RELATIONSHIPS BETWEEN HIGHWAY NOISE, NOISE MITIGATION, AND RESIDENTIAL HOUSING VALUES

by

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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ABSTRACT

This report 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 I-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 1978-79 at these sites where barriers have since been completed were then used to estimate economic benefits received by property owners.

Among the 413 transactions, in which residences changed hands, only one of five noise measures, the level of noise exceeded 10% of the time (L_{10}), proved to be a statistically significant influence on market price, and this was the case only for houses sold in Northern Virginia. In Tidewater Virginia, the relationship between market price and noise was not statistically significant except at low confidence levels. For the Northern Virginia sample, 1 dB(A) increases in L_{10} noise levels were associated with a 0.15% reduction in the market price of dwellings. Linear regression estimates of market willingness to pay for noise reduction revealed that a 1 dB(A) change in L_{10} levels was valued at approximately \$94 ± \$88 — that is, the maximum consumers willingly pay to avoid noise in the markets studied is about \$182 per dB(A).

Using these estimates as a gauge of economic benefits, recent public expenditures in these markets on highway noise abatement per household far exceed such benefit levels, even for noise reductions of 10 dB(A).

SUMMARY AND CONCLUSIONS

The Federal Aid Highway Act of 1970 mandates that where improvement to highways results in an intrusion of traffic noise into residential communities lying adjacent, an effort must be made to reduce that intrusion. The same law that requires consideration of noise mitigation states that there may be instances where the costs of noise abatement are so excessive compared to the benefits derived that mitigation in the usual sense of the word is impracticable.

The present study was undertaken to provide the Department with some way of gauging the reasonableness of noise mitigation expenditures because of the lack of such information for input to decisions about the construction of noise barriers. While public requests have largely been influential in past decisions, financial information could aid in future decisions about alternatives to the construction of barriers.

After establishing an economic relationship between noise and the market price of housing, detailed data on housing characteristics, prices, and noise were collected for sites along I-495 in Northern Virginia and along Great Neck Road and Denbigh Boulevard in the Tidewater area. The Northern Virginia sample consisted of 206 observations and the Tidewater sample contained 207. The hypothesis that noise reduces the market price of single-family, owner occupied housing was then tested for the two samples using multiple regression analysis.

Five measures of noise were examined for their influence on market price: (1) 70 dB(A) noise levels where exceeded at least 10% of the time (L_{10} value) as compared to lower L_{10} levels of noise; (2) L_{10} noise levels as compared to L_{90} levels ($L_{10} - L_{90}$); (3) L_{10} levels of noise considered alone; (4) an index of traffic noise used in previous studies which heavily weights variations in noise levels due to truck stack noise; and (5) average levels of noise (L_{eq}).

In the Northern Virginia sample, the market price of houses sold was found to be significantly influenced in the statistical sense only by the noise level exceeded 10% of the time. At the 97.5% level of confidence, the estimated influence of noise on market price was \$94 ± \$88 per dB(A). This finding suggests that consumers are willing to pay a maximum of \$182 per decibel to live at quieter locations as opposed to noisier ones along I-495. To illustrate, for the typical case in which the barrier attenuates the L_{10} noise level by 10 dB(A) — that is, for two otherwise identical houses, one of which is half as noisy as the other — consumers appear to be willing to pay up to \$1,820 more for the quieter house.

In the Tidewater sample, noise influences on market price were not statistically different from zero, except at very low levels of confidence. At confidence levels as low as 85%, which those who make policy decisions may prefer to accept,* for the Tidewater sample, L_{10} was, however, significant. Interestingly, at the 85% level of confidence the estimated influence per dB(A) was similar to that for the Northern Virginia sample: $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 to avoid noise of between $16 and $160 per dB(A), with the mean estimate being $88.

The findings of the present study led the author to conclude the following:

1. Estimates of the influence of highway generated noise on the market price of housing will vary among study sites; however, even when the statistical tests for significance are set at very low levels, the levels of noise mitigation which typical barriers produce tend to have little influence on price. Thus, consumers do not appear willing to pay large sums to avoid noise in urban residential housing.

2. If market willingness to pay to avoid noise is used as an indicator of the order of magnitude of the economic benefits from the construction of noise barriers, expenditures on barriers per dwelling protected exceed the estimate of benefits so calculated. For the sites examined in this study, the average expenditure per dwelling protected was $7,440; but, for a reduction of 10 dB(A) in L_{10} noise, which a typical barrier can be expected to produce, the estimate of what consumers willingly pay to avoid such an amount is at most $1,600 to $1,800, and is on average $880 to $940.** While the author agrees that nonmonetary considerations are important to noise

*The acceptability of an 80% or 85% level of statistical confidence simply allows the user to err in the direction of judging noise as being an important influence when it really isn't, rather than to judge it as having no influence when it really does.

**The economic purist may argue that the technique used in this study underestimates true economic benefits by an amount called "consumer's surplus;" however, upward adjustment for this will still result in expenditures far in excess of such benefit estimates.

mitigation decisions, signals from the market can be helpful in assessing the weight which should be given to cost as a decision element.

3. Estimates of the influence of highway noise on residential property values obtained in this study are consistent with those obtained in early studies conducted by other researchers. Those studies estimated the influence of noise to be approximately $65 per dB(A) in 1974. The fact that the results obtained in the early studies as well as those obtained in this study agree suggests that the estimates are not site specific in terms of order of magnitude and that estimates from market data can be used as an aid in decision making.

4. Expenditures on noise abatement were as high as $24,800 per dwelling protected at a site in Northern Virginia. While costs of barriers per linear foot were highly variable, this variability is largely the result of differences in design requirements, and heights; in addition, early efforts at noise mitigation lacked the benefit of the formal process for noise abatement decisions currently used by the Department.

RECOMMENDATION

Because of the controversial nature of the problem studied, only one general recommendation is offered.

1. It is recommended that the joint FHWA VDHT Noise Abatement Study Committee, which has responsibility for the administrative process for decisions related to noise abatement, incorporate the findings and flavor of the conclusions of this study as a technical input factor in their decision process. While the Department's administrative procedure for making noise mitigation decisions, as prompted by FHPM 7-7-3, is well defined, the process can be strengthened by having technical estimates of economic benefits with which costs of alternative abatement features can be compared.

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INTRODUCTION AND PROBLEM STATEMENT

The Federal Aid Highway Act of 1970 directed the Secretary of Transportation to develop and promulgate standards to assure that highways are designed in the overall public interest to achieve noise levels compatible with land uses. Part 772 of Title 23 of the Code of Federal Regulations contains those standards. However, in addition to the standards, the Code emphasizes that final decisions about 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.*

While cost and benefit comparisons have been less influential than public requests in decisions by the Virginia Department of Highways and Transportation concerning the construction of noise walls, experience with the construction of noise barriers in Richmond, Hampton, Newport News, Virginia Beach, Portsmouth, and Springfield suggests that the costs of mitigating noise can be more than an insignificant proportion of the total costs of a highway project. Recent expenditures at these sites total $4,493,824 and many more barriers are in the planning stage.

Cost information, in the absence of estimates of the economic benefits from mitigation, offers decision makers only marginal help regarding what is, in fact, in the public interest as concerns reducing noise pollution from mobile sources. At least one author has attempted to provide evidence regarding the social impacts of noise;(1) yet, the lack of economic data represents a gap in knowledge. While there is a near absence of empirical evidence in the literature, Gamble et al.(2) and Nelson(3) have provided useful information.

There is a strong need to empirically estimate the economic benefit of noise abatement in order to provide information whereby decisions about the construction of noise walls can be rationally approached from the standpoint of both social and economic effects. Without such information in hand, the necessity for some type of barrier to mitigate noise will be assumed from the outset for projects to which noise standards apply, whether or not the provision of a barrier is practical from a financial standpoint.

OBJECTIVES AND SCOPE

The objectives of this study were (1) to empirically estimate the effect of highway generated noise on residential housing values, and (2) to suggest financial criteria for the construction of noise barriers consistent with the estimated benefits 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, which 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 multi-family properties were excluded from the analysis.

METHODOLOGY

Because the methodology employed was so important to the study, it is explained in moderate detail in the subsections which follow. Simply described, the method employed involved —

1. the demonstration of a theoretical relationship between residential property values and noise;

2. the 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. the collection of detailed housing and noise data in areas of Virginia where noise levels are sufficiently high to require consideration of noise mitigation; and

4. the use of multiple regression analysis to estimate the willingness of consumers of housing to pay for quiet as opposed to relatively noisy houses.

The Conceptual Framework

The economic literature is replete with examples of the basic notion upon 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 Alonso,[4] Nelson,[3] Allen,[5] and Henderson and Quandt[6], an economic relationship can be shown to exist between housing services and market price.* 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 which compensate consumers for the differences in the housing services at those locations. To illustrate, consider a consumer faced with choosing between identical housing in separate locations. Assume that accessibility to the employment site has no influence and also assume that the quantity of local public goods supplied and the level of property taxes are the same. If the perceived noise level is higher at one location than the other, the consumer will not be indifferent between the locations, unless the housing at the higher noise location is sufficiently lower in price to compensate for that higher noise level. 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 which will just compensate buyers for the additional noise.** Otherwise the consumer will be better off by living at location 2.

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*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. To illustrate, while two houses may have identical floorspace, one might have a finished family room in the basement while the other might have only a bare storage area. The services from the floorspace of the two houses are quite different even though size is the same.[7]

**For a comprehensive discussion of this idea see references (8) and (9).

Development of An Empirical Test

Having established an economic relationship between the market price of housing, the flow of housing services, and noise, there remains to be developed a method to empirically examine this relationship. While it has been shown that if housing services are identical, which empirically translates to "can be controlled for", differences in noise levels should be reflected by compensating differences in the price of housing, the inclusion of housing services in such a model of residential location does not allow for empirical testing because housing services are not directly observable. Thus, an indirectly observable measure of housing services is required so that the influence of housing services on the price of housing can be separated from the influence of noise.

Arguments in the housing literature which conceptualize that housing is a bundle of diverse items analagous to the description of food as a basket of goods are presented by a number of authors. Among these are Richard Muth,[7] William Alonso,[4] Hays Gamble et al.,[10] A. T. King,[11] and Jon 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.[12,13,14] In the same sense that food consists of many items — bread, steaks, eggs, fish — housing consists of a group of obvious structural characteristics. Unlike the basket of food, however, the attributes, or components, of a housing bundle do not usually have price tags because they are not sold separately, that is, apart from the housing bundle, in the market. The absence of separate markets for these stock components does not, however, preclude relating the price of housing to the attributes of that housing. In fact, it is quite logical that the flow of services is related to the attributes of a particular housing bundle. (While Muth argues that differences in services account for differences in market price, the next logical step is to argue that differences in stock characteristics account for different service flows and thus different prices for housing.) This approach is known technically as hedonic pricing.[15,16,17,18] 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, in turn, help explain variations in price.[16] Assuming that housing services are a function of housing characteristics, one can say that

$$h = f\ (w_1,\ w_2\ .\ .\ .\ w_n), \qquad (1)$$

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 all other 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 above,[5] one can say that

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

where

P_{ij} = the market price of house i at location j;

W_i = the attributes of house i;

A_{ij} = the supply of local public goods;

d_i = the 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} and d_i.

Although the literature gives ample support for the relationship expressed in equation (2), the same cannot be said for the help the literature gives in choosing an appropriate mathematical form by which to test it empirically.[19,20] Only recently has the literature addressed the implications of the use of hedonic pricing on choice of functional forms for empirical testing. However, Muellbauer,[21] Pollak and Wachter,[22] 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.[5]

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

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

3. Estimation of equation (3) with dependent and independent variables in logs. This is the log-log form. (3B)

The Data

The most frequently used data for studies of the type reported here have been derived from the United States Census of Housing.* In such studies, the price of the housing variable is a figure taken from the census and labeled "median value of owner occupied dwelling." This figure is the calculated average of what each interviewed household in the census area estimated the value of its property to be. Usually the independent variables were also average figures taken from the census. Factors included were average number of rooms, average floorspace, and average number of bathrooms. The use of this kind of data for empirical work has received criticism in the literature from two fronts. First, there is very little supportive evidence to show that a homeowner's estimate (for census purposes) of the value of his dwelling is reasonably close to its value on the market. Secondly, Ball, in his recent survey article, is critical of the use of census data in the study of house prices because the use of averaged data, rather than original observations, gives an inflated estimate of the statistical relationship between housing price and the explanatory variables and estimates of the coefficients, which are inefficient although unbiased.(24) Johnson explains that the inflated estimate that results from running an ordinary least squares regression on averaged data simply reflects the fact that the group means tend to be less dispersed around the fitted regression line than individual observations tend to be. He further suggests that where grouped data are used there is always the possibility of incomplete analysis because important variations might be obscured when the regression is run.(25)

The data collected for this study are not, however, subject to these criticisms because individual house transactions were used rather than data from census tracts. Furthermore, 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

*For examples, see references (7), (8), (3), (12), (13), (14), and (23).

developed extensive noise data. Areas that met these requirements were neighborhoods contiguous to I-495 in Northern Virginia, between I-66 and Telegraph Road in Alexandria, the neighborhood contiguous to Denbigh Boulevard in Newport News, and the neighborhoods contiguous to Great Neck Road in Virginia Beach. While the traffic on the highways abutting these neighborhoods differs in terms of volume and speed, the unmitigated noise levels generated are sufficient at each site to require noise mitigation. That is, the noise levels experienced by many households in these neighborhoods would exceed 70 dB(A) without some type of noise attenuator being erected.

Once these sites were selected, an aerial photo of each with the 70 dB(A) noise contour* superimposed upon it was obtained from the Environmental Quality Division. Also, site-specific noise level estimates at different distances from the roadway were developed for each neighborhood from data collected in an earlier Research Council study.[26] Detailed 1978 and 1979 data on house price 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 of 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 can, however, be dropped from the analysis in this study. Two facts allow this simplification:

1. Within the neighborhoods in the Northern Virginia sample and within the neighborhoods in the Tidewater area sample, neither accessibility nor the

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*The 70 dB(A) contour is defined as that area along the roadway which will experience a 70 dB(A) noise level if a noise attenuator is not erected.

supply of local public services (school quality, etc.) varies enough to be expected to influence the price of houses in the respective samples.

2. The Northern Virginia sample is treated separately from the sample drawn from the Tidewater area, thus rendering empirically unimportant the across-sample differences in accessibility and local public goods supplied.

Equation (3) has now been revised for the samples under study to argue that the market price of house A at location B within a neighborhood which abuts a highway which 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 the same for houses within the samples noted above; therefore, empirical testing of these influences on housing price is not necessary either.

The measures of housing characteristics and noise which are used to test the relationship between noise and property values are listed in Table 1.

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 2. 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 to those of houses outside the contour, that is, those further away from the highway. The other equations in Table 2 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 measure used to explain differences in market price should not be linearly related. Otherwise, it is impossible to separate the influence of a particular variable, for example noise, on market price. Such independence is rarely, if ever, exhibited by data bases typically used in empirical research. For this study, however, the collection of a disaggregate data base comprised of a wide variety of house sizes, styles and prices was expected to capture more than adequate variation among the variables used to estimate the model. The correlation matrix presented in Table 3 confirmed that expectation. Among the variables describing the physical aspects of housing, the pairwise correlation coefficients are quite low, many in the range of 0.01 to 0.30. To place these figures in perspective, a correlation coefficient of 0.01 says that between the two variables in question the variation of one explains only 1% of the variation in the other. The pairwise correlations 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.* Thus, the multiple regression technique should be able to effectively separate noise from other influences on market price.

Structural Attribute Prices

While physical or structural attribute estimates 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. Secondly, the large majority of variables are significant and of the expected sign. Thirdly, the coefficient estimates appear reasonable on a priori grounds.

These observations are now examined in more detail. The constant term of approximately $71,000 refers to a house having 3 bedrooms, 1 bath, a carport or garage, central air conditioning, natural gas heat, a formal dining room, brick construction, a full basement, and a style other than a rambler. To gain familiarity with the interpretation of Table 2, the reader can inspect equation (1). For the age variable, the coefficient, -873.95, is to be interpreted as the reduction in the market price of a house due to its age in years compared to a newer house. For example, a house ten years old would sell for 5 times $873.95 = $4,367 less than a house only 5 years old if all other characteristics of the houses are identical. Likewise, a fireplace is worth an additional $2,752, and each extra bath is worth about $2,400. Similar interpretations can be placed on the other coefficient estimates shown. The figure in parentheses is the statistical test for the significance of the variable in question in terms of its ability to explain variations in housing prices; a negative sign on the coefficient signifies that a

*Multiple regression of noise on other variables showed correlations in the range of 0.02 to 0.13. This is a stronger test of linear independence than is an examination of pairwise coefficients.

negative relationship exists between market price and the variable being tested. All of the structural variables showed the expected sign, and with the exception of lot size and type of basement, the variables are significant at the 99% level of confidence. Because lot size was approximately the same for the houses sold, the lack of influence of this variable on market price is not surprising. Approximately 70% 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 1. Furthermore, the low standard error of $5,800 is indicative of the ability of the model to explain housing prices. The reader may at first glance surmise that explaining 70% of the variation in market price leaves a great deal unexplained. However, two rebuttals of such a concern are offered: (1) Cross section studies employing disaggregate data bases and many more variables rarely explain more than 50% to 60% 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 variables 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 as compared to those outside or beyond 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 this author's 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 which supposedly correlate well with annoyance.[23,28] Among these are the difference between typical ambient or background noise (L_{90}) and that level exceeded 10% of the time (L_{10}); L_{eq}, which is the equivalent sound level, usually 2.5 to 3.5 dB(A) lower than L_{10}; and a traffic noise index which heavily weights variations in noise due to truck stack noise. In addition to these three noise variables, L_{10} was tested as well.

Table 1

Variables Used to Test the Influence of Noise on the Market Price of Housing

Variable Name	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 SMSAs[27]

(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

Linear Estimates
Northern Virginia Sample
(N=206)

Equation Variables	1	2	3	4	5
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	2,393.72(3.32)	2,480.00(3.40)	*	*	*
FIRE	2,752.58(4.24)	2,688.47(4.08)	*	*	*
STYLE	-3,955.00(3.97)	-3,864.90(3.87)	*	*	*
BSMT	-1,073.51(1.00)	-1,012.51(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	$5,809.00	$5,804.00	$5,803.00	$5,747.00	$5,796.00
F Statistic	57.6	57.7	57.7	59.3	57.9

NOTE: Figures in parentheses are t statistics. 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.

*Indicates coefficients and significance levels approximate those in equation (1).

Table 3

Correlation Matrix
Northern Virginia Sample
(N=206)

	SPA TNI	AGE LTEN	LOT FIRE	BTH STYLE	NOISE BSMT	TN LEQ
SPA	1.0000 -0.20242	-0.25727 -0.22690	0.14047 0.32350	0.43305 -0.14011	-0.13578 -0.53344	-0.19723 -0.20533
AGE	-0.25727 -0.41290E-01	1.0000 -0.33620E-01	-0.51826 -0.20699	-0.54766 0.35957	0.62220E-01 0.28525	-0.44362E-01 -0.23662E-01
LOT	0.14047 -0.62161E-01	-0.51826 -0.20363E-01	1.0000 0.17148	0.39286 -0.28279	-0.17459 -0.12982	-0.68792E-01 -0.69079E-01
BTH	0.43305 0.31553E-01	-0.54766 0.62443E-02	0.39286 0.29856	1.0000 -0.30455	-0.10518 -0.47150	0.24551E-01 0.21193E-01
NOISE	-0.13578 0.74995	0.62220E-01 0.61552	-0.17459 -0.22189	-0.10518 -0.61802E-01	1.0000 0.17474E-01	0.75414 0.76918
TN	-0.19723 0.99212	-0.44362E-01 0.82802	-0.68792E-01 -0.22535	0.24551E-01 0.36730E-01	0.75414 0.11864	1.0000 0.99064
TNI	-0.20242 1.0000	-0.41290E-01 0.81323	-0.62161E-01 -0.23797	0.31553E-01 0.26857E-01	0.74995 0.11616	0.99212 0.98485
LTEN	-0.22690 0.81323	-0.33620E-01 1.0000	-0.20363E-01 -0.23820	0.62443E-02 -0.35117E-02	0.61552 0.10212	0.82802 0.82893
FIRE	0.32350 -0.23797	-0.20699 -0.23820	0.17148 1.0000	0.29856 0.14345	-0.22189 -0.18642	-0.22535 -0.20873
STYLE	-0.14011 0.26857E-01	0.35957 -0.35117E-02	-0.28279 0.14345	-0.30455 1.0000	-0.61802E-01 0.35589	0.36730E-01 0.45866E-01
BSMT	-0.53344 0.11616	0.28525 0.10212	-0.12982 -0.18642	-0.47150 0.35589	0.17474E-01 1.0000	0.11864 0.12102
LEQ	-0.20533 0.98485	-0.23662E-01 0.82893	-0.69079E-01 -0.20873	0.21193E-01 0.45866E-01	0.76918 0.12102	0.99064 1.0000

Results in Table 2 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 during peak traffic periods. The coefficient point estimate of $94 per decibel is significant at the 97.5% 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 which 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 times $94 = $1,598 at 1978 prices.

Log-linear and Log-log Equation Results

Because the log-linear functional form is less restrictive as an estimator,* results are presented in Table 4. Parameter estimates for the structural variables (when converted to anti-logs) are comparable to the estimates 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% 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 times 0.0015 = $101.04 at the 97.5% level of confidence. As was the case for the linear equation, none of the other noise measures was statistically significant. Appendix Table A-1 presents the log-log estimates.

Noise as an Influence of Length of Time on the Market

One might reasonably expect that houses which experience higher levels of noise than others would remain on the market longer. This hypothesis was tested for the Northern Virginia sample using linear regression analysis.**

*See discussion under the section "Developing an Empirical Test".

**Data on number of days on the market were not available for the sample from Tidewater Virginia.

Table 4

Log-linear Estimates
Northern Virginia Sample
(N=206)

Variables \ Equation	1	2	3	4	5
CONSTANT	11.14(44.00)	*	*	*	*
SPA	0.0002(7.02)	*	*	*	*
AGE	-0.013 (5.17)	*	*	*	*
LOT	0.00005(1.58)	*	*	*	*
BTH	0.024(2.10)	*	*	*	*
FIRE	0.051(4.99	*	*	*	*
STYLE	-0.063(4.02)	*	*	*	*
BASEMENT	-0.023(1.36)	*	*	*	*
NOISE	-0.006(0.44)				
TN		-0.0006(0.97)			
TNI			-0.0002(1.02)		
LTEN				-0.0015(2.23)	
LEQ					-0.0008(1.19)
R^2	0.69	0.69	0.69	0.70	0.69
Standard Error	55.03	55.3	55.3	56.9	55.5
F Statistic	0.091	0.091	0.091	0.09	0.091

NOTE: Figures in parentheses are t statistics. For a one-tail test 2.33 is significant at 0.99 level of confidence, 1.97 is significant at 0.975, 1.65 is significant at 0.95, and 1.29 is significant at 0.90.

*Indicates parameter estimates and significance levels approximate those in equation (1).

Table 5

Correlation Matrix
Tidewater Virginia Sample
(N=207)

	VAL STYLE	AGE CONST	SPA LTEN	BTH TN	PBTH TNI	FIRE LEQ
VAL	1.0000 0.16426	-0.45187 0.10503	0.76840 -0.30794E-01	0.53588 -0.54446E-01	-0.34079E-01 -0.29147E-01	0.44537 -0.13654E-01
AGE	-0.45187 -0.24959	1.0000 -0.28121	-0.36447 0.11183	-0.25737 0.57861E-01	-0.14000E-01 0.10430	-0.30180 0.12333
SPA	0.76840 0.31402	-0.36447 0.33764E-01	1.0000 0.35568E-01	0.60285 -0.25079E-02	0.92808E-01 0.36158E-01	0.33519 0.58113E-01
BTH	0.53588 0.17422	-0.25737 0.85032E-01	0.60285 0.90940E-01	1.0000 0.65482E-01	-0.42992 0.88262E-01	0.18666 0.99812E-01
PBTH	-0.34079E-01 0.20829	-0.14000E-01 -0.47272E-01	0.92808E-01 0.18455E-01	-0.42992 0.17212E-01	1.0000 0.25618E-01	-0.92647E-01 0.34798E-01
FIRE	0.44537 0.19089E-01	-0.30180 0.85641E-01	0.33519 0.73318E-01	0.18666 0.51519E-01	-0.92647E-01 0.72384E-01	1.0000 0.88035E-01
STYLE	0.16426 1.0000	-0.24959 0.29719	0.31402 0.14922E-02	0.17422 -0.17838E-01	0.20829 0.19874E-02	0.19089E-01 0.11737E-01
CONST	0.10503 0.29719	-0.28121 0.10000	0.33764E-01 -0.63491E-01	0.85032E-01 -0.94966E-01	-0.47272E-01 -0.66132E-01	0.85641E-01 -0.51007E-01
LTEN	-0.30794E-01 0.14922E-02	0.11183 -0.63491E-01	0.35568E-01 1.0000	0.90940E-01 0.96544	0.18455E-01 0.99713	0.73318E-01 0.98788
TN	-0.54446E-01 -0.17838E-01	0.57861E-01 -0.94966E-01	-0.25079E-02 0.96544	0.65482E-01 1.0000	0.17212E-01 0.97437	0.51519E-01 0.93915
TNI	-0.29147E-01 0.19874E-02	0.10430 -0.66132E-01	0.36158E-01 0.99713	0.88262E-01 0.97437	0.25618E-01 1.0000	0.72384E-01 0.98940
LEQ	-0.13654E-01 0.11737E-01	0.12333 -0.51007E-01	0.58113E-01 0.98788	0.99812E-01 0.93915	0.34798E-01 0.98940	0.88035E-01 1.0000
NOISE	-0.076	0.15077 -0.0539	-0.209	-0.0398	-0.0639	0.03405

Results showed that for houses having identical sales prices, those lying within the 70 dB(A) noise contour remain on the market about 11 days longer than identical houses lying outside the 70 dB(A) line. Estimates of the relationship between days on the market and the other measures of noise showed that at the 97.5% level of confidence (L_{10} - L_{90}) L_{eq}, and the Traffic Noise Index were statistically significant but L_{10} was not. Coefficient estimates for these noise measures showed that for a 10 dB(A) difference a noisier house would remain on the market about 4 days longer. Regression analysis revealed no statistically significant relationship between price and days on the market.

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 tables 6 and 7. The correlation matrix is presented in Table 5. Interpretation of those tables is identical to the tables used to present the results for the Northern Virginia sample.

The results show that for reasonable levels of confidence (95% and above) none of the noise measures used has a statistically significant influence on the market price of properties sold in the Tidewater area sample.* However, for confidence levels as low as 85% (which those who make policy decisions may prefer to accept**) noise was significant. Interestingly, at the 85% level of confidence the estimated influence per dB(A) was similar to that for the Northern Virginia sample for L_{10}: \$88 $\pm$ \$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 to avoid noise of between \$16 and \$160 per dB(A) with the mean estimate being equal to \$88.

Results are similar for the log-log equation estimates and these are shown in Appendix Table A-2.

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*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.

**The acceptability of an 80% or 85% level of statistical confidence simply allows the policy maker to err in the direction of judging noise as being an important influence when it really isn't, rather than to judge it as having no influence when it really does.

Table 6

Linear Estimates
Tidewater Virginia Sample
(N=207)

Variables \ Equation	1	2	3	4	5
CONSTANT	18,735.00(6.97)	*	*	*	*
SPA	16.15(10.5)	*	*	*	*
AGE	-420.77(4.20)	*	*	*	*
LOT[a]	1,562.21(3.52)	*	*	*	*
BTH	2,030.42(1.88)	*	*	*	*
FIRE	2,693.21(2.98)	*	*	*	*
STYLE	-1,555.58(1.58)	*	*	*	*
CONST	694.80(0.65)	*	*	*	*
NOISE	-531.75(0.58)				
TN		-102.07(1.33)			
TNI			-22.55(1.27)		
LTEN				-88.26(1.27)	
LEQ					-100.98(1.29)
R^2	0.69	0.69	0.69	0.69	0.69
Standard Error	\$6,049	\$6,042	\$6,044	\$6,044	\$6,043
F Statistic	54.8	49.0	48.9	48.9	49.0

[a] In thousands of square feet

NOTE: Figures in parentheses are t statistics. For a one-tail test 2.33 is significant at 0.99 level of confidence, 1.97 is significant at 0.975, 1.65 is significant at 0.95, and 1.29 is significant at 0.90.

*Indicates parameter estimates and significance levels approximate those in equation (1).

Table 7

Log-linear Estimates
Tidewater Virginia Sample
(N=207)

Variables \ Equation	1	2	3	4	5
CONSTANT	10.15(200)	*	*	*	*
SPA	0.0003(9.56)	*	*	*	*
AGE	-0.006(3.43)	*	*	*	*
LOT	0.027(3.19)	*	*	*	*
BTH	0.053(1.99)	*	*	*	*
FIRE	0.073(4.19)	*	*	*	*
STYLE	-0.028(1.48)	*	*	*	*
CONST	0.018(0.90)	*	*	*	*
NOISE	-0.013(0.78)				
TN		0.002(1.27)			
TNI			-0.0004(1.18)		
LTEN				-0.0015(1.18)	
LEQ					-0.0018(1.18)
R^2	0.70	0.70	0.70	0.70	0.69
Standard Error	0.117	0.117	0.117	0.117	0.119
F Statistic	58.2	51.8	51.8	51.8	54.5

NOTE: Figures in parentheses are t statistics. For a one-tail test 2.33 is significant at 0.99 level of confidence, 1.97 is significant at 0.975, 1.65 is significant at 0.95, and 1.29 is significant at 0.90.

*Indicates parameter estimates and significance levels approximate those in equation (1).

IMPLICATIONS OF RESULTS FOR NOISE MITIGATION POLICY

One of the objectives of this study was to suggest financial criteria for the construction of noise barriers consistent with the estimated economic benefits noise walls provide the owners of residential properties close to heavily traveled highways. More generally, this objective can be expanded to provide inferences about noise mitigation policies in the broader sense.

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%. For this variable, LTEN, the elasticity estimates showed that a 1 dB(A) increase in the L_{10} noise level would reduce market price for the Northern Virginia houses by approximately 0.15%. For a 5 dB(A) difference, the reduction would be about 0.75%, 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. Comparison of the results from this study and those of earlier studies 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,[3] and 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 this writer's 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 the market price of housing and noise.

A second conclusion 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 showing that at the 97.5% level of confidence a change of 1 dB(A) in the L_{10} noise level would be reflected by a change in the market price equal to $94 ± $88 (or a maximum change of $182 per

*This confidence interval is based on a point estimate of $94 ± the critical t-value times the standard error of the point estimate.

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 to 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 ($7,273 per dwelling). Assuming the barrier achieved typical attenuation levels and reduced the L_{10} noise level by 10 dB(A) per house, the maximum changes in market price are $182 (10 dB[A]) = $1,820 per dwelling. Even with a large margin for error, benefits (as estimated by willingness to pay) are well below the $7,300 expenditure per dwelling.

The third conclusion which relates to noise mitigation policy is that expenditures per dwelling protected have been extremely variable.* In the example given previously, the expenditure was about $7,300 per dwelling. At two other sites in Northern Virginia differences in design and dwellings protected yielded costs of $14,919 and $24,800 per 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.

CONCLUDING REMARKS

Previously published research on the public perception of noise barriers(1) found that noise attenuation is not as widely perceived as a benefit from barrier construction as are increases in privacy, shielding, and aesthetics. Furthermore, many of those individuals surveyed suggested vegetation as an alternative for barriers.

Clearly, in light of the economic benefit estimates developed in this study as well as the responses gathered from the public, some consideration should be given less expensive alternatives to noise mitigation than that of constructing elaborate barriers. While the nonmonetary impacts of noise have a place in noise mitigation considerations, cost considerations, in the author's opinion, deserve consideration as well.

*See Table 2 reference (1) for financial data on previously constructed barriers.

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Appendix Table A-1
Log-Log Estimates
Northern Virginia Sample
(N=206)

Variables \ Equation	1	2	3	4
CONSTANT	9.56 (22.2)	*	*	*
SPA	0.213(8.13)	*	*	*
AGE	-0.22 (4.74)	*	*	*
LOT	0.087(2.57)	*	*	*
BTH	0.048(1.74)	*	*	*
FIRE	0.047(4.72)	*	*	*
STYLE	-0.054(3.57)	*	*	*
BASEMENT	-0.02 (1.32)	*	*	*
TN	-0.0001(0.21)			
TNI		-0.00005(0.27)		
LTEN			-0.00103(1.48)	
LEQ				-0.0003(0.45)
R^2	0.71	0.71	0.71	0.71
Standard Error	0.089	0.089	0.088	0.089
F Statistic	60.4	60.4	61.3	60.4

NOTE: Figures in parentheses are t statistics. For a one-tail test 2.33 is significant at 0.99 level of confidence, 1.97 is significant at 0.975, 1.65 is significant at 0.95, and 1.29 is significant at 0.90.

*Indicates parameter estimates and significance levels approximate those in equation (1).

Appendix Table A-2
Log-Log Estimates
Tidewater Virginia Sample
(N=207)

Variables / Equation	1	2	3	4
CONSTANT	6.32(18.6)	*	*	*
SPA	0.60(13.0)	*	*	*
AGE	-0.051(4.52)	*	*	*
LOT	-0.027(3.27)	*	*	*
BTH	-0.055(0.95)	*	*	*
FIRE	-0.069(4.09)	*	*	*
STYLE	-0.034(1.84)	*	*	*
CONST	-0.020(0.99)	*	*	*
TN	-0.0013(0.95)			
TNI		-0.0003(0.94)		
LTEN			-0.0012(0.96)	
LEQ				-0.0014(0.98)
R^2	0.71	0.71	0.71	0.69
Standard Error	0.115	0.115	0.115	0.118
F Statistic	60.5	60.5	60.5	74.5

NOTE: Figures in parentheses are t statistics. For a one-tail test 2.33 is significant at 0.99 level of confidence, 1.97 is significant at 0.975, 1.65 is significant at 0.95, and 1.29 is significant at 0.90.

*Indicates parameter estimates and significance levels approximate those in equation (1).