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Highway Noise, Noise Mitigation, and Residential Property Values

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This paper presents the findings of a study of the relationship between different noise levels and market values for a sample of 206 single-family residences abutting Interstate-495 in Northern Virginia and for a sample of 207 residences along two heavily traveled urban streets in the Tidewater area of Virginia. Estimates of the influence of noise on the market price of houses sold in 1978-1979 at these sites, where barriers have since been completed, were then used to estimate economic benefits received by property owners. By using these estimates, it was concluded that recent public expenditures on highway noise abatement per household far exceed reasonable economic benefit levels, even for noise reductions of 10 dB(A).

Part 772 of Title 23 of the Code of Federal Regulations emphasizes that final decisions about highway noise mitigation are not to be made without serious consideration of the costs of abatement. Paraphrasing the law, there may be sections of highways where the costs of abatement are so high in relation to the benefits received that it would be impracticable to apply noise abatement measures.

At least one author has attempted to provide evidence regarding the social impacts of noise (1); yet, economic data are necessary as an aid in decisions about noise mitigation. Early empirical evidence on the effects of highway noise was provided by Gamble and others (2) and Nelson (3); however, the results of these and more recent studies appear to have had only marginal influence on noise mitigation policies.

OBJECTIVES AND SCOPE

The objectives of this study were (a) to empirically estimate the effect of highway-generated noise on residential housing values and (b) to suggest financial criteria for the construction of noise barriers consistent with the estimated benefits that noise walls provide the owners of residential properties within the noise contour of heavily traveled highways. These major objectives were closely related in the sense that estimates of the reduction in property value, if any, that results from high levels of highway noise from mobile sources provide inferences about the potential benefits to be derived from noise abatement. With this estimate of potential benefits in hand, the second objective could be met.

The scope of the research was limited to an analysis of single-family, owner-occupied dwellings within the noise contours of highways to which Part 772 of Title 23 of the Code of Federal Regulations applies. Business, recreation, and multifamily properties were excluded from the analysis.

METHODOLOGY

The methodology used in this study is explained in moderate detail in the subsections that follow. Simply described, the method involved

1. Demonstration of a theoretical relationship between residential property values and noise,
2. Development of a mathematical equation to test the hypothesis that variations in the market price of housing adjacent to heavily traveled suburban highways can be largely explained by differences in the structural attributes of housing and differences in levels of noise,
3. Collection and development of detailed housing and noise data in areas of Virginia where noise levels are sufficiently high to require noise mitigation, and
4. Use of multiple regression analysis to estimate the willingness of housing consumers to pay for quiet as opposed to relatively noisy houses.

Conceptual Framework

The economic literature is replete with examples of the basic notion on which this study is predicated. Simply stated, the notion is that households, in choosing their residential location, are forced to reveal their preferences (willingness to pay) for certain characteristics or attributes of housing, including levels of noise. In other words, if people value quiet, the market will reflect that preference. Given this basic premise, the residential choice problem can be formalized mathematically into an equation by which the relationship between the market price of housing and noise can be tested empirically.

Following Nelson (3) and Allen (4), an economic relationship can be shown to exist between housing services and market price, where housing services refer to the idea that the market value of a dwelling reflects the quantity of services that a house will supply to a user. This relationship implies that for consumer equilibrium in the housing market--that is, for a given consumer to remain at a particular location--there must be price differentials among various house locations that compensate consumers for the differences in the housing services at those locations. Stated another way, consumer equilibrium, which will result because of mobility and the ability to buy and sell in the housing market, requires that for identical housing at locations 1 and 2, where noise at 1 is greater than noise at 2, the price of housing at location 1 must be less than that at location 2 by an amount to compensate buyers for the additional noise (5,6). Otherwise, the consumer will be better off by living at location 2.

Arguments in the housing literature that consider housing as a bundle of diverse items analogous to the description of food as a basket of goods are presented by a number of authors. Among these are Muth (7), King (6), and Nelson (3). This approach allows one to control empirically for differences in housing services when estimating the influence of such factors as noise or public expenditures on the market price of property (8-10). It is known technically as hedonic pricing (11-14). Specifically in the case at hand, the attributes of a house serve as surrogates for the flow of services associated with that house when one attempts to relate housing price to the flow of services. To the extent that observable attributes capture differences in perceivable service flows, they will help explain variations in price (12). Assuming that housing services are a function of housing characteristics, one can say that

$$h = f(w_1, w_2 \ldots w_n) \quad (1)$$

where w_1 and w_n are stock components of the housing bundle. Nevertheless, the arguments presented in the previous section concerning locational equilibrium still hold. It follows that household locational equilibrium requires, if other significant factors are controlled, that differences in housing attributes must be compensated for by differences in housing prices, since differences in observable attributes account for different service flows.

Now, based on the development in Allen (4), one can say that

$$P_{ij} = k(W_i, A_{ij}, d_i) \quad (2)$$

where

P_{ij} = market price of house i at location j;
W_i = attributes of house i;
A_{ij} = supply of local public goods;
d_i = distance of house i to the central city, a measure of accessibility; and
k = some mathematical function relating P_{ij} to W_i, and A_{ij} to d_i.

Only recently has the literature addressed the implications of the use of hedonic pricing on choice of functional forms for empirical testing. However, Muellbauer (15), Pollak and Wachter (16), and Nelson (3) have discussed the assumptions under which Equation 2 is linear. Nevertheless, as is explained elsewhere, the testing of several equation forms is the most appropriate empirical approach (4).

Accordingly, the parameters of Equation 2 will be estimated under three alternative functional specifications. These specifications are as follows:

1. $P_{ij} = \alpha_i W_i + \beta_j A_{ij} - \delta_i d_i \quad (3)$

where the variables are defined as in Equation 2 and α_i, β_j, and δ_i are estimates of the implicit price of the variable in question;

2. Estimation of Equation 3 with the dependent variable as log P_{ij} instead of P_{ij} (this is the log-linear form); and
3. Estimation of Equation 3 with dependent and independent variables in logs (this is the log-log form).

Data

Because noise data were the most difficult to obtain, the study design called for the housing data to be taken from parts of Virginia for which the Department of Highways and Transportation had either taken or developed extensive noise data. Areas that met these requirements were neighborhoods contiguous to Interstate-495 in Northern Virginia, between Interstate-66 and Telegraph Road in Alexandria; to Denbigh Boulevard in Newport News; and to Great Neck Road in Virginia Beach.

Once these sites were selected, an aerial photo of each with the 70-dB(A) noise contour superimposed on it was obtained. Also, site-specific unmitigated noise level estimates for properties both inside and beyond the 70-dB(A) contour were developed for each neighborhood from data collected in an earlier Research Council study (17). Detailed 1977, 1978, and 1979 data on house prices and characteristics were obtained for the Northern Virginia sites from the multiple listing files of the Washington Metropolitan Council of Governments. Similar data were obtained for the Tidewater area sites from the housing data file maintained by Market Data Center, Incorporated, for the savings and loan companies in that area.

EMPIRICAL RESULTS

The results of multiple regression estimations of the extent to which the market price of residential housing is influenced by noise are discussed below on the basis of two study sites. Simplification of Equation 3 is required for the analysis. Equation 3 argues that, in general, the price of a particular house equals the sum of the implicit price of its characteristics times the quantity of each and the value of local public services minus the cost associated with accessibility to the central business district. The accessibility variable and the local public service variable, however, can be dropped from the analysis in this study because (a) within the neighborhoods studied neither varies enough to be expected to influence the price of houses and (b) separate treatment of the Northern Virginia and Tidewater samples renders the across-sample differences in accessibility and local public goods empirically unimportant (18-21).

Equation 3 has now been revised to argue that the market price of house A at location B within a neighborhood that abuts a highway that has traffic generating relatively high levels of noise can be explained largely by the characteristics of house A and the level of noise at its location. Neighborhood amenities, such as the neatness of lawns, cleanliness of streets, and friendliness of neighbors, can be assumed to be the same for houses within the samples.

The measures of housing characteristics and noise used to test the relationship between noise and property values are listed in Table 1. Table 2 presents the means and standard deviations of these measures.

Table 1. Variables used to test influence of noise on market price of housing.

Variable	Type of Variable	Characteristic Measured
VAL[a]	Dependent	Sale price
SPA	Explanatory	Square feet of floorspace
AGE	Explanatory	Age of house in years
LOT	Explanatory	Lot size in square feet
BTH	Explanatory	Number of baths less 1
FIRE	Explanatory	Number of fireplaces
STYLE[b]	Explanatory	Style of house
BSMT[c]	Explanatory	Type of basement
CONST[d]	Explanatory	Type of construction
NOISE	Explanatory	House location: 1 = inside noise contour, 0 = outside noise contour
TN	Explanatory	Noise: $L_{10} - L_{90}$
TNI	Explanatory	Noise: Traffic noise index TNI = 4(TN) + $(L_{90} - 30)$
LTEN	Explanatory	Noise: L_{10}
LEQ	Explanatory	Noise: L-equivalent

[a]Sales occurring in different years have been adjusted to 1978 constant dollars by Housing Price Indexes for Virginia standard metropolitan statistical areas (21).
[b]Northern Virginia: 1 = ramblers or ranchers, 0 = other styles; Tidewater Virginia: 0 = ranchers, 1 = other styles.
[c]Northern Virginia: 1 = crawl space or slab, 0 = full basement; Tidewater Virginia: Basement not used as variable.
[d]Northern Virginia: 1 = other than full brick, 0 = brick.

Table 2. Sample characteristics: Northern Virginia and Tidewater areas.

	Northern Virginia		Tidewater Virginia	
Variable	Mean	SD	Mean	SD
VAL	68 161.40	10 404.10	47 112.70	10 636.50
SPA	1 714.77	221.42	1 723.07	395.92
AGE	20.45	3.36	9.64	5.01
TNI	49.56	36.01	34.99	24.33
TN	7.45	9.53	3.95	5.61
LEQ	54.31	9.56	50.97	5.59
LTEN	57.16	9.49	54.54	6.24
DAYS	24.88	28.23	-	-
LOT	11 383.00	3 013.34	1.28	1.03
BTH	0.61	0.76	0.83	0.49

Northern Virginia Sample

Linear Equation Results

Estimates of the parameters of the linear equation for the Northern Virginia sample (N=206) are summarized in Table 3. Each equation uses basically the same set of physical house characteristics. The first equation compares the prices of houses lying within the 70-dB(A) noise contour with those of houses outside the contour--that is, those further from the highway. The other equations examine the influence of more location-specific noise measures on the market price of houses close to I-495.

For the statistical technique used in this study to perform adequately, several conditions are ideally required. One of the most important is that the explanatory variables and noise measures used to explain differences in market price should not be linearly related. Among the variables describing the physical aspects of housing, the pairwise correlation coefficients are quite low; many are in the range from 0.01 to 0.30. Those between the noise measures and the structural characteristics variables ranged from 0.06 to 0.22, and more powerful statistical tests for independence showed even weaker relationships between noise and the other explanatory variables. Multiple regression of noise on other variables showed correlations in the range from 0.02 to 0.13. This is a stronger test of linear independence than is an examination of pairwise coefficients. Thus, the multiple regression technique should be able to effectively separate noise from other influences on market price.

Structural Attribute Prices

Although estimates of physical or structural attributes are not the primary concern of the study, their inspection is important as a gauge of the reasonableness of the results. Several observations can be made. The first is that the coefficient estimates are consistent with one another in each of the equations. Second, the large majority of variables is significant and of the expected sign. Third, the coefficient estimates appear reasonable on a priori grounds.

Approximately 70 percent of the variation in the market price of housing was explained by the structural and noise variables tested in Equations 1 through 5 as indicated by the R^2 estimates shown in Table 3. Furthermore, the low standard error of

Table 3. Linear estimates: Northern Virginia sample (N=206).

	Equation									
Variable	1	t-Statistic	2	t-Statistic	3[a]	t-Statistic	4[a]	t-Statistic	5[a]	t-Statistic
Constant term	71 172.00	14.63	71 577.00	14.64						
SPA	16.07	6.97	15.90	6.85						
AGE	-873.95	5.43	-884.18	5.47						
LOT	0.19	1.21	0.19	1.21						
BTH	2393.72	3.32	2480.00	3.40						
FIRE	2752.58	4.24	2688.47	4.08						
STYLE	-3955.00	3.97	-3864.90	3.87						
BSMT	-1073.51	1.00	-1012.51	0.94						
NOISE	-379.48	0.41								
TN			-32.49	0.71						
TNI					-8.94	0.74				
LTEN							-94.37	2.10		
LEQ									-44.96	1.00
R^2	0.70		0.70		0.70		0.71		0.70	
Standard error ($)	5809		5804		5803		5747		5796	
f-statistic	57.6		57.7		57.7		59.3		57.9	

Note: For a one-tail test, 2.33 is significant at 0.99; 1.97 is significant at 0.975; 1.65 at 0.95; and 1.29 at 0.90.
[a]Blank cells indicate coefficients and significance levels approximate to those in Equation 1.

$5800 is indicative of the ability of the model to explain housing prices. The reader may at first glance surmise that explaining 70 percent of the variation in market price leaves a great deal unexplained. However, two rebuttals of such a concern are offered:

1. Cross-section studies that use disaggregate data bases and many more variables rarely explain more than 50-60 percent of housing market variation; therefore, by comparison the model tested here performs quite well; and
2. More importantly, the objective of the study is to examine the influence noise has on market price rather than to forecast market price (as noted earlier, the independence of the structural and noise variables used to explain variations in housing prices is sufficient to test for such noise influences).

Noise Influences on Market Price

An obvious test for noise influence is to examine houses inside the 70-dB(A) contour compared with those outside the 70-dB(A) line. (Equation 1 shows a negative but statistically insignificant relationship between houses lying within the noise contour and price.) Such a test, in my opinion, does not adequately reflect potential changes in noise levels for properties located at successively increasing distances from the noise source; therefore, the noise measures in Equations 2 through 5 were tested. The justification for choosing these measures is fairly straightforward. It is reasonable to argue that annoyance might be a key factor regarding how noise might influence consumers' decisions in the market. Further, one can find several suggestions in the literature of noise measures that supposedly correlate well with annoyance (18,23). Among these are the difference between typical ambient or background noise (L_{90}) and that level exceeded 10 percent of the time (L_{10}); L_{eq}, which is the equivalent sound level, usually 2.5-3.5 dB(A) lower than L_{10}; and a traffic noise index that heavily weights variations in noise due to truck stack noise. In addition to these three noise variables, L_{10} was tested as well.

Results in Table 3 show that (L_{10} - L_{90}) = TN, the traffic noise index = TNI, and the equivalent sound level = LEQ are statistically insignificant influences on price within any reasonable confidence levels. Equation 4, however, shows that for the Northern Virginia sample, house prices do appear to be influenced somewhat by the L_{10} noise levels. The coefficient point estimate of $94/decibel is significant at the 97.5 percent level of confidence and suggests that in the relevant range of noise, where the average L_{10} for houses sampled along I-495 is approximately 63, a house that experiences an L_{10} = 69 dB(A) will have a market price of about $565 less [6 dB(A) x $94] than a house with otherwise identical characteristics and an L_{10} noise level = 63. For a house experiencing 80 dB(A) the estimated reduction in price would on average be 17 x $94 = $1598 at 1978 prices.

Log-Linear and Log-Log Equation Results

Because the log-linear functional form is less restrictive as an estimator (see section, Developing an Empirical Test), a summary of results is presented in Table 4. Although they are not shown, estimates for the structural variables (when converted to antilogs) are comparable to the estimates by using the linear equation. The R^2, standard error of the estimate, and the f-statistics are also comparable.

The appropriate interpretation of the parameter estimates on the noise variables is that they are constant elasticity coefficients; more simply, for LTEN the coefficient in Table 4 = -0.0015 means that a 1-dB(A) increase in noise brings about a 0.15 percent reduction in the market price of the property in question. Evaluated at the mean house price for the Northern Virginia sample, this implies that 1 dB(A) is worth $67 360 x 0.0015 = $101.04 at the 97.5 percent level of confidence. As was the case for the linear equation, none of the other noise measures was statistically significant. Table 4 also presents the log-log estimates.

Tidewater Virginia Sample

Results of regression analysis on a sample of 207 house sales in two neighborhoods abutting Denbigh Boulevard and Great Neck Road in the Tidewater area are shown in Table 5. The interpretation of this table is identical to that of the table used to present the results for the Northern Virginia sample.

The results show that, for reasonable levels of confidence (95 percent and above), none of the noise measures used has a statistically significant influ-

Table 4. Estimates summary: Northern Virginia sample (N=206).

	Parameter Estimates			
Variable	Log-Linear[a]	t-Statistic	Log-Log[b]	t-Statistic
NOISE	-0.006	0.44	-	-
TN	-0.0006	0.97	-0.000 1	0.21
TNI	-0.0002	1.02	-0.000 05	0.27
LTEN	-0.0015	2.23	-0.001 0	1.48
LEQ	-0.0008	1.19	-0.000 3	0.45

[a] $R^2 = 0.69$. [b] $R^2 = 0.71$.

Table 5. Estimates summary: Tidewater Virginia sample (N=207).

	Parameter Estimates					
Variable	Linear[a]	t-Statistic	Log-Linear[b]	t-Statistic	Log-Log[c]	t-Statistic
NOISE	-531.75	0.58	-0.013	0.78	-	
TN	-102.07	1.33	-0.002	1.27	-0.0013	0.95
TNI	-22.55	1.27	-0.0004	1.18	-0.0003	0.94
LTEN	-88.26	1.27	-0.0015	1.18	-0.0012	0.96
LEQ	-100.98	1.29	-0.0018	1.18	-0.0014	0.98

[a] $R^2 = 0.69$. [b] $R^2 = 0.70$. [c] $R^2 = 0.71$.

ence on the market price of properties sold in the Tidewater area sample. (The sample was also stratified by high and low property prices and according to neighborhood, but the results still showed an insignificant relationship between price and noise.) However, for confidence levels as low as 85 percent (which policymakers may prefer to accept), noise was significant. Interestingly, at the 85 percent level of confidence the estimated influence per dB(A) was similar to that for the Northern Virginia sample for L_{10}: \$88 ± \$72. These estimates show that, even when one arranges the statistical tests to allow every possible chance for noise to be judged as an important influence on the market price of property, the parameter estimates will not equal large amounts of money. More specifically, these estimates for the Tidewater area show a willingness to pay between \$16 and \$160 per dB(A) with the mean estimate being equal to \$88 to avoid noise.

Results are similar for the log-log equation estimates, which also are shown in Table 5.

IMPLICATIONS OF RESULTS FOR NOISE MITIGATION POLICY

The examination of the results presented earlier, along with financial data on noise barriers previously constructed at the Northern Virginia and Tidewater Virginia sites, suggests three conclusions relevant to future policy on noise mitigation.

First, the regression results presented for the 413 houses at the study sites strongly suggest that the influence of highway noise on the market price of housing is relatively minor. In particular, the reader will recall that only one of the five variables used to test noise sensitivity proved significant for levels of confidence as high as 97.5 percent. For LTEN, the elasticity estimates showed that a 1-dB(A) increase in the L_{10} noise level would reduce the market price for the Northern Virginia houses by approximately 0.15 percent. For a 5-dB(A) difference, the reduction would be about 0.75 percent, or for a \$65 000 house about \$500. For the Tidewater study sites, noise was not a statistically significant influence on price, except for low levels of confidence. A comparison of the results from this study and those of earlier studies of Northern Virginia strengthens the conclusion that noise is a weak influence on housing price. In a 1974 study of properties in Springfield, Virginia, a 5-dB(A) difference was estimated to result in a \$380 reduction in market price (2); in a 1975 study of the same area, the estimates for noise influence were comparable. Given the increase in general housing prices in the period from 1975 to 1979, the estimate obtained in this study of \$94 ± \$88 for 1-dB(A) change is certainly reasonable. Furthermore, in my opinion, the results of these studies offer important evidence about the order of magnitude of the influence of noise on property values. One can strongly argue that empirical evidence supports only small monetary relationships between noise and the market price of housing.

A second conclusion that is important to the establishment of future noise mitigation policy is that past expenditures on noise mitigation have not been reasonably aligned with economic benefits as estimated in this study. The relevance of the estimates developed here is that the market reflects willingness to pay, which is a good monitor of the value of something to consumers--i.e., the benefits received. Thus, the figures presented earlier for the Northern Virginia sample that show a change of 1 dB(A) in the L_{10} noise level at the 97.5 percent level of confidence would be reflected by a change in the market price equal to \$94 ± \$88 [or a maximum change of \$182/dB(A)] give an estimate of what consumers, as they perceive noise nuisance, believe reductions in noise are worth to them as reflected by their decisions in the market. Given this interval estimate, one can compare public expenditures on noise mitigation per house with what the market indicates people are willing to pay to avoid higher levels of noise. In Northern Virginia, for example, one noise barrier was built to protect 60 houses at a total cost of \$436 375 (\$7273/dwelling). Assuming the barrier achieved typical attenuation levels and reduced the L_{10} noise level by 10 dB(A)/house, the maximum estimated benefits are \$182 [10 dB(A)] = \$1820/dwelling. Even with a large margin for error, benefits (as estimated by willingness to pay) are well below \$7300/dwelling.

The third conclusion that relates to noise mitigation policy is that expenditures per dwelling protected have been extremely variable. In the example given previously, the expenditure was about \$7300/dwelling. At two other sites in Northern Virginia differences in design and dwellings protected yielded costs of \$14 919 and \$24 800/household. If economic benefits as reflected by differences in market price between relatively noisy and quiet houses were to have served as technical input to the decision process in these cases, one may have reasonably expected the range of expenditures per dwelling protected to have been smaller.

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Effects of Beltways on the Location of Residences and Selected Workplaces

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Beltways have been cited as factors that encourage the decentralization of people and jobs from central cities and thereby contribute to inefficient patterns of urban development. This study compares changes in total population, manufacturing employment, retail employment, and commuting in 24 standard metropolitan statistical areas, half of which had a beltway constructed during the study period. When the data are divided into a prebeltway and either a beltway construction or a postbeltway period, no statistically significant effects on the central cities are found. The study period is 1950-1970 for population and 1958-1977 for employment; the population data represent an advance on prior research because they have been corrected for annexations by the central cities between 1950 and 1970. Comparison with another statistical study by using regression analysis and eight case studies suggests that other forces such as land use regulation or local opportunities for annexation outweigh the beltway's influence on decentralization.

Energy, environmental, and economic factors have recently created new demands for downtown development. This demand in many cities, however, is felt to be fragile and susceptible to erosion if governmental actions favor suburban areas (1,2). Beltways--high-speed, limited-access highways encircling central cities--have been specifically criticized as