Planes, Trains, and Automobiles;
The Impact of Traffic Noise on House Prices

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Abstract:

Because of large planned infrastructural projects like expansion of the main airport and construction of high-speed railways, noise nuisance has become a national social topic in the Netherlands. Moreover, according to EU-guidelines, determination and enforcement of differentiated noise limits will be delegated from national to local governments in the near future. The value of noise has never been this important. In this paper, we estimate the non-linear impact of traffic noise on property prices. The used data set is very extensive; over 100,000 sales transactions are studied, with many individual property characteristics, combined with noise levels for 2 million small 100 by 100 meter areas. We use spatial autocorrelation techniques to overcome the regular problems of traditional NIMBY-analysis performed by hedonic regression. We find that the maximum impact of traffic noise will be a 3 to 10 percent house price reduction. The reduction is a non-linear function of the noise level; reducing noise from loud to rather loud levels is more beneficial than reducing it from very loud to loud.

Keywords: traffic noise, property values, hedonic regression, spatial autocorrelation.

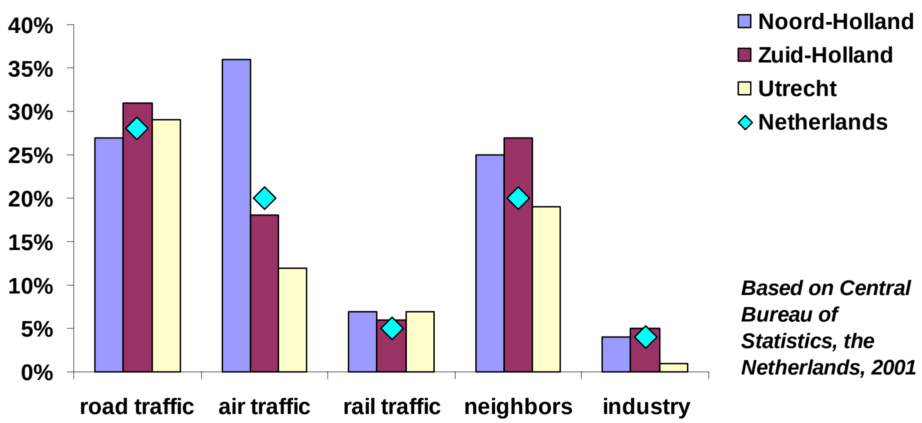
1. Introduction

Amsterdam Schiphol Airport and a group of 350 environmentalists have been fighting over fifteen square meters of land for seven years. The airport faced capacity problems and intended to expand its number of runways to five, but in 1994, a pressure group bought a parcel to obstruct the expansion plans of the airport. Only a small part of this parcel was required to realize the fifth runway. One of the major arguments of the environmentalists is noise pollution.

Schiphol Airport is located the Netherlands, a country belonging to the most densely populated nations in the World, with the highest population density of all OECD-countries after Korea[1]. Even within this crowded country, the population is concentrated in the western part. This multiple-centric urban area is frequently referred to as a seven-million people city.

That is why the airport is not the only major cause of noise nuisance. These millions of people need transportation to move to and from work and social activities, and consume and produce goods that need to be transported. The available infrastructure is used very intensively for this, compared to other European countries. There are fewer miles of roads per person, leading to an above-average usage of the road system of which 15 percent is seriously congested every day. The intensity of the railroad usage is three times the EU average. The area is served by two major airports, which face the problem of insufficient capacity, aggravated by strict noise regulations and pressure groups strongly opposing expansion. But with economic and population growth, traffic intensity is only increasing.

Figure 1: *Percentage of population annoyed by noise, for three Dutch provinces, 1999.*



[1] OECD, Selected Social Data(1), October 2001

One of the unwelcome side effects of intense traffic in high dense areas is noise pollution. Noise generated by traffic even forms the major category of all noise nuisances, as is shown in Figure 1. More people are annoyed by the noise of passing cars than by noise produced by neighbors. Since more persons are exposed to car traffic than to planes or trains, fewer complaints are caused by the latter two categories of traffic, except for the province of North-Holland where Amsterdam Schiphol Airport is located. Besides that, studies like Miedema and Oudshoorn (2001) show that with equal noise levels, noise from airplanes is perceived as most annoying, followed by car noise and finally noise from passing trains.

Table 1: *Indication of sound levels*[2].

Data class	dB(A)	Indication	Example	Comment
1	0-10	Hearing threshold	Heartbeat	
	10-20	Just audible	Rustling of leaves	
	20-30	Very quiet	Whisper	
	30-40	Quiet	Quiet street noises	<35 dB(A) desired for sleep
2	41-45	Quiet		
3	46-50	Quiet	Light traffic	<50 dB(A) desired for work
4	51-55	Quiet		
5	56-60	Moderately loud	Noise in average restaurant	
6	61-65	Moderately loud		
7	66-70	Moderately loud	Normal city/freeway traffic	Annoyance
8	71-75	Moderately loud		
9	76-80	Loud	Heavy traffic	
10	80-90	Very loud	Motorcycles at 25 feet	Hearing loss if persistent exposure
	90-100	Very loud	Helicopter at 100 feet	
	100-110	Uncomfortably loud	Rock 'n Roll band	
	110-120	Uncomfortably loud	Loud thunder	Pain and distress
	120-140	Uncomfortably loud	Airplane during departure	

The Dutch government provides protection against noise pollution by imposing maximum noise levels for air, rail and road traffic. The Noise Nuisance Act prescribes a preferred maximum level of 50 decibels at facades of properties within a specific distance from major roads and railways. As shown in Table 1, this level is equal to the noise caused by light traffic. Only if certain conditions are met, the maximum allowed noise is raised to a decibel level between 55 and 70. A level of 70 decibel is moderately loud and comparable to the noise caused by freeway traffic. Nevertheless, there are still properties located in areas with higher average noise levels; for example, about 1 percent of the observations in our data set is located in areas with an average sound level exceeding 70 decibels.

[2] This table is based on Bateman (2001) and Humphreys and Patterson (1996). For ease of comparison, we also show the 10 ranges that will be used as sound variable in this chapter.

Since noise is one of the factors contributing to the quality of a property location, noise could be capitalized in housing prices. Properties located along a road with heavy traffic are likely to sell for less than comparable properties located elsewhere, while properties situated at very quiet locations might even sell at a premium compared to other properties.

This capitalized value is of substantial importance. Large infrastructural projects are planned for the Netherlands, like expansion of the main airports and construction of high-speed railways. Moreover, the European Union decided that the determination and enforcement of differentiated noise limits will be delegated from national to local governments in the near future. When making these policy decisions, the harm or benefits to homeowners should not be neglected.

The price impact of noise nuisance is a widely studied area. However, most analyzed geographical areas concern the United States and the United Kingdom, and other regions are largely neglected. Most of the Anglo-Saxon studies date from the late seventies and early eighties. Is it reasonable to assume that these results apply to other countries too, and still?

In this paper, we analyze the impact of traffic noise on property prices for the western part of the Netherlands with use of hedonic regression and spatial autocorrelation. To our knowledge, these techniques have never been applied to study this topic in the Netherlands, and the combination of techniques for externality analysis has never been used in the literature before. This combination allows for more efficient estimates and a nonlinear relationship between noise and property prices. Sections 2 and 3 provide an overview of the literature regarding the valuation of traffic noise, and a description of our methodology, respectively. Our data set is very extensive; many variables are used to filter over 100,000 property prices for other influences, and the noise information is very detailed, since traffic noise is known for every square area of 100 by 100 meter. Section 4 presents details on the data. The focus of the paper will be on estimating the property value reduction caused by the nuisance from cars, trains and airplanes. These estimates are discussed in section 5, after which we will make some general inferences and conclusions in the final section 6.

2. Literature review

A clear way to express the annoyance people perceive from traffic noise is to express the hassle in money. The estimated amount could be used by national or local governments to compensate citizens suddenly faced with a new highway in their backyard or inhabitants of properties in the near vicinity of an expanding airport, or alternatively to estimate the benefits of noise reducing policies.

Expressing traffic noise and other environmental conditions in money is widely studied. Many studies on traffic noise date from the late seventies and early eighties, and are extensively summarized and analyzed by Nelson for road traffic (1982) and air traffic (1980). More recent publications on road nuisance impact are from Hughes and Sirmans (1992) and Huang and Palmquist (2001), while aircraft nuisance has been studied by Collins and Evans (1994) and Levesque (1994), amongst others. Poon (1978) is amongst the small number of authors studying noise generated by railroads.

The value of environmental goods could be found in a direct way by means of surveys and experiments, or indirectly by analyzing actually observed market data like property prices[3]. Although the latter alternative is the most popular by far, both methods find proponents and opponents in literature.

Surveys versus hedonics

The most common survey method is contingent valuation, a method deriving monetary values by means of surveys. Relative to hedonic regression, it is less dependent on costly data and will suffer less from econometric problems, although the disadvantage of a large potential subjectivity might outweigh this advantage. Examples of monetizing traffic noise by means of contingent valuation are Saelensminde (1999), Grosclaude and Soguel (1994), and Van Praag and Baarsma (2001).

Using survey approaches for the Netherlands, Van Praag en Baarsma found that people living in non-insulated properties should be compensated for every increase in aircraft noise of 10 Ku with a percentage of their net income varying from 1.2 to 2.2 percent[4]. If the properties are insulated, the compensation would be about one third of the non-insulation compensation. However, Baarsma (2000) found that people would be willing to pay an additional 57.1 percent of their housing expenses if aircrafts do no longer cause nuisance during the night, and 25.5 percent for avoiding noise during daytime.

The hedonic approach derives values by analyzing actually observed market data, like property transaction prices. By means of regression, this approach analyzes the contribution of physical and locational property characteristics to property transaction prices. As will be clear, this method uses actual choices instead of willingness. However, estimates and their interpretation are dependent on selected variables and specification of the regression equation, and on the validity of underlying assumptions. Nevertheless, most academic publications rely on the hedonic approach. Examples of use of hedonics to express the value of traffic noise are Hughes and Sirmans (1994), Uyeno, Hamilton and Biggs (1993), and Wilhelmsson (2000). As argued by Dubin (1998) Pace, Barry and

[3] Besides these valuation methods, estimating the value of environmental goods could be performed by pricing methods, like analysis of opportunity costs or government payments, amongst others. Since we do not use survey or pricing methods in this paper, we will not discuss this. An overview can be found in Bateman et al (2001).

[4] Ku, or Kosten Unit, is a noise index used in the Netherlands, derived from the so-called NNI-index. From 2003, this index will be replaced by the more common Lden-index for Dutch policy decisions.

Sirmans (1998) and Pace and Gilley (1997), spatial estimation techniques correct partly for the estimation bias caused by missing variables in hedonic regression.

Since we have a data set that is rich enough to derive the price of noise by hedonic regression, and since we consider this method to be more reliable than contingent valuation, we will express the perceived annoyance in a monetary value by means of hedonic regression.

Noise variable

To estimate the price of noise with hedonic regression, an index reflecting the noise is frequently added to the list of attributes explaining property prices. If homeowners were indeed annoyed by noise, noise would be capitalized in housing prices. The price of a property located along a road with many passing trucks and cars would be higher if the property would be situated in an area where warbling birds cause the loudest noise, all else equal. In that case, the estimated contribution of noise to house prices will be significantly negative.

Noise is usually expressed in decibels, which measure the loudness of sound as perceived by the human ear. However, annoyance is not just caused by the loudness of sound, also aspects like frequency, variability, time of the day, and the usual background level matter. To account for these additional aspects, many different noise indices have been developed, different across countries and noise types. The indices could be cumulative weighted averages of the number of decibels for a specific time period, or a measure indicating the percentage of the total time for which a sound level is exceeded[5]. Nelson (1982) concluded that there could not be a single index that is best suited for all purposes, since each index discards some information. Nevertheless, Levesque (1994) argued that, with analyzing aircraft noise, cumulative indices do not perform as well as other indices.

The large variety of noise indices complicates the comparison of outcomes of different studies. A useful instrument to compare study outcomes is the noise depreciation sensitivity index (NDSI). This index calculates the percentage value change caused by a 1-decibel decrease in noise exposure, by relating the percentage difference between prices P_0 and P_1 to the difference between noise levels dB_0 and dB_1. The NDSI could be calculated as

$$(1) \qquad NDSI = \frac{\text{change in property value}}{\text{change in noise exposure}} = \frac{\delta V}{\delta N} = \frac{1}{P_0} \times \frac{P_1 - P_0}{dB_0 - dB_1}$$

[5] Frequently used sound indices are LAeq (energy mean sound level), Ldn (day-night average sound level), L_{10} (noise level exceed in 10% of time), NEF (Noise Exposure Forecast), NNI (Noise and Number Index), NPL (Noise Pollution Level), and TNI (Traffic Noise Index). A more elaborate description of these alternative indices can be found in Nelson (1980) and Berglund and Lindvall (1995).

If it is assumed that a reduction in noise levels will lead to higher property values, both numerator and denominator will be positive, leading to a positive NDSI.

In two review studies (1980, 1982), Nelson compared many studies using this index. He found that property values rise with on average 0.4 percent if road traffic noise is reduced by 1 decibel, and with 0.6 percent if noise from air traffic decreases 1 decibel. According to Nelson, the different NDSI's for road and air traffic noise are due to differences in methodology and data, although the higher price for airplane noise is in line with the higher perceived annoyance from air traffic for the same sound level of road traffic.

3. Methodology

Externalities are mostly analyzed by including their presence as additional explanatory variables in the hedonic regression. Presence is usually measured by a variable like straight-line distance between individual properties and the externality. In case of niose studies, a noise index is used. As shown by Dubin (1998) and Pace and Gilley (1997), amongst others, using the spatial configuration of data by means of spatial regression techniques could improve hedonic regressions in real estate studies in terms of efficiency.

When using hedonic regression, a frequently used model specification is the semi-log specification, in which the natural logarithm of transaction prices is regressed on variables reflecting physical and locational property characteristics. With standard Ordinary Least Squares (OLS) regression, the noise variable could be added to the list of regressors:

(2) $$\ln P = f(\text{physical}, \text{locational}, \text{traffic noise}) + error$$

In this equation, physical and locational attributes are included, just as time dummies to capture general market changes, and variables measuring the impact of the externality. Note that we use log transformations of prices in this equation. Log prices provide coefficients that can be interpreted in a straightforward way, and are relatively easy to compare with other non-Dutch studies and over time. If for example the parameter for 'garage' is 0.170, the presence of a garage rises the price of a property with $e^{0.17}$-1=18.5%, relative to a 'no garage' default situation. If, instead of log prices, the actual prices would be regressed on attributes, the coefficient for garage would be a price in Euros. This would be difficult to compare with US studies from 1990, for example, because of both inflation and exchange rates. Moreover, Box-Cox transformations used to determine the best specification for a hedonic regression frequently indicate this so-called semi-log specification as the best one.

However, with use of spatial autoregression, equation (2) would look like:

(3) $$\ln P = f(\text{physical}, \text{locational}, \text{prices other properties}, \text{traffic noise}) + error$$

since this technique uses prices of surrounding properties as additional information to estimate the price of a specific property, comparable to the sales comparison approach an appraiser might use.

A 3-step approach

If the negative externality, or NIMBY ("Not-In-My-Backyard"), is included as a separate category, the following equation will be the core of the analysis, and will be referred to as the '*full regression*'.

$$\ln \mathit{(PRICE)} = \beta_0 + \beta_1 X_{MARKET} + \beta_2 X_{PHYSICAL} + \beta_3 X_{LOCATIONAL} + \beta_4 X_{NIMBY} + \varepsilon \tag{4}$$

Ideally, the equation mentioned above is estimated in one procedure, with use of spatial autocorrelation. Spatial autocorrelation corrects for regularities in prices over space, to correct for wrongly omitted locational attributes. As shown by Dubin (1988), amongst others, omitted variables will not affect the sign and magnitude of a parameter estimate, but does affect its variance. In case of positive spatial dependence, as will be likely in a housing market, its variance will be biased downward, thereby overstating precision. Spatial techniques therefore avoid artificially raised t-values, and provide more accurate estimates. However, even when working with a Pentium 3 personal computer, we still face computer limitations when estimating (4) for all properties and all accommodation centers with spatial regression. Therefore, we used a nested model in which computations are split into three stages.

$$\text{stage I: } \ln \mathit{(PRICE)} = \beta_0 + \beta_1 X_{MARKET} + \beta_2 X_{PHYSICAL} + \beta_3 X_{LOCATIONAL} + \tilde{\varepsilon} \tag{5}$$

$$\text{stage II: } X_{NIMBY} = \gamma_0 + \gamma_1 X_{MARKET} + \gamma_2 X_{PHYSICAL} + \gamma_3 X_{LOCATIONAL} + \tilde{u} \tag{6}$$

$$\text{stage III: } \tilde{\varepsilon} = \beta_4 \tilde{u} + v \tag{7}$$

In the first stage, we regressed logarithmic prices with Ordinary Least Squares (OLS) on physical and locational property attributes, and time dummies to capture general market movements. The unexplained parts of prices, the residuals from this regression, will reflect the part of prices caused by omitted attributes and white noise. Amongst these omitted attributes is traffic noise.

The residuals from stage I could be regressed on this traffic noise, but the noise will have to be corrected first for correlation with the variables that determined these residuals. The Equation (6) for stage II takes care of this correction. If the variable describing traffic noise is completely independent on the other characteristics, residuals $\tilde{u}$ will be equal to the NIMBY-variable, minus the estimated average reflected by γ_0. In the completely opposite case, in which the NIMBY-variable is an exact function of the other variables, the residuals $\tilde{u}$ will be zero. If matrix X_{NIMBY} contains more than one variable, for each of these variables a corrected versions has to be calculated separately.

The third stage in (7) finally estimates the corrected NIMBY-variable as a function of the residuals from the regression (6). The estimated coefficient β_4 will be the OLS estimator from the full regression. This can be shown by rewriting stage III of Equation (7) with use of Equations (5) and (6):

(8) $$\ln P - \tilde{\beta}_0 - \tilde{\beta}_1 X_{MA} - \tilde{\beta}_2 X_{PH} - \tilde{\beta}_3 X_{LO} = \beta_4 \left(X_{NIMBY} - \gamma_0 - \gamma_1 X_{MA} - \gamma_2 X_{PH} - \gamma_3 X_{LO} \right) + \upsilon$$

or

(9) $$\ln P = \left(\tilde{\beta}_0 - \beta_4 \gamma_0 \right) + \left(\tilde{\beta}_1 - \beta_4 \gamma_1 \right) X_{MA} + \left(\tilde{\beta}_2 - \beta_4 \gamma_3 \right) X_{PH} + \left(\tilde{\beta}_3 - \beta_4 \gamma_3 \right) X_{LO} + \beta_4 X_{NIMBY} + \upsilon$$

Equation (9) shows that the equation of stage III is the same as the full equation in (4), with β_0 equal to $\left(\tilde{\beta}_0 - \beta_4 \gamma_0 \right)$, β_1 to $\left(\tilde{\beta}_1 - \beta_4 \gamma_1 \right)$, β_2 to $\left(\tilde{\beta}_2 - \beta_4 \gamma_2 \right)$, and β_3 equal to $\left(\tilde{\beta}_3 - \beta_4 \gamma_3 \right)$. The estimate for β_4 of Equation (9) is the same as in Equation (4). Moreover, since the stage III regression is similar to the full regression, it can be shown that the residuals v will be identical to the residuals ε, if estimated by OLS.

Parameters from the stage I-regression in (5) will not be exactly equal to the parameters from the full regression (4). However, this is not important in this paper: the focus is on estimation of parameter β_4 in stage III. Just as the full model could be estimated with spatial autocorrelation, we could solely estimate parameter β_4 with spatial techniques too, in stage III. After all, if there is spatial autocorrelation in the information used in stage I, OLS will not exploit it, such that this information will show up unused in the residuals. Since the estimates of β_4 from (4) and (7) will not differ, spatial techniques applied to (7) will produce the same estimate, but without overstates accuracy.

If matrix X in the next equation would contain the NIMBY variable, the coefficient matrix β is estimated as

(10) $$\beta_4 = \left(\left(X_{NIMBY} \right)' \Psi^{-1} \left(X_{NIMBY} \right) \right)^{-1} \left(X_{NIMBY} \right)' \Psi^{-1} \tilde{\varepsilon}$$

Depending on whether one specifies spatial autocorrelation with SAR or CAR, matrix Ψ^{-1} is specified as

(11) $$\Psi_{SAR}^{-1} = (I - \rho W)'(I - \rho W)$$

(12) $$\Psi_{CAR}^{-1} = (I - \rho W)$$

with matrix W containing *n-by-n* weights assigned to neighboring observations, parameter ρ specifying the degree of spatial autocorrelation, and matrix I a unity matrix. In these so-called lattice models, W and ρ should be specified by trial and error, in order to find the best regression performance. Details on the difference between modeling with SAR and CAR can be found in Dubin (1998), amongst others.

Homogeneity

The hedonic technique tries to reveal a hedonic price schedule underlying actual property prices, but the results are dependent on the selected model specification and the set of used variables. Moreover, it is assumed that the studied housing market is homogenous. If large differences exist between regions within the studied market, the mixture of market segments will yield an unreliable price for noise nuisance. Moreover, with a less homogenous housing market, the problem of omitted variables will become more important. For example, if a toxic waste site lowers property prices in a noisy area, the regression will attribute the lower prices to the loud noise if information on the waste side location is omitted. If a sample only contains properties in the small area around the waste site, this externality would impact all properties, leading to a more accurate estimation of noise value. Besides being homogenous over space, the hedonic regression requires the variables to be homogenous over time as well. This means that no significant shocks should have occurred within the period the data set describes.

The geographical area we use in this study is large compared to other hedonic studies, which might cause a violation of regional homogeneity. However, the three provinces in our sample show rather similar price developments over time. Nevertheless, we control for differences between the regions by means of regional dummy variables, the semi-log specification, and spatial autoregression. First, 59 dummy variables correct for differences in absolute price levels between regions. For example, Amsterdam property prices are generally higher than Rotterdam property prices; in 2000, the price of Amsterdam apartments exceeded Rotterdam apartment prices by 80 percent, for single-family properties this difference was about 50 percent[6]. The dummies are based on zip codes and are created such that for each area represented by a dummy sufficient observations are available in our data set[7]. Secondly, the semi-log specification of the hedonic equation makes the estimates less sensitive to differences in absolute price levels between regions, since it uses percentage price contributions instead of dollar amounts. Thirdly, the spatial autoregression corrects for omitted variables by considering the prices of neighboring properties explicitly. The price impact of the unknown neighborhood characteristics will be rather similar for neighboring properties.

Moreover, we estimate the price of traffic noise for a number of sub-markets, as suggested in the literature. For example, Uyeno, Hamilton and Biggs (1993) found that detached houses will suffer less from noise than multi-family properties. Palmquist (1980) on the other hand suggested that property prices in high-income areas will show a larger discount than properties in low-income areas. Therefore, we create sub-samples by dividing the set of properties in sets with multi-family, detached single-family and non-detached single-family properties, as well as in sets with low-, middle- and high-income

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[6] Based on information from Dutch Association of Real Estate Agents (*NVM*), 2000.

[7] Dummy variables represent in between 131 and 4,619 transactions, with an average of 1,925 sold properties.

areas. Besides, we split the dataset in areas with a low, average and high population density, and we perform estimations for each of the separate years of our dataset.

The constant price of every decibel

The form of the relationship between noise and value discounts is not known beforehand. Most studies assume a straight-line relationship between discounts and decibels, and find or assume a minimum noise level at which sound starts to influence house prices. Most studies find a level of around 55 dB as the ambient noise level, like Huang and Palmquist (2001) and Palmquist (1982).

However, the question is why noise prices should be a linear function of noise level as measured in decibels? Decibels are expressed on a logarithmic scale: each increase of 10 decibel (dB) means a doubling of the absolute loudness. So, 80 dB is about twice as loud as 70 dB, and four times as loud as 60 dB. Reducing the sound level from 80 to 70 dB means a larger noise reduction in absolute terms than reducing it from 70 to 60 dB. With a linear relationship between discounts and decibels, very loud noises have to be reduced more than less loud sounds in order to achieve an equal percentage increase of property prices. However, to our knowledge, no studies analyze whether the price of noise reduction depends on the actual original noise level.

We will not add a noise index to the set of explanatory variables, but a set of dummy variables. The dummies are zero, except for the dummy indicating the noise range the specific property is located in. In this way, the ambient noise level can be distinguished easily, and the results might reveal a nonlinear pattern for noise. For example, reducing the noise level from a very loud 80 decibels to a still high 70 decibels might not be valued as much by the market as a reduction from 70 to a more convenient 60-decibel noise level. A constant value per reduction of one decibel would indicate that the value of both reductions would be equal.

The NDSI of a noise level decrease from dB_0 to dB_1 could be calculated with use of the estimated semi-logarithmic coefficients β_0 and β_1 as:

$$NDSI_{0,1} = \frac{1}{\exp(\beta_0)} \times \frac{\exp(\beta_1) - \exp(\beta_0)}{dB_0 - dB_1} \tag{13}$$

This value is the percentage change in property value caused by a 1-decibel decrease of noise level. Since we use 5-decibel classes of noise instead of one noise index, the noise difference will be 5 or a multiple of 5.

Positive and negative externalities

The construction of a new road might not only cause annoyance by increased noise or air pollution, but it might also generate positive externality effects like improved accessibility. The pure negative impact could for instance be revealed by including a dummy variable indicating whether the property has view on the road to correct for positive impacts. Most of these added variables show high correlation with the noise variables, and will therefore not add much to the analysis. Moreover, if the government decides to construct a new road or if the airport expands, inhabitants of adjacent properties will not pay for the new positive externalities if they are compensated for the pure negative impact. Especially when used for the infrequently applied second phase of the hedonic approach, estimation of demand curves by means of preferences revealed by the regression, breaking down the net effect will be useful. However, for valuing the harm or benefit of changes in noise exposure to house prices, correction for positive side effects has no practical implications. It is the change in net effect that matters.

Summarizing, this paper estimates the net impact of noise generated by cars, trains, and airplanes on property values. We will use the hedonic approach, estimated with use of spatial autoregression, and use noise dummies to allow for a nonlinear relationship between noise and prices. The next section describes the data we used for this.

4. Data description

In this paper, we analyze the entire Western part of the Netherlands, consisting of the provinces of North-Holland, Utrecht, and South-Holland. These provinces form the most densely populated region of the Netherlands. Despite focusing on a selected area, a tremendous amount of data is required. First of all, information about transacted properties is needed to obtain price information, and to filter the prices for differences in property quality. We obtained transaction price information and characteristics of over 160,000 transactions from the Dutch Association of Brokers (*NVM*), from properties sold in the years 1997 through 1999 in this area. The *NVM* is the largest Dutch association of brokers, with a national market share of over 60 percent. The broker records contain information on many variables, like 26 different house type classifications, parcel size, property volume, details on the garage, heating system, garden size and sun position, inner and outer property maintenance conditions, and construction year. Details on the data are provided by Appendix Table A.1.

Besides physical attributes, we also used locational features to filter property prices. Neighborhood information is obtained from Locatus and the Central Bureau of Statistics. Locatus is a Dutch organization providing information about retail locations. In this paper, we use locational variables reflecting distance to one of the 8 major city centers and the share of owner-occupied single-family properties relative to the total number of owned properties for all individual properties; the average share of elderly, western and non-western immigrants and single-person households of the specific 4-digit zip code area; and the population density of the municipality.

From the National Institute of Public Health and the Environment (abbreviated in Dutch as 'RIVM') we obtained noise levels for small square areas of 100 by 100 meters. Since the noise areas were indicated by the national coordinate system and the sold properties could be linked to this coordinate system too, each individual property could be linked to a square sound area.

The noise index used is the cumulative energy level index LAeq. This noise index concerns the accumulated 24-hour noise pressure generated by road, rail and air traffic for 1999. The noise levels concern averages for 100 by 100 meter areas, and are translated into 10 categories of 5 decibels each. However, the levels with the lowest and the highest sound levels concern wider ranges of noise.

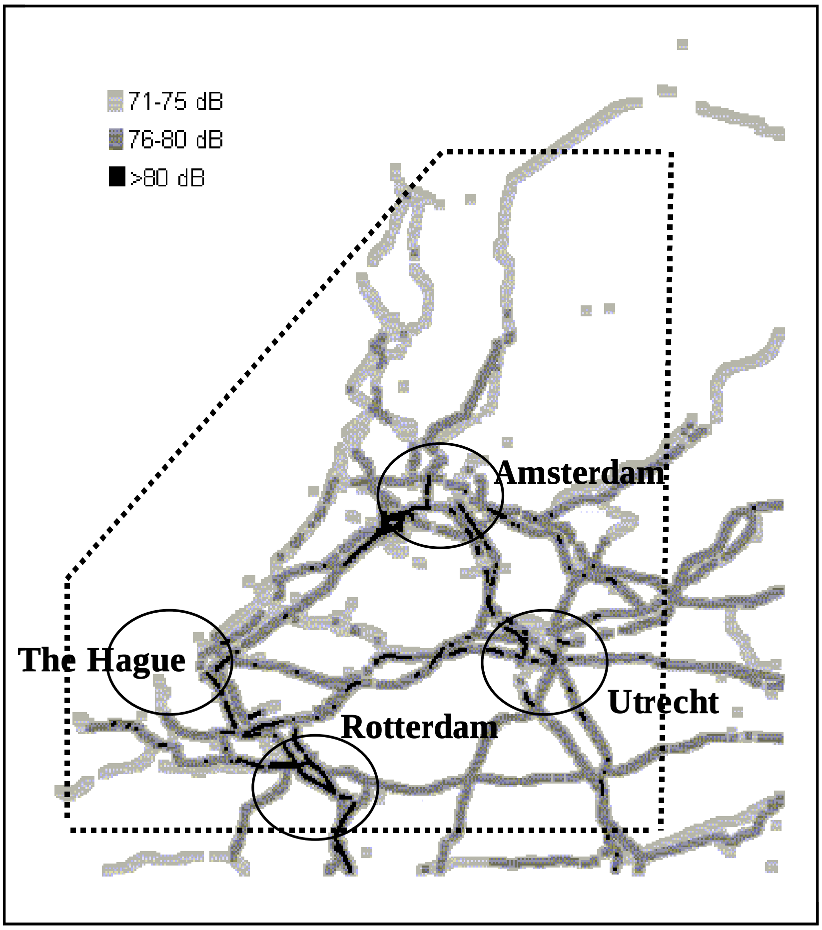
Table 2 provides more information about the noise data. More than half of all squared areas are very quiet with an average decibel level of below 40. However, most of these areas are non-residential, since only 1 percent of all properties is located within such a silence area. As could be inferred from Figure 2 for the Netherlands and Figure 3 for Amsterdam, areas with the highest noise levels concern locations directly adjacent to freeways, railroads and airports. Especially the figure for Amsterdam illustrates how detailed the noise data set is; crowded streets, freeways, and the airport runways in the southwestern part of the map with their approach routes are clearly visible. Only 14 percent of all properties is located in areas with a lower sound level than the desirable 50 decibels indicated by the Dutch government. However, less than 1 percent of all sample properties is located in areas with a sound level of above 70, the absolute legal maximum of noise generated by road or railroad traffic. In our data set, these are almost 900 such properties.

Table 2: *Description of noise data.*

Sound range	Decibel range	100x100m areas in total data set	Properties located within area	
		percentage	percentage	cumulative
1	0 –40 dB	55.18%	1.11%	1.11%
2	41-45 dB	9.20%	2.87%	3.98%
3	46-50 dB	11.03%	10.25%	14.23%
4	51-55 dB	10.15%	27.84%	42.07%
5	56-60 dB	7.53%	34.49%	76.56%
6	61-65 dB	4.00%	18.20%	94.76%
7	66-70 dB	1.78%	4.46%	99.22%
8	71-75 dB	0.70%	0.64%	99.86%
9	76-80 dB	0.36%	0.13%	99.99%
10	>80 dB	0.07%	0.01%	100.00%
total		2,073,650	113,574	

In order to create sub-markets for analysis, we divided our data set four times in three sub-samples, along the dimensions neighborhood income, year of sale, property type and address density.[8] Sub-samples are created such that each set has about the same number of observations, except for the housing type and year of sale dimension. Table 3 specifies characteristics of these sub-sets. However, some breakdown dimensions used to create sub-samples will be correlated. High noise areas generally have a higher address density, relatively more multi-family properties and lower average incomes. In quiet areas the address density is lower, and the share of (detached) single-family properties and average income is higher. So, results for data segmentation based on income and address density and property type will be rather similar. More details on the similarity of sub-markets are provided in Table 4.

Figure 2: *Areas with high traffic noise, and indication of studied region.*



[8] Address-density is a statistic created by the Dutch Central Bureau of Statistics (CBS). It denotes the average number of addresses per square kilometer within a straight-line distance of 1 kilometer around all individual properties. It represents the concentration of human activity, and is used by the CBS to classify municipalities on degree of urbanization.

Figure 3: Noise in Amsterdam, noise levels above 50 decibels.

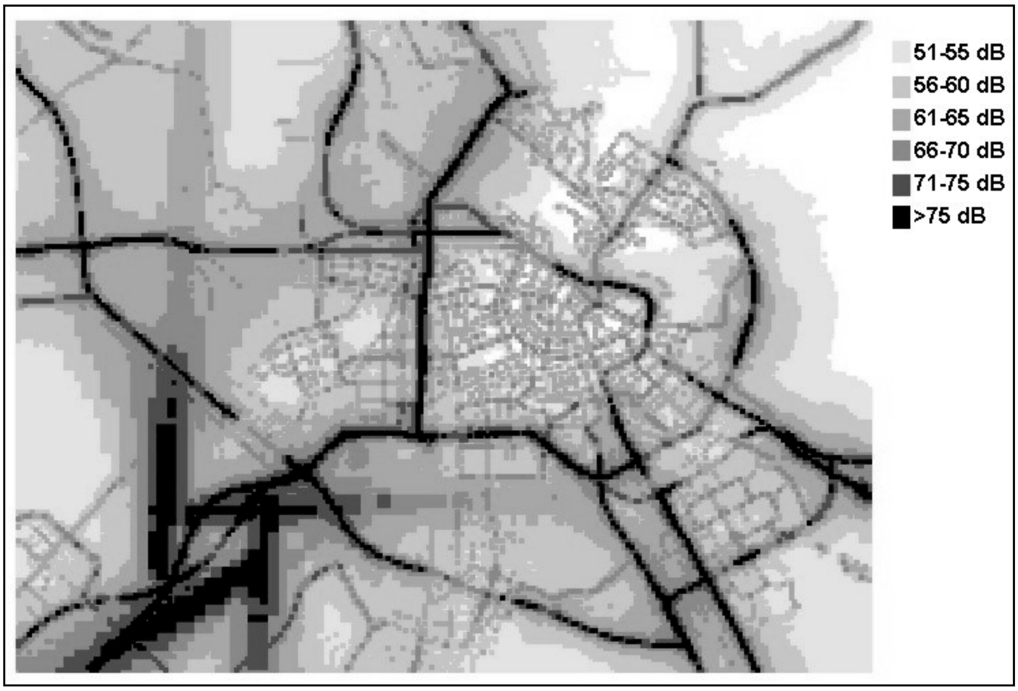


Table 3: Characteristics of sub-samples.

Break-down dimension	Range	Observations	% Observations
Income (€, per head)			
Lower income	18,300-21,500	37,628	33.1%
Middle income	21,500-24,700	38,474	33.9%
Higher income	24,700-33,000	37,472	33.0%
Years			
1997	-	35,915	31.6%
1998	-	44,491	39.2%
1999	-	33,168	29.2%
Property type			
Single-family, non-detached	-	53,755	47.3%
Single-family, detached	-	20,218	17.8%
Multi-family	-	39,601	34.9%
Address density			
Lower address-density	104-1,406	37,741	33.2%
Middle address-density	1,411-2,418	38,123	33.6%
Higher address-density	2,671-5,926	37,710	33.2%

Table 4: *Similarities between sub-markets.*

	Obs	Mean sound range	Mean address-density	Mean income x € 1,000	House type			Year		
					non-detach. sf	detach. sf	multi-family	1997	1998	1999
Address-density										
lower	37,741	4.4	*968*	25.8	60%	26%	13%	35%	38%	26%
middle	38,123	4.6	*1,934*	23.5	57%	16%	27%	34%	38%	27%
higher	37,710	5.1	*3,979*	20.0	25%	11%	64%	26%	41%	34%
Income										
Lower	37,628	5.0	3,848	*19.9*	31%	10%	59%	27%	40%	33%
Middle	38,474	4.5	1,842	*23.2*	55%	17%	28%	32%	39%	29%
Higher	37,472	4.6	1,192	*26.2*	57%	26%	17%	35%	39%	26%
House type										
non-detach. sf	53,755	4.5	1,790	23.8	*100%*	*0%*	*0%*	34%	39%	27%
detached sf	20,218	4.6	1,814	24.3	*0%*	*100%*	*0%*	36%	39%	25%
multi-family	39,601	5.0	3,218	21.6	*0%*	*0%*	*100%*	26%	39%	35%
Year										
1997	35,915	4.7	2,101	23.3	51%	20%	29%	*100%*	*0%*	*0%*
1998	44,491	4.7	2,320	23.1	47%	18%	35%	*0%*	*100%*	*0%*
1999	33,168	4.7	2,461	22.8	44%	15%	41%	*0%*	*0%*	*100%*
Total	113,574	4.7	2,292	23.1	47%	18%	35%	32%	39%	29%

5. Results

The impact of traffic noise is estimated by means of the hedonic approach. An OLS-regression for (5) yields estimates as specified in Appendix Table A.1. Despite the large number of explanatory variables, tolerance levels indicate that the selection does not suffer from severe multicollinearity. In (6), the location of a property within a specific range of decibels is represented by NIMBY-dummies. Estimation of these noise dummies occurs with both an OLS-specification and a spatial CAR-specification[9]. However, the spatial estimation procedure could yield slightly different estimation results for the same specification. We therefore performed the spatial estimation 5 times, and selected the results from the estimation with the lowest root mean squared error. For multicollinearity reasons, the decibel range 56-60 decibels is chosen as default, since this

[9] The CAR-specifications are based on are Delaunay-triangles. Alternative CAR-specifications with a larger number of neighbors and varying spatial correlation coefficients only resulted in decreases of root mean squared errors of below 0.002, while requiring extremely longer computation time. Spatial SAR-specifications showed higher root mean squared error and lower log likelihoods.

is the most common noise range. The ranges 76-80 and above 80 are merged into one class because of an insufficient number of observations for most examined sub-samples.

Results for entire sample

Table 5 shows the estimation results obtained with the total data sample. Although the estimations of OLS and the spatial techniques are rather similar, the latter approach yields a lower root mean squared error and a higher maximum likelihood, indicating more efficient estimates. The significance levels do show differences, however.

Table 5: *Estimated price impact of noise, compared to 56-60 decibel.*

Noise range	Obs.	OLS		Spatial	
		Estimated impact on house price	Probability	Estimated impact on house price	Probability
<=40 dB	1,259	2.1%	0.001	3.6%	0.000
41-45 dB	3,265	-1.0%	0.005	-0.7%	0.132
46-50 dB	11,638	-0.7%	0.002	-0.3%	0.195
51-55 dB	31,616	0.3%	0.043	-0.3%	0.050
56-60 dB	39,177	0.0%	*default*	0.0%	*default*
61-65 dB	20,669	-0.6%	0.001	0.2%	0.322
66-70 dB	5,064	-1.1%	0.000	-0.7%	0.040
71-75 dB	732	-3.2%	0.000	-3.9%	0.000
>=76 dB	154	-5.4%	0.000	-5.2%	0.001
Loglik		-475,894		-458,665	
rmse		0.196		0.162	
obs		113,574		113,574	

Estimated coefficients are transformed into percentages. Probability levels indicate the significance of the estimates. Also given are the maximum log likelihood of the estimation, the root mean squared error, and the number of observations. Estimates and probabilities of different specifications are comparable, since all regressions use Maximum Likelihood.

Judging on the spatial results, prices appear to be affected by traffic noise only if the sound level exceeds 65 decibels. This is in line with the 68-decibel level Bateman et al (2001) found for Scotland. The negative impact rises with the sound level, but the maximum price impact is rather modest, just above 5 percent. This is in accordance with the results of most other studies too, if we assume a NDSI value of 0.4 percent per decibel, an ambient noise level of 65 decibels, and a maximum noise of just above 75 decibels. However, since the discount does not rise linearly with sound level, it is not correct to assume a constant price per decibel. Remarkable is the significant premium for very quiet locations. However, in between 40 and 65 decibels, the impact of noise does not differ from the impact of the default noise range. The upper panel of Figure A.1 in the Appendix provides a graphical representation of the estimated price impact, for different noise levels.

The value of reducing traffic noise with one decibel is dependent on the original noise level. This means that the NDSI is not constant. We estimate the index to vary between 0.14 and 0.65 percent, values that are still in the range of frequently found values. Table 6 specifies the calculations of this index.

Table 6: *Estimated Noise Depreciation Sensitivity Index, for different noise levels.*[10]

Reduction from		**To**		**% Price change**	**NDSI**
Range	Used	Range	Used		
41-65 dB	*62.5*	<=40 dB	*37.5*	3.7%	0.15%
66-70 dB	*67.5*	41-65 dB	*62.5*	0.7%	0.14%
71-75 dB	*72.5*	66-70 dB	*67.5*	3.3%	0.65%
>=76 dB	*77.5*	71-75 dB	*72.5*	1.3%	0.25%

If the estimated discounts from regression with the total sample are used, one could calculate the total change in property values caused by changes in noise exposure. For example, one could estimate the compensation the local government should distribute to owners of properties located to a newly constructed road with heavy traffic. If the results of Table 7 are applied, the owner of a 200,000 Euro residential property faces a loss of 6,400 Euro, if this road rises traffic noise from 68 decibel to 73 decibel. Alternatively, the value of a planned noise barrier or more rigid airport noise contours to property owners could be approximated. The largest price change per decibel is caused by a change in noise level from 71-76 to 66-70 decibels.

Our results are quite similar to the results found in other studies. If we apply a NDSI of 0.4% to our ambient noise level of 65 decibels, calculated value changes are rather comparable, as depicted in Table 8.

Table 7: *Estimated property price changes for changes in noise exposure.*

		to				
		<=40 dB	**41-65 dB**	**66-70 dB**	**71-75 dB**	**>=76 dB**
from	**<=40 dB**	0.0%	-3.6%	-4.2%	-7.3%	-8.4%
	41-65 dB	3.7%	0.0%	-0.7%	-3.8%	-5.0%
	66-70 dB	4.4%	0.7%	0.0%	-3.2%	-4.4%
	71-75 dB	7.8%	4.0%	3.3%	0.0%	-1.3%
	>=76 dB	9.2%	5.3%	4.6%	1.3%	0.0%

Table 8: *Property price changes with NDSI of 0.4% and ambient noise level of 65 dB.*

		to				
		<=40 dB	**41-65 dB**	**66-70 dB**	**71-75 dB**	**>=76 dB**
from	**<=40 dB**	0.0%	0.0%	-2.0%	-3.9%	-5.8%
	41-65 dB	0.0%	0.0%	-2.0%	-3.9%	-5.8%
	66-70 dB	2.0%	2.0%	0.0%	-2.0%	-3.9%
	71-75 dB	4.0%	4.0%	2.0%	0.0%	-2.0%
	>=76 dB	6.0%	6.0%	4.0%	2.0%	0.0%

[10] Note that the NDSI-calculations depend on the selected noise values within the noise ranges. The same selected levels are used for calculations in Tables 7 and 8. Percentage price changes are calculated by subtracting the semi-log estimates and taking the exponent.

Results for sub-samples

We also estimated the noise impact for different sub-samples. When discussing these results, we use the outcomes from the spatial regression, since these estimates are more efficient than the OLS-outcomes. Results shown are entirely based on sub-samples.[11]

Some literature suggests that high-income areas will be more affected than low-income areas. Table A.2 in the Appendix confirms this suggestion, although the difference is not large. The OLS results suggest that the impact rises with income, but the spatial results for middle-income areas show a higher discount for middle-income areas than for high-income areas. It should be noted, however, that the number of observations for high noise properties in the middle-income area is rather small. High-income areas show significant discounts for sound levels above 65 decibels, while other areas are only affected with a level of above 70. The premium for very quiet locations is only significant for high-income areas.

In 1999, the Dutch housing market was tenser than in previous years. It might be expected that traffic noise will be of less importance in tense years, but the spatial results even show the opposite. The maximum estimated impact is the highest for 1999. The ambient noise level is 65 decibels for all years. These results are shown in Table A.3 in the Appendix.

According to literature, multi-family properties are affected more by traffic noise than detached single-family properties. This conclusion seems to be rather counter-intuitive, since it might be assumed that citizens in quiet areas would be annoyed more quickly by traffic noise than people living in crowded areas. Our results are more intuitively, since we find that multi-family properties and properties in areas with a high urbanization degree suffer less than other properties from traffic noise. Appendix Tables A.4 and A.5 show detailed results, which are illustrated in Appendix Figure A.1. Since the discount for detached properties starts decreasing from a low ambient noise level, inhabitants of these properties are relatively quickly annoyed.

Because of the similarity of sample breakdown dimensions, results for multi-family properties are quite similar to results for crowded and low-income areas, while estimates for detached single-family properties are comparable to estimates for less crowded and high-income areas.

[11] Both noise parameter estimates and estimates for physical and locational attributes are based on the separate sub-samples.

6. Summary and conclusions

Since traffic intensity is growing with population and welfare, the impact of the resulting noise nuisance has become a widely studied area. However, most analyzed geographical areas concern the United States and the United Kingdom, and other regions are largely neglected. Most of the Anglo-Saxon studies date from the late seventies and early eighties. Is it reasonable to assume that these results apply to other countries too, and still?

The issue of noise nuisance has become very important for the Netherlands. Currently, large infrastructural projects are planned, like expansion of the main airport and the construction of railroads for high-speed international trains. These projects face strong opposition from pressure groups. Moreover, in the near future, local governments will be allowed to determine and enforce differentiated noise limits for specific areas within their municipality.

Understanding the value of noise is therefore gaining importance, and it validates a study after the impact of noise on property prices. First of all, one should know the impact of new infrastructure or more compliant noise limits on values of surrounding properties, as a reference for potential compensation to harmed homeowners. Alternatively, the capitalized value of noise in house prices could be used to estimate the benefits of noise reduction, for example by construction of noise barriers along highways or by more rigid noise contours for airports.

Most studies found that sound levels below 55 decibels do not harm property prices, but for each additional decibel, the property loses 0.4% of its value, on average. In this chapter, we estimate the price impact of noise for the western part of the Netherlands, with a very rich data set. Usage of spatial autoregression techniques will yield more accurate estimates than conventional estimation techniques. Moreover, we use dummy variables for noise ranges instead of one noise index, to allow for a nonlinear relationship between noise level and property prices. No study known to us has ever tried this intuitive approach before.

We find that traffic noise indeed has a significant impact on property prices. Noise levels above 65 decibels appear to be capitalized into prices, with a maximum discount of approximately 10 percent. Although this net price impact matters, the pure impact of noise might be canceled out to some extent by the positive effects generated by infrastructure. The net discount is not a linear function of noise; reducing noise from a loud (71-75 dB) to moderately loud level (66-70 dB) has a larger impact on property values than reducing noise from very loud (over 75 dB) to loud, or a reduction from moderately loud to quiet. For properties confronted with traffic noise levels between 41 and 65 decibels, the actual noise level does not matter. However, if the property is located in a very quiet area (below 40 dB), it will sell at a significant premium of around 3.5 percent. Because of this non-linearity, the estimated prices per reduction of noise (NDSI) depend on the original noise level, but range between 0.14 and 0.65%. These findings are in line with literature.

We also examined separate parts of the housing market of the western Netherlands. We find weak evidence that properties in high-income areas are affected more by traffic noise than properties in low-income areas. Residents of high-income areas are annoyed with lower noise levels than other residents. Since high-income areas have a larger percentage of detached single-family properties and will have a lower address density than other areas, more or less the same results are found if sub-markets are created with these other dimensions. Nevertheless, the differences between sub-markets do not seem to be very large. Although the housing market was more tensed in 1999 than in previous years, we do not find large changes in traffic noise impact for separate years.

Our estimated price impacts will contain regression noise and are dependent on the chosen specifications. Nevertheless, all specifications indicate that traffic noise will impact property prices if it is above 65 decibels. Moreover, most specifications show a maximum impact on property prices of in between 3 and 10 percent. These findings will provide sufficient foothold in future traffic noise discussions.

Acknowledgements

The NVM, the Kadaster and the RIVM are thanked for providing their valuable data, just as Evert Verkuijlen from the GIS-center of the University of Amsterdam and Wiebe Tamminga from the Kadaster for their data assistance. I gratefully applied the Spatial Statistics Tool from Kelley Pace from the Louisiana State University.

Appendix

Appendix Table A.1: *Data description and regression results.*

Property characteristic	Average	Sd	Estimate	T-val	Prob	Tolerance
Rooms						
Rooms on ground (1st) floor	1.8	1.2	5.8%	65.47	0.000	0.29
Rooms at second floor	1.9	1.4	3.6%	39.03	0.000	0.21
Rooms at third floor	0.5	0.8	2.5%	24.99	0.000	0.60
Rooms at fourth floor	0	0.2	3.1%	7.58	0.000	0.92
Size						
Property volume (m^3)	337	157	0.1%	165.40	0.000	0.33
Parcel size (m^2)	196.7	581.8	0.0%	40.80	0.000	0.76
Time to market (days)	58	69.8	0.0%	-21.09	0.000	0.93

Property characteristic	Freq.	% Freq.	Estimate	T-val	Prob	Tolerance
Housing type						
Single-family						
'simple'	5,048	4.4%	-7.7%	-25.15	0.000	0.77
'row house'	47,172	41.5%	*default*			
'mansion'	12,334	10.9%	9.7%	37.15	0.000	0.55
'villa'	4,504	4.0%	25.6%	58.07	0.000	0.57
'country house'	675	0.6%	28.1%	29.72	0.000	0.82
'country estate'	14	0.0%	8.3%	1.51	0.131	0.98
'bungalow'	739	0.7%	30.2%	33.74	0.000	0.85
'bungalow with patio'	400	0.4%	10.0%	9.47	0.000	0.95
'semi bungalow'	1,002	0.9%	24.8%	33.25	0.000	0.86
'split level'	207	0.2%	-1.2%	-0.88	0.379	0.97
'meander'	39	0.0%	-1.3%	-0.41	0.680	0.99
'property w. in-home office'	248	0.2%	-3.8%	-3.08	0.002	0.97
'house with built-in garage'	812	0.7%	-3.2%	-4.26	0.000	0.82
'farm house'	270	0.2%	-1.4%	-1.14	0.255	0.87
'canal house'	280	0.3%	5.8%	4.58	0.000	0.90
Multi-family						
'ground floor dwelling unit'	4,811	4.2%	-16.5%	-45.52	0.000	0.53
'upper floor dwelling unit'	5,944	5.2%	-16.9%	-45.80	0.000	0.41
'ground and upper fl. dw. unit'	267	0.2%	-6.1%	-5.17	0.000	0.96
'stairwell dwelling unit'	797	0.7%	-28.8%	-43.88	0.000	0.80
'maisonnette'	3,071	2.7%	-14.4%	-34.26	0.000	0.62
'service flat'	172	0.2%	-33.4%	-26.23	0.000	0.92
'apartment in bld. w. elevator'	8,174	7.2%	-19.2%	-50.71	0.000	0.29
'apartment in bld. wo. elevator'	9,051	8.0%	-24.0%	-67.56	0.000	0.28
'luxurious apartment'	7,486	6.6%	-16.9%	-45.75	0.000	0.33
'Other1'	25	0.0%	-26.8%	-11.35	0.000	0.97
'Other2'	32	0.0%	-51.1%	-8.17	0.000	0.99
Facilities						
Garage						
No garage, or unknown	92,332	81.3%	*default*			
Connected garage of bricks	6,719	5.9%	15.3%	51.92	0.000	0.80
Detached garage of bricks	7,845	6.9%	16.8%	61.60	0.000	0.82
Connected garage of wood	235	0.2%	16.1%	11.66	0.000	0.99
Detached garage of wood	775	0.7%	18.3%	23.30	0.000	0.95
Built-in garage	5,668	5.0%	15.6%	47.36	0.000	0.75

Appendix Table A.1 continued.

Property characteristic	Freq.	% Freq.	Estimate	T-val	Prob	Tolerance

Bathrooms						
No bathroom	29,438	25.9%	-6.2%	-37.55	0.000	0.60
1 bathroom	72,691	64.0%	*default*			
2 bathrooms	10,336	9.1%	2.1%	9.58	0.000	0.83
3 bathrooms	1,069	0.9%	2.2%	3.53	0.000	0.95
4 or more bathrooms	40	0.0%	-4.3%	-1.41	0.158	0.99
Heating						
Central heating	99,942	88.0%	*default*			
Gas heater	13,632	12.0%	-8.6%	-44.42	0.000	0.77
No open fireplace	98,994	87.2%	*default*			
Open fireplace	14,580	12.8%	4.9%	25.33	0.000	0.86
Garden sun position						
No garden, unknown, or North	42,113	37.1%	*default*			
Northeast	4,973	4.4%	-0.2%	-0.58	0.559	0.73
East	9,458	8.3%	-0.1%	-0.48	0.629	0.61
Southeast	9,973	8.8%	1.2%	4.42	0.000	0.59
South	17,765	15.6%	1.5%	6.33	0.000	0.49
Southwest	11,869	10.5%	2.1%	8.24	0.000	0.56
West	12,552	11.1%	0.9%	3.68	0.000	0.56
Northwest	4,871	4.3%	1.0%	2.94	0.003	0.73
Garden length						
No garden, or unknown	34,906	30.7%	*default*			
1 to 5 meters	5,962	5.3%	0.3%	0.79	0.429	0.60
5 to 10 meters	25,601	22.5%	1.9%	6.34	0.000	0.21
10 to 15 meters	33,465	29.5%	4.1%	13.29	0.000	0.17
15 to 20 meters	7,684	6.8%	8.8%	23.64	0.000	0.42
20 to 50 meters	4,415	3.9%	16.3%	37.11	0.000	0.54
50 meters or larger	1,541	1.4%	11.2%	18.39	0.000	0.75
Maintenance						
Interior						
Unknown	217	0.2%	0.5%	0.27	0.784	0.59
Excellent	18,124	16.0%	6.8%	27.31	0.000	0.43
Good	81,324	71.6%	*defaul*			
Reasonable	11,410	10.1%	-5.5%	-24.14	0.000	0.66
Mediocre	2,153	1.9%	-7.7%	-15.18	0.000	0.65
Bad	346	0.3%	-13.6%	-10.41	0.000	0.56
Exterior						
Unknown	246	0.2%	-3.6%	-2.29	0.022	0.59
Excellent	16,151	14.2%	2.3%	8.80	0.000	0.42
Good	86,233	75.9%	*defaul*			
Reasonable	9,257	8.2%	-5.2%	-20.53	0.000	0.66
Mediocre	1,456	1.3%	-8.3%	-13.77	0.000	0.66
Bad	231	0.2%	-9.8%	-6.03	0.000	0.57
Other						
Sales condition						
Transaction costs for buyer	113,258	99.7%	*default*			
Transaction costs for seller	316	0.3%	13.3%	11.21	0.000	0.97
Monument						
No monument	112,527	99.1%	*default*			
Monument	1,047	0.9%	10.8%	14.52	0.000	0.74

Appendix Table A.1 continued.

Property characteristic	Freq.	% Freq.	Estimate	T-val	Prob	Tolerance
Ground						
Ground owner unknown	28,005	24.7%	0.2%	1.18	0.236	0.80
Ground owned	75,695	66.7%	*default*			
Ground leased, fixed term	8,461	7.5%	-1.0%	-3.98	0.000	0.72

Ground leased, floating	1,413	1.2%	-1.8%	-3.33	0.001	0.92
Construction year						
1500-1750	437	0.4%	17.3%	12.79	0.000	0.83
1750-1800	134	0.1%	11.1%	10.13	0.000	0.82
1800-1850	158	0.1%	7.8%	16.48	0.000	0.70
1850-1900	2,666	2.4%	6.6%	16.88	0.000	0.63
1900-1910	4,347	3.8%	2.0%	5.03	0.000	0.71
1910-1920	3,429	3.0%	3.3%	11.53	0.000	0.53
1920-1930	9,763	8.6%	3.4%	13.67	0.000	0.44
1930-1940	16,514	14.5%	1.6%	2.27	0.023	0.92
1940-1950	863	0.8%	0.5%	1.71	0.088	0.61
1950-1960	8,546	7.5%	-2.7%	-12.13	0.000	0.53
1960-1970	16,170	14.2%	5.6%	25.36	0.000	0.52
1970-1980	17,984	15.8%	*defaul*			
1980-1990	19,118	16.8%	19.1%	70.47	0.000	0.52
1990-2000	13,445	11.8%	-8.6%	-44.42	0.000	0.77
Sales moment						
January 1997	2,729	2.4%	*default*			
February 1997	2,970	2.6%	1.6%	3.15	0.002	0.49
March 1997	2,819	2.5%	2.6%	4.97	0.000	0.50
April 1997	3,143	2.8%	3.9%	7.43	0.000	0.48
May 1997	2,953	2.6%	4.9%	9.20	0.000	0.49
June 1997	3,174	2.8%	6.1%	11.62	0.000	0.47
July 1997	3,201	2.8%	5.4%	10.36	0.000	0.47
August 1997	2,664	2.4%	6.7%	12.27	0.000	0.52
September 1997	3,196	2.8%	6.3%	12.05	0.000	0.47
October 1997	3,287	2.9%	7.9%	15.06	0.000	0.47
November 1997	3,037	2.7%	8.3%	15.45	0.000	0.49
December 1997	2,742	2.4%	7.9%	14.34	0.000	0.51
January 1998	3,372	3.0%	9.5%	17.98	0.000	0.46
February 1998	3,567	3.1%	11.0%	20.98	0.000	0.45
March 1998	3,993	3.5%	11.6%	22.61	0.000	0.42
April 1998	3,803	3.4%	13.6%	25.98	0.000	0.43
May 1998	3,744	3.3%	14.9%	28.21	0.000	0.43
June 1998	3,887	3.4%	15.7%	29.72	0.000	0.42
July 1998	3,862	3.4%	16.5%	31.12	0.000	0.42
August 1998	3,178	2.8%	17.4%	31.24	0.000	0.47
September 1998	3,745	3.3%	19.2%	35.45	0.000	0.43
October 1998	4,046	3.6%	20.5%	38.32	0.000	0.41
November 1998	3,803	3.4%	22.3%	40.81	0.000	0.43
December 1998	3,491	3.2%	22.0%	39.61	0.000	0.45
January 1999	3,459	3.1%	23.6%	41.92	0.000	0.45
February 1999	3,564	3.1%	25.9%	46.00	0.000	0.44
March 1999	3,884	3.4%	28.0%	50.11	0.000	0.42
April 1999	3,376	3.0%	30.6%	52.52	0.000	0.45
May 1999	3,203	2.8%	32.5%	54.79	0.000	0.46
June 1999	3,405	3.0%	35.3%	59.50	0.000	0.45
July 1999	2,967	2.6%	36.7%	59.57	0.000	0.48
August 1999	2,146	1.9%	38.7%	57.37	0.000	0.56
September 1999	2,144	1.9%	42.4%	61.92	0.000	0.56
October 1999	2,170	1.9%	40.8%	60.11	0.000	0.55
November 1999	1,772	1.6%	43.5%	59.91	0.000	0.60
December 1999	1,078	1.0%	44.2%	51.47	0.000	0.70

Appendix Table A.2: *Estimation of noise impact on house prices; results for different income-areas.*

Noise range	obs	OLS		spatial	
		percentage	probability	percentage	probability
Lower income					
<=40 dB	84	9.00%	0.000	1.60%	0.550
41-45 dB	546	5.80%	0.000	0.80%	0.477
46-50 dB	3,002	0.80%	0.068	-0.70%	0.163

51-55 dB	8,309	1.20%	0.000	-0.60%	0.080
56-60 dB	14,221	0.00%		0.00%	
61-65 dB	10,391	-0.40%	0.172	0.10%	0.769
66-70 dB	2,415	0.30%	0.574	0.10%	0.863
71-75 dB	363	-3.40%	0.002	-5.40%	0.000
>=76 dB	77	-5.90%	0.011	-6.10%	0.017
Loglik		-139,314		-133,833	
rmse		0.209		0.174	
obs		37,628		37,628	
Middle income					
<=40 dB	725	0.50%	0.465	1.20%	0.243
41-45 dB	1,386	-2.60%	0.000	-1.60%	0.011
46-50 dB	4,788	-0.80%	0.015	-0.40%	0.306
51-55 dB	12,290	0.10%	0.752	-0.30%	0.276
56-60 dB	12,825	0.00%		0.00%	
61-65 dB	5,053	-0.70%	0.012	0.10%	0.731
66-70 dB	1,224	-1.40%	0.009	-0.50%	0.402
71-75 dB	166	-1.20%	0.380	-1.70%	0.247
>=76 dB	17	-6.70%	0.101	-7.50%	0.035
Loglik		-135,670		-130,921	
rmse		0.173		0.148	
obs		38,474		38,474	
Higher income					
<=40 dB	450	1.60%	0.076	3.30%	0.004
41-45 dB	1,333	-2.00%	0.000	-0.80%	0.257
46-50 dB	3,848	-0.60%	0.060	0.20%	0.704
51-55 dB	11,017	0.30%	0.141	0.10%	0.796
56-60 dB	13,911	0.00%		0.00%	
61-65 dB	5,225	-0.40%	0.129	-0.20%	0.512
66-70 dB	1,425	-4.10%	0.000	-2.90%	0.000
71-75 dB	203	-6.60%	0.000	-6.30%	0.000
>=76 dB	60	-7.40%	0.001	-7.00%	0.002
Loglik		-131,245		-127,847	
rmse		0.172		0.152	
obs		37,472		37,472	

Appendix Table A.3: *Estimation of noise impact on house prices; results for different years.*

Noise range	obs	OLS		spatial	
		percentage	probability	percentage	probability
1997					
<=40 dB	365	0.7%	0.492	2.6%	0.029
41-45 dB	1014	-0.8%	0.170	0.4%	0.568
46-50 dB	3610	-0.5%	0.184	-0.2%	0.591
51-55 dB	10239	0.9%	0.000	0.4%	0.125
56-60 dB	12604	0.0%		0.0%	
61-65 dB	6298	-0.4%	0.166	0.3%	0.309
66-70 dB	1506	-1.5%	0.002	-0.9%	0.086
71-75 dB	241	-5.1%	0.000	-4.9%	0.000
>=76 dB	38	-6.3%	0.025	-3.6%	0.172
Loglik		-126,218		-122,495	
rmse		0.177		0.154	
obs		35,915		35,915	
1998					
<=40 dB	495	0.9%	0.322	0.5%	0.627
41-45 dB	1239	-0.1%	0.922	-0.2%	0.798
46-50 dB	4596	-0.9%	0.006	-0.3%	0.347
51-55 dB	12522	0.0%	0.952	-0.2%	0.361
56-60 dB	15413	0.0%		0.0%	
61-65 dB	7944	-0.8%	0.002	-0.2%	0.544
66-70 dB	1955	-0.4%	0.369	-0.3%	0.500
71-75 dB	254	-1.6%	0.195	-2.9%	0.014
>=76 dB	73	-5.0%	0.023	-7.0%	0.001
Loglik		-164,019		-158,909	
rmse		0.189		0.162	
obs		44,491		44,491	
1999					
<=40 dB	399	4.0%	0.001	5.2%	0.000
41-45 dB	1012	-2.6%	0.000	-1.7%	0.027
46-50 dB	3432	-0.7%	0.099	-0.4%	0.417
51-55 dB	8855	0.3%	0.381	0.2%	0.436
56-60 dB	11160	0.0%		0.0%	
61-65 dB	6427	-0.4%	0.197	0.3%	0.440
66-70 dB	1603	-1.6%	0.004	-1.3%	0.024
71-75 dB	237	-3.0%	0.030	-3.1%	0.020
>=76 dB	43	-7.3%	0.018	-8.0%	0.006
Loglik		-120,615		-116,843	
rmse		0.208		0.179	
obs		33,168		33,168	

Appendix Table A.4: *Estimation of noise impact on house prices; results for different housing types.*

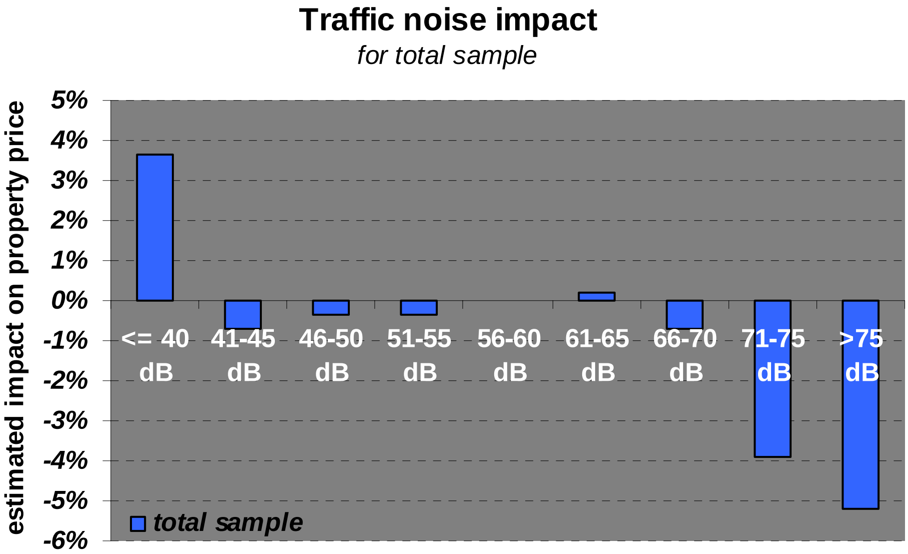
Noise range	obs	OLS		spatial	
		percentage	probability	percentage	probability
Non-detached single-family					
<=40 dB	765	1.6%	0.007	1.7%	0.028
41-45 dB	2,204	-1.8%	0.000	-1.3%	0.003
46-50 dB	6,634	-1.7%	0.000	-0.5%	0.054
51-55 dB	16,370	-0.2%	0.154	-0.3%	0.141
56-60 dB	18,598	0.0%		0.0%	
61-65 dB	7,221	-0.3%	0.202	0.0%	0.898
66-70 dB	1,649	-1.9%	0.000	-1.6%	0.000
71-75 dB	264	-3.2%	0.000	-3.3%	0.000
>=76 dB	50	-8.5%	0.000	-10.3%	0.000
Loglik		-189,757		-182,300	
Rmse		0.147		0.124	
obs		53,755		53,755	
Detached single-family					
<=40 dB	368	-2.4%	0.036	1.0%	0.470
41-45 dB	684	-0.3%	0.746	0.8%	0.373
46-50 dB	2,238	0.6%	0.211	1.3%	0.024
51-55 dB	5,665	0.3%	0.489	0.5%	0.239
56-60 dB	6,824	0.0%		0.0%	
61-65 dB	3,377	-1.5%	0.000	-1.0%	0.016
66-70 dB	907	-5.1%	0.000	-4.5%	0.000
71-75 dB	117	-7.6%	0.000	-6.4%	0.000
>=76 dB	38	-6.1%	0.053	-3.2%	0.306
Loglik		-67,621		-66,458	
rmse		0.199		0.183	
obs		20,218		20,218	
Multi-family					
<=40 dB	126	8.4%	0.000	3.2%	0.161
41-45 dB	377	0.2%	0.822	-0.7%	0.575
46-50 dB	2,766	0.8%	0.057	0.1%	0.817
51-55 dB	9,581	1.1%	0.000	0.4%	0.248
56-60 dB	13,755	0.0%		0.0%	
61-65 dB	10,071	0.1%	0.759	0.6%	0.065
66-70 dB	2,508	0.3%	0.430	0.7%	0.184
71-75 dB	351	-1.8%	0.087	-3.5%	0.005
>=76 dB	66	-2.9%	0.206	-4.5%	0.088
Loglik		-143,605		-137,239	
rmse		0.189		0.154	
obs		39,601		39,601	

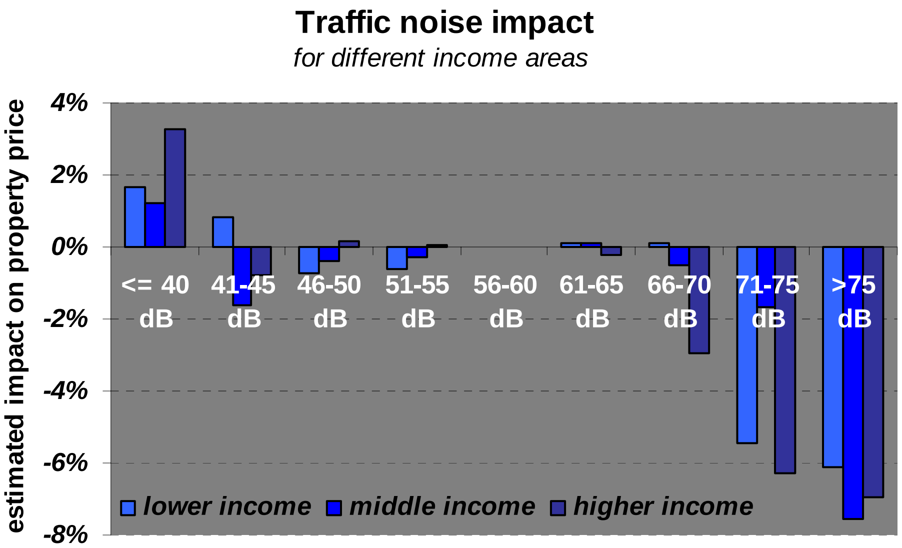
Appendix Table A.5: *Estimation of noise impact on house prices; results for different address densities.*

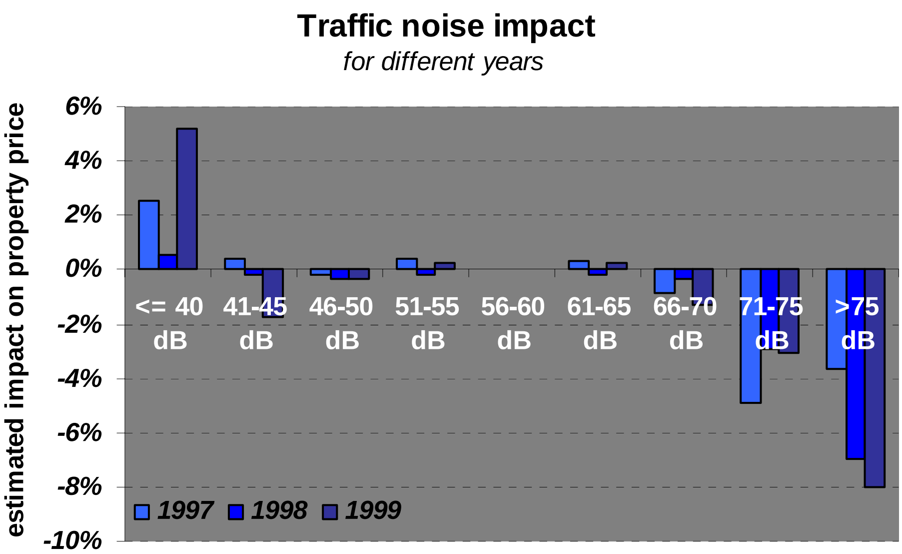
Noise range	obs	OLS		spatial	
		percentage	probability	percentage	probability
		Lower address density			
<=40 dB	966	0.7%	0.291	1.8%	0.040
41-45 dB	1,843	-2.0%	0.000	-1.0%	0.084
46-50 dB	5,142	-0.1%	0.765	0.0%	0.979
51-55 dB	11,587	-0.4%	0.093	-0.5%	0.055
56-60 dB	11,889	0.0%		0.0%	
61-65 dB	4,623	-0.3%	0.380	-0.2%	0.553
66-70 dB	1,403	-3.9%	0.000	-3.2%	0.000
71-75 dB	212	-6.5%	0.000	-6.2%	0.000
>=76 dB	66	-7.1%	0.001	-6.8%	0.002
Loglik		-133,767		-130,713	
Rmse		0.178		0.160	
obs		37,741		37,741	
		Middle address density			
<=40 dB	240	3.7%	0.001	4.1%	0.005
41-45 dB	1,048	-1.1%	0.059	-1.0%	0.121
46-50 dB	4,103	-0.1%	0.870	-0.2%	0.672
51-55 dB	11,293	1.1%	0.000	0.3%	0.177
56-60 dB	14,686	0.0%		0.0%	
61-65 dB	5,420	-0.7%	0.005	-0.1%	0.667
66-70 dB	1,146	-1.3%	0.008	0.4%	0.501
71-75 dB	173	0.4%	0.727	-0.9%	0.509
>=76 dB	14	-9.9%	0.017	-8.3%	0.024
Loglik		-131,709		-126,788	
rmse		0.162		0.137	
obs		38,123		38,123	
		Higher address density			
<=40 dB	53	10.7%	0.000	3.3%	0.353
41-45 dB	374	5.8%	0.000	1.9%	0.181
46-50 dB	2,383	0.1%	0.880	-0.3%	0.613
51-55 dB	8,736	0.4%	0.141	-0.7%	0.040
56-60 dB	12,602	0.0%		0.0%	
61-65 dB	10,626	-0.4%	0.188	0.3%	0.431
66-70 dB	2,515	0.1%	0.850	0.0%	0.930
71-75 dB	347	-4.1%	0.000	-5.3%	0.000
>=76 dB	74	-5.6%	0.019	-5.5%	0.040
Loglik		-139,514		-133,977	
rmse		0.208		0.173	
obs		37,710		37,710	

Appendix Figure A.1: *Estimated impact of traffic noise on property prices for entire sample and sub-samples.*

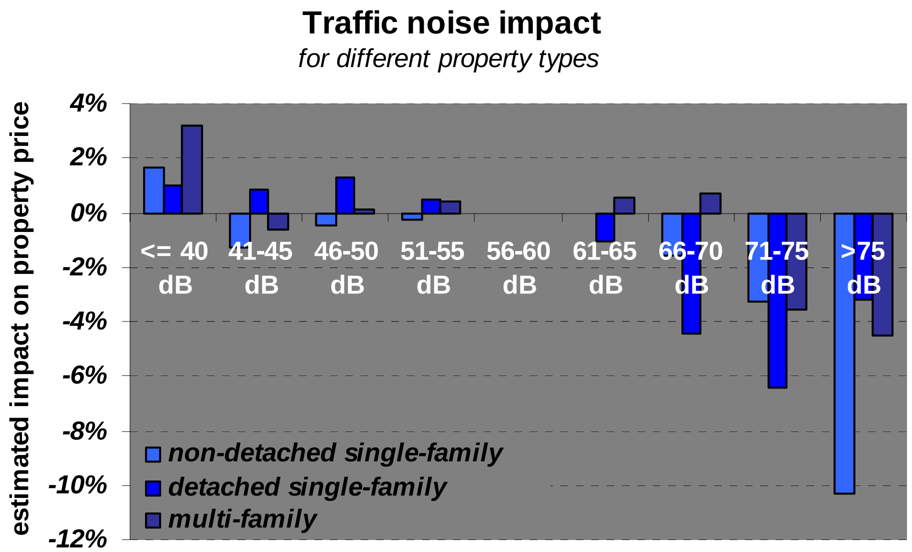
Shown are percentage transformations of semi-logarithmic coefficients, estimated with spatial autoregression. Selected are the results of the estimation with the lowest root mean squared error.

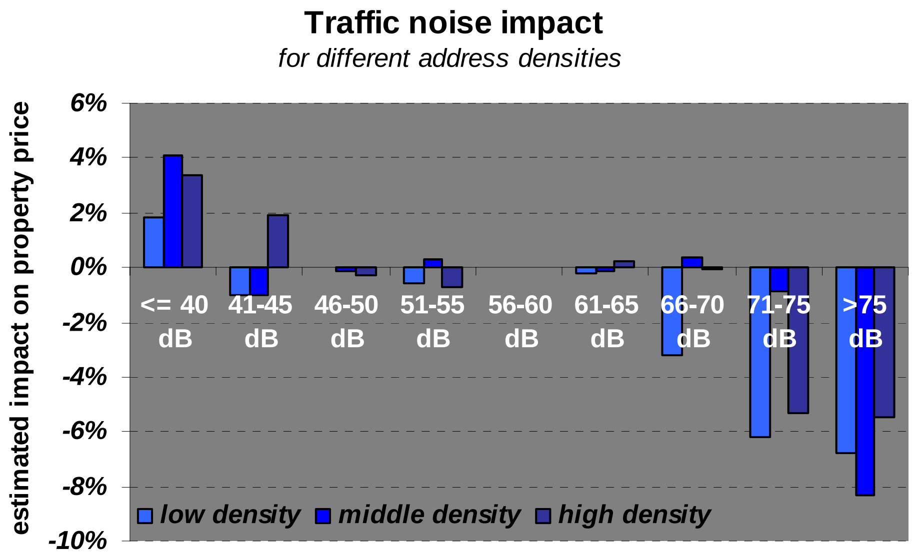






Appendix Figure 8A.1 continued.





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