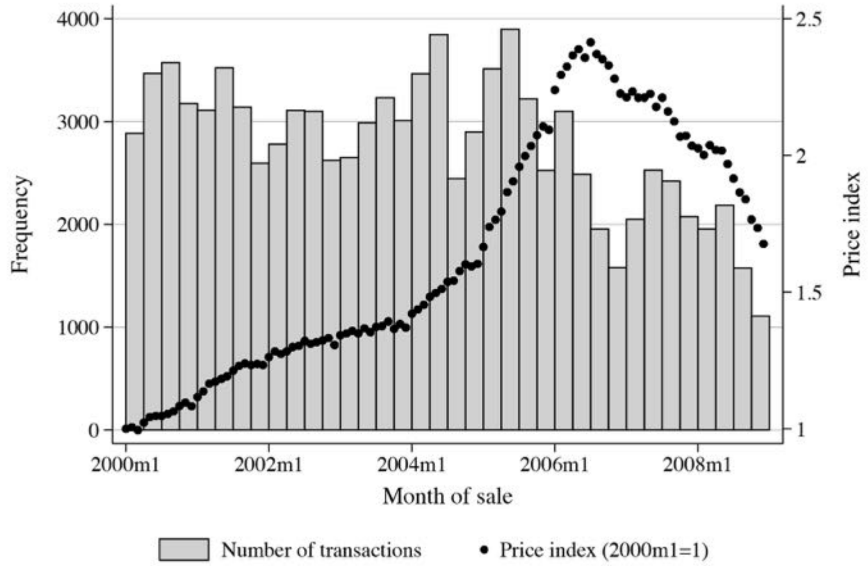


Figure 1: House price evolution, 2000-2008

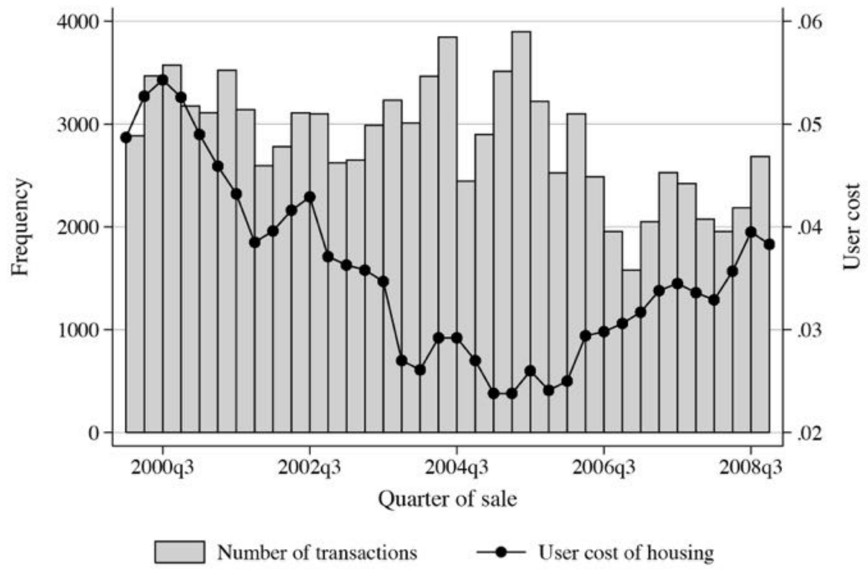


Figure 2: User cost of housing, Danish Central Bank

The changes in real estate financing and taxation directly impact the annual user cost of housing. The Danish Central Bank calculates the user cost of housing following the formula:

$$uc_t = (1 - d_\tau)r_t - E_t\left(\frac{dp}{dt}\right) + \tau_{h,t} + \delta$$

Here d_τ is a tax discount on interest payments, r_t is the weighted average interest rate: $r_t = (1 - v_t)r_{long,t} + \alpha_t r_{short,t}$, where v_t is the share of variable rate loans at time t and r_x is the long term and short term bond interest rate. The term $\frac{dp}{dt}^e$ captures the expected change in the house price. It is based on an Hodrick-Prescott-filtered time series of house prices. τ_h is the property tax and δ is depreciation (set to 0.01). The user cost generally fell from 2000 until 2006 before rising slightly as seen in figure 2. The main reason for the changes in the user cost of housing can be found in changing interest rates and the increasing proportion of households with variable rate loans.

References

Niels Arne Dam, Tina Saaby Hvolbøl, Erik Haller Pedersen, Peter Birch Sørensen, and Susanne Hougaard Thamsborg. Boligboblen der bristede: Kan boligpriserne forklares? og kan deres udsving dæmpes? In *Quarterly Report (Kvartalsoversigt)*. Danish Central Bank, 2011.

A.2 List of variables and descriptive statistics

Tables

Table 1: Continuous variables: 200 m sample descriptive statistics

200 m sample	10th P	25th P	Median	75th P	90th P	mean
Price_2000	540,710.38	660,246.63	863,288.56	1,279,652.38	1,705,904.50	1,036,369.90
Living space (sqm)	49.00	57.00	74.00	106.00	140.00	85.56
Lot size (sqm)	0.00	0.00	0.00	0.00	693.00	141.70
Central Business District (Km)	1.55	2.59	4.79	7.92	11.87	5.74
Industry (meters)	0.00	0.00	0.00	0.00	0.00	4.87
Coast line (meters)	0.00	0.00	0.00	0.00	0.00	17.09
Green space within 250 m	0.00	0.00	0.00	0.05	0.13	0.04
Lake (meters)	0.00	0.00	0.00	213.16	402.51	104.88
Station (meters)	0.00	0.00	0.00	180.59	375.48	89.92
Road noise (45 dB = 0)	6.20	10.75	15.30	21.60	25.95	15.72
Train noise (55 dB = 0)	0.00	0.00	0.00	0.00	0.00	0.23
Air noise (45 dB = 0)	0.00	0.00	0.00	0.00	0.00	0.10

Note: P stands for percentile of the distribution.

Table 2: Continuous variables: Full sample descriptive statistics

Full sample	10th P	25th P	Median	75th P	90th P	mean
Price_2000	581,784.69	716,576.00	1,033,628.75	1,432,539.38	1,893,202.25	1,163,916.54
Living space (sqm)	51.00	60.00	83.00	116.00	149.00	92.43
Lot size (sqm)	0.00	0.00	0.00	399.00	772.00	207.13
Central Business District (Km)	1.58	2.63	4.99	8.72	12.82	6.12
Industry (meters)	0.00	0.00	0.00	0.00	0.00	7.29
Coast line (meters)	0.00	0.00	0.00	0.00	0.00	19.33
Green space within 250 m	0.00	0.00	0.00	0.06	0.16	0.05
Lake (meters)	0.00	0.00	0.00	236.06	400.04	110.82
Station (meters)	0.00	0.00	0.00	229.65	398.67	105.92
Road noise (45 dB = 0)	0.90	7.06	12.70	18.12	23.44	12.72
Train noise (55 dB = 0)	0.00	0.00	0.00	0.00	0.00	0.14
Air noise (45 dB = 0)	0.00	0.00	0.00	0.00	0.00	0.19

Note: P stands for percentile of the distribution.

Table 3: Continuous sociodemographic variables: descriptive statistics

200 m sample	10th P	25th P	Median	75th P	90th P	mean
Income net of housing cost	86,477.47	131,856.88	198,552.00	300,163.69	395,422.63	228,109.61
Average age, adults	22.00	25.50	30.00	38.00	53.00	34.49
Full sample	10th P	25th P	Median	75th P	90th P	mean
Income net of housing cost	93,056.07	143,072.67	224,215.06	333,856.84	429,855.66	251,742.19
Average age, adults	23.00	27.00	32.00	40.00	55.00	35.80

Note: P stands for percentile of the distribution.

Table 4: Categorical variables - table I

Housing type	200 m sample	%	Full sample	%
Single family house	5182	17.10	19174	24.34
Terraced house	2215	7.31	8036	10.20
Apartment *	22912	75.59	51561	65.46
Bathrooms	200 m sample		Full sample	
0	505	1.67	1136	1.44
1 *	27846	91.87	70170	89.08
2	1886	6.22	7145	9.07
3 or more	72	0.24	320	0.41
Toilets	200 m sample		Full sample	
0	54	0.18	84	0.11
1 *	25524	84.21	61514	78.09
2	4235	13.97	15501	19.68
3 or more	496	1.64	1672	2.12
Elevator	200 m sample		Full sample	
0 *	26701	88.10	70468	89.46
1	3608	11.90	8303	10.54
Rooms	200 m sample		Full sample	
1 room	2219	7.32	4785	6.07
2 rooms	11378	37.54	24554	31.17
3 rooms	6905	22.78	17837	22.64
4 rooms	5400	17.82	16512	20.96
5 rooms	2591	8.55	8635	10.96
6 or more rooms *	1816	5.99	6448	8.19
Basement	200 m sample		Full sample	
0 *	26235	86.56	64547	81.94
1	4074	13.44	14224	18.06
Story	200 m sample		Full sample	
-*	7551	24.91	27524	34.94
Ground floor	4688	15.47	10882	13.81
1	5484	18.09	12318	15.64
2	5323	17.56	11805	14.99
3	3344	11.03	7802	9.90
4	2401	7.92	5645	7.17
5	958	3.16	1999	2.54
6	182	0.60	337	0.43
7 or more	378	1.25	459	0.58
Wall 3 (brick)	200 m sample		Full sample	
Concrete	3496	11.53	7914	10.05
Brick *	26277	86.70	68936	87.51
Other	536	1.77	1921	2.44
Listed	200 m sample		Full sample	
0 *	29738	98.12	76944	97.68
1	571	1.88	1827	2.32

Table 5: Categorical variables - table II

Stories_tot	200 m sample		Full sample	
1	6455	21.30	23862	30.29
2	2498	8.24	7602	9.65
3	6669	22.00	12581	15.97
4	2558	8.44	6819	8.66
5	8219	27.12	20538	26.07
6	2669	8.81	5076	6.44
7	363	1.20	944	1.20
8	208	0.69	392	0.50
10	56	0.18	184	0.23
11	203	0.67	317	0.40
13	0	0.00	22	0.03
14	20	0.07	43	0.05
15	146	0.48	146	0.19
16 *	245	0.81	245	0.31
Roof	200 m sample		Full sample	
Other	939	3.10	3110	3.95
Built up (flat roof)	2970	9.80	7567	9.61
Cement	1248	4.12	3589	4.56
Fibercement, asbestus	8758	28.90	22894	29.06
Tar paper	4720	15.57	10573	13.42
Glazed *	11674	38.52	31038	39.40
Constr_year	200 m sample		Full sample	
1900-1920	3946	13.02	10464	13.28
1920-1940	10066	33.21	22836	28.99
1940-1960	4569	15.07	13870	17.61
1960-1980	7383	24.36	19081	24.22
1980-2000	1008	3.33	2962	3.76
After 2000 *	405	1.34	2200	2.79
Before 1900	2932	9.67	7358	9.34
Renovations	200 m sample		Full sample	
5-10 years before	491	1.62	1359	1.73
none	28922	95.42	74276	94.29
After sale	423	1.40	1646	2.09
Less than 5 years before *	473	1.56	1490	1.89
Train noise F	200 m sample		Full sample	
55-59 dB	741	2.44	2057	2.61
60-64 dB	183	0.60	476	0.60
65-69 dB	6	0.02	38	0.05
under 55 dB *	29379	96.93	76200	96.74

Table 6: Categorical variables - table III

Municipality	200 m sample	%	Full sample	%
Copenhagen *	16384	54.06	36143	45.88
Frederiksberg	1742	5.75	7079	8.99
Ballerup	454	1.50	1545	1.96
Brøndby	406	1.34	1264	1.60
Dragør	0	0	1015	1.29
Gentofte	2054	6.78	6313	8.01
Gladsaxe	1794	5.92	4174	5.30
Glostrup	396	1.31	1239	1.57
Herlev	310	1.02	1081	1.37
Albertslund	375	1.24	1295	1.64
Hvidovre	1260	4.16	3349	4.25
Høje-Taastrup	649	2.14	2530	3.21
Lyngby-Taarbæk	1241	4.09	4259	5.41
Rødovre	1260	4.16	2911	3.70
Taarnby	862	2.84	2788	3.54
Vallensbæk	1122	3.70	1786	2.27
Postal code groups (aggregated)	**200 m sample**	**%**	**Full sample**	**%**
Copenhagen K (999-1499)	842	2.78	2690	3.41
Vesterbro (1500-1799)	883	2.91	2219	2.82
Frederiksberg (1800-2000)	1742	5.75	7079	8.99
Østerbro (2100)	2406	7.94	5832	7.40
Nørrebro (2200)	2527	8.34	4080	5.18
Amager (2300)	2957	9.76	8156	10.35
Copenhagen NW (2400)	1673	5.52	2726	3.46
2450-2665	7450	24.58	19074	24.21
2700-2791	4471	14.75	12193	15.48
2800-2880	3937	12.99	10195	12.94
2900	1020	3.37	1988	2.52
2920-2930	401	1.32	2539	3.22

Table 7: Categorical variables (Sociodemographics)

Gender ratios	200 m sample	%	Full sample	%
More female adults	7349	26.45	17864	24.76
Equal *	12469	44.88	36026	49.94
More male adults	7967	28.67	18245	25.29
Part time employed	200 m sample		Full sample	
0 *	22545	81.14	59651	82.69
1	5240	18.86	12484	17.31
Whole HH foreign born	200 m sample		Full sample	
0 *	25447	91.59	67039	92.94
1	2338	8.41	5096	7.06
Some HH members foreign born	200 m sample		Full sample	
0 *	25243	90.85	65253	90.46
1	2542	9.15	6882	9.54
More than two adults	200 m sample		Full sample	
0 *	26195	94.28	68129	94.45
1	1590	5.72	4006	5.55
Possible tenants	200 m sample		Full sample	
0 *	23196	83.48	61494	85.25
1	4589	16.52	10641	14.75
Demographics	200 m sample		Full sample	
Retired	2393	8.61	6962	9.65
Family w/ children	6462	23.26	20615	28.58
Students	5723	20.60	12428	17.23
Singles	7851	28.26	17932	24.86
Families, no children *	5356	19.28	14198	19.68
Age of youngest child	200 m sample		Full sample	
no children under 18*	21323	76.74	51520	71.42
Youngest child under 2 yrs	3291	11.84	10735	14.88
Youngest child 3-5 yrs	1464	5.27	4758	6.60
Youngest child 6-9 yrs	611	2.20	1921	2.66
Youngest child 10-14 yrs	747	2.69	2213	3.07
Youngest child 15-17 yrs	349	1.26	988	1.37
Highest education level	200 m sample		Full sample	
Primary school	2372	8.54	5174	7.17
Highschool equivalent	4642	16.71	10353	14.35
Vocational training *	7315	26.33	18126	25.13
Academy profession	1751	6.30	4652	6.45
Bachelor degree or equivalent	4920	17.71	13779	19.10
Master's degree	4696	16.90	14621	20.27
PhD	2089	7.52	5430	7.53

A.3 Estimation results and joint significance test

Joint test (Roadnoise and Roadnoise (house)

For model (1), Road border research design with fixed effects.

Table 8: Joint significance tests: Road noise and Road noise (house)

Pairwise F-tests	Period 1			Period 2			Period 3		
	F	den df	p value	F	den df	p value	F	den df	p value
Noise $\leq$ 55 dB	1.52	159	0.22	0.23	126	0.79	0.47	95	0.62
Noise $(55 - 65\, dB]$	10.18	159	0.00	2.50	126	0.09	9.18	95	0.00
Noise $>$ 65 dB	25.17	159	0.00	18.79	126	0.00	7.89	95	0.00

Table 9: Period 1: Full estimation results

	(1)	(2)	(3)	(4)
	xt_200fe	reg_200	xt_fullfe	reg_full
Single family house	1.235***	1.097***	1.140***	1.050***
	(9.32)	(10.93)	(11.07)	(17.64)
Terraced house	1.027***	0.870***	0.922***	0.812***
	(5.59)	(6.44)	(6.43)	(9.94)
Log Living space (sqm)	0.724***	0.773***	0.745***	0.778***
	(38.37)	(67.68)	(45.26)	(102.65)
Liv. sp. (single fam. house)	-0.236***	-0.211***	-0.233***	-0.222***
	(-8.79)	(-10.40)	(-10.65)	(-18.37)
Liv. sp. (terr. house)	-0.202***	-0.170***	-0.196***	-0.177***
	(-5.12)	(-5.90)	(-6.51)	(-10.23)
1 room	-0.195***	-0.182***	-0.179***	-0.168***
	(-8.58)	(-11.00)	(-11.67)	(-16.58)
2 rooms	-0.0817***	-0.0815***	-0.0692***	-0.0675***
	(-4.86)	(-6.06)	(-6.45)	(-8.62)
3 rooms	-0.0187	-0.0231*	-0.00317	-0.00249
	(-1.28)	(-1.97)	(-0.38)	(-0.38)
4 rooms	0.00561	-0.00238	0.00901	0.00971
	(0.52)	(-0.23)	(1.34)	(1.71)
5 rooms	-0.00276	-0.0145	-0.00331	-0.00537
	(-0.27)	(-1.45)	(-0.50)	(-0.99)
Log Lot size (sqm)	0.00745*	0.00728**	0.0115***	0.0107***
	(2.29)	(2.66)	(4.24)	(5.84)
2 toilets	0.0269***	0.0283***	0.0345***	0.0352***
	(3.51)	(4.12)	(4.89)	(9.11)
3 or more toilets	0.0658**	0.0838***	0.0643***	0.0828***
	(3.22)	(4.21)	(5.21)	(7.95)

	(1)	(2)	(3)	(4)
No own toilet	-0.179**	-0.192***	-0.152**	-0.166***
	(-2.94)	(-4.65)	(-2.85)	(-4.36)
2 bathrooms	-0.00626	-0.00215	0.00239	0.00607
	(-0.67)	(-0.25)	(0.42)	(1.32)
3 or more bathrooms	-0.0127	0.0132	-0.0248	-0.0350
	(-0.40)	(0.35)	(-1.38)	(-1.68)
No own bathroom	-0.0373**	-0.0644***	-0.0564***	-0.0689***
	(-2.70)	(-4.54)	(-5.44)	(-7.11)
Basement	0.0874***	0.100***	0.0879***	0.0975***
	(9.67)	(13.25)	(14.55)	(23.91)
Story: Ground floor	-0.0497*	-0.0646***	-0.0811***	-0.0776***
	(-2.36)	(-3.65)	(-3.74)	(-5.39)
Story: 1st	-0.0367	-0.0506**	-0.0631**	-0.0612***
	(-1.69)	(-2.88)	(-2.82)	(-4.26)
Story: 2nd	-0.0249	-0.0394*	-0.0449*	-0.0430**
	(-1.18)	(-2.22)	(-1.98)	(-2.98)
Story: 3rd	-0.0177	-0.0312	-0.0428	-0.0402**
	(-0.81)	(-1.73)	(-1.93)	(-2.75)
Story: 4th	-0.00614	-0.0217	-0.0349	-0.0328*
	(-0.26)	(-1.17)	(-1.49)	(-2.21)
Story: 5th	-0.00390	-0.0190	-0.0302	-0.0217
	(-0.15)	(-0.94)	(-1.30)	(-1.37)
Story: 6th	0.00882	-0.00343	0.00215	0.00882
	(0.28)	(-0.12)	(0.07)	(0.37)
Story: 7th	0.0244	0.00789	0.0341	0.0414
	(0.84)	(0.30)	(0.95)	(1.68)
Total stories: 1	0.195***	0.125***	0.00892	-0.0529
	(6.73)	(3.35)	(0.33)	(-1.00)

	(1)	(2)	(3)	(4)
Total stories: 2	0.203***	0.166***	0.0192	-0.0331
	(8.08)	(4.68)	(0.81)	(-0.63)
Total stories: 3	0.167***	0.130***	-0.0124	-0.0677
	(6.74)	(3.68)	(-0.60)	(-1.29)
Total stories: 4	0.164***	0.141***	-0.0278	-0.0687
	(7.13)	(4.00)	(-1.49)	(-1.32)
Total stories: 5	0.140***	0.0968**	-0.0231	-0.0810
	(4.90)	(2.75)	(-1.24)	(-1.55)
Total stories: 6	0.144***	0.0960**	-0.0277	-0.0865
	(4.42)	(2.73)	(-1.45)	(-1.66)
Total stories: 7	0.141**	0.0546	-0.0316	-0.0522
	(3.22)	(1.44)	(-1.35)	(-0.98)
Total stories: 8	0.222***	0.186***	0.0772*	0.00900
	(7.97)	(4.87)	(2.57)	(0.17)
Total stories: 10	0	0	-0.0597	-0.117*
	(.)	(.)	(-1.67)	(-2.14)
Total stories: 11	0.152*	0.144***	-0.0343	-0.0600
	(2.43)	(3.67)	(-0.85)	(-1.09)
Total stories: 12	0	0	0	0
	(.)	(.)	(.)	(.)
Total stories: 13	0.184***	0.157	-0.0452***	-0.0559
	(5.29)	(1.82)	(-4.78)	(-0.82)
Total stories: 14	0.108***	0.0603	-0.131***	-0.147**
	(5.28)	(1.43)	(-6.89)	(-2.59)
Total stories: 15	0.181***	0.0470	0.0385	-0.122*
	(4.65)	(1.05)	(1.03)	(-2.11)
Construction year: 1900-1920	-0.298***	-0.287***	-0.274***	-0.245***
	(-7.35)	(-16.75)	(-10.20)	(-27.05)

	(1)	(2)	(3)	(4)
Construction year: 1920-1940	-0.301***	-0.315***	-0.283***	-0.275***
	(-7.67)	(-19.48)	(-10.64)	(-31.99)
Construction year: 1940-1960	-0.299***	-0.334***	-0.276***	-0.281***
	(-7.58)	(-20.56)	(-10.06)	(-32.78)
Construction year: 1960-1980	-0.290***	-0.323***	-0.262***	-0.269***
	(-7.00)	(-20.27)	(-9.63)	(-32.39)
Construction year: 1980-2000	-0.163***	-0.194***	-0.127***	-0.122***
	(-4.15)	(-11.43)	(-4.62)	(-13.07)
Construction year: Before 1900	-0.308***	-0.255***	-0.268***	-0.213***
	(-7.52)	(-14.32)	(-9.01)	(-22.33)
Listed building	0.0705***	0.177***	0.0792*	0.103***
	(3.49)	(10.64)	(2.42)	(11.10)
Renovated 5-10 years before sale	-0.0187	-0.0101	-0.0262	-0.0301*
	(-0.32)	(-0.48)	(-0.90)	(-2.23)
Renovated after sale	-0.1000***	-0.0995***	-0.138***	-0.141***
	(-4.22)	(-5.68)	(-8.83)	(-15.14)
Not renovated	-0.00707	0.00415	-0.0472***	-0.0394***
	(-0.38)	(0.32)	(-3.84)	(-5.53)
Roof: Other	0.00979	0.00980	0.00334	0.00651
	(0.80)	(1.02)	(0.45)	(1.20)
Roof: Built up (flat)	-0.0280	-0.0142	-0.0318**	-0.0308***
	(-1.86)	(-1.92)	(-2.92)	(-6.51)
Roof: Cement	0.00205	-0.00409	-0.00260	-0.00778
	(0.17)	(-0.49)	(-0.33)	(-1.53)
Roof: Asbestus	-0.00860	-0.00545	-0.0130*	-0.0133***
	(-1.17)	(-1.20)	(-2.60)	(-4.78)
Roof: Tar paper	-0.00234	0.00450	-0.0158*	-0.0113**
	(-0.28)	(0.84)	(-2.20)	(-3.29)

	(1)	(2)	(3)	(4)
Wall: Other	-0.0662**	-0.0715***	-0.0469***	-0.0499***
	(-3.06)	(-5.02)	(-4.09)	(-6.46)
Wall: Concrete	-0.0576***	-0.0754***	-0.0509***	-0.0565***
	(-4.01)	(-11.54)	(-6.05)	(-13.79)
Less than 5 km to CBD	-0.0658***	-0.0405***	-0.0266*	-0.0402***
	(-9.37)	(-16.12)	(-2.40)	(-24.53)
5-10 km to CBD	-0.0115	0.00336	-0.0145	0.00349*
	(-1.31)	(1.04)	(-1.41)	(1.99)
More than 10 km to CBD	-0.0116	0.00815*	0.0220*	0.00768***
	(-0.71)	(2.46)	(2.08)	(4.67)
Distance to industry (max. 500 m)	0.0000	0.0003***	0.0001	0.0001***
	(0.18)	(6.27)	(1.43)	(5.33)
Distance to coast line (max. 500 m)	-0.0000	0.0003***	0.0001*	0.0003***
	(-0.50)	(11.72)	(2.44)	(17.75)
Green space within 250 m	0.0563	0.130***	0.0949**	0.113***
	(1.27)	(5.32)	(2.81)	(8.95)
Distance to lake (max. 500 m)	0.0000	-0.0000	-0.0000	0.0000**
	(0.44)	(-0.08)	(-0.57)	(2.77)
Distance to station (max. 500 m)	-0.0000**	-0.0001***	-0.0000*	-0.0000***
	(-2.76)	(-4.69)	(-2.37)	(-6.73)
Elevator	-0.0185	0.0304***	-0.0163	0.0199***
	(-0.87)	(3.88)	(-1.65)	(3.79)
Train noise >55 dB	-0.395*	-0.166	-0.879***	-0.453***
	(-2.30)	(-1.15)	(-3.51)	(-3.98)
Train noise (F): 55-59 dB	-0.0241*	-0.0279*	-0.0147	-0.0036
	(-2.25)	(-2.57)	(-1.61)	(-0.57)
Train noise (F): 60-64 dB	-0.0141	-0.0026	-0.0062	0.0062
	(-0.64)	(-0.13)	(-0.23)	(0.46)

	(1)	(2)	(3)	(4)
Train noise (F): 65-69 dB	-0.131***	-0.140	-0.0433	-0.0500
	(-7.40)	(-1.72)	(-1.25)	(-1.42)
Airplane noise >45 dB	-0.0243	-0.433*	0.241	-0.312**
	(-0.17)	(-2.21)	(1.60)	(-2.77)
Road noise ≤55 dB	0.316	0.282*	-0.0369	-0.129*
	(1.66)	(2.51)	(-0.31)	(-2.11)
Road noise (55-65 dB]	-0.0795	-0.128	-0.102	-0.160***
	(-0.94)	(-1.95)	(-1.30)	(-3.65)
Road noise >65 dB	-0.430***	-0.560***	-0.500***	-0.595***
	(-3.53)	(-6.63)	(-4.58)	(-8.62)
Road noise ≤55 dB (house)	-0.388	-0.613***	-0.0514	-0.00552
	(-1.59)	(-3.44)	(-0.35)	(-0.07)
Road noise (55 -65 dB] (house)	-0.491**	-0.434***	-0.406**	-0.354***
	(-3.32)	(-3.36)	(-3.15)	(-4.28)
Road noise >65 dB (house)	-0.848***	-0.948***	-1.058***	-1.097***
	(-3.64)	(-4.49)	(-4.57)	(-5.66)
Frederiksberg	0.0742*	0.0773***		0.0981***
	(2.38)	(11.22)		(25.61)
Ballerup	-0.112**	-0.113***		-0.122***
	(-3.13)	(-5.65)		(-10.91)
Brøndby	-0.152***	-0.159***		-0.174***
	(-3.88)	(-8.55)		(-16.64)
Dragør	0	0	0	0.0091
	(.)	(.)	(.)	(0.74)
Gentofte	0.0255	0.197***		0.252***
	(1.07)	(20.59)		(38.69)
Gladsaxe	0.0328	0.0488***		0.0299***
	(0.67)	(3.69)		(3.97)

	(1)	(2)	(3)	(4)
Glostrup	-0.0714*	-0.0879***		-0.126***
	(-2.23)	(-4.59)		(-11.27)
Herlev	-0.111***	-0.0492**		-0.0712***
	(-4.47)	(-2.77)		(-6.44)
Albertslund	-0.155**	-0.118***		-0.195***
	(-3.09)	(-5.15)		(-16.13)
Hvidovre	-0.0437	-0.0644***		-0.0902***
	(-1.31)	(-6.51)		(-15.03)
Høje-Taastrup	0	-0.189***	0	-0.202***
	(.)	(-6.38)	(.)	(-13.14)
Lyngby-Taarbæk	0.00328	0.120***		0.138***
	(0.05)	(7.05)		(14.25)
Rødovre	-0.0483	-0.0445***		-0.0609***
	(-1.89)	(-4.43)		(-9.50)
Taarnby	0.0570**	-0.0137		-0.0423***
	(2.92)	(-1.09)		(-5.71)
Vallensbæk	-0.0907	-0.137***		-0.146***
	(-1.87)	(-7.14)		(-12.55)
Constant	11.21***	10.86***	11.20***	11.08***
	(101.07)	(148.01)	(99.93)	(166.53)
#groups (FE)	160		167	
R^2	0.775	0.848	0.789	0.853
Observations	15073	15073	37074	37074

t statistics in parentheses, SEs clustered for the FE models at the road border zone (1) and school district level (3).

Note: School districts are completely contained in municipalities, so municipalities drop out for school district FE.

Road, railway and airport noise have all been divided by 100 so the coefficient can be interpreted as % change in P.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 10: Period 2: Full estimation results

	(1)	(2)	(3)	(4)
	xt_200fe	reg_200	xt_fullfe	reg_full
Single family house	1.007***	0.915***	1.040***	0.918***
	(7.46)	(6.32)	(9.28)	(11.25)
Terraced house	1.144***	1.242***	0.988***	0.968***
	(4.97)	(5.70)	(5.92)	(8.13)
Log Living space (sqm)	0.712***	0.750***	0.754***	0.769***
	(34.60)	(49.45)	(44.51)	(83.40)
Liv. sp. (single fam. house)	-0.201***	-0.183***	-0.204***	-0.181***
	(-6.75)	(-6.23)	(-8.68)	(-11.10)
Liv. sp. (terr. house)	-0.235***	-0.254***	-0.197***	-0.193***
	(-4.73)	(-5.46)	(-5.72)	(-7.71)
1 room	-0.141***	-0.142***	-0.132***	-0.133***
	(-4.63)	(-5.97)	(-7.28)	(-10.14)
2 rooms	-0.0601**	-0.0699***	-0.0617***	-0.0636***
	(-2.77)	(-3.54)	(-4.64)	(-6.00)
3 rooms	-0.00526	-0.0197	-0.00741	-0.00790
	(-0.30)	(-1.10)	(-0.69)	(-0.85)
4 rooms	-0.000423	-0.0170	0.00445	0.00318
	(-0.03)	(-1.05)	(0.48)	(0.38)
5 rooms	0.00122	-0.0178	-0.00276	-0.00576
	(0.08)	(-1.14)	(-0.33)	(-0.73)
Log Lot size (sqm)	0.0117**	0.0150***	0.0111***	0.0108***
	(2.81)	(3.72)	(3.71)	(4.31)
2 toilets	0.00871	0.0176	0.0112	0.0144**
	(0.73)	(1.72)	(1.40)	(2.66)
3 or more toilets	0.0688*	0.0979***	0.0460*	0.0564***
	(2.37)	(3.53)	(2.59)	(3.79)

	(1)	(2)	(3)	(4)
No own toilet	-0.121	-0.104	-0.0464	-0.0572
	(-1.81)	(-1.92)	(-0.84)	(-1.20)
2 bathrooms	-0.0114	-0.00998	0.0147*	0.0170**
	(-0.92)	(-0.76)	(2.04)	(2.60)
3 or more bathrooms	0.00692	-0.00409	0.0282	0.0216
	(0.13)	(-0.07)	(1.18)	(0.81)
No own bathroom	-0.0711***	-0.0968***	-0.0717***	-0.0824***
	(-4.13)	(-4.38)	(-5.39)	(-5.92)
Basement	0.0925***	0.0994***	0.0923***	0.0994***
	(7.80)	(8.96)	(12.16)	(17.51)
Story: Ground floor	-0.0634*	-0.0569*	-0.0331	-0.0220
	(-2.36)	(-2.11)	(-1.10)	(-1.08)
Story: 1st	-0.0372	-0.0337	-0.0106	-0.0010
	(-1.39)	(-1.25)	(-0.34)	(-0.05)
Story: 2nd	-0.0352	-0.0274	0.00171	0.0126
	(-1.33)	(-1.02)	(0.06)	(0.62)
Story: 3rd	-0.0228	-0.0153	0.0084	0.0188
	(-0.83)	(-0.56)	(0.27)	(0.91)
Story: 4th	-0.0208	-0.0140	0.0149	0.0241
	(-0.76)	(-0.51)	(0.46)	(1.15)
Story: 5th	0.00770	0.0210	0.0418	0.0478*
	(0.27)	(0.72)	(1.30)	(2.20)
Story: 6th	-0.00495	0.00919	0.0698	0.0735**
	(-0.15)	(0.26)	(1.75)	(2.80)
Story: 7th	0.0262	0.0230	0.0824	0.0935***
	(0.61)	(0.69)	(1.94)	(3.52)
Total stories: 1	0.194***	0.138	0.00143	0.0526
	(4.42)	(1.71)	(0.05)	(0.97)

	(1)	(2)	(3)	(4)
Total stories: 2	0.196***	0.165*	-0.0055	0.0534
	(5.22)	(2.11)	(-0.23)	(0.99)
Total stories: 3	0.179***	0.144	-0.0182	0.0336
	(5.39)	(1.85)	(-0.88)	(0.63)
Total stories: 4	0.185***	0.160*	-0.0345	0.0358
	(6.14)	(2.05)	(-1.59)	(0.67)
Total stories: 5	0.174***	0.138	-0.0377	0.0321
	(6.46)	(1.78)	(-1.95)	(0.60)
Total stories: 6	0.152***	0.129	-0.0431*	0.0343
	(5.51)	(1.66)	(-2.15)	(0.64)
Total stories: 7	0.160**	0.0755	-0.0505	0.0045
	(2.82)	(0.95)	(-1.93)	(0.08)
Total stories: 8	0.149***	0.109	-0.0655*	-0.0172
	(3.86)	(1.37)	(-2.55)	(-0.32)
Total stories: 10	0.196***	0.163	-0.0330	0.0251
	(5.87)	(1.67)	(-1.87)	(0.43)
Total stories: 11	0.106**	0.132	-0.0561	-0.00725
	(2.89)	(1.66)	(-1.12)	(-0.13)
Total stories: 12	0	0	0	0.114
	(.)	(.)	(.)	(1.47)
Total stories: 13	0	0	-0.108***	0
	(.)	(.)	(-13.43)	(.)
Total stories: 14	0.117***	0.0945	-0.166***	-0.0731
	(3.45)	(1.18)	(-7.69)	(-1.28)
Total stories: 15	0.0524	-0.0727	-0.135***	-0.157**
	(0.89)	(-0.85)	(-3.68)	(-2.62)
Construction year: 1900-1920	-0.184***	-0.184***	-0.165***	-0.127***
	(-6.60)	(-9.79)	(-6.52)	(-14.32)

	(1)	(2)	(3)	(4)
Construction year: 1920-1940	-0.198***	-0.208***	-0.178***	-0.158***
	(-7.96)	(-12.13)	(-7.42)	(-19.85)
Construction year: 1940-1960	-0.214***	-0.250***	-0.202***	-0.191***
	(-8.18)	(-14.51)	(-8.51)	(-23.66)
Construction year: 1960-1980	-0.229***	-0.253***	-0.193***	-0.181***
	(-8.81)	(-15.31)	(-8.06)	(-24.77)
Construction year: 1980-2000	-0.140***	-0.163***	-0.102***	-0.0732***
	(-5.15)	(-8.09)	(-3.67)	(-7.76)
Construction year: Before 1900	-0.187***	-0.163***	-0.155***	-0.102***
	(-6.67)	(-8.13)	(-5.92)	(-10.54)
Listed building	0.0781**	0.164***	0.0721***	0.0859***
	(3.05)	(8.75)	(4.14)	(8.44)
Renovated 5-10 years before sale	-0.0455	-0.0263	0.0151	0.0312*
	(-1.78)	(-1.26)	(0.82)	(2.46)
Renovated after sale	-0.126***	-0.103**	-0.0789**	-0.0717***
	(-3.41)	(-2.80)	(-2.74)	(-4.41)
Not renovated	-0.0404*	-0.0275	-0.0097	-0.0037
	(-2.05)	(-1.66)	(-0.75)	(-0.37)
Roof: Other	-0.0039	-0.0078	-0.0049	-0.00636
	(-0.27)	(-0.65)	(-0.52)	(-0.89)
Roof: Built up (flat)	-0.0051	0.00685	-0.0458***	-0.0413***
	(-0.28)	(0.70)	(-4.04)	(-7.04)
Roof: Cement	0.0171	0.00997	-0.0119	-0.0160*
	(1.10)	(0.76)	(-1.14)	(-2.20)
Roof: Asbestus	-0.00291	0.00475	-0.0175**	-0.0170***
	(-0.39)	(0.77)	(-3.18)	(-4.52)
Roof: Tar paper	-0.0055	0.0058	-0.0200**	-0.0096*
	(-0.54)	(0.81)	(-2.89)	(-2.16)

	(1)	(2)	(3)	(4)
Wall: Other	0.0136	0.0052	-0.0103	-0.0213*
	(0.65)	(0.31)	(-0.87)	(-2.28)
Wall: Concrete	-0.0230	-0.0429***	-0.0202**	-0.0291***
	(-1.32)	(-4.69)	(-2.66)	(-5.32)
Less than 5 km to CBD	-0.0692***	-0.0412***	-0.0454***	-0.0419***
	(-7.07)	(-13.05)	(-3.78)	(-20.95)
5-10 km to CBD	-0.0078	0.0023	-0.0231*	-0.0007
	(-0.76)	(0.54)	(-2.07)	(-0.29)
More than 10 km to CBD	-0.0188	-0.0023	0.0078	0.0046*
	(-0.78)	(-0.46)	(0.70)	(2.02)
Distance to industry (max. 500 m)	-0.0001	0.0001*	0.0001*	0.0001***
	(-1.17)	(2.50)	(2.30)	(5.07)
Distance to coast line (max. 500 m)	0.0000	0.0002***	0.0001	0.0002***
	(0.16)	(7.47)	(1.42)	(10.00)
Green space within 250 m	0.138*	0.168***	0.104***	0.0844***
	(2.37)	(4.98)	(3.76)	(5.20)
Distance to lake (max. 500 m)	0.0000	0.0000	0.0000	0.0000***
	(0.38)	(0.54)	(1.48)	(3.68)
Distance to station (max. 500 m)	-0.0000	-0.0000	-0.0000	-0.0000*
	(-1.77)	(-1.63)	(-1.13)	(-2.21)
Elevator	-0.0257	0.0054	-0.0050	0.0169**
	(-1.15)	(0.54)	(-0.37)	(2.78)
Train noise >55 dB	-0.133	0.378*	-0.570**	-0.195
	(-0.75)	(1.99)	(-2.94)	(-1.32)
Train noise (F): 55-59 dB	0.0072	0.0128	-0.0203*	-0.0096
	(0.36)	(0.97)	(-2.23)	(-1.10)
Train noise (F): 60-64 dB	0.0142	0.0237	-0.0145	-0.00435
	(0.56)	(1.01)	(-0.67)	(-0.26)

	(1)	(2)	(3)	(4)
Train noise (F): 65-69 dB	-0.0908***	-0.117***	-0.0472	-0.0748
	(-3.54)	(-5.55)	(-1.03)	(-1.29)
Airplane noise >45 dB	0.0598	-0.283	-0.260	-0.683***
	(0.15)	(-1.01)	(-1.74)	(-4.74)
Road noise ≤55 dB	-0.0729	-0.0840	-0.155	-0.160*
	(-0.34)	(-0.63)	(-1.20)	(-2.24)
Road noise (55-65 dB]	-0.0678	-0.0410	-0.114	-0.192***
	(-0.73)	(-0.46)	(-1.31)	(-3.43)
Road noise >65 dB	-0.550***	-0.634***	-0.527***	-0.558***
	(-4.08)	(-5.72)	(-4.01)	(-6.32)
Road noise ≤55 dB (house)	-0.0830	-0.257	-0.0734	-0.137
	(-0.23)	(-1.05)	(-0.38)	(-1.29)
Road noise (55 -65 dB] (house)	-0.364	-0.362	-0.509***	-0.373**
	(-1.64)	(-1.85)	(-3.45)	(-3.22)
Road noise >65 dB (house)	-0.801**	-0.769*	-0.853**	-1.021***
	(-2.67)	(-2.51)	(-2.93)	(-4.25)
Frederiksberg	0.0511**	0.0685***		0.0764***
	(3.33)	(7.85)		(15.36)
Ballerup	0.0335	-0.166***		-0.140***
	(0.56)	(-6.00)		(-9.12)
Brøndby	-0.237***	-0.211***		-0.197***
	(-5.20)	(-7.45)		(-13.41)
Dragør	0	0	0	-0.0365
	(.)	(.)	(.)	(-1.94)
Gentofte	0.0942	0.177***		0.237***
	(1.84)	(12.61)		(26.17)
Gladsaxe	0.119*	-0.0436**		-0.0262**
	(2.38)	(-2.59)		(-2.62)

	(1)	(2)	(3)	(4)
Glostrup	-0.179***	-0.148***		-0.177***
	(-5.15)	(-5.69)		(-11.93)
Herlev	-0.0239	-0.128***		-0.116***
	(-0.50)	(-4.80)		(-7.82)
Albertslund	-0.223***	-0.205***		-0.253***
	(-3.67)	(-6.66)		(-15.73)
Hvidovre	-0.0661**	-0.124***		-0.118***
	(-2.81)	(-8.97)		(-14.36)
Høje-Taastrup	0	-0.242***	0	-0.275***
	(.)	(-5.52)	(.)	(-13.15)
Lyngby-Taarbæk	0.118*	0.0680**		0.111***
	(2.18)	(2.90)		(8.31)
Rødovre	-0.0891**	-0.115***		-0.118***
	(-3.28)	(-9.91)		(-14.87)
Taarnby	-0.0150	-0.0877***		-0.0831***
	(-0.48)	(-4.78)		(-8.36)
Vallensbæk	-0.184**	-0.183***		-0.189***
	(-3.09)	(-6.92)		(-11.75)
Constant	11.59***	11.31***	11.46***	11.24***
	(89.52)	(95.63)	(110.81)	(148.96)
#groups (FE)	127		167	
R^2	0.722	0.810	0.736	0.810
Observations	9889	9889	25805	25805

t statistics in parentheses, SEs clustered for the FE models at the road border zone (1) and school district level (3).

Note: School districts are completely contained in municipalities, so municipalities drop out for school district FE.

Road, railway and airport noise have all been divided by 100 so the coefficient can be interpreted as % change in P.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 11: Period 3: Full estimation results

	(1)	(2)	(3)	(4)
	xt_200fe	reg_200	xt_fullfe	reg_full
Single family house	1.248***	1.092***	1.414***	1.309***
	(5.31)	(5.16)	(11.13)	(13.24)
Terraced house	0.690	0.876***	1.175***	1.135***
	(1.91)	(3.52)	(6.10)	(9.07)
Log Living space (sqm)	0.797***	0.843***	0.844***	0.879***
	(39.81)	(45.05)	(50.90)	(77.58)
Liv. sp. (single fam. house)	-0.238***	-0.218***	-0.292***	-0.277***
	(-4.96)	(-5.03)	(-10.85)	(-13.92)
Liv. sp. (terr. house)	-0.131	-0.180***	-0.250***	-0.248***
	(-1.71)	(-3.36)	(-6.12)	(-9.38)
1 room	-0.198***	-0.222***	-0.151***	-0.144***
	(-7.16)	(-7.72)	(-9.11)	(-9.16)
2 rooms	-0.123***	-0.148***	-0.0884***	-0.0913***
	(-5.36)	(-6.32)	(-6.88)	(-7.54)
3 rooms	-0.0489*	-0.0765***	-0.0270*	-0.0345***
	(-2.36)	(-3.68)	(-2.53)	(-3.34)
4 rooms	-0.0146	-0.0399*	-0.0103	-0.0158
	(-0.82)	(-2.10)	(-1.00)	(-1.72)
5 rooms	-0.0249	-0.0483**	-0.0111	-0.0175*
	(-1.50)	(-2.66)	(-1.23)	(-1.97)
Log Lot size (sqm)	-0.00352	0.000635	0.0149***	0.0136***
	(-0.55)	(0.13)	(4.05)	(4.63)
2 toilets	0.0323*	0.0268*	0.0108	0.0118*
	(2.24)	(2.20)	(1.29)	(1.99)
3 or more toilets	0.0826**	0.0899**	0.0779***	0.0985***
	(2.66)	(2.62)	(3.59)	(5.30)

	(1)	(2)	(3)	(4)
No own toilet	-0.0547	-0.0714	-0.0440	-0.0481
	(-0.70)	(-1.09)	(-0.95)	(-1.06)
2 bathrooms	0.0188	0.0226	0.0266***	0.0240**
	(1.05)	(1.34)	(3.53)	(3.18)
3 or more bathrooms	-0.140	-0.149	-0.00378	-0.0236
	(-1.98)	(-1.48)	(-0.09)	(-0.61)
No own bathroom	-0.0465	-0.0702***	-0.0294	-0.0406**
	(-1.78)	(-3.38)	(-1.96)	(-3.15)
Basement	0.121***	0.128***	0.0921***	0.0997***
	(6.21)	(8.02)	(10.37)	(14.96)
Story: Ground floor	-0.0680	-0.0736	-0.0783**	-0.0844***
	(-1.75)	(-1.89)	(-2.86)	(-3.69)
Story: 1st	-0.0416	-0.0516	-0.0529	-0.0588**
	(-1.09)	(-1.33)	(-1.95)	(-2.58)
Story: 2nd	-0.0256	-0.0363	-0.0439	-0.0496*
	(-0.66)	(-0.93)	(-1.55)	(-2.17)
Story: 3rd	-0.0147	-0.0279	-0.0323	-0.0403
	(-0.37)	(-0.71)	(-1.14)	(-1.74)
Story: 4th	-0.0165	-0.0291	-0.0201	-0.0302
	(-0.41)	(-0.74)	(-0.68)	(-1.30)
Story: 5th	0.00227	-0.00101	-0.0197	-0.0190
	(0.06)	(-0.02)	(-0.66)	(-0.77)
Story: 6th	0.0108	0.0004	0.0031	-0.0007
	(0.24)	(0.01)	(0.09)	(-0.02)
Story: 7th	0.0408	0.0305	0.0616	0.0668*
	(0.87)	(0.66)	(1.64)	(2.16)
Total stories: 1	0.205***	0.268***	0.194***	0.116
	(5.22)	(5.29)	(7.36)	(1.55)

	(1)	(2)	(3)	(4)
Total stories: 2	0.174***	0.264***	0.197***	0.126
	(4.96)	(5.52)	(9.56)	(1.69)
Total stories: 3	0.126***	0.217***	0.148***	0.0784
	(4.13)	(4.69)	(7.08)	(1.06)
Total stories: 4	0.110***	0.213***	0.127***	0.0723
	(4.25)	(4.50)	(6.46)	(0.98)
Total stories: 5	0.0612*	0.154**	0.1000***	0.0408
	(2.14)	(3.28)	(5.10)	(0.55)
Total stories: 6	0.0420	0.132**	0.0848***	0.0264
	(1.33)	(2.84)	(4.31)	(0.36)
Total stories: 7	0.0813*	0.103*	0.0936***	0.0195
	(2.04)	(2.19)	(4.58)	(0.26)
Total stories: 8	0.0379	0.190***	0.138***	0.0563
	(1.34)	(3.62)	(5.37)	(0.75)
Total stories: 10	0.0159	0.135**	0.0858**	0.0684
	(0.42)	(2.66)	(2.62)	(0.89)
Total stories: 11	-0.117	0.0939	-0.0323	-0.0631
	(-1.53)	(1.96)	(-0.90)	(-0.83)
Total stories: 12	0	0	0.0723***	0.0836
	(.)	(.)	(9.94)	(0.81)
Total stories: 13	0	0.124	0	0
	(.)	(1.08)	(.)	(.)
Total stories: 14	0.141*	0.247***	0.0860***	0.0590
	(2.48)	(5.13)	(3.52)	(0.76)
Total stories: 15	0.0112	0	0.0995*	-0.112
	(0.17)	(.)	(2.52)	(-1.40)
Construction year: 1900-1920	-0.120***	-0.139***	-0.147***	-0.0882***
	(-4.38)	(-6.22)	(-9.52)	(-8.50)

	(1)	(2)	(3)	(4)
Construction year: 1920-1940	-0.152***	-0.187***	-0.182***	-0.147***
	(-5.76)	(-8.94)	(-12.16)	(-15.40)
Construction year: 1940-1960	-0.164***	-0.206***	-0.192***	-0.166***
	(-5.87)	(-9.51)	(-12.62)	(-17.58)
Construction year: 1960-1980	-0.190***	-0.225***	-0.196***	-0.172***
	(-7.37)	(-11.00)	(-14.06)	(-19.90)
Construction year: 1980-2000	-0.0858*	-0.114***	-0.0849***	-0.0479***
	(-2.35)	(-4.28)	(-5.11)	(-4.06)
Construction year: Before 1900	-0.132***	-0.0947***	-0.155***	-0.0588***
	(-4.62)	(-4.05)	(-8.46)	(-5.28)
Listed building	0.0285	0.122***	0.0434**	0.0778***
	(1.03)	(4.20)	(2.65)	(5.55)
Renovated 5-10 years before sale	-0.0198	-0.0114	-0.0179	-0.0118
	(-0.55)	(-0.37)	(-0.81)	(-0.65)
Renovated after sale	-0.176**	-0.185*	-0.130**	-0.119**
	(-2.79)	(-2.46)	(-3.21)	(-3.12)
Not renovated	-0.0397	-0.0209	-0.0359	-0.0317*
	(-1.47)	(-0.92)	(-1.68)	(-1.98)
Roof: Other	-0.0091	0.0011	0.0052	0.0037
	(-0.48)	(0.07)	(0.50)	(0.46)
Roof: Built up (flat)	0.0062	0.0310*	-0.0244	-0.0217**
	(0.36)	(2.56)	(-1.89)	(-3.09)
Roof: Cement	-0.0156	0.00447	-0.0140	-0.0125
	(-0.87)	(0.30)	(-1.32)	(-1.45)
Roof: Asbestus	-0.0121	0.00583	-0.0152**	-0.0105*
	(-1.27)	(0.77)	(-2.65)	(-2.41)
Roof: Tar paper	0.0259	0.0505***	0.00611	0.0157**
	(1.96)	(5.98)	(0.81)	(3.05)

	(1)	(2)	(3)	(4)
Wall: Other	-0.00620	-0.00136	-0.0306*	-0.0393***
	(-0.28)	(-0.06)	(-2.41)	(-3.75)
Wall: Concrete	-0.0473	-0.0596***	-0.0330**	-0.0481***
	(-1.96)	(-4.83)	(-3.31)	(-7.47)
Less than 5 km to CBD	-0.0878***	-0.0543***	-0.0461**	-0.0524***
	(-8.06)	(-13.99)	(-3.29)	(-22.39)
5-10 km to CBD	-0.0305**	-0.0175**	-0.0165	-0.0036
	(-3.02)	(-2.62)	(-1.16)	(-1.19)
More than 10 km to CBD	-0.0476*	-0.0203**	0.0134	0.0027
	(-2.58)	(-3.11)	(0.95)	(0.94)
Distance to industry (max. 500 m)	-0.0001	0.0003**	0.0001	0.0001***
	(-0.95)	(2.77)	(1.60)	(3.95)
Distance to coast line (max. 500 m)	-0.0001	0.0002***	0.0001	0.0002***
	(-1.15)	(4.59)	(1.69)	(9.45)
Green space within 250 m	-0.0193	0.0875*	0.132***	0.129***
	(-0.28)	(2.04)	(4.31)	(7.22)
Distance to lake (max. 500 m)	0.0000	0.0000	0.0000	0.0000***
	(0.35)	(0.83)	(1.19)	(4.21)
Distance to station (max. 500 m)	-0.0000	-0.0000	0.0000	-0.0000
	(-1.79)	(-0.46)	(0.01)	(-1.30)
Elevator	-0.00454	0.0252*	0.00247	0.0353***
	(-0.18)	(2.10)	(0.21)	(4.89)
Train noise >55 dB	-0.495*	0.192	-0.889***	-0.195
	(-2.12)	(0.89)	(-3.95)	(-1.07)
Train noise (F): 55-59 dB	-0.00760	0.0220	0.00145	0.0209*
	(-0.45)	(1.20)	(0.10)	(2.18)
Train noise (F): 60-64 dB	-0.0393	-0.00663	-0.0351*	-0.0294
	(-1.53)	(-0.22)	(-2.31)	(-1.80)

	(1)	(2)	(3)	(4)
Train noise (F): 65-69 dB	-0.0711	-0.102	-0.111	-0.124**
	(-1.01)	(-1.47)	(-1.79)	(-2.62)
Airplane noise >45 dB	0.168	-0.339	-0.407	-0.741***
	(0.20)	(-0.72)	(-1.35)	(-4.73)
Road noise ≤55 dB	-0.139	-0.229	-0.417***	-0.488***
	(-0.60)	(-1.11)	(-3.40)	(-5.06)
Road noise (55-65 dB]	-0.296**	-0.293**	-0.161*	-0.250***
	(-3.10)	(-2.81)	(-2.11)	(-3.85)
Road noise >65 dB	-0.428*	-0.562***	-0.540***	-0.612***
	(-2.48)	(-4.15)	(-3.64)	(-5.81)
Road noise ≤55 dB (house)	-0.0753	-0.0157	0.329	0.272*
	(-0.19)	(-0.05)	(1.65)	(2.08)
Road noise (55 -65 dB] (house)	-0.452	-0.433	-0.662***	-0.474***
	(-1.74)	(-1.74)	(-4.08)	(-3.58)
Road noise >65 dB (house)	-1.032*	-0.862*	-0.811*	-0.931**
	(-2.19)	(-2.22)	(-2.42)	(-2.86)
Frederiksberg	0.0897***	0.0455***		0.0886***
	(4.05)	(4.68)		(15.89)
Ballerup	0.0714	-0.00287		-0.134***
	(1.53)	(-0.07)		(-7.04)
Brøndby	-0.397***	-0.121**		-0.193***
	(-8.04)	(-2.89)		(-11.44)
Dragør	0	0	0	0.0335
	(.)	(.)	(.)	(1.60)
Gentofte	0.0759	0.182***		0.256***
	(1.86)	(9.66)		(23.20)
Gladsaxe	0.255***	0.0790**		-0.00334
	(5.24)	(3.01)		(-0.26)

	(1)	(2)	(3)	(4)
Glostrup	-0.151***	-0.00983		-0.118***
	(-4.12)	(-0.26)		(-6.52)
Herlev	-0.121***	-0.0941*		-0.0983***
	(-3.86)	(-2.20)		(-5.58)
Albertslund	-0.177**	0.0417		-0.206***
	(-2.66)	(0.95)		(-10.48)
Hvidovre	0.0556	-0.0232		-0.0731***
	(1.78)	(-1.25)		(-7.48)
Høje-Taastrup	0	0.0566	0	-0.225***
	(.)	(0.93)	(.)	(-8.68)
Lyngby-Taarbæk	0.217*	0.203***		0.125***
	(2.52)	(5.89)		(7.51)
Rødovre	-0.0505	-0.0380		-0.0656***
	(-1.76)	(-1.88)		(-6.16)
Taarnby	0.0315	-0.0165		-0.0461***
	(1.29)	(-0.72)		(-4.43)
Vallensbæk	-0.258***	-0.0175		-0.125***
	(-4.74)	(-0.45)		(-6.71)
Constant	11.54***	11.08***	11.14***	11.00***
	(80.07)	(94.90)	(101.85)	(111.65)
#groups (FE)	96		167	
R^2	0.829	0.869	0.815	0.863
Observations	5347	5347	15892	15892

t statistics in parentheses, SEs clustered for the FE models at the road border zone (1) and school district level (3).

Note: School districts are completely contained in municipalities, so municipalities drop out for school district FE.

Road, railway and airport noise have all been divided by 100 so the coefficient can be interpreted as % change in P.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

A.4 WTP for a 3 dB reduction as a function of demographics

Table 12: WTP for 3 dB reduction explained by demographics

	(1) Coefficient	t-statistic
Income net of housing exp. (log)	0.374***	18.86
Average age, adults	0.0348***	11.02
Average age, sq.	-0.000164***	-4.74
Female	-0.238***	-9.31
Male	-0.222***	-8.68
Part time employed	-0.0318	-1.52
HH foreign born	-0.210***	-7.63
Some foreign born	-0.0610*	-2.19
More than 2 adults	0.420***	10.64
Possible tenant	0.00416	0.19
Retired	-0.267***	-4.50
Student	-0.150***	-5.52
Single	-0.271***	-9.46
Youngest child - under 2 yrs	0.446***	15.50
- 3-5 yrs	0.603***	15.72
- 6-9 yrs	0.551***	9.55
- 10-14 yrs	0.507***	9.87
- 15-17 yrs	0.373***	5.37
Highest completed education - Primary school	-0.100***	-3.40
- Highschool or equivalent	0.0707**	2.95
- Academy profession	0.0809*	2.53
- Bachelor	0.0265	1.17
- Master	0.0655**	2.82
- PhD	-0.171***	-4.79
Constant	0.0372	0.15
R^2	0.249	
Observations	21606	

Note: Omitted: Families w/o children; Education: Vocational training. SEs are Huber/White.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$