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The Impact of Traffic Noise on the Values of Single-family Houses

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ABSTRACT *The objective of this paper is to provide an empirical analysis of the impact traffic noise has on the values of single-family houses. Under the assumption that negative externalities are capitalized into house values, the hedonic price method is used. Issues of asymmetric information and disequilibrium are discussed and tested. Furthermore, the cost–benefit valuation has been corrected for the existence of property tax. Noise pollution was found to have a substantial negative effect on housing values. A single-family house of SEK975 000 would sell for SEK650 000 if located near a road where noise is loud, equivalent to a total discount of 30%.*

Introduction

Cost–benefit analysis of road investment has been used in Sweden since the beginning of the 1980s. Environmental externalities have formed one part of these analyses. In the middle of the 1980s, economic values were placed on traffic noise. The empirical analysis in this paper examines the impact of traffic noise on property prices in a Stockholm suburb and is one part of a total revision of all the monetary values used in the cost–benefit analysis in Sweden.

This paper employs the hedonic pricing model developed by Rosen (1974), a valuation technique that uses house prices to estimate the amenity values of housing attributes. The method relies on the proposition that an individual's utility for a good is based on the attributes that it possesses. Furthermore, the hedonic analysis assumes that the price of the house can be decomposed into those attributes and, therefore, that implicit prices can be assigned to each house attribute, such as living area and quality of the house as well as exposure to traffic noise.

A number of studies have examined the effects of environmental attributes on house prices and estimated the willingness-to-pay for negative externalities, especially those of road traffic (see, for example, Palmquist, 1992; Hughes & Sirmans, 1993; Powe *et al.*, 1995).

The second section introduces the hedonic technique, and both the underlying assumptions and the interpretation of the model are addressed. The model is applied to data from Stockholm in the third section. The section starts with a discussion about which variables should be included in the hedonic price equation and, in particular, the inclusion of the noise variable is discussed. The

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results from the empirical analysis are presented in the fourth section, and show that traffic noise has a very strong impact on house value, but it is especially the combination of noise and visual view of the road that has an impact. An individual exposed to 73 dBA is willing to pay SEK8 000 per year to reduce the noise completely. The fifth section concludes the theoretical and empirical analysis.

Theory

The Hedonic Technique

We may assume that, as demonstrated formally by Rosen (1974), a consumer in the hedonic model maximizes a utility function $U(\mathbf{z},X)$, where $\mathbf{z}$ is a vector of housing attributes, $\mathbf{z} = (\mathbf{z}_l, \ldots, \mathbf{z}_k)$, such as size, amenities, traffic noise, views, etc. and X is a composite good. Supposing that consumers buy only one house and the price of all other goods (X) normalizes to 1, then the budget constraint can be written as:

$$Y = X + p(z_i) \tag{1}$$

where Y is the household's income and $p(z_i)$ is the hedonic price equation. If the utility function is maximized under restriction of the above budget, and if an interior solution exists, the first-order condition will be:

$$\frac{\partial p}{\partial z_i} = p_{z_i} = \frac{\partial U / \partial z_i}{\partial U / \partial X} \tag{2}$$

The consumer chooses the ith household attribute so that the implicit price of the attribute (p_{z_i}) equals the marginal rate of substitution between the attribute and the composite good X. Accordingly, by taking the partial derivative of the hedonic price equation with respect to traffic noise, the implicit price can be estimated, which can be interpreted as marginal willingness-to-pay for a marginal reduction of noise.

The functional form of the price equation has been the subject of some debate but, as Rosen (1974) has stressed, economic theory fails to indicate any particular form as being appropriate. Halvorsen & Pollakowski (1981) use a flexible multi-parameter Box–Cox model to find the best-fitting transformation, which is also employed in this analysis.

Criticisms of the Hedonic Price Model

The hedonic theoretical framework makes a number of assumptions, among them equilibrium in the housing market and symmetric information between seller and buyer. Both these assumptions will be analysed. Furthermore, the problem of interpreting the implicit price when property tax exists will be addressed.

Disequilibrium in the housing market. Interpreting the marginal implicit price, as a measure of marginal willingness-to-pay, requires the assumption that each household is in equilibrium, not only with respect to housing prices but also in the respect that prices clear the market for a given stock of houses and attributes. Unless each household is perfectly informed as to house prices, which also fully adjust to changes in demand or supply, and transaction and moving costs are zero the partial derivative cannot be interpreted as the marginal willingness-to-pay.

As Freeman (1979) has pointed out, there is a risk that when demand or supply, or both, are changing rapidly, the single-family housing market is not in equilibrium. The main reason is that the adjustment of price in the housing market is not an instantaneous process caused by the reality of high transaction and moving costs. Additionally, information imperfections in the housing market imply that the adjustment following a shock to demand is slow (Hort, 2000). Consequently, when this is so the hedonic price approach should be used cautiously. However, Meese & Wallace (1997) have concluded that the speed of adjustment after a demand shock in the Paris dwelling market was about 30% per month, i.e. an almost instantaneous process. On the other hand, DiPasquale & Wheaton (1994) have found empirical confirmation that the housing market may need years to adjust fully to an exogenous shock. Maclennan (1977) argued that the housing market is almost always in disequilibrium, although he concluded that, if the duration and physical extent of a studied market are restricted and not subject to severe shocks, an equilibrium condition can reasonably be assumed.

Considering stability and the volatility in the estimated parameters over the sample period tests if the equilibrium condition holds. The hypothesis in the present paper is that during periods with rapid house price increases, the implicit price of traffic noise may be biased because observed house prices will be dynamic disequilibrium prices. Consequently, instability and high volatility in the parameters indicate disequilibrium. This hypothesis will be tested using a Chow test and by looking at recursive regressions, i.e. regression estimated repeatedly with a larger data set, where the first data set only fulfils the rank condition. Although this is not a unique test for the existence of equilibrium in the housing market, it will give some indication as to whether or not disequilibrium may cause any interpretation problems.

Information bias between buyer and seller. The existence of information bias may cause a problem when estimating hedonic prices (Kask & Maani, 1992). If information is limited between seller and buyer, one may estimate a biased implicit price. The implicit price concerning noise will be biased upward if the buyer has less information about traffic noise than the seller does. Alternatively, one may estimate a zero implicit price when the true price is negative. Where traffic noise is concerned, there is a large potential risk that the buyer and seller will not have the same information about the level of noise and the related disturbance.

In order to detect information bias, the turnover rate is analysed.[1] If information bias exists, the hypothesis here is that houses from which the road can be seen will have larger turnover rates because when their owners (who bought with either biased or no information about the road noise) eventually become aware of it, they will try to find prospective buyers at least as poorly informed as they were: thus the turnover rate will be higher.[2]

The existence of property tax. In this paper the existence of a property tax will also be considered in estimating willingness-to-pay for noise, because the property tax is not a local tax in Sweden.[3] The following model (Niskanen &

Hanke, 1977) illustrates the relation between differences in the total value of land and differences in the market price. The total value (V) for society can be expressed as:

$$V = P + G = P + \frac{tP}{r} = P\left(1 + \frac{t}{r}\right) \qquad (3)$$

where P is the market price of land, G the capitalized value of property taxes for the government, t is the property tax and r is the real opportunity cost of capital. The total benefit to society of reducing noise levels will equal ΔV, not the difference in market price, ΔP. If estimates of welfare gains were based on information about market prices, the magnitude of the percentage error would be indicated by the ratio t/r (if the property taxes were fully capitalized in property values). The underestimate in Sweden would be in the range of 30%–35%.[4]

Application

Data

The analysis in the present study is based on a sample of sale prices, collected by Statistics Sweden, for 292 single-family houses between January 1986 and July 1995, in Ängby, a suburb of Stockholm. The data set was originally used for assessment purposes by the tax authority. The author of the present study has visually inspected all the single-family houses.

The houses in Ängby are largely homogeneous in type: almost all were built in the 1930s. The area is a short distance from the central business district of Stockholm, approximately 20 minutes by subway. A major east–west road (Bergslagsvägen), south of which the area is more heterogeneous, divides the area.

Variable Selection

When deciding to buy a house, households consider a number of factors, which can be divided into four main categories the house's structural attributes; its location in relation to urban services; its environmental attributes; and its macro attributes. Variables included in this study are presented in Table 1 and the hedonic price equation can be written in the following general form:

$$P = p(z_{1i}, z_{2j}, z_{3k}, z_{4l}) \qquad (4)$$

where z_{1i} are structural attributes ($i = 1, \ldots, n$), z_{2j} are location attributes ($j = 1, \ldots, m$), z_{3k} are environmental attributes ($k = 1, \ldots, o$) and z_{4l} are macro-economic attributes ($l = 1, \ldots, p$).

Structural attributes. Structural attributes are of course very important, but which are typically used in this type of study? To obtain an idea about which attributes are used most frequently, all the articles relating to hedonic price (total 28) in the *Journal of Real Estate Research* and the *Journal of Urban Economics* during the years 1990–95 have been investigated. Table 2 shows the results of this investigation.

Table 1. Variable definition

Variable name	Definition	Expected sign
Structural attributes		
Living area	Square metre	+
Lot size	Square metre	+
Quality	Index	+
Age	Year	−
Corner	Dummy for corner lot	+
Location attributes		
SA	Dummy variable for south Ängby area	?
SAliving area	South Ängby living area	?
SAlot size	South Ängby lot size	?
SAquality	South Ängby quality	?
Park	Dummy for close to park	+
Environmental attributes		
Noise	dBA	−
Exp	Visually exposed to road	−
Noiseexp	(Noise-68 dBA) visually exposed to road	−
SAnoise	South Ängby noise	?
HV	Dummy for nearby road (Hedebyvägen)	−
BBV	Dummy for nearby road (Beckombergavägen)	−
BV	Dummy for nearby road (Bällstavägen)	−
VV	Dummy for nearby road (Vultejusvägen)	−
Macro attributes		
FPI	Property price index	+

Table 2. Attributes used in empirical articles published, 1990–95 (percentage)

Variable	Journal of Real Estate Research	Journal of Urban Economics
Living area	81	83
No. of bathrooms	75	58
No. of bedrooms	50	42
Garage	63	67
Fireplace	44	50
Pool	19	17
Air conditioning	25	50
Age	50	75
Lot size	56	75
Subjective judgement	25	33

The most common structural attributes included in the hedonic price equation are living area, number of bathrooms, age, garage and lot size. Quality is an attribute that is difficult to measure, but subjective judgement is, however, not used especially commonly. Rather, the inclusion of the number of bathrooms and age serve as a proxy for the quality of the house.

Five variables are used in the present article for controlling for differences between houses: living area; lot size; age; whether it is a corner lot; and a quality measure. The expected signs for the coefficients of structural attributes are all positive. Information about garages, fireplaces, pools and air conditioning is not available in this study. However, the quality variable works as a proxy for some of these aspects. The quality measurement is an index initially used for tax assessment purposes, and is based on information from the household. It includes information about construction material and amenities. The quality index is a composite of 25 questions about indoor quality, where some of the questions can give up to three units. One additional unit of quality can mean very different things, for example the existence of a sauna or whether the house is built of bricks.

Location attributes. Location attributes concern the position of the house in relation to urban facilities such as proximity to public transportation, shops, schools and open space, and neighbourhood attributes. In this study, the attribute of closeness to parks and neighbourhood characteristics will be analysed.

Closeness to parks (in this study a dummy variable where 1 indicates property next to a park or open space) is assumed to be positively capitalized in the property value. The importance of neighbourhood will be analysed by dividing the studied area into two separate sub-areas, as other location attributes are highly dependent on whether the property is situated south (the more heterogeneous area) or north of the major road. We have included a dummy variable (SA, where 1 is south of the major road) and a set of interaction variables (SAquality, SAliving area, SAlot size and SAnoise) to test whether or not location differences are present.

Environmental attributes. Environmental attributes can be regarded as location attributes and in the sample area two potential amenities are studied, namely proximity to major and minor roads. A road has both negative and positive effects on property value, negative effects in the form of noise and air pollution and positive effects in the form of increased accessibility. If a variable relating only to the negative effects is included in the hedonic price equation, the estimated implicit price will not measure the negative effects alone but instead measure the net value that the road generates (Li & Brown, 1980). However, traffic noise is an externality that is very much local, which makes it possible to estimate the hedonic price equation for a relatively small and homogeneous area (Palmquist, 1992). At a distance of over 300 m from the road the marginal contribution of traffic noise to the surrounding noise level is equal to zero (Nelson, 1978). Therefore, to eliminate the positive effects that roads generate the studied area is rather narrowly limited. The boundary of the sample area in this analysis is a rectangle of 600×1000 m (300 m from each side of the road). The assumption is that the positive effects in the area will be effectively constant within this range, while the negative will vary with distance from the major road.

The distance between each house and the road was derived using air photography. The average volume of traffic on Bergslagsvägen is about 35 000 vehicles per day and was constant over the period studied. The level of traffic noise depends not only on the traffic volume and distance to the road, but also on the speed and number of trucks. In addition, other factors affect the noise level, such as topography, vegetation and weather conditions. That traffic noise

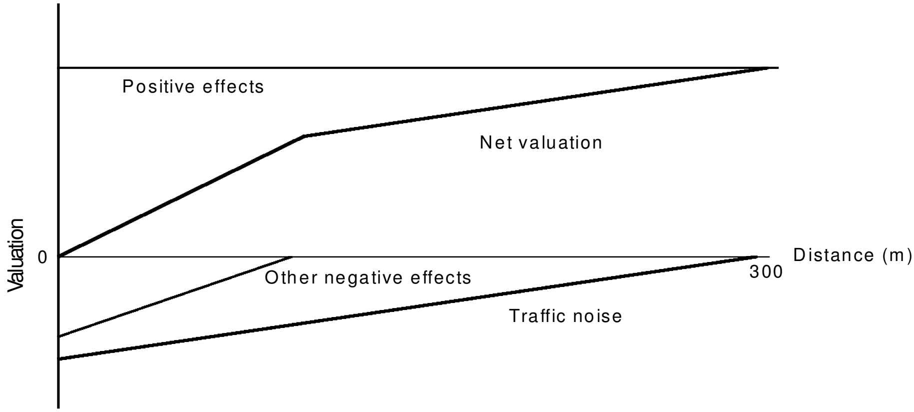

Figure 1. Assumptions about the positive and negative valuation effects of distance to the road.

is dependent on weather conditions makes it difficult to measure the level of noise accurately. Here, therefore, the noise level at every house is estimated using the Nordic Noise Model (see Naturvårdsverket, 1996) and distance, speed and number of vehicles and trucks are used as input data in the estimation procedure. The estimates were calibrated with an actual measurement of the noise level 1 m from the road.

The dBA was used as a measure of noise level.[5] This is a noise measure that seeks to approximate the perception of the human ear, so that a noise level of 70 dBA (e.g. a pick-up truck) is twice as loud to a listener as a level of 60 dBA (e.g. air conditioning), which is twice as loud as 50 dBA (e.g. a clothes dryer). Hence, the relationship between distance and dBA (all other things being equal) is non-linear. The noise level, dBA, was measured as L_{eq}, which is the average dBA over 24 hours.

Furthermore, noise is only one of the negative externalities that traffic generates. Others include air pollution and aesthetic and barrier effects. Thus, the inclusion of dBA measures not only the noise effect on property values but also the other negative externalities. However, it is reasonable to assume that these other effects are more dominant closer to the road. Here it is assumed, therefore, that the negative effects decline with distance from the road at different rates. Figure 1 summarizes the hypotheses.

The access effect is a positive constant in the interval studied and the valuation of the negative effect declines with distance from the road. The valuation concerning noise declines, however, at a lower rate than all the other negative effects.[6]

One way of incorporating the fact that noise is not the only negative externality from the road was to enter the noise variable in two forms in the hedonic price equation: first, an untransformed version (noise), which captures the noise level at all houses; and second, an interaction variable, where excess noise (actual noise level–68 dBA) is multiplied with a dummy variable that indicates whether or not the house has a view of the major road (noiseexp).[7] The second variable is intended to capture noise and all of the other negative effects that the road generates, i.e. if all other negative effects are highly correlated with visual exposure. The expected signs for the two coefficients regarding the noise levels are negative.

Hughes & Sirmans (1993) use traffic volume as a variable in the hedonic price equation, but they do not consider that other factors, such as the speed and number of trucks, may have an impact on the noise level. Palmquist (1992) uses L_{10} (average of noise level that is exceeded 10% of the time), which is a comparable measurement of noise level, but he uses a contour map (2.5 dBA, L_{10}) and not the noise levels at each house. In addition he uses only one variable concerning noise in the price equation and does not, therefore, consider that the noise variable measures other attributes at different distances.

Thus, the major road will be included as two noise-level variables in the hedonic price equation. Minor roads will be included as dummy variables, where 1 is equal to visual exposure to the road.

Macro-economic attributes. It is not necessary to consider macro-economic attributes such as unemployment rate, inflation and real interest rate if cross-sectional data are used in the empirical analysis. For a household it is not the inflation rate that explains the observed differences in house prices within the same period. However, in this study a pooled cross-section time-series sample is used and a house that was sold in 1990 did not have the same price as if it was sold in 1995 (all other things equal), due to real changes in the economy. Therefore, the property price index (FPI, Statistics Sweden) was included in the hedonic price equation to control for aggregate price movements.

Empirical Analysis

Descriptive Analysis

The mean and standard deviation concerning price (1995 prices) and the continuous attributes can be found in Table 3. The descriptive statistics are presented for the whole sample area and for the area south of the major road. Notably, the number of years since construction is about 57 years, but the standard deviation is very small and house prices are on average higher south of the major road, but the same is true for living area and lot size. Furthermore, the average level of traffic noise is lower in this area.

The noise variable has a negative correlation with all of the included variables; that is, lot size and living area are normally smaller closer to the road, where the noise level is higher. The high negative correlation between living area and noise

Table 3. Descriptive statistics, 1986–95

	Ängby total		South Ängby	
	Mean	Standard deviation	Mean	Standard deviation
Price 1995	1 238 786	527 538.5	2 112 507	603 643.6
Noise	61.8	4.2	58.6	1.2
Living area	84.9	30.8	135.6	34.3
Lot size	502.9	107.3	666.7	91.3
Age	56.8	6.2	57.2	6.3
Quality	25.4	5.2	29.6	6.8

Table 4. Turnover rate

	Stock		Sample		
	No.	Percentage	No.	Percentage	Turnover per year (%)
Total	821	100	256	100	3.1
View of Bergslagsvägen	97	12	35	14	3.6
View of Bällstavägen	15	2	6	2	4.0
View of Hedebyvägen	49	6	6	2	1.2
View of Vultejusvägen	10	1	4	2	4.0
View of Beckombergavägen	45	5	16	6	3.6

means that the interpretation of the coefficients of these variables could be difficult and that some caution must be used in interpreting the estimated parameters. There is also a high correlation between living area and lot size. Therefore, the question about multicollinearity has been analysed further in the econometric analysis.

Table 4 describes the turnover rate. The hypothesis was that the rate would be higher if the house had a view of Bergslagsvägen (the major road). If it were true, it could indicate that the information about the noise disturbance between buyer and seller is not the same.

In Table 4, one can see that the turnover rate is higher for properties that have a view of the road (Bergslagsvägen and some of the minor roads), but none of the differences is statistically significant. Therefore, the hypothesis of the existence of symmetric information cannot be rejected, and estimated willingness-to-pay should not be biased.

Econometric Analysis

As a first, exploratory step in measuring the impact of traffic noise on housing prices, house prices were regressed on all measured housing attributes where b denotes the coefficient to be estimated and e_i is the error term:

$$\begin{aligned}\text{Price} = {} & b_0 + b_1 \text{ living area} + b_2 \text{ lot size} + b_3 \text{ age} + b_4 \text{ quality} + b_5 \text{ corner} \\ & + b_6 \text{ park} + b_7 \text{ FPI} + b_8 \text{ HV} + b_9 \text{ BBV} + b_{10} \text{ VV} + b_{11} \text{ SA} \\ & + b_{12} \text{ SAliving area} + b_{13} \text{ SAquality} + b_{14} \text{ SAnoise} \\ & + b_{15} \text{ SAlot size} + b_{16} \text{ noise} + b_{17} \text{ noiseexp} + e_i \end{aligned} \quad (5)$$

The simplest model implies that house prices are sensitive to traffic noise, but not to proximity to the other minor roads in the area. The same is true for the dummy variables park and corner. Because year of construction differs only slightly the variable age had no significant effect on the price and the same appears to be true for the variable lot size, but this could be explained by the fact that lot size and living area are highly correlated. The estimation made it clear that one should use interaction variables SAliving area and SAquality rather than a shift variable, SA; that is, the marginal willingness-to-pay for an additional unit of living area and quality is different in the two areas. Thus, the result suggests that there exists a difference between north and south Ängby, but it could be a consequence of decreasing marginal utility regarding living area and quality. The variable SAnoise was not statistically significantly different from zero and has therefore been excluded in the next step.

In the next step, a search across the parameters of the linear Box–Cox functional form (equation (6)) was undertaken to find the best specification concerning the hedonic price equation:[8]

$$\frac{P_i^{\lambda}-1}{\lambda}=b_0+\sum_{1}^{k} b_k\left(\frac{Z_i^{\gamma}-1}{\gamma}\right)+e_i \tag{6}$$

The estimated parameters in the Box–Cox transformation are presented in Table A1 in the Appendix. A grid search was used to approximate maximum-likelihood estimates. The pairs of transformation parameters (λ and γ) maximizing the generalized likelihood function are ($\lambda=0.25$, $\gamma=0.25$), on which four null hypotheses are tested: log linear; linear; semi-log linear; and inverse semi-log linear. The conclusion is that the sample shows evidence in favour of the logarithmic transformation over the other functional forms. Therefore, the log linear specification is used for the rest of the analysis.

As a log linear price equation was used, the marginal willingness-to-pay for traffic noise equals the estimated variable coefficient multiplied by the ratio price and level of noise (equation (7)). The first part of equation (7) measures only the implicit price of noise and the second part measures the implicit price of noise plus all other negative effects. Equation (7) may be interpreted as the upper bound of the marginal willingness-to-pay for a reduction in traffic noise and the first part of the equation as the lower bound:

$$p_{\text{noise}}=\left(b_{16}\,\frac{\text{price}}{\text{noise}}\right)+\left(b_{17}\exp\cdot\frac{\text{price}}{\text{excess noise}}\right) \tag{7}$$

As shown in Table 5, the estimates of the noise variables are robust to different specifications. The implicit price concerning noise varies from SEK8327 in the linear specification to SEK9438 in the inverse semi-log linear specification. The differences in implicit prices between the different models are not statistically significant. It is also to be expected, when the standard deviation of the variable noise is small, that log linear and linear equations will tend to produce similar results.

To test whether aggregation over the period 1986–95 was appropriate, a Chow test was employed. In contrast to Palmquist (1992), the test considers the stability of all the estimated coefficients. The test compares the model in two periods, 1986–89 and 1990–95. An aggregation is possible if the estimated parameters are not statistically different. The results are reported in Table 6.[9]

There are large differences in the estimated parameters, in some cases even a switch of sign. In the full data model (1986–95), the coefficient on noise is negative, but in the period 1986–89 it is positive. The parameter concerning the

Table 5. Average implicit price with different specifications (SEK)

	Mean	Standard deviation
Linear	−8327	10 313
Log linear	−9070	18 654
Semi-log linear	−8560	11 334
Inverse semi-log linear	−9438	15 960

Note: F value = 0.234, critical value (5%) = 2.62.

Table 6. Ordinary least-squares result (log linear specification)

	1986–95		1986–89		1990–95	
	Coefficient	*t* value	Coefficient	*t* value	Coefficient	*t* value
Living area	0.609	10.05	0.514	4.90	0.635	11.02
SAquality	0.347	0.10	0.574	1.13	0.237	1.41
SAliving area	− 0.222	0.07	− 0.369	− 1.06	− 0.147	− 1.26
Noise	− 0.103	− 0.40	0.209	0.45	− 0.198	− 0.68
Noiseexp	− 0.103	− 2.10	− 0.061	− 0.70	− 0.138	− 2.31
FPI	1.014	18.10	0.975	9.84	1.100	9.94
Quality	0.206	3.01	− 0.209	− 1.34	0.314	3.94
Constant	5.470	5.17	6.137	3.12	4.945	3.56
SSR	11.104 51		3.813		6.434 9	
N	290		97		196	
F value	124.021 0		24.714		85.22	
$R^2_{adjusted}$	0.747		0.633		0.751	

Note: Chow test: test statistics = 2.89, critical value (5%) = 1.97. Variance of inflation test rejects the hypothesis about multicollinearity. Jarque–Bera test cannot reject the hypothesis of normality. White test cannot reject the hypothesis of heteroscedasticity[10]. SSR: Regression sum of squares.

variable quality also changes sign and there are rather large differences between the estimated coefficients concerning the location variables.

The model for the first period explains the variation in price least effectively. The model could explain only 63% of the price variation, compared with the model for the period 1990–95, which explains almost 75% of the variation.

The aim of the Chow test is to test whether all the estimated parameters are jointly statistically different between the different periods. The hypothesis about stability should be rejected if F_t is larger than the critical value. The test statistic (2.89) is larger than the critical value (1.97) at the 5% significance level and, accordingly, the test allows the hypothesis of the stability of the coefficients over the studied years to be rejected.

In addition to the Chow test, the high volatility of the parameters over the period has been analysed using a recursive regression. The conclusion is that almost all the parameters are stable over time, with the exception of the parameters concerning the noise variables.

One explanation for the volatility could be that the years 1986–90 exhibited a strong price increase (19% per year) and, as has been discussed earlier, one should be careful when studying periods when demand changes rapidly. Therefore, because of the Chow test and the recursive regression it was decided to make no further use of the data from 1986 to 1989 in the analysis.

Thus, only the last column in Table 6 will be analysed, i.e. the years 1990–95. The model can explain approximately 75% of the variation in price, which can be considered quite high with this type of data. The variables living area, quality and FPI were all significant and have expected signs and magnitudes.[11] The individual parameter estimate regarding noise is not statistically significant at the 5% level. However, a test of the hypothesis that both noise parameters are jointly zero is rejected.

The coefficients concerning noise indicate that a 1% increase in noise level will reduce the price by 0.2% below 68 dBA and 0.3% above 68 dBA. An increase of 1 dBA will reduce the price by SEK3000 at 57 dBA and SEK25 000 at 72 dBA, or

0.3%–3% of the property value per decibel. In Palmquist's (1992) study, property values were reduced in the range of 0.08%–0.48% for each decibel, depending on income class. If one considers that the average noise level was 55 dBA (L_{10}) in his area, i.e. lower than in the present study, and that L_{eq} is usually 3–5 dBA less than L_{10} under the same condition, the estimated parameters of noise are of a reasonable magnitude. Hughes & Sirmans (1993) use the number of cars as the independent variable and a comparable result indicates that a house receives a 0.8% premium if noise level increases by 1 dBA. The lower reduction in price probably arises from the fact that the analysis only considers houses within an area that is exposed to a high traffic volume. Hughes & Sirmans (1993) also analysed the difference between a noisy and a quiet area and estimated a lump-sum price premium of 11%, i.e. considerably lower than the present result (30%). However, the difference between houses in noisy and quiet locations is smaller in their study than in the present one.

Capitalization of Property Tax

The property tax variable should be included in the hedonic equation if the tax is not local; otherwise, the estimated marginal willingness-to-pay for a reduction in noise level will be underestimated. The question is whether the property tax is fully capitalized. For example, Feldstein (1977) showed that a newly imposed tax on land would reduce its market price by its fully capitalized value. The capitalization rate was estimated by using the following model and the whole data set:[12]

$$\text{In (price)} = a + b \cdot \ln(z) + c \cdot \ln(\text{tax}) \tag{8}$$

where tax is $1-(-\Delta$ property tax) and z is all other variables. The results are presented in the Appendix (Table A4). The tax variable has an expected negative sign and is statistically significantly different from zero. The estimated parameter (c) is equal to -0.84, which means that the property tax is not fully capitalized in the property value, although the coefficient is not statistically different from -1 (full capitalization).

Benefit Valuation

The empirical analysis suggests an average noise discount of 0.6% per decibel. In this sample, houses in noisy and quiet locations differ by 17 dBA of noise exposure. Thus, a house of SEK975 000 would sell for SEK650 000 if located near a road where the noise is loud, which is equivalent to a total discount of 30%. The expected reduction, as a function of noise, in the price of a standardized property is plotted in Figure 2. The property has an average living area and quality and is located north of the major road.

The expected price for a standardized property declines relatively slowly in the interval below 68 dBA. However, above 68 dBA the reduction is distinct. The 'kink' in the expected price curve is a direct result of the specification of the hedonic price function, i.e. the inclusion of the interaction variable noiseexp, even if the magnitude of the 'kink' is a result of the estimated parameters.

A household's marginal benefit from a small improvement in noise level is its marginal willingness-to-pay, as estimated by the marginal implicit price. Table 7 summarizes the estimate of an average individual's valuation of

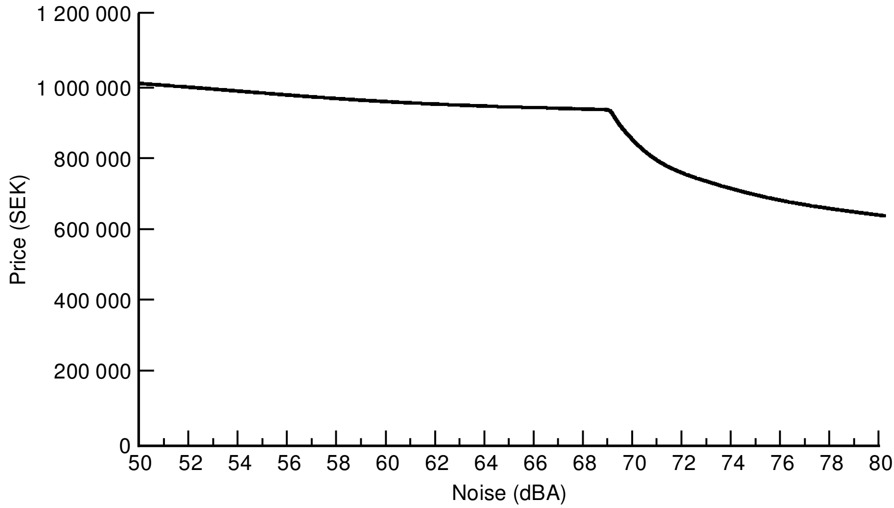

Figure 2. Standard property in locations with different noise levels.

Table 7. Noise level and valuation per adult and year

	With correction for property tax (SEK)		No correction for property tax (SEK)		
Noise level (dBA)	1990–95	1986–95	1990–95	1986–95	Valuation today (SEK)
56–60	349	181	268	139	400
61–65	885	460	681	354	1600
66–70	1372	716	1055	551	4000
71–75	8060	5846	6200	4497	8000

removing the road. The valuation is calculated as the difference in price between a property that is not exposed to noise (54 dBA) and at all other noise levels based on the coefficients in Table 6. The estimates are presented with and without correction for the property tax. The benefit valuation is estimated as an annuity with a 5% real interest rate and an internal time horizon of the differences in price of the standardized property. It is also corrected for the average number of adults in each household: in Ängby this is 1.9 persons.

To summarize the findings, an adult who lives near the road (more than 71 dBA) has an estimated non-marginal willingness-to-pay of almost SEK8000 per year. If the period 1986–95 is used, the estimated willingness-to-pay is only SEK5846 per year. A large difference between estimates that include property tax and those that do not can be observed. If the valuation is based on an analysis that does not fully recognize the problem of aggregation and does not correct for the existence of property tax, the analysis will produce an underestimate of the valuation. The valuation used currently is more an *ad hoc* valuation, even if it is originally based on a revealed-preference study. The valuation estimated in the present study is very close to the valuation used currently in the higher noise interval. The main difference occurs in the noise classes below and above the highest and lowest noise interval. The valuation used currently is linear, while the valuation estimated here is non-linear.

Conclusion

The existence of noise is a disturbance that is not very well recognized in planning, although a number of surveys in different countries support the notion that the non-existence of silence is one of the highest ranked environmental problems in society. Road traffic is one of the most common sources of noise in Sweden, and almost 1.6 million people are affected by it in their homes. Nearly 20% of these people live in residential areas where the level of noise is above 65 dBA; that is, highly noise-polluted areas. The aim of this study was, therefore, to estimate a benefit valuation of a reduction of traffic noise that could be used in different sorts of investment analysis, e.g. of new roads and in evaluating different residential plans.

This study analyses the impact traffic noise has on prices of single-family houses. The major difference between this and earlier studies is its inclusion of the noise variable in the hedonic price equation. In estimating the marginal willingness-to-pay an attempt has been made to separate the noise effect from all other effects that the road generates, such as access, air pollution and aesthetic effects. The stability of the parameters over the studied years is also analysed, and an attempt has been made to find whether any information bias exists between buyers and sellers. Furthermore, the effect of property taxes in interpreting the estimated parameters has been considered.

The noise effects on property value are considerable. The empirical analysis suggests an average noise discount of 0.6% of the house price per decibel or a total discount of 30% of the price for a house in a noisy location compared with a house in a quiet one. The benefit valuation is estimated to be around SEK8000 per person and per year at noise levels above 72 dBA.

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Notes

1. The number of transactions divided by the total number of houses in stock in a given year.
2. Of course, visual exposure to a road may increase the information to the buyer, since they will be aware immediately of the potential problem of noise.
3. A local property tax may also be capitalized into the housing prices, but so will the locally provided public goods. That is, there is in that case a strong connection between the property tax and publicly provided goods and services.
4. With 1.7% property tax and a 5% real interest rate, the underestimate is equal to 34%.
5. The reason why dBA is chosen is that the measure is used in the cost–benefit analysis in Sweden.
6. The relationship between valuation and distance need not, however, be linear as in Figure 1.
7. The houses that are visually exposed to the road are primarily located in the first and, in some cases, in the second row from the major road. All the houses that are visually exposed have a noise level above 68 dBA.

8. If

$\lambda = \gamma = 0 \quad \Rightarrow$ linear;
$\lambda = \gamma = 1 \quad \Rightarrow$ log linear;
$\lambda = 1$ and $\gamma = 0 \Rightarrow$ semi-log linear;
$\lambda = 0$ and $\gamma = 1 \Rightarrow$ inverse semi-log linear.

9. The specification of the hedonic price equation is based on the data material from the years 1990–95. Consequently, the specification may not be the 'best' model for the years 1986–89 with regard to the selection of variables and the choice of functional form.
10. An additional weighted least-squares regression was estimated using lot size as a weight. The results are presented in the Appendix (Table A2): only small differences were detected in the estimated parameters between the two regression specifications.
11. Separate dummy variables indicating sale year were tested to see whether the use of FPI as a proxy for macro-economic characteristics did influence the estimated parameters. The results are presented in the Appendix (Table A3) and the conclusion is that the use of FPI had no such influence.
12. The property tax has been changed (lowered) during the sample period, i.e. the analysis here is of whether or not the reduction in property tax is fully capitalized.

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Appendix

Table A1. Box–Cox transformation (log likelihood function)

λ	$\gamma=1.00$	$\gamma=0.75$	$\gamma=0.50$	$\gamma=0.25$	$\gamma=0.00$	$\gamma=-0.25$	$\gamma=-0.50$	$\gamma=-0.75$	$\gamma=-1.00$
1.00	−2682	−2684	−2686	−2689	−2692	−2697	−2702	−2706	−2711
0.75	−2672	−2672	−2673	−2675	−2678	−2682	−2685	−2689	−2694
0.50	−2667	−2666	−2665	−2666	−2668	−2671	−2674	−2677	−2681
0.25	−2666	−2664	−2662	−2662	−2663	−2665	−2667	−2670	−2672
0.00	−2669	−2667	−2665	−2664	−2664	−2665	−2666	−2667	−2669
−0.25	−2678	−2675	−2672	−2671	−2670	−2669	−2670	−2670	−2671
−0.50	−2690	−2686	−2684	−2682	−2680	−2679	−2678	−2678	−2679
−0.75	−2705	−2701	−2699	−2696	−2694	−2693	−2692	−2691	−2691
−1.00	−2722	−2719	−2716	−2714	−2712	−2710	−2709	−2708	−2707

Table A2. Weighted least-squares estimates, 1990–95

	Ordinary least-squares		Weighted least-squares	
	Coefficient	*t* value	Coefficient	*t* value
Living area	0.635	11.02	0.636	11.12
SAquality	0.236	1.40	0.231	1.43
SAliving area	−0.146	−1.25	−0.143	−1.28
Noise	−0.198	−0.67	−0.210	−0.71
Noiseexp	−0.137	−2.30	−0.135	−2.25
FPI	1.099	9.94	1.101	9.93
Quality	0.313	3.93	0.319	4.01
Constant	4.945	3.56	4.957	3.57
N	196		196	
F value	85.22		430.63	
R^2_{adjusted}	0.751		0.939	

Table A3. FPI compared with time dummies: ordinary least-squares results, 1990–95

	Equation (1)			Equation (2)		
	Coefficient	*t* value	VIF[a]	Coefficient	*t* value	VIF[a]
Living area	0.635	11.02	1.95	0.664	11.24	2.04
SAquality	0.236	1.40	205.32	0.308	1.82	208.17
SAliving area	−0.146	−1.25	207.74	−0.191	−1.63	210.71
Noise	−0.198	−0.67	2.27	−0.102	−0.35	2.29
Noiseexp	−0.137	−2.30	2.10	−0.126	−2.12	2.11
FPI	1.099	9.94	1.07	—		
Quality	0.313	3.93	1.46	0.259	3.21	1.49
d91	—			0.034	0.80	1.98
d92	—			−0.152	−3.09	1.78
d93	—			−0.365	−7.35	1.70
d94	—			−0.108	−2.22	1.77
d95	—			−0.190	−3.17	1.39
Constant	4.945	3.56		10.635	8.35	
N	196			196		
F value	85.222			54.318		
White test	12.067			14.470		
Jarque–Bera test	8.265			12.397		
R^2_{adjusted}	0.751			0.750		

[a]VIF, Variance of inflation test.

Table A4. Capitalization of property tax, 1990–95

	Coefficient	t value
Living area	0.651	11.55
SAquality	0.250	1.52
SAliving area	−0.152	−1.33
Noise	0.019	0.67
Noiseexp	−0.040	−2.85
FPI	0.296	3.79
Quality	1.244	10.69
Tax	−0.840	−3.12
Constant	2.890	1.98
N	196	
F value	80.714	
R^2_{adjusted}	0.766	