The Effect of Noise Barriers on the Market Value of Adjacent Residential Properties

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The problem of how highway noise affects house prices and how highway noise barriers alter that effect is addressed. The project began with a set of house price data available in the Property Office of the Ontario Ministry of Transportation and Communications. These data were augmented with housing characteristics and sales data obtained from the Toronto Real Estate Board. All of the data were from three residential areas of Toronto situated behind highway noise barriers. In a multiple linear regression, in which a variety of other housing characteristics are controlled for, the coefficient of noise level (in 1981 dollars) varies from –$312/dB at one site to –$356/dB at a second site, to –$2,971/dB at a third site, all of which coefficients are statistically significant at the .05 level. The pooled sample estimate is –$778/dB. The first two values are generally consistent with results of earlier studies, although perhaps a bit lower. Nonlinear regressions of noise level and functions that ignored noise until it was around 65 db were also investigated. Those results supported neither a quadratic function nor any clear threshold effect. Close inspection of the data at the site with a –$2,971/dB value suggests that these data may not be representative of the relevant population, in that expensive houses in high noise environments are not properly represented in the sample. As a result, the extremely large estimated noise penalty is probably a statistical anomaly. Because the pooled sample noise penalty of –$778/dB reflects in part the data from that site, it too may be nonrepresentative of the population noise penalty. It is clear from these data that house sales in areas protected by noise barriers reflect the same kind of valuation of noise as do sales in unprotected noisy areas.

Highway noise is detrimental to those living adjacent to highways. When the noise level is high enough, these effects are severe enough to be reflected in housing prices. Several previous studies have been conducted to estimate these effects, but none have been conducted in areas where highway noise barriers are present.

The main question addressed in this study is whether and to what extent barriers overcome the impact that highway noise has on house prices. In particular, is the dollar-per-decibel effect at locations with noise barriers commensurate with that at sites without barriers? In order to obtain a good answer to this question, the research also considers whether it is correct to speak of a dollar-per-decibel effect (which implies a linearity of effect over the range of the data), or whether the effect is a nonlinear function of the decibel level.

The most relevant of the previous studies for purposes of comparison is the one reported by Taylor et al. in 1982 *(1)* from work done for a master's thesis by Breston at McMaster University. That study utilized data on 2,277 individual housing sales at 51 sites in southern Ontario, and involved collection of highway noise data at those sites specifically for the analysis. The results showed that noise was valued at approximately $250/dB to $300/dB (in 1977 dollars), comparing similar housing at different distances (and therefore noise levels) from the roadway. For the average house price of $60,000, this represents a depreciation rate of 0.5 percent per decibel. Noise-level differences between the first two rows of houses parallel to a highway ranged from 7 to 16 dB in that study, implying that the effect of the noise varied between 3.5 and 8 percent of the price of similar but quieter houses. Because that study was conducted in southern Ontario and used detailed noise-level data, its results should provide the most appropriate comparison for results of the current study.

Nelson *(2)* reports on a study using 1970 census data for 456 tracts for the Washington, D.C., metropolitan area. His results (*2*, p. 95) "imply that a 1 dBA increase in L_{dn} will decrease a given property value by about 0.8 percent, all other things being equal." Unfortunately, this study did not collect noise data and was not based on individual sales data. Instead, census tract data for average sales prices and average housing characteristics were used, and noise levels were estimated on the basis of population densities.

Nelson also provides a summary of three earlier studies of the effects of road traffic noise on house prices, for which the results are all remarkably similar. Gamble et al. *(3)* find decreases in property values of between 0.20 and 0.42 percent/dB, except for one site where the decrease as estimated by the regression equation was 2.22 percent/dB. Anderson and Wise *(4)* obtain a pooled sample result of 0.25 percent/dB, which compares very closely with a pooled sample result of 0.26 percent/dB for Gamble et al. Both Gamble et al. and Anderson and Wise used the same data—individual real estate records for four eastern U.S. communities. The Gamble et al. data were for the period 1969 to 1971, with an average house price of $31,100 across the sample. The Anderson and Wise study covered 1965 to 1971. No average value is available. Within specific sites, however, the Anderson and Wise results varied considerably, from a nonsignificant effect at two sites to as high as 1.0 percent/dB. Vaughn and Huckins *(5)* found results ranging from 0.4 to 0.6 percent/dB, depending on the noise measure and regression form, with a best estimate of about 0.6 percent/dB. They used a Chicago-based sample for 1971 to 1972, with an average house price of $22,500.

This paper is based on data collected at two sites in Toronto, Ontario, with noise barriers and on data from a third site before and after barrier construction. The study began with data

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previously acquired by the Property Office of the Ontario Ministry of Transportation and Communications (MTC). The existence of those data determined the sites to be used for the current study, which was limited to three locations in the Toronto metropolitan area. The first analysis reported here was based solely on the MTC data. A second analysis drew upon additional data for the same three sites collected from the Toronto Real Estate Board. Those analyses are described, starting with the available data for each, comparing these results with those from the earlier studies, and suggesting some possibilities for additional research.

DATA FROM MTC PROPERTY OFFICE

Recent data available in the MTC Property Office files come from three sites in Toronto:

1. Etobicoke along Highway 427 before barrier construction and with a few observations since a concrete barrier was erected,
2. Between Leslie Street and Bayview Avenue along Highway 401 after barrier construction, and
3. Between the Don Valley Parkway and Victoria Park Avenue along Highway 401 after barrier construction.

For these sites, the files contain information on the recent sale price and the date of the sale, the original sale price at the time that the house was first built and the date of that sale, the lot size, and the amount of cash paid as part of the sale.

The first step to prepare these data for a multiple regression analysis of house price on its determinants was to remove the effects of inflation from the house prices over the period covered by the data. Several price indexes were considered for this purpose: the owned-accommodation component of the consumer price index (CPI), the residential construction cost index, and an index of average prices for Toronto real estate sales. The real estate index was chosen for four main reasons. First, it clearly incorporates seasonal effects and the effects of brief periods of speculative activity in the housing market, which neither of the other indexes does. Second, the owned-accommodation index includes many items that are extraneous for consideration of sale price (for example, utility and heating charges and repair costs) and also costs associated with condominium ownership. Third, the construction cost index cannot include the various factors that affect resale prices of housing, such as market demand, because it is based solely on costs of new home construction. Fourth, the real estate index is available for each of the three Toronto sites, making it the index most representative of the price experience of the homes in the study. These factors combine to make the real estate index the best choice for measuring house price behavior.

The Toronto Real Estate Board made available information on the average selling price, for houses only, in each of three districts within Metropolitan Toronto for each month from January 1977 through November 1985. These prices were used to construct a housing price index, using 1981 as the base year. The sale price for each of the individual sales in the file was then converted to 1981 dollars by division by the index value for the month, year, and location of the actual sale.

Several other variables were also added to the data file. Noise data for each site, used in these and later calculations, were obtained from Soren Pedersen of the Highway Design Office of MTC, who generated the values appropriate to each site by using the noise prediction model STAMINA 2.0. In all, 107 observations were available for this analysis.

Two regressions were run to identify the dollar-per-decibel effect. The first used the original sale price as a proxy for the housing characteristics; the second excluded that variable. Results for the two runs are shown in Table 1. The first result to note is that the coefficient of sound is consistent between the two runs: noise is valued at about –$466/dB to –$486/dB. This coefficient is significant in both cases at the 5 percent level, but the sample is small. With a larger sample, one might expect this to be significant at more stringent acceptance levels. This value is reasonably close to that found by Taylor et al. *(1)* of –$312/dB at expressway sites. The difference between that value and the new one may be due either to the variation still present in the current small sample (standard errors of the regression coefficients are about 270) or to general inflation. Taylor's values are in 1977 constant dollars; the ones in this paper are in 1981 dollars. Applying the price index value from June 1977 to Taylor's results would bring them to –$505/dB in 1981 dollars, which is remarkably close to the current results.

However, inspection of the coefficients of the other variables suggests that this particular regression is not the strongest one possible. The coefficients of Toronto West and "detached house" change substantially when "original price" is excluded from the equation, suggesting that original price is correlated with these other variables. The simple correlation matrix confirms this. Although the original price acts to some extent as a proxy for housing characteristics, it is at best an imperfect measure for this purpose, because variation in this variable is due to several factors, including inflation. Because the housing price index does not go back as far as these original sales, many of which took place in the early 1960s, it is not possible to standardize the original price variable to the 1981 base. Although the effects of inflation are removed from the variable on the left-hand side in the regressions, these effects are presented in the original price variable on the right-hand side. Thus, these results with original price, though quite suggestive, argue strongly for expansion of the data set to include a complete set of housing characteristics.

The secondary question for consideration here is whether the noise effect is linear or nonlinear in decibels. There was some indication by Taylor et al. of a threshold noise level below which a noise discount was not found. It seems plausible to expect people to put a larger (negative) dollar value on noise at high levels than at low ones, and it is reasonable to suppose also that levels below 55 dB are not likely to engender may negative reactions or negative pricing. The foregoing analysis implicitly assumes that the same dollar penalty is placed on a 5-dB noise increment at 70 dB as at 50 dB. Four additional regression runs were carried out to consider other possibilities.

The first two of these were based on a suggestion by Eldred *(6)* that the integral over time of the total sound pressure experienced, measured in Pascal-squared seconds, may better reflect individual reaction to noise than a measure based on a logarithmic scale. Eldred's measure contains the assumption that changes in the squared pressure rather than changes in

TABLE 1 RESULTS OF ANALYSIS TO FIND DOLLAR-PER-DECIBEL VALUE: MTC DATA SET

	Including Original Price			Not Including Original Price		
Variable	Regression Coefficient	Std. Error	t value	Regression Coefficient	Std. Error	t value
Original Price	1.90	0.769	2.48	-	-	-
Sound Level	-486.2	267.0	-1.82	-466.0	273.0	-1.70
Lot Area	1.50	1.45	1.03	2.73	1.40	1.95
Toronto Centre	5917.0	3755.0	1.58	6415.0	3845.0	1.67
Toronto West	-10950.0	9739.0	-1.12	-29440.00	6412.0	-4.59
Detached House	10320.0	9607.0	1.07	27780.0	6690.0	4.15
Interest Rate	-39.03	390.0	-0.10	37.42	398.5	0.09
Constant	79890.0	22380.0	3.57	101600.0	21110.0	4.81

decibels are valued equally. For example, moving from 50 to 55 dB would be reflected in a move from roughly 3 to roughly 10 $Pa^2 \cdot$ sec, or an increase of 7 $Pa^2 \cdot$ sec. An increase from 70 to 75 dB would be reflected in this measure in an increase of 680 $Pa^2 \cdot$ sec (from 320 to 1,000 $Pa^2 \cdot$ sec). Clearly the implication is that a given decibel increment at higher decibel values will be evaluated much more severely on this scale than on the logarithmic decibel scale if the coefficient of this variable is significant.

The results appearing in Table 2 for this analysis are not encouraging. Without the original price variable in the equation, Eldred's measure is not significant at any conventional level. Even when original price is included, the t-statistic of the coefficient of sound (–1.34) is still not very close to conventional acceptance levels. On the basis of these data, it appears that house prices are more closely related to decibel measures of sound than to measures based on the total sound pressure experienced.

A second procedure to identify nonlinearity involved use of a set of dummy variables to characterize the sound levels in place of the actual decibel value. Intervals of 3 dB were used, starting at 55 dB and going up to 73 dB. The results (Table 3) suggest that there are some anomalies in this small data set that may be producing misleading results. In particular, the coefficients of the noise variable set in this sample do not show a sensible progression, in that people in this sample are willing to pay more, other things being equal, for a home in the noisiest category than for one a bit quieter. This finding is questionable because only 5 of the 107 sales in the sample are in this noisiest group. The procedure itself, however, has some promise for uncovering nonlinearities in the house price effect of highway noise, as shown by the shift from positive to negative valuations at 60 dB. The current sample is not, however, appropriate to uncover this effect completely.

DATA FROM TORONTO REAL ESTATE BOARD

The Toronto Real Estate Board keeps as part of the historical record of sales a copy of the original Multiple Listing Service (MLS) card on the sale. Thus there is a brief verbal description of key features of the house, as well as a summary of the most relevant characteristics. A university student was hired to collect and code information from that source to be entered into the computer for analysis. Some of the sales in the MTC Property Office file could not be retained in this new data set because they were not carried on the MLS files, and therefore the detailed housing characteristics were not available. On the other hand, because the MLS records spanned a number of years not covered in the MTC studies, there were many more sales for the three sites in the multiple-listing files than were contained in the Property Office reports; thus there is a much larger data base for this analysis. The complete sample based on the Toronto Real Estate Board data acquisition contains 394 observations, of which 136 are from the Highway 427 site, 103 are from the Highway 401 and Leslie Street site, and 155 are from the Highway 401 and Victoria Park site.

The complete list of variables used for the regressions is shown in Table 4. As is clear from this list, the Toronto Real Estate Board sample permits regression estimation of noise

TABLE 2 REGRESSION RESULTS FOR PASCAL-SQUARED SECONDS (ELDRED): MTC DATA SET

	Including Original Price			Not Including Original Price		
Variable	Regression Coefficient	Std. Error	t value	Regression Coefficient	Std. Error	t value
Original Price	1.90	0.78	2.48	-	-	-
Eldred Measure	-0.000394	0.0003	-1.34	-0.00037	0.0003	-1.23
Lot Area	1.53	1.46	1.05	2.75	1.41	1.95
Toronto Centre	6571.0	3750.0	1.75	7048.0	3837.0	1.84
Toronto West	-9931.00	9806.0	-1.01	-28390.0	6424.0	-4.42
Detached House	10856.0	9669.0	1.12	28240.0	6724.0	4.20
Interest Rate	-35.30	388.0	0.09	109.0	397.0	0.28
Constant	48350.0	13100.0	3.69	71260.0	9397.0	7.58

TABLE 3 DUMMY-VARIABLE REGRESSION FOR NOISE LEVELS: MTC DATA SET

	Including Original Price			Not Including Original Price		
Variable	Regression Coefficient	Std. Error	t value	Regression Coefficient	Std. Error	t value
Original Price	1.68	0.79	2.12	-	-	-
Noise Levels:						
58-60.9	2856.0	4177.0	0.68	4783.0	4150.0	1.15
61-63.9	-4087.0	3872.0	-1.06	-3536.0	3933.0	-0.90
64-66.9	-3010.0	4122.0	-0.73	-2671.0	4193.0	-0.64
67-69.9	-6251.0	3761.0	-1.66	-5569.0	3814.0	-1.46
70-72.9	-1565.0	5914.0	-0.27	-100.0	5979.0	-0.02
Toronto Centre	5856.0	4290.0	1.36	5769.0	4367.0	1.32
Lot Area	1.40	1.50	0.93	2.45	1.44	1.70
Toronto West	-11627.0	10222.0	-1.14	-27550.0	7052.0	-3.91
Detached House	10877.0	9965.0	1.09	25720.0	7214.0	3.56
Interest Rate	-152.6	400.0	-0.38	-105.9	407.0	-0.26
Constant	57230.0	14152.0	4.04	77640.0	10550.0	7.36

TABLE 5 REGRESSION COEFFICIENTS FOR FUNCTIONS CONTAINING 24-HR L_{eq} USING ALL 21 VARIABLES FOR THE VICTORIA PARK SITE (N = 155)

Independent variables	Regression coefficient	t-statistic
24-hour L_{eq}	-312.11	-1.68
constant term	93828.00	7.46
1-storey semi-detached	-11834.00	-4.92
2-storey detached	25461.00	6.82
1-car garage	6844.00	3.85
swimming pool	6096.00	3.40
number of rooms	1357.00	1.73
number of bedrooms	1393.00	1.03
mortgage interest rate	257.00	0.98
partly finished basemt	-2792.00	-1.48
number of bathrooms	1984.00	1.17
number of fireplaces	1491.00	0.71
finished basement	-1383.00	-0.78
2-car garage	3343.00	0.80
carport	1253.00	0.71
no. of additional apts	-1920.00	-0.53
shared driveway	1020.00	0.41
2-storey semi-detached	1161.00	0.20
no. of appliances incl	-68.00	-0.18
lot size	-0.0664	-0.11
central air condition	-58.00	-0.04

The adjusted R-squared for the equation is 0.6416

Notes: The implied base case for the regression is a 1-storey detached house with an unfinished basement and a private driveway.

The value of t required for significance at the 5% level for a one-tailed test is 1.645, and for the 1% level is 2.326

its mean for the full sample as shown in Table 4, namely, a 60-dB noise level, a 5,300-ft² lot, seven rooms, 1.5 bathrooms, three bedrooms, one appliance included, and an interest rate of 14.1 percent):

$$\begin{aligned} \text{Price} &= 93{,}828 - 312 * 60 - 0.06639 * 5{,}300 + 1{,}357 * 7 \\ &\quad + 1{,}984 * 1.5 + 1{,}393 * 3 - 68 * 1 + 257 * 14.1 \\ &= \$94{,}966 \end{aligned}$$

This example is a reasonable indication of the nature of the equation. One drawback, however, is that some of the coefficients are not statistically significant in that equation (see Table 5). For example, the coefficient of lot size, –0.06639, has a negative sign, which is contrary to expectations, although it is not significantly different from zero. More important, in some equations, the noise variable itself does not have a significant coefficient. Consequently, it has been chosen to report results based on the equations with all variables entered, as indicated by the result in Table 5. Table 5, however, is the only one that will show all the coefficients. Subsequent discussion will be focused solely on coefficients for the noise variables from similar equations. These coefficients for all four data sets are summarized in Table 6 for three of the noise variables and in Table 7, which describes results for the threshold functions.

The results in Table 6 for all three noise variables for the Victoria Park site are relatively easy to interpret. The 24-hr L_{eq} is significant at the 5 percent confidence level, and its coefficient indicates that each additional decibel reduces the price of a house by, on average, $312.

It is important to be aware that a single coefficient, particularly the one on decibels, cannot be interpreted in isolation. In particular, it is not correct to say from this result that locating a house in a 60-dB neighborhood reduces the selling price by $18,700. The correct interpretation, and the important result of this analysis, is that within the range of data available at this site (roughly 55 to 70 dB, 24-hr L_{eq}), each added decibel decreases house prices by roughly $312. Given that the average house price in the area is $87,187 (in constant 1981 dollars), this translates to a change of 0.35 percent of the house price per decibel. The large product obtained when number of decibels is multiplied by this coefficient also explains the large constant term in the equation.

The second variable used to represent noise is Eldred's measure. This variable is also significant at the 5 percent level. The change in magnitude of the estimated coefficient is a function of the different scale of the underlying noise variable, as discussed earlier. When translated back to its decibel equivalent, this measure gives a nonlinear shape for the relationship.

TABLE 4 VARIABLES USED IN ANALYSIS OF TORONTO REAL ESTATE BOARD DATA AND POOLED SAMPLE CHARACTERISTICS (N = 394)

CATEGORIES, REPRESENTED BY BINARY VARIABLES	percentage of sample in each category
Location in the city:	
West (near Hwy 427)	34.5%
Central (Leslie St)	26.1%
East (Victoria Park)	39.3%
Dwelling type:	
one-storey detached	44.4%
two-storey detached	14.0%
one-storey semi-detached	41.1%
two-storey semi-detached	0.5%
Driveway type	
private	97.0%
shared	3.0%
Size of garage	
single-car	25.9%
two-car	14.7%
carport	10.7%
no garage	48.7%
Basement condition	
finished	51.8%
partly finished	33.2%
unfinished	14.2%
Presence of central air conditioning	24.9%
Presence of a swimming pool	14.5%
VARIABLES MEASURED ON RATIO SCALE	**mean value in sample**
Number of rooms	6.89
Number of bedrooms	3.38
Number of bathrooms	1.64
Number of fireplaces	0.22
Number of appliances included	1.43
Number of additional apartments in the house	0.04
Lot size (sq. ft.)	5307.
Recent sale price (constant 1981 $)	102476.
VARIABLES OBTAINED ELSEWHERE	**mean value in sample**
Calculated sound level at house (dB, 24-h L_{eq})	60.3
Presence of a barrier (absent at most Etobicoke sales)	69.3%
Price index for housing sales (1981 = 100)	0.9517
Interest rate on 5-yr mortgages at time of sale	14.1%

effects while an extensive set of characteristics likely to influence house prices is held constant.

As with the MTC Property Office data set, three measures of noise are used: the 24-hr L_{eq}, Eldred's proposal, and a set of dummy variables. Each one is used in a separate regression equation. As an additional test of whether nonlinear functions of noise might be appropriate, equations are estimated by using a noise variable computed as the difference (in decibels) between the measured level and a threshold level.

The discussion, then, covers four ways of treating the noise variables and involves estimation across four data sets: the Victoria Park Avenue, Etobicoke, and Leslie Street sites, plus the pooled set consisting of all of these. Each of the three sites will be discussed separately and then the pooled results will be considered.

Victoria Park Site

The Victoria Park or Toronto East site has the largest number of observations (155). The complete equation based on 24-hr L_{eq} is shown in Table 5. The implied base case for these estimates is a one-story detached house with an unfinished basement, no air conditioning, no pool, and a private driveway but no garage. For such a house, the equation using the decibel measure yields an estimated selling price (in 1981 dollars) as follows (assuming that each of the other relevant variables had a value close to

TABLE 6 REGRESSION COEFFICIENTS OF NOISE BY AREAS IN TORONTO

Noise measure		Victoria Park site	Etobicoke site	Leslie Street site	Pooled sample
24 hour L_{eq}		-312.11	-356.00	-2970.67	-775.26
		(-1.68)	(-2.36)	(-2.30)	(-3.28)
Pascal-squared seconds		-23.06	-12.33	-99.45	-27.34
		(-1.96)	(2.21)	(-2.05)	(-2.67)
Intervals:	58-60	1816.00	-6809.00	base	1648.00
		(1.072)	(-3.05)	case	(0.59)
	61-63	451.00	1583.00	-18208.00	-6634.00
		(0.16)	(0.68)	(-1.77)	(-1.92)
	64-66	54.00	-5889.00	-7208.00	-4453.00
		(0.03)	(-1.77)	(-0.37)	(-1.23)
	67-69	-3384.00	-3660.00	-20107.00	-9222.00
		(-1.31)	(-1.49)	(-1.69)	(-2.54)
	70-72	zero	-9060.00	-34386.00	-9857.00
		observatns	(-2.19)	(-1.52)	(-1.30)
Sample Size		155	136	103	394

t-values in parentheses

The critical values of t are 1.645 for the .05 level and 2.326 for the .01 level.

This figure led to an attempt at quadratic functions of the 24-hr L_{eq}, which were not supported by the data, as well as the threshold functions reported in Table 7. Not only does the pressure-squared measure produce a nonlinear function (which it should by the very nature of the variable), but also the set of dummy variables representing noise intervals constitutes an approximation to a nonlinear function.

The interval results also suggest some peculiarities of these data at the Victoria Park site, which stand out very clearly in Figure 1 as well as in Table 6. In particular, at one level, an increase in the noise level is associated with an increase in the selling price of the house: moving from levels in the 55- to 57-dB range to levels in the 58- to 60-dB range adds $1,816 to the selling price. However, none of the coefficients for the intervals is statistically significant.

The fourth treatment of the noise variable was by way of a series of regression equations, using a threshold function for noise. The noise variable was defined as

$$x = 0 \quad \text{for } dB < T$$
$$x = dB - T \quad \text{for } dB > T$$

where T is the threshold. Values of the threshold T from 55 to 65 dB were used in steps of 1 dB. These results (Table 7) can be interpreted in two ways. The first is to note that there is very little difference in the adjusted R^2 for any of the equations. Hence an argument could be made that a threshold function is not necessary and offers little improvement over a linear function. The second interpretation focuses on the changes that do occur (in the third and fourth decimal places of the adjusted R^2 and in the t-statistic). In this view, the best threshold for the Victoria Park site is 65 dB, and above that level, additional noise is valued at –$1,804/dB. Selection from among regression equations on the basis of differences in R^2, however, normally requires differences greater than this, and so the first view is probably correct. There is no evidence from these data that nonlinear functions are needed.

Etobicoke Site

The results for the Etobicoke site appearing in Table 6 are largely similar to those just discussed for three of the treatments of the noise variable. The coefficient of 24-hr L_{eq} is –$356/dB, about $40 lower than for the Victoria Park site, but quite comparable. The coefficient of Eldred's measure is significant, although smaller than before. The threshold functions again show a change only in the third decimal place of the adjusted R^2. This time if one were to selected the highest R^2, a threshold of 56 dB would appear to be best. Hence the conjunction of the results for the two sites supports the notion that threshold function is not warranted.

For the set of dummy variables representing noise intervals, however, there is a difference in these results, in that three of the coefficients are significant. The problem of increasing house prices in noisier areas is still present, however—this time for two steps: that from 58–60 dB to 61–63 dB and again in the move from 64–66 dB to 67–69 dB. The anomalous coefficients are not significant, however, and so this may be a problem because of a relatively small sample with a nonrepresentative distribution of prices across the range of noise levels.

Leslie Street Site

The results for the Leslie Street site are quite different from those for the two previous sites. For example, the coefficients of 24-hr L_{eq} and Pascal-squared seconds are roughly an order of

TABLE 7 THRESHOLD CALCULATIONS FOR THE FOUR DATA SETS

Threshold Level, dB	Regression Coefficient ($/dB)	t-statistic	adjusted R-squared
Victoria Park Site			
56	-312	-1.68	.6416
57	-330	-1.83	.6430
58	-349	-1.82	.6428
59	-369	-1.72	.6420
60	-429	-1.75	.6422
61	-524	-1.80	.6427
62	-658	-1.87	.6433
63	-883	-1.96	.6442
64	-1172	-1.93	.6440
65	-1804	-2.07	.6454
Etobicoke			
56	-342	-2.19	.3845
57	-342	-2.03	.3805
58	-350	-1.93	.3797
59	-360	-1.81	.3786
60	-365	-1.67	.3771
61	-403	-1.67	.3770
62	-472	-1.75	.3783
63	-577	-1.88	.3807
64	-660	-1.88	.3805
65	-775	-1.87	.3803
Leslie St. site			
56	-2971	-2.31	.6636
57	-2971	-2.31	.6636
58	-2971	-2.31	.6636
59	-2971	-2.31	.6636
60	-3056	-2.09	.6599
61	-3387	-2.04	.6591
62	-3658	-1.73	.6545
63	-4160	-1.75	.6548
64	-5391	-1.79	.6554
65	-7220	-1.79	.6533
Pooled Sample			
55	-757	-3.23	0.7540
56	-803	-3.24	0.7543
57	-837	-3.35	0.7545
58	-913	-3.43	0.7549
59	-1090	-3.86	0.7569
60	-1148	-3.60	0.7556
61	-1219	-3.36	0.7546
62	-1242	-2.96	0.7529
63	-1409	-2.83	0.7524
64	-1581	-2.61	0.7517
65	-1855	-2.45	0.7511

Notes: The noise variable used in the regression was defined to be zero if less than or equal to the value shown in the left hand column, and (L-threshold) if greater.

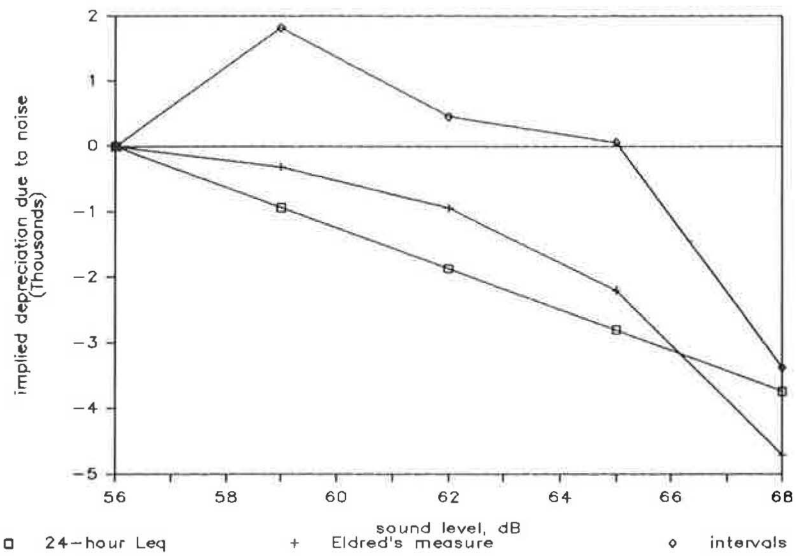

FIGURE 1 House-price effect relative to 55 dB.

magnitude larger than the earlier ones. Likewise the results for the dummy variables and for the threshold functions show much larger coefficients, although otherwise they support the same conclusions as did results for the two previous sites. The question that needs to be addressed is why the coefficients are so much larger at the Leslie Street site.

The first approach attempted was to look for something different about the Leslie Street site. Three possibilities were considered, arising from the fact that noise is highly correlated with distance from the roadway, and that therefore the coefficient of the noise variable may be biased by the omission of some other correlate of housing price in this area that is also related to distance from the road.

The first possibility is that the important difference is in the type of barrier built at the site. The barrier at the Leslie Street site is of green metal, whereas the other two sites have concrete barriers. If such a barrier is deemed to be unpleasant, there may well be a property value effect based on living with it in the backyard as opposed to simply being able to see it as opposed to not being able to see it. This explanation seems unlikely, however.

A second possibility draws on an unusual aspect of the topography at the site. For about half the length of the site, measured along the expressway, the roadway is elevated relative to the housing. Consequently, the barrier is exceedingly high in some of the backyards, and is very dominant visually. It may well be this "Great Wall" effect rather than the green metal barrier material that is leading to the difference, but in the same way just explained for the first possibility.

The third possibility is also based on this unusual topography. The prices for the houses closest to the roadway may reflect some kind of fear of the traffic on the elevated roadway on the part of buyers or prospective buyers and of the prospect of damage or injury from vehicles leaving the road. The prices would then reflect a risk discount in addition to a noise discount.

To test these last two possible explanations, the site was revisited and the exact addresses of the houses that experience this Great Wall effect were recorded with the intention of adding a dummy variable to the analysis to represent it. To the authors' considerable surprise, none of the houses with the "Great Wall" in their backyard was represented in the data file. Therefore, the second and third possibilities can be rejected as irrelevant, and only the first one remains. The only site-related difference identified was the difference in the type of barrier.

There is, however, a second answer to the question of how this difference between areas may arise. There is the possibility that the result is simple a statistical anomaly. There is some tentative support for this view. It can be seen in Table 8 that the sample for the Leslie Street site contains very few observations at high noise levels—only 2 in the 70- to 72-dB range; 11 in the 67- to 69-dB range, and only 2 in the 64- to 66-dB range. Sixty-six percent of the observations fall in the 58- to 60-dB range. These features of the sample raise serious questions about the representativeness of the sample to the population of house prices; a few unusual house prices at high noise levels could easily bias the coefficient of the noise variable.

To further investigate this explanation, the noisiest houses were deleted from the central Toronto sample, and the analyses were rerun. The results are surprising. When all houses experiencing levels of 67 dB or above were deleted, the regression coefficient of 24-hr L_{eq} dropped sharply (and became nonsignificant). This suggests some unusual behavior in the joint distribution of noise levels and house prices, which is shown for the Leslie Street sample in Table 8 and Figure 2, examination of which reveals that at this site the more expensive houses are located in quieter environments. For the 13 data points at noise levels of 67 dB and above, the highest house price (in 1981 constant dollars) is $152,500. Forty-two homes in this sample have higher constant-dollar values (ranging up to $272,000) and all of these are at noise levels below 64 dB. To the extent that higher-valued houses exist at the higher noise levels, this particular sample may be nonrepresentative of the population joint distribution of house prices and noise levels, and thus noise coefficient estimates based on this sample may be seriously biased.

TABLE 8 HOUSE-PRICE AND NOISE-LEVEL DISTRIBUTION FOR LESLIE STREET SITE

	All obs. at site	50K-100K	100K-150K	150K and Up
52-54.9 dB	0	0	0	0
55-57.9 dB	0	0	0	0
58-60.9 dB	68	11	17	40
61-63.9 dB	20	13	5	2
64-66.9 dB	2	1	1	0
67-69.9 dB	11	6	4	1
70-72.9 dB	2	1	1	0
Sample size	103	32	28	43

Note: Values are expressed as frequencies.

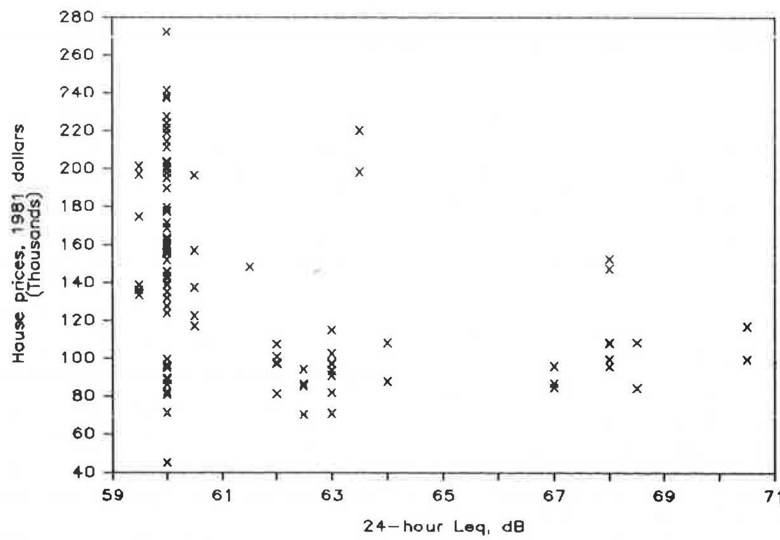

FIGURE 2 Leslie Street data.

Given the scale of Figure 2, a population \$350/dB noise penalty would be consistent with a population regression function with only a slight negative tilt from the horizontal, to reflect a drop of \$4,550 over the 13-dB range from 59 to 72 dB in the Leslie Street sample. It is clear from the scatter, however, that an estimated regression line through these data points will have a much steeper slope than this, because, except for outliers at 64 dB, all of the remaining observations at noise levels of 61 dB and above occur at house prices below \$153,000, with the majority at prices of less than \$120,000. These features lead to the much higher noise penalty (almost \$3,000/dB) than was found at the Etobicoke and Victoria Park sites. It is easy to see in Figure 2 that discarding the high noise observation (at or above 67 dB) only leads to a steeper negative relationship between house prices and noise levels, as was observed in the calculations. Accordingly, the results for the Leslie Street site should be viewed with skepticism.

Pooled Sample

These remarks about the joint distribution of house prices and noise levels for the Leslie Street site also call into question the representativeness of the results estimated for the pooled sample, for example, the coefficient of –\$775/dB for 24-hr L_{eq} (Table 6). It is clear that the Leslie Street sample is the source of the difficulty, because it contains all but one of the high-valued homes, all but one of which have low noise levels. Because the Leslie Street sample forms part of the pooled sample, any bias in the noise effect at that site due to nonrepresentativeness of the sample will be built into the pooled sample noise coefficient; if the Leslie Street sample is nonrepresentative, the value of –\$775/dB simply cannot be generalized to the population as a whole. The same reasoning applies to the other pooled sample coefficients for noise variables in Tables 6 and 7. Basically, because of the nature of the sample at the Leslie Street site, any results that incorporate those data are probably suspect. With a different sample design, this problem might be eliminated. However, given the fact that the sample was not (and could not have been) designed to maximize the variation in the noise levels, or to have representative numbers of observations at each of the several noise levels, it is unavoidable to have problems of this kind, which can strongly affect the results. In the pooled sample only 30 percent of the observations occur in the noisiest four of the seven noise-level categories. This is, of course, to be expected, given the way sound propagates (with equal reductions per doubling of distance, rather than for equal increases of distance away from the source). However, it makes estimating regression coefficients difficult, particularly when housing prices are distributed irregularly as well.

CONCLUSIONS

Two main questions were identified for this paper. Is the dollar-per-decibel value found in other studies of highway noise property values also found at sites with noise barriers? And is it correct to consider property value effects as a linear function of noise? Unfortunately, this study has not been able to provide unequivocal answers to those questions. The general indication is that the results for housing sales behind barriers are consistent with those of other studies, but there are some differences. Linear functions of noise level perform as well as any other function, but one of the nonlinear approaches also performed well.

The main question was whether the dollar-per-decibel effect at locations with noise barriers is consistent with the effect at sites without barriers. The bases for this comparison were described briefly in the introduction to the paper: studies done in the United States summarized by Nelson *(2)*, which reported results in terms of percent change in house price for a 1-dB change in noise level; and the study by Taylor et al. *(1)* conducted in the Toronto area, which reported results in a dollar-per-decibel format. (For the comparison, only the decibel noise measure from this study is appropriate; the other nonlinear measures were not used in the previous studies.)

The various studies reported by Nelson showed effects of noise on house price that ranged from 0.20 to 2.22 percent/dB, with the great bulk of them being between 0.2 and 1.0 percent/dB. Pooled sample estimates varied from 0.25 percent/dB for two studies to 0.8 percent/dB. For the Property Office data set, the results showed a change, on average, of 0.52 percent/dB. For the Real Estate Board data, the changes were 0.335 percent/dB in Victoria Park, 2.10 percent/dB at Leslie Street, 0.39 percent/dB in Etobicoke, and 0.76 percent/dB for the pooled sample. These are broadly consistent, even to having one outlier at a value above 2.0 percent/dB.

Results based on the MTC Property Office data set showed a dollar-per-decibel value of –$466 or –$486. This compared very favorably with the results of Taylor et al. of –$505/dB (in 1981 dollars). The results from the more detailed Toronto Real Estate Board data set are not so close to the Taylor results: dollar-per-decibel values range from –$312 in the Victoria Park sample to –$2,971 at the Leslie Street site, with a pooled sample estimate of –$775 (in 1981 dollars). This is 50 percent higher than in the Taylor study, yet without the Leslie Street data, it appears as though these results would be only about 60 percent of the Taylor (and Property Office data) results.

This leads to some interesting speculation. With coarse data (the MTC Property Office set, lacking housing characteristics), the dollar-per-decibel results for noise barriers are broadly consistent with those of other studies. With more complete data, the new results are generally lower (ignoring the unusual data for the Leslie Street site). If the lower estimate for the noise barrier sites is accepted, this may be partial evidence in favor of a nonlinear function between noise levels and house prices. The Taylor et al. result came from locations where the highest noise levels experienced were all above 70 dB. For the two sites whose results are accepted in this study, only 4 of the 291 observations were at levels above 70 dB. Alternatively, these results may be viewed as partial evidence for the proposition that the noise penalty is lower at barrier sites than at sites without barriers; that is, barriers do matter. However, that must remain speculation; the data are certainly inadequate to provide a clear test of that suggestion.

The overall conclusion is that the results from these analyses are generally consistent with the earlier studies of the house-price effects of road traffic noise. This means that noise barriers appear to be fully effective in improving the aural environment, at least as perceptions of that characteristic are reflected in housing prices.

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