META-ANALYSIS OF AIRPORT NOISE AND HEDONIC PROPERTY VALUES: PROBLEMS AND PROSPECTS

by

Jon P. Nelson
Department of Economics
Pennsylvania State University
University Park, PA 16802
jpn@psu.edu

Abstract

Meta-analysis is applied to the negative relationship between airport noise exposure and residential property values. The effect size in the analysis is the percent depreciation per decibel increase in airport noise, or the noise discount. Twenty hedonic property value studies are analyzed, covering 33 estimates of the noise discount for 23 airports in Canada and the United States. About one-third of the estimates have not been previously reported in the literature or were not included in previous meta-analyses. The weighted-mean noise discount is 0.58% per decibel. A meta-regression analysis examines the variability in the noise discounts that might be due to country, year, sample size, model specification, mean property value, data aggregation, or accessibility to airport employment and travel opportunities. The analysis indicates that country and model specification have some effect on the measured noise discount, but the other variables have little systematic effect. The cumulative noise discount in the U.S. is about 0.5% to 0.6% per decibel at noise exposure levels of 75 dB or less, while in Canada the discount is 0.8 % to 0.9% per decibel.

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Introduction

Aircraft noise continues to be an issue at many airports, especially where capacity expansions are underway or are being considered. In the United States, airport noise exposure has been reduced through operating requirements, quieter aircraft, and by soundproofing or purchase of surrounding residential properties. As a result, the past twenty-five years have seen a dramatic decline in the number of persons exposed to significant noise levels of 65 decibels (dB) or more.[1] However, as of January 2000, the entire U.S. commercial fleet had been converted to Stage 3 aircraft and further mitigation of noise at the source will require investments in improved technologies by airlines. The projected growth of air travel also could slow or reverse the decline in the exposed population, although presently there is considerable uncertainty in these forecasts. According to the Federal Aviation Administration, 75% of large hub airports and 47% of transfer airports have proposed or begun building new runways (FAA, 2002). Because noise is the number one environmental concern at major airports, capacity expansion is often slowed by public concern with noise exposure (GAO, 2000a, 2000b).[2] This concern highlights the importance of valuation of noise effects if expansion decisions are based on economic efficiency criteria and benefit-cost analysis.

Measurement of the economic value of quietude has traditionally focused on the effect of significant noise exposure on residential property values. Using hedonic price analysis, a number of studies have measured this value empirically for airports located in Australia, Canada, Netherlands, United Kingdom, United States, and other countries. First-generation studies for the U.S. employed aggregate census tract and block data, while second-generation studies made use of sales data for individual houses. It can be anticipated that the next generation of hedonic studies will use geographical information systems (GIS), which has been applied to noise

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[1] Since 1979, federal agencies have considered a Day-Night Average Sound Level (DNL) of 75 dB or greater as incompatible with all residential use, except transient lodging (FAA, 1985, 2000; FICUN, 1980; FICON, 1992a). Under the Aviation Safety and Noise Abatement Act of 1979, the FAA adopted the DNL metric and 65 dB compatibility standard. Lands exposed to DNL 65-74 dB are regarded as “normally” incompatible with residential use, while lands exposed to a DNL of less than 65 dB are regarded as “normally” compatible with such use. Further, at 65 dB and above, increases in exposure of 1.5 dB or more are regarded as a significant addition of noise, and require an environmental impact statement.

[2] These problems also exist at smaller airports or where airport conversions have been proposed. See, for example, the controversy in Orange County, CA, surrounding the proposed conversion of the El Toro Marine Air Station to an international airport to compete with Los Angeles International Airport (http://www.eltoroairport.org).

generated by road traffic (Bateman et al., 2002; Lake et al., 2000). Similarly, contingent valuation methods have been used to analyze airport noise valuation, but at present only one such study exists for Canada or the U.S. (Feitelson et al., 1996; see also Navrud, 2002). In light of these recent developments, a first objective of this study is to provide a benchmark that can be compared against results from studies using alternative methodologies.

Hedonic price models have been used to estimate the effects of numerous amenities and disamenities on the value of residential housing.[3] These models exploit the differentiation that exists in housing markets in terms of locational attributes or characteristics of a sample of properties. The model is especially useful if the attribute in question is "localized" such that only a small fraction of the properties within a metropolitan area is affected or exposed (Palmquist, 1992a). For example, noise from a major highway or an airport affects adjacent and nearby properties, while leaving unaffected the general level of urban values.[4] In this case, the hedonic price of the attribute identifies a marginal benefit or willingness-to-pay schedule, which is useful for the evaluation of public policies. Several analytical issues remain regarding: (1) the model specification used to separate the effect of noise from numerous other possible influences on property values; and (2) the transferability of noise abatement benefit estimates across urban markets, regions, or countries. In particular, proximity to an airport also provides access to travel and employment opportunities, and a major airport might be expected to have both positive and negative effects on property values. Ignoring accessibility could result in a downward bias for the effect of noise alone. Further, benefits transfer issues arise with respect to noise abatement projects at specific airports; "full cost" estimates for alternative modes of transportation (Greene et al., 1997; Levinson et al., 1998; NAS, 2002); and benefit-cost analyses of major public policies (Morrison et al., 1999).

Given a large number of hedonic studies of airport noise, problems of model specification and benefit transfers can be addressed using meta-analysis techniques. This paper presents a

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[3] There are a large number of narrative surveys of the hedonic price literature. For surveys of the general model, see Palmquist (1992b) and Sheppard (1999). For recent surveys of externality issues, see Boyle and Kiel (2001), EPA (2000), Freeman (2003), and Palmquist and Smith (2002). Follain and Jimenez (1985) contains a survey of empirical results from two-step estimation of structural demand functions for attributes.

[4] Morrison et al. (1999, p. 734) examined noise exposure maps for 35 major airports in the U.S. They concluded that airport noise typically affects less than 2% of the total number of housing units in a metropolitan area.

meta-analysis of the effect of airport noise on property values in the vicinity of civilian airports in Canada and the United States. Twenty different studies are included in the analysis, providing 33 estimates of the effect of noise. About one-third of the estimates have not been previously reported in the property value literature or included in similar analyses. Average values for the estimates are presented and the variation in the estimates is analyzed using “meta-regression” analysis (Stanley, 2001; Stanley and Jarrell, 1989). Because two previous meta-analyses have considered subsets of the available estimates, the paper also comments on the problems that exist in these studies.

The remainder of the paper is divided into four sections. The next section provides a brief background on hedonic price studies of airport noise and discusses several measurement problems that can arise due to model specification, accessibility, and benefits transfer. This is followed by a discussion of meta-analysis of environmental effects and the average values for the sample of twenty studies. A summary of the shortcomings found in two previous meta-analyses of airport noise also is presented. In the third section, a meta-regression analysis is presented, which sorts out the possible sources of variation in the values. The conclusions from the study are found in the fourth section. Two appendices provide references for the empirical studies included in the analysis and those studies excluded and reasons for the exclusions.

Airport Noise and Property Values

Noise is unwanted or unpleasant sound. At 65 dB and above, the most common human effects associated with aircraft noise are annoyance, speech and learning interference, and sleep disturbance. In turn, these effects disrupt normal daily activities, such as conversation, television viewing, school work, productivity, outdoor recreation and living, and family activities. Annoyance is the adverse psychological response to a given noise exposure, including the anxiety or apprehension that the noise may cause (FICON, 1992b). At noise levels above 75 dB, the Environmental Protection Agency (EPA, 1982) cautions that more severe health effects may occur for some portion of the population, including temporary hearing loss. Those persons who are frequently outdoors are of greatest concern, including young children, retired people in warm climates, and persons in certain outdoor occupations.

Hedonic Model and Noise Annoyance

Consider two residential properties that are identical in all respects, except that one house is located close to or under an aircraft flight path, and the other is not. A **but for analysis** establishes that the adverse environment for the first house will result in a market value that is lower than the market value of the second house. This occurs because potential buyers reduce their demand for the first house relative to the second house, reflecting the discounted present value of the costs of annoyance, loss of tranquility, and possible health effects. A measure of the noise-induced damages is the difference between the market-determined value of the two houses. The analysis can be extended to analyze different levels of noise exposure because annoyance and other adverse effects of noise rise predictably with increased exposure levels (EPA, 1982; FAA, 1985; FICON, 1992a, 1992b). Hence, while there is a missing market for tranquility, a complementary market exists wherein individuals register their willingness to pay to avoid different levels of aircraft noise exposure. Consumers thus **reveal** the implicit value that they place on quietude by the explicit choices that they make in the housing market. The willingness to pay for quietude and other amenities are part of the asset price of the "housing bundle," and econometric techniques are available that unbundle complex products and thereby reveal the implicit or hedonic price. As indicated above, a large empirical literature has developed using the hedonic method.

It is rare that two residential properties will be identical in all respects, except for the pollutant in question. Consequently, in order to isolate a given hedonic price, it is necessary to control statistically for other influences on property values, such as the size of house and lot, quality of construction, design of the house, merits of the neighborhood, quality of local schools, crime rates, governmental services, and so forth.[5] Some of these characteristics will vary little within a given data set, and separate measurement is not required to explain the observed variation in property values. In other cases, the excluded characteristics are uncorrelated or

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[5] A referee argued that the discount associated with an externality, such as noise, could be affected by general housing market conditions in an urban area, such as the presence of strong demand for housing in a "hot" market. Although the direction of the effect is uncertain, this is a general equilibrium issue for which no published empirical evidence seems to exist for aircraft noise. As such the issue is partly one of aggregation across areas that may not be homogeneous with respect to, say, the general level of housing price appreciation. However, as indicated above, properties that are in close proximity to an airport are generally a small proportion of the total housing market for an urban area. For discussion of aggregation issues associated with hedonic property value models, see Bartik and Smith (1987), Freeman (2003), and Palmquist (1992a, 1992b).

orthogonal to noise levels, and exclusion will not bias the resulting estimate of the hedonic price. Given differences in statistical methods, samples, time periods, and urban locations, empirical studies have not produced a singular value for the effects of airport noise on property values. However, hedonic price studies have shown that airport noise has a negative impact on residential property values, and central tendencies can be determined based on the distribution of estimates. Further, meta-analysis can establish the extent to which the variation is systematic.

Each house and lot represents a unique combination of characteristics and locational attributes, which means that the decision to purchase a given property is complex. However, if the characteristics and attributes are provided in various combinations, it is possible to estimate an implicit price function that shows how these values vary conditional on the distribution of a given characteristic. Formally, let V be a sample of observations on housing prices; S is a vector of structural variables (house size, number of bedrooms, lot size, etc.); L is a vector of locational variables; T is a vector of local taxes; G is a vector of local government services; and E is a vector of localized environmental-quality attributes. The market-determined asset value of houses in the sample is given by $V = V(S, L, T, G, E)$. The marginal implicit price for each characteristic represents the increase in expenditures required to obtain one more unit of that characteristic, holding constant all other variables. The marginal price is the partial derivative of the V relationship with respect to the j-th characteristic, or $\partial V/\partial E_j$. A given marginal price could be a constant, but, more generally, it is function of the data.

Many empirical studies employ a non-linear function for property values, either a log-log or a semi-log relationship. The hedonic function for properties in the vicinity of an airport can be represented by $V = b_0 Z^{b1} A^{b2} u_1$, where V is the property value; Z is all other physical and locational characteristics (that is, S, L, T, and G); A is annoyance due to aircraft noise; u_1 is a stochastic error term; and b_0, b_1, and b_2 are parameters. Annoyance can be approximated by the following semi-logarithmic relationship: $A = c_0 e^{c1(DNL)} u_2$, where DNL is the Day-Night Sound Level in decibels; u_2 is a stochastic error term; e is the natural log base; and c_0 and c_1 are parameters (Nelson, 1980).[6] Taking logs of both relationships, and substituting for $\ln A$, yields

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[6] The "Schultz curve" displays the percent of exposed persons highly annoyed as a function of environmental noise (Finegold et al., 1994). The Schultz curve includes low levels of noise exposure (e.g., 40-50 dB), which is the non-linear left-hand tail of the curve. These noise exposures are typically not due to aircraft noise. The semi-log approximation of the Schultz curve is due to Bishop (1966).

the following relationship for property values: $ln\ V = d_0 + d_1(ln\ Z) + d_2\ DNL + u_3$, where $d_2 = b_2\ c_1$, etc. The regression coefficient $d_2 \times 100 = (\partial V/\partial DNL \bullet 1/V) \times 100$ represents the percentage decrease in a given property value due to a one dB increase in noise exposure on the DNL scale.[7] For the log (or semi-log) function, the marginal implicit price is $P = (\partial V/\partial DNL) = d_2 V$. In other words, the marginal price for noise increases as a function of the property value V.

Meta-analysis requires a **common effect size** measure of damages due to airport noise. That is, the outcomes from the set of studies must be expressed in terms of a common metric and its standard error. With some adjustments, the findings of empirical studies of airport noise can be summarized by means of a Noise Depreciation Index (NDI), which is the percentage rate of depreciation per dB (Walters, 1975, p. 102). For two properties that differ but for their level of noise exposure, the absolute amount of housing depreciation per decibel (the unit cost of noise) is given by D = (difference in the total noise discount) ÷ (difference in noise exposure in dB). Dividing D by the price of the given house (or an average house price), the percentage rate of deprecation is given by NDI = (D ÷ property value) × 100 = (difference in total percentage deprecation) ÷ (difference in noise exposure in dB). This is the same result as $d_2 \times 100$ above.

Functional Form Problems

Many empirical studies use the logarithmic (or semi-log) model outlined above, and these studies directly estimate the NDI. The regression coefficient on DNL multiplied by 100 is the percent decrease in a property value due a one dB increase in noise exposure. For example, if the NDI is 1%, a property exposed to 70 dB is worth 10% less than a property exposed to 60 dB, and so forth. However, some studies use a linear functional form, where $V = f_0 + f_1 Z + f_2\ (DNL) + u$. Hence, an estimate of the discount is $NDI = f_2\ (1/V_M) \times 100$, where V_M is, say, the mean value for the sample. As a result, the NDI estimates for studies using a linear form might be systematically different from studies using a log specification. In the meta-analysis, a dummy variable is included for those studies that used a linear functional form.

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[7] This functional form allows the marginal price to depend on the levels of other characteristics of the property. As pointed out by a referee, there is still a possibility that households might substitute among other activities in the face of increased noise exposure, such as reducing the amount of outdoor activity. Some evidence to the contrary is provided by Hoyt and Rosenthal (1997), who demonstrate that U.S. households appear to sort efficiently based on preferences for locational amenities.

Threshold Noise Problems

Because the ear's pattern of response is more nearly logarithmic in nature, decibels are measured on a log scale. The perception of noise doubles in loudness for every 10 dB increase in sound level. An 80 dB sound is perceived to be twice as loud as a 70 dB sound, four times louder than a 60 dB sound, and eight times louder than a 50 dB sound. However, the absence of aircraft noise is not associated with a zero value of the Day-Night Sound Level. The DNL is the average sound level generated by all major environmental noise sources during a 24-hour period, with a 10 dB penalty for nighttime noise events.[8] Noise levels in the vicinity of airports range from about 65 to 80 dB, and noise contour data are generally available in 5 dB increments for this range. Typical background noise levels in urban areas are about 50-60 dB during daytime hours and 40 dB during nighttime. (A level of 50-60 dB corresponds to the noise from light traffic at 100 feet or an air conditioner at 100 feet.) A few studies incorrectly account for the threshold noise level. In most cases, they simply ignore the background level of urban noise and treat it implicitly as zero, rather than 55 or 60 dB. This is especially true where the sample of property values covers a larger portion of an urban area, which leads to a relatively large sample size. A control variable for sample size is used to correct for this problem in the meta-analysis.

Accessibility Specification Problems

Major airports are commercial facilities which have the potential to create significant travel and employment opportunities. Employment opportunities exist at the airport site as well as at commercial facilities that develop in the vicinity of a major airport. For individuals who might work at (or near) the airport or who use the airport for travel, the benefits of proximity can be reflected in residential property values. Because it is possible for an airport to have negative and positive effects on property values, the net effect can be negative or positive. The empirical problem is the extent to which a particular empirical study has separated out the effect of noise from the effect of accessibility (if any). Failure to allow for accessibility could lead to a downward bias in the hedonic price of airport noise.

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[8] Some empirical studies used an older noise metric, the Noise Exposure Forecast (NEF) in A-weighted decibels. The two metrics are highly correlated. The relationship between DNL and NEF is given by DNL = NEF + 35 dB (EPA, 1982). The summaries below reflect this adjustment of noise metrics, and all noise levels are expressed using the DNL metric, regardless of the original metric used in the study.

Previous studies have addressed the accessibility problem in a variety of ways. DeVany (1976) was the first to investigate this issue, and he proposed a solution using a dummy variable specification. Nelson (1979) suggested another solution based on the elongated shape of aircraft noise contours and sampling for limited areas with more or less the same degree of accessibility. Li and Brown (1980) examined the general effects of disamenities and accessibility on property values in the Greater Boston metropolitan area. Several studies of the Manchester Airport (U.K.) have reached conflicting conclusions about the importance of accessibility and noise. In particular, Tomkins et al. (1998) used straight-line distance to the airport as a measure of accessibility. The NDI was 0.78%, but they found that the effect of accessibility was greater for certain properties. Hence, for some properties, the net effect of the Manchester Airport on property values was positive.

The purpose of the present analysis is to **isolate** the effect of noise on property values. Each of the twenty studies was examined for controls on accessibility to the airport. In general, three control methods have been used in past studies. First, many studies exploit the elongated nature of noise contours and select a sample area that holds accessibility constant and allows noise levels to vary importantly. This approach is illustrated by Figure 1, which shows elongated noise contours and circular rings for access to the airport. Note that some properties can have a high degree of proximity, but low or moderate noise levels. As a result, the correlation between noise and accessibility is not necessarily high.[9] Second, some studies use DNL noise contours and straight-line distance to the airport as a measure of accessibility. This solution tends to ignore commercial opportunities that are not located at the airport. Third, dummy variable specifications have been used to isolate the effects of aircraft noise. In the meta-analysis, a dummy variable is included for those studies that entirely ignored the accessibility problem.

Benefit Transfer Problems

Benefit transfer is the general problem of using damage estimates based on primary data from a specific study (or studies) to estimate the benefits of abatement efforts at another setting

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[9] Several of the excluded studies used only the straight-line distance to the airport as a measure of the noise impact of the airport (see Appendix B). The difficulty with this approach is illustrated by Figure 1, which depicts a low correlation between noise and access. For example, using a sample of 424 individual property sales from DeAraujo (1986), I calculated the correlation between aircraft noise exposure and straight-line distance to the Lambert St. Louis International Airport. The simple correlation between noise and distance was only -0.024.

or location (Brookshire and Neill, 1992; Desvousges et al., 1998). Benefit transfers assume that the parameter estimate is applicable in both areas, which requires that the parameter is drawn from a common population, or the estimate can be adjusted to be applicable to the transfer area. Because benefit transfers reduce the costs of decision making, the central issue is the acceptable degree of variability for a set of estimates to be a reliable guide for public policy. In this context, using all of the available estimates of noise damages is probably unwarranted and undesirable. Hence, the present study examines: (1) hedonic price studies of airports in Canada and the U.S.; and (2) studies based on data from 1967 and later. These sample restrictions also facilitate the collection of data for the meta-analysis.

Meta-Analysis of Twenty Studies: Basic Results

Meta-analysis was developed to address the general issue of research synthesis.[10] A meta-analysis combines the findings of studies to assess the magnitude and significance of a measure of effect size. Among the hallmarks of a high quality meta-analysis are **comparability, completeness, and transparency**. A meta-analysis compares studies to identify possible moderators of effect size, such as the sample characteristics, time period, model specification, or location. Meta-analysis also can be used to assess the consistency of research findings by determining the extent to which variation in findings is systematic or due to random factors. However, caution is required regarding the set of estimates that form the basis for the analysis. For example, Johnson and Button (1997) examined a subset of noise damage estimates that included airports in Australia, Canada, U.K., and U.S. They also included studies using data from the early 1960s as well as more recent data sets. Not surprisingly, they concluded that the range of damage estimates is wide. The position in the present study is that a more complete and controlled application of meta-analysis is required before the existing research in this area is cast aside or labeled inadequate for benefit transfers and public policy analysis. Additional comments on previous meta-analyses are presented after the summary of the twenty studies.

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[10] Meta-analysis has seen fairly wide applications in economics, especially for non-market valuation studies in the environmental, natural resource, and transportation areas (Smith and Pattanayak, 2002; van den Bergh et al., 1997). Representative applications include Smith and Huang (1995) on air pollution; Espey et al. (1997) and Dalhuisen (2003) on residential water demand; Rosenberger and Loomis (2001) on outdoor recreation; and Waters (1996) on value of time savings. Standard reference for technical aspects of meta-analysis are Hedges and Olkin (1985), Hedges (1992), and Lipsey and Wilson (2001).

Summary of the Twenty Studies

Table 1 displays information from twenty studies of property values in the vicinity airports in Canada and the U.S. A number of new studies were uncovered by searches using web-based resources, especially *Dissertation Abstracts* (http://wwwlib.umi.com/dissertations). These studies provide 33 estimates of the NDI for 23 different airports. Except for Reno and Rochester, the airports are major facilities for all regions of each country. Some studies use the same data set or cover different aspects of the same study (e.g., the two studies of the Vancouver Airport). In order to avoid problems of statistical dependence, only one estimate is used from these joint cases. Using independent samples, several airports have been studied more than once, including Atlanta, Dallas, Reno, St. Louis, San Francisco, and Washington, D.C. Table 1 also presents relevant information for each study that is used in the meta-regression analysis. This information is discussed below.

Assume N independent studies, each yielding an estimate, $D_{i,}$ of the noise depreciation index I_i, where i = 1, 2, ..., N. In meta-analysis, this outcome is labeled the “effect size” estimate. A “no structure” model or fixed-effects analysis assumes that $I_1 = I_2 = ... = I_N$. That is, each study is estimating an identical, but unknown, true population value of I. Following Hedges and Olkin (1985, p. 111), the asymptotically efficient estimator of I is a weighted-mean of the individual effects D_i, with the optimal weights given by the inverse of the variance of each estimate. The fixed-effects model assumes that this variance is due to sampling error only. The inverse variance weight is $w_i = (1/s_i^2)$, where s_i^2 is the estimated conditional variance of D_i for any i. The weighted-mean and variance are given by

$$D = \sum_{i=1}^{N} w_i D_i \Big/ \sum_{i=1}^{N} w_i \ , \qquad\qquad V(D) = 1 \Big/ \sum_{i=1}^{N} w_i \qquad (1)$$

where *D* is the cumulative effect size and *V(D)* is its variance. As indicated, these estimates are obtained without imposing any structure on the data.

In order to test for equivalence of effect sizes among the studies, Hedges and Olkin (1985, p. 123) suggest the following homogeneity test statistic

$$Q = \sum_{i=1}^{N} w_i \left(D_i - D\right)^2 \tag{2}$$

which has a chi-square distribution with N –1 degrees of freedom. If Q is large, the null hypothesis is rejected and the fixed-effects model is inappropriate; i.e., each study may not be estimating the same population value and a single cumulative estimate is inappropriate. A significant Q indicates that the variance among the effect sizes is greater than expected due to sampling error alone.

If homogeneity of the estimates is rejected, several alternatives to the fixed-effects model can be considered for a given data set. A meta-regression analysis seeks to explain categorical within-study variability, while a “random-effects” analysis incorporates both the within-study variability and sampling variation that may be due to an underlying population of effect sizes, i.e., the between-study variability. In a random-effects model, the random component of the effect-size variation is calculated and incorporated into the summary statistics. A brief discussion of these alternative models follows.

In a meta-regression, the studies are grouped together according to one or more differentiating characteristics or predictors (e.g., time period, country, linear vs. log specification, etc.). The true effect size is assumed to a function of the predictors, i.e., each estimate D_i is an unbiased estimate of I_i. The general form of the meta-regression model is

$$D_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \ldots + \beta_P X_{iP} + \varepsilon_i\ , i = 1,\ldots, N \tag{3}$$

where (X_{i1}, X_{i2}, ..., X_{iP}) is a vector of predictor variables, which typically are dummies; (β_0, β_1, ..., β_P) are unknown parameters; and ϵ_i is a random error term with zero mean and constant variance. The estimates of the parameters are obtained using a weighted least-squares model. Tests or comparisons can be made to determine if the effect sizes are heterogeneous **after** removing the variability associated with the predictor variables. If the effect sizes are homogeneous conditional on the predictor variables, the regression constant term β_0 is an estimate of the “true” effect size. The results of a meta-regression analysis are reported in the next section.

A second alternative is a random-effects analysis, which allows for random variation in the true effect size from one study to another. Each estimate D_i is a draw from the same statistical distribution for I. The true effect sizes are not assumed to be identical, but rather to be observations of the same statistical distribution. Application of random-effects analysis requires an estimate of the unknown variance due to sampling, and the total variance, v_i^*, is the sum of the random or between-studies variance and the within-study variance. The inverse variance weight is given by $w_i^* = (1/v_i^*)$. Hence, random-effects analyses involve greater variance around the average estimate and weaker results generally. Subjective statements about the results also are weaker, such as “on average, the effect size is D,” or “in most cases, the effect size is D.”

Hedges and Olkin (1985, p.) recommend the following method-of-moments estimate of the random-effects variance component

$$v_I = \frac{Q - (N-1)}{\sum w_i - (\sum w_i^2 / \sum w_i)} \qquad (4)$$

where Q is the value of the homogeneity test statistic in (2); N is the number of effect size estimates; and w_i is the inverse variance-weight defined above. Previous meta-analyses of airport noise have ignored random-effects models.

The bottom row of Table 1 summarizes the results for the fixed-effects and random-effects models. The unweighted mean NDI (standard deviation) is 0.75 (.295) and the median is 0.67. The fixed-effects weighted-mean NDI is 0.58 (.041). The Q statistic is 31.868, and the null hypothesis of homogeneity is rejected at the 5% confidence level. The random-effects variance component is only 0.0015, which is added to the variance of each effect size to obtain the total variance. Using this new set of weights, the random-effects weighed mean NDI is 0.59 (.043). Hence, application of the random-effects model does not alter the summary statistics in a substantial manner. The “no structure” model suggests an NDI of about 0.60% per dB, which is a cumulative sum of 31 estimates in Table 1. The fixed-effect 95% confidence interval is 0.58 ± 0.080, which yields a fairly tight range of estimates from 0.50 to 0.64% per dB. Hence, further analysis of the variability in Table 1 requires a meta-regression analysis.

Comparisons With Previous Meta-Analyses

The results in Table 1 can be compared to those reported in three previous studies. Nelson (1980) summarized NDI estimates from thirteen studies covering 18 airports, including Australia (2 estimates), Canada (2), U.K. (1), and U.S. (13). Only unweighted means were calculated, although pooled results were presented for six U.S. airports. The study concluded that "... the noise discount is commonly 0.5 - 0.6%, although a higher value may occur in some high-income areas" (Nelson, 1980, p. 46). This result compares favorably with the estimates derived in Table 1. However, a second study by Johnson and Button (1997) reached a different conclusion. Their study covered 18 estimates of the NDI for airports located in Australia (1 estimate), Canada (5), U.K. (3), and U.S. (9). They presented a fixed-effects regression with three predictor variables, but none of the predictors were statistically significant and the observations were not weighted.[11] A random effects analysis was not included. Despite the limited nature of the analysis, the study concluded that "... the results provide little by way of overall explanation for variability in results" (Johnson and Button, 1997, p. 228).

A third study provided a more ambitious application of meta-analysis. Schipper et al. (1998) examined nineteen studies that provide 30 NDI estimates for airports located in Australia (2 estimates), Canada (5), U.K. (2) and U.S. (21). Standard errors for the NDI estimates were not reported. The simple mean NDI was 0.83 (.72), but this result is affected by one very large estimate for London and by several estimates from the time period of the early 1960s. The median NDI was 0.61. The Q test rejected homogeneity, but the authors did not report the weighted mean. Weighted least-squares were used to obtain the effect of four predictor variables on the variation of the NDIs, but the constant term is inexplicably negative. The most important predictor variable was the "relative mean sample house price," which is the mean sample house price divided by per capita income. This variable is interpreted as a measure of buying power. However, there are two reasons why the variable is misspecified: (1) the value of a house is itself a measure of household permanent income; and (2) the authors fail to explain how they estimate

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[11] The simple mean NDI in Johnson and Button (1997, p. 229) is 0.68, but standard errors of the NDIs are not reported. Further, results in several studies are misreported (e.g., Nelson, 1979; Paik, 1972) and other relevant studies are omitted (e.g., Nelson, 1978). In related work, Button and Nijkamp (1997) pooled estimates of the NDI for airport noise with estimates for road traffic noise. They failed to report standard errors for the regression analysis of this sample. The subjective nature of these studies is inconsistent with the objectives of meta-analysis, which stresses comparability, completeness, and transparency.

per capita income for studies that use disaggregate data for individual houses. Dividing the mean value of a house by the average level of per capita income in the entire urban area is clearly a misspecification. A predictor variable for log-linear and semi-log functional forms had a significantly negative sign and the year of publication had a significantly positive sign. A dummy variable for studies that use data for 1960 (e.g., Paik 1972) was positive and weakly significant. The study concluded that "... the noise depreciation is larger for locations or samples that have a larger average house price" (Schipper et al., 1998, p. 121). This conclusion must be questioned due to the problems associated with the specification of the relative house price variable and the significantly negative intercept term.

In summary, two previous meta-analyses covered a variety of countries and dates. Neither study considered the effect of accessibility on the estimates of the NDIs. Statistical results are incompletely reported. The present study restricts the sample by country and years to better insure a homogeneous sample. The remainder of the paper seeks to improve the regression analysis by expanding the sample to include several new studies, and by reconsidering the effects of average house price, accessibility, and other influences on the range of estimates.

Meta-Regression Analysis

This section presents a fixed-effects regression analysis of the studies in Table 1, which covers 33 NDI estimates for airports in Canada (7 estimates) and the U.S. (26 estimates). All estimates are for the year 1967 and later. About one-third of the NDI estimates have not been previously reported in the literature. Table 1 presents the following information set that is relevant for application of meta-regression analysis:

Sample Characteristics

- Airport and country (area if applicable)
- Sample time period
- Sample size
- Census data or individual sales
- Mean property value (2000 U.S. dollars)

Econometric Specification and Results

- NDI estimate (absolute value) and standard error (page no. for estimates)
- Logarithmic vs. linear functional form
- Coefficient of determination (R-square)
- Specification for airport accessibility ("no" means explicit adjustment is absent)

Given this information set, a regression analysis was conducted for a sample of 29-31 observations. (Two estimates are deleted due to lack of mean property values and two estimates are omitted in some regressions due to lack of standard error estimates.) Results are reported for three different corrections for heteroscedasticity: (1) White's heteroscedastic-consistent standard errors; (2) weighted least-squares using inverse variance weights; and (3) weighted least-squares using inverse standard error weights. The residuals are assessed using the Jarque-Bera statistic for normality. The overall fit of the regression model is assessed by a standard F-test, which is equivalent to a partitioning of Q into explained and unexplained portions (Lipsey and Wilson, 2001, p. 123). I also report two additional diagnostics for the quality of the regressions, which are White's heteroscedasticity test and Ramsey's RESET test for specification error bias.

Table 2 shows the results of six regressions, which illustrate different treatments of heteroscedasticity and model specification. Regressions (1) and (2) do not use a weighted least-squares method, but standard errors are computed by White's heteroscedastic-consistent estimator. The quality of these two regressions is poor as judged by the high p-values for the F-test and the low p-values for the Jacques-Bera normality test. Only the constant term is significant in regression (1), while the constant and average real property value are significant in regression (2). The two dummy variables for aggregate census data and 1967-1970 data performed poorly in regression (2), and have been omitted from the other regressions.

Regressions (3) and (4) are estimated by weighted least-squares using inverse variance weights. The summary and diagnostic statistics indicate high-quality regressions on all counts. The only qualification is an outlier among the residuals, which is due to the NDI estimate by Fromme (1978) for Washington, D.C. Regression (3) has a significant constant of 0.53, and the coefficients for linear models and Canada are both significantly positive. There is some overlap between sample size and the access dummy variable. When the latter variable is dropped from the model, the constant term declines slightly to 0.51 in regression (4). The coefficient magnitudes for linear models and Canada are not affected. Regressions (5) and (6) show the results using inverse standard error weights. Although a strong case can be made for this weighting scheme (Saxonhouse, 1976), the overall results are somewhat poorer as judged by the F-test and RESET test. The constants in regressions (5) and (6) are 0.65 and 0.67, respectively.

The main result in Table 2 is a significant and positive constant term that lies between 0.51 and 0.67. Using regression (4), the 95% confidence interval for the constant term is 0.28 to

0.79, which includes 22 of the 33 estimates in Table 1. Three of the estimates that lie outside of this range are based on a linear functional form, including Los Angeles and New York City, and four of the outliers involve Canadian airports. The NDIs from linear models required an estimate of the effect size based on the mean property value. The NDI estimates for Canada may reflect special or unique features of Canadian real estate markets, climate, or operating conditions (curfews, frequency). The other outliers are two estimates for Washington, D.C.; one estimate for Rochester; and one estimate for Dallas. Hence, there are the only four estimates for three airports that are unexplained by the meta-regression model. Using the constant terms in regressions (4) and (6), the effect of airport noise on U.S. property values is 0.51% and 0.67% per dB, respectively, which compare favorably to the weighted-mean of 0.58% per dB in Table 1.

Conclusions

The results in the present study are consistent with an earlier contribution by the author (Nelson, 1980), which concluded that the noise discount was about 0.50 to 0.60% per dB. The present study expands the sample of estimates from 18 to 33, including a doubling of the number of estimates for U.S. airports. Although a number of estimates in Table 1 employ data for the 1970s, there does not seem to a measurable effect of time on the NDIs. Hence, a given property located at 55 dB would sell for about 10-12 percent less if it was located at 75 dB, all other things held constant. Stated differently, under these same circumstances, a $200,000 house would sell for $20,000 to $24,000 less, which yields a hedonic price of $1000 to $1200 per dB. The noise discount in Canada appears to be greater, 0.80 to 0.90% per dB, and may reflect differences in legal rules as well as other economic differences.

It remains to be shown that the results in this paper are robust in the face of other analytical methods, such as GIS studies, contingent valuation methods, and new hedonic studies that consider spatial autocorrelation of housing prices (Salvi, 2003). Further, empirical estimation of structural demand models has not been applied to noise avoidance, although additional progress has been made on the theoretical front (Sheppard, 1999). Lastly, caution should be exercised in applying the estimates in this paper to residential areas near airports that are affected by noise in excess of 75 dB. Survey studies by Feitelson et al. (1996) and Frankel (1991) suggests that the noise discount per dB could be substantially higher where the level of noise exposure makes land virtually unsuitable for any residential use.

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Appendix A
Hedonic Studies Included in Table 1

Biggs, A.J.G. (1990): *The Impact of Airport Noise: A Case Study of Vancouver International Airport*, Unpublished M.S. thesis, University of British Columbia.

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Appendix B
Hedonic Studies Excluded from the Meta-Analysis

Al-Khabbaz, A.A. (1987): *Modeling Aviation Facilities Impact on Residential Property Values*, Unpublished Ph.D. dissertation, University of Arizona. [Only distance measures used to obtain noise impacts.]

Clark, D.E. and W.E. Herrin (2000): "The Impact of Public School Attributes on Home Sale Prices in California," *Growth and Change*, 31, 385-407. [Only distance measures used to obtain noise impacts.]

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Lane, T. (1998): "The Impact of Airport Operations on Land Values: A Case Study of Seattle Tacoma International Airport," Paper presented at the 32nd Annual Pacific Northwest Regional Economic Conference, Olympia, WA. [Only distance measures used to obtain noise impacts.]

Li, M.M. and H.J. Brown (1980): "Micro-Neighborhood Externalities and Hedonic Housing Prices," *Land Economics*, 56, 125-41. [Noise estimates are apparently due to traffic and general noise.]

McClure, P.T. (1969): *Some Projected Effects of Jet Noise on Residential Property Near Los Angeles International Airport by 1970*, P-4083, RAND Corp., Santa Monica, CA. [Could not compute an NDI.]

McDougall, G.S. (1976): "An Inquiry into the Demand for Aircraft Noise Abatement," *Review of Regional Studies*, 6, 59-69. [Could not compute an NDI.]

Paik, I.K. (1972): *Measurement of Environmental Externality in Particular Reference to Noise*, Unpublished Ph.D. dissertation, Georgetown University. [Uses census data for 1960.]

West, R.J. (1988): "Statistical Inference: An Avigation Easement Analysis," *Real Estate Issues*, 13, 35-39. [Could not compute an NDI.]

Table 1

Meta-Analysis of Airport Noise and Property Values
(NDI = % depreciation per decibel)

Study (publication date & page no.)	*Airport (& area)*	*Study period (smpl size)*	*Data type*	*Mean property value (2000 US $)*	*NDI %: abs value (std err)*	*Dep. variable (R-sq)*	*Access adjust?*
BAH-FAA (1994, p18)	Baltimore	1990 (30)	ind. prop.	$123,698 ($170,703)	1.07 (.823)	linear (0.91)	Yes (1)
BAH-FAA (1994, p22)	Los Angeles	1991 (24)	ind. prop.	$351,062 ($449,359)	1.26 (.788)	linear (0.83)	Yes (1)
BAH-FAA (1994, p27)	New York (JFK)	1993 (30)	ind. prop.	$422,500 ($523,900)	1.20 (na)	linear (0.77)	Yes (1)
BAH-FAA (1994, p27)	New York (La Guardia)	1993 (30)	ind. prop.	$222,534 ($275,942)	0.67 (na)	linear (0.57)	Yes (1)
Blaylock (1977, p79)	Dallas	1970 (4,264)	census blocks	$25,000 ($136,250)	0.99 (.330)*	linear (0.82)	Yes (2)
DeVany (1976, p213); NAS (1977, p139)	Dallas	1970 (1,270)	census blocks	$22,000 ($119,900)	0.80 (.267)*	linear (0.82)	Yes (3)
Dygert (1973, p105)	San Francisco (San Mateo)	1970 (82)	census tracts	$27,600 ($150,420)	0.50 (.250)*	log (0.66)	Yes (2)
Dygert (1973, p113)	San Jose	1970 (98)	census tracts	$21,000 ($114,450)	0.70 (.422)*	log (0.67)	Yes (2)
Emerson (1969, p68; 1972, p271)	Minneapolis	1967 (222)	ind. prop.	$19,683 ($132,270)	0.58 (.366)	log (0.80)	Yes (1)
Fromme (1978, p100)	Wash. DC (National)	1970 (28)	census tracts	$30,068 ($163,871)	1.49 (.753)*	log (0.75)	Yes (1)
Kaufman (1996, p33); Espey & Lopez (2000)	Reno	1991-95 (1,596)	ind. prop.	$110,970 ($137,603)	0.28 (.183)	log (0.85)	Yes (2)
Levesque (1994, p207)	Winnipeg	1985-86 (1,635)	ind. prop.	$72,316 CN$ ($70,104)	1.30 (.342)*	log (0.80)	No
Mark (1980, p112)	St. Louis	1969-70 (6,553)	ind prop.	$15,015 ($81,832)	0.56 (.240)*	log (0.67)	No
Maser et al. (1977, p130); Quinlan (1970)	Rochester (urban)	1971 (398)	ind. prop.	$19,100 ($99,893)	0.86 (.319)*	linear (0.62)	No
Maser et al. (1977, p130); Quinlan (1970)	Rochester (suburban)	1971 (990)	ind. prop.	$21,800 ($114,014)	0.68 (.279)*	linear (0.84)	No
McMillian et al. (1980, p319);McMillan (1979)	Edmonton	1975-76 (352)	ind. prop.	$51,933 CN$ ($108,730)	0.51 (.224)*	log (0.71)	No
Mieszkowski & Saper (1978, p430)	Toronto (Mississauga)	1969-73 (509)	ind. prop.	$31,450 CN$ ($89,982)	0.87 (.212)*	log (0.90)	Yes (1)
Mieszkowski & Saper (1978, p430)	Toronto (Etobicoke)	1969-73 (611)	ind. prop.	$37,770 CN$ ($108,063)	0.95 (.187)*	log (0.92)	Yes (1)
Myles (1997, p21)	Reno	1991 (4,332)	ind. prop.	$135,000 ($178,200)	0.37 (.111)*	log (0.74)	No

Table 1
(Continued)

Nelson (1978, p98)	Wash. DC (National)	1970 (52)	census tracts	$27,455 ($149,630)	1.06 (.714)	log (0.86)	Yes (1)
Nelson (1979, p325; 1980, p45)	Buffalo	1970 (126)	census blocks	$20,656 ($112,575)	0.52 (.200)*	log (0.61)	Yes (1)
Nelson (1979, p325; 1980, p45)	Cleveland	1970 (185)	census blocks	$20,898 ($113,894)	0.29 (.128)*	log (0.89)	Yes (1)
Nelson (1979, p325; 1980, p45)	New Orleans	1970 (143)	census blocks	$21,975 ($119,763)	0.40 (.195)*	log (0.75)	Yes (1)
Nelson (1979, p325; 1980, p45)	St. Louis	1970 (113)	census blocks	$16,411 ($89,440)	0.51 (.267)*	log (0.74)	Yes (1)
Nelson (1979, p325; 1980, p45)	San Diego	1970 (125)	census blocks	$32,241 ($175,713)	0.74 (.233)*	log (0.76)	Yes (1)
Nelson (1979, p325; 1980, p45)	San Francisco	1970 (153)	census blocks	$29,686 ($161,789)	0.58 (.184)*	log (0.71)	Yes (1)
Nelson (1979, p327; 1980, p69; 1981)	Six airports	1970 (845)	census blocks	$23,713 ($129,236)	0.55 (.200)	log (0.84)	Yes (2)
O'Byrne et al. (1985, p175)	Atlanta (blocks)	1970 (248)	census blocks	$18,964 ($103,354)	0.64 (.200)*	log (0.74)	No
O'Byrne et al. (1985, p173)	Atlanta (houses)	1979-80 (96)	ind. prop.	$28,889 ($81,178)	0.67 (.300)*	log (0.71)	Yes (1)
Price (1974, p40 & 59)	Boston (rentals)	1970 (270)	census tracts	$103 per month (na)	0.81 (.238)*	linear (0.50)	No
Tarassoff (1993, p83)	Montreal	1989-90 (427)	ind. prop.	$148,525 CN$ ($118,985)	0.65 (.325)*	linear (0.64)	No
Uyeno et al. (1993, p9); Biggs (1990, p136)	Vancouver (houses)	1987-88 (645)	ind. prop.	$139,100 CN$ ($124,076)	0.65 (.164)*	log (0.64)	Yes (2)
Uyeno et al. (1993, p11)	Vancouver (condos)	1987-88 (907)	ind. condos	n.a.	0.90 (.323)*	log (0.79)	Yes (2)
Mean NDI (sd) – unwt.					0.75 (.295)*		
Median NDI – unwt.					0.67		
Wt. mean NDI (sd)					0.58 (.041)*		
Q statistic					31.868		
Random effect variance					0.0033		
Random effect mean					0.59 (.043)*		

Notes: All individual housing values are actual sales or list prices, except for Baltimore where professional appraisal values are used; the census values are based on self-appraisals by owner-occupants. Asterisks indicate that the t-statistic > 2.0. The mean property values were obtained by inflating by the consumer price index (CPI-U) and, if necessary, converting to Canadian dollars using the exchange rate in 2000. All other data and information are obtained from the individual studies as listed in the table. See text for explanation of accessibility adjustments and for explanation of the calculation of the means. The critical value for the Q statistic at the 5% confidence level is 19.01.

Table 2

Meta-Regression Results for the Noise Depreciation Index (NDI)

Variable	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
Constant	0.8316 (.3062)*	0.7020 (.2969)*	0.5332 (.1893)*	0.5069 (.1425)*	0.6466 (.2254)*	0.6651 (.2043)*
Mean real property value (× .001)	0.0006 (.0004)	0.0008 (.0004)*	-0.0001 (.0013)	-0.0001 (.0013)	-0.0002 (.0012)	-0.0002 (.0011)
Accessibility dummy (no adj =1)	-0.0106 (.1207)	0.0100 (.1363)	0.0196 (.0900)	---	-0.0208 (.0959)	---
Sample size (log)	-0.0504 (.0469)	-0.0475 (.0447)	-0.0186 (.0342)	-0.0140 (.0261)	-0.0231 (.0336)	-0.0272 (.0274)
Linear model dummy (linear =1)	0.1862 (.1180)	0.2021 (.1175)	0.3320 (.1579)*	0.3340 (.1544)*	0.3035 (.1225)*	0.3004 (.1192)*
Country dummy (Canada = 1)	0.2236 (.1354)	0.2708 (.1600)	0.3389 (.0834)*	0.3357 (.0805)*	0.2797 (.0939)*	0.2807 (.0919)*
Census data dummy (census=1)	---	0.0502 (.1406)	---	---	---	---
Year dummy (1967-70 = 1)	---	0.0553 (.1653)	---	---	---	---
R-sq	0.309	0.322	0.774	0.773	0.234	0.233
F-test (p value)	0.083	0.196	0.002	0.001	0.023	0.010
RESET test (p)	0.322	0.470	0.129	0.202	0.088	0.062
White test (p)	0.171	0.123	0.500	0.420	0.509	0.397
J-B test (p)	0.041	0.042	0.141	0.146	0.530	0.502
Weights used	White se	White se	inv. var.	inv. var.	inv. se	inv. se
Sample size	31	31	29	29	29	29
Mean dep. var. (sd)	0.739 (.303)	0.739 (.303)	0.568 (.370)	0.568 (.370)	0.632 (.223)	0.632 (.223)

Notes: Dependent variable is the absolute value of the noise depreciation index (NDI) from Table 1. Asterisks indicate that the t-statistic > 2.0. Sample size = 31 omits two studies without a mean property value estimate and sample size = 29 omits additionally two studies without a standard error estimate. F-statistic for the test of joint significance of all regressors; the null hypothesis is jointly insignificant. RESET test for specification error bias; the null hypothesis is no bias. White's test statistic for heteroscedastic residuals; the null hypothesis is no heteroscedasticity. Jarque-Bera (J-B) test statistic for normally distributed residuals; the null hypothesis is normality.

FIGURE 1

Airport Noise Contours and Accessibility Rings