Hedonic Property Value Studies of Transportation Noise: Aircraft and Road Traffic

by

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2.1 Introduction

Noise from aircraft and road traffic is an example of an uncompensated external cost or externality. A negative externality is defined as a by-product of production or consumption activities that adversely affects third parties not directly involved in the associated market transactions. Environmental noises that exceed ambient levels can disturb valuable activities such as conversation, TV viewing, leisure, work or sleep, and in severe cases can have adverse effects on long-term health and thereby reduce productivity and quality of life.[1] The third parties can take defensive steps to avoid the physical effects of noise, such as screening their property using fencing or vegetation, installing air conditioning and insulation, or moving to a new residence. A role of economics is to help determine the socially optimal amount of noise and the appropriate mixture of source abatement, operational changes, and housing adjustments (relocation, zoning, soundproofing). Recent legislative changes, such as the European Commission's "Green Paper on Future Noise Policy" (EC 1996) and Directive 2002/49/EC on noise assessment (EC 2002), have focused attention on noise valuation as part of benefit-cost analyses of mitigation projects. The information from valuation studies also can be used for cost-effective policy design, including the choice between regulations and noise pollution taxes.

[1] The unit of sound intensity is the decibel (dB), measured on a logarithmic scale. A tenfold increase in sound intensity is a 10 dB increase or roughly a doubling of perceived loudness. Sound-levels are weighted to account for human ability to hear sounds of different frequencies, e.g., the A-weighted sound level is used to describe sounds from transportation sources. Representative sound levels are a quiet suburban street (50 dBA); conversational speech at 3 feet (60 dBA); freight train at 100 feet (70 dBA); and busy city cross-streets (80 dBA). The statistical distribution of noise also is described by the levels in dBA exceed 10, 50, and 90% of the time: L_{10} (peak level), L_{50} (median), and L_{90} (background). Lastly, the day-night average sound level (DNL or L_{DN}) is the *equivalent* energy-averaged sound level (L_{EQ}) in dBA during a 24-hour period, with a 10 dB penalty for nighttime noise. "Equivalent" means the acoustical energy of the average steady-state sound equals the energy from the actual sounds.

Valuation of noise damages would be relatively straightforward if an explicit private market existed for tranquility, but in general this market is missing. In simple cases, a market can be created by assigning clearly-defined legal rights to either the polluter or the polluted. Aircraft operators and their customers value the surrounding airspace as an input to air travel and freight operations, and would be willing to pay for legal rights to ensure that the airspace is available for these purposes (Gillen 2003). For different reasons, airport neighbors also value the surrounding environment and would be willing to pay for their right to use the resource. Thus, in the absence of transaction costs, market exchange would solve the problem of noise abatement. However, the airspace is an example of a common property resource, where there is little or no delineation of use rights for private parties (Cheung 1987). Absent private ownership, the main alternative for allocation of common property is some system of government ownership and regulation. Regulation means that airports and their neighbors are given "rank" to enjoy different rights and privileges, which creates valuable implicit property rights. Under the Aviation Safety and Noise Act of 1979, the US Federal Aviation Administration declared 65 L_{DN} as the critical day-night average sound level for aircraft noise regulation, although evidence from complaints suggests that some fraction of the population is annoyed by lower noise levels. Due to increased transportation activity, income growth, and other economic changes, government ownership creates pressure for new abatement regulations and endogenous changes in rank. Economic analysis and valuation methods have the promise to provide objectivity in this essentially political process.

Economic valuation methods are divided into two categories: revealed preference methods such as the hedonic price (HP) method for housing values; and stated preference (SP) methods such as contingent valuation surveys. Revealed preference methods exploit the fact that there are private markets that are complementary to noise avoidance, including the market for residential housing. Suppose a house either has a quiet residential environment or it does not. The difference in market values of an identical house in these two environments yields an implicit discount for noise, which compensates the occupants of the noisy house. Informed market participants reveal this price as a result of purchase and sale decisions in the market for real estate. The sorting of buyers and sellers in a stable noise environment produces an outcome in which noisy houses tend to be occupied by individuals who have a low willingness to pay for quietude (imperturbables) and quiet houses tend to be occupied by those with a high willingness to pay. A change in the noise environment alters the relative supply of noisy and quiet houses, and creates a new equilibrium outcome. In practice, environmental conditions in residential neighborhoods are more complex. Noise is a localized public bad, so fixed proportions between houses and noises do not exist (Walters 1975). Potential buyers of houses can choose to live close to a busy highway or airport, far from these facilities, or somewhere in-between. They also can choose houses with physical attributes that partially offset the effects of noise, such as double-glazed windows and central air conditioning. Furthermore, relocation is not costless and future noise levels are uncertain. The differences in housing values and noise levels yields a “noise discount” that falls as distance from an airport or highway increases. Regression analysis of real estate transactions is used to unbundle housing prices and calculate an implicit hedonic price for quiet. A difference in market value of $20000 and a difference in noise exposure of 10 dB results in a hedonic price of $2000 per dB, other things being equal. In order to avoid use of nominal values, this price is often expressed as a percentage of a base house (Walters 1975; Nelson 1980). If the market value of the house without noise is $200 000 and its value with noise is $180 000, the Noise Depreciation Index (NDI) is 1.0% per dB.

The main alternatives to hedonic valuation are survey methods that ask respondents to state their willingness to pay for environmental improvements, including the contingent valuation method, contingent ranking, conjoint analysis, and other SP models. These methods are still relatively new, but several survey-based studies of noise valuation are available. While the purpose of this paper is to critically review recent studies using hedonic valuation methods, it is useful to include results from SP studies. An examination of survey-based results also serves to illustrate the strengths and weaknesses of the HP method. The next two sections of this paper provide a brief history of hedonic valuation of noise and a topical outline. This is followed by a five-part discussion of issues that confront empirical researchers in this area.

2.2 Early HP Noise Studies and Prior Literature Reviews

Although the basic concepts date to 1939 and earlier, Rosen’s (1974) classic article on product differentiation and competition was an important theoretical contribution that formed the basis for much of the empirical work on housing markets using the HP model. Rosen’s paper raised several theoretical issues that have not been entirely resolved, including the concept of two-stage estimation. Prior literature reviews that emphasize theoretical and welfare issues associated with the HP model include Freeman (1993), Haab and McConnell (2002), Palmquist (2005), and Taylor (2003, 2008). There also have been several reviews of the empirical literature, including Boyle and Kiel (2001), Palmquist and Smith (2002), and Pearce et al. (2006).

The first major application of HP methods to aircraft noise was Emerson’s (1972) study of housing sales for 1967 in the vicinity of the Minneapolis-St. Paul International Airport. Another early study by Paik (1972) examined housing values in US census data for 1960 for three areas: John F. Kennedy Airport, New York; Los Angeles International Airport; and Love Field Airport, Dallas. This early work was followed by HP studies of San Francisco International Airport (Dygert 1973), Toronto International Airport (Crowley 1973), National Airport, Washington, DC (Nelson 1975, 1978), and Heathrow Airport, London (Gautrin 1975). The latter study is notable for the analysis of the tradeoff between accessibility and noise disamenities. Reflecting possible access effects, a few studies have obtained a null effect of aircraft noise (Lipscomb 2003; Tomkins et al. 1998; van Praag and Baarsma 2005).

Although several limited studies of highway noise and house prices appeared before Gamble et al. (1974), this was the first major study that applied HP methods to road traffic noise. They studied US interstate highways in four communities in New Jersey, Virginia, and Maryland. Other early work includes HP studies of traffic noise for Washington, DC (Nelson 1975, 1978), Chicago (Vaughan and Huckins 1975), and Toronto (Taylor et al. 1980), and a repeat-sales analysis for Spokane, Washington, by Palmquist (1982). The repeat-sales model is derived from the HP model by observing the sale of the same house at two or more points in time. Early European studies include a 1974 study for Stockholm by Hammar (cited in Navrud 2002) and a study of Copenhagen by Hjorth-Andersen (1978).

2.2.1 Meta-Analyses of Transportation Noise

By the year 2007, there were approximately 40 HP studies for airports in Canada and the US, and probably an equal number for non-North American airports. The aircraft noise literature was previously reviewed by Bateman et al. (2001), Nellthorp et al. (2007), Nelson (1978, 1980, 2004), Schipper (1999), and Schipper et al. (1998). Nelson (2004) conducted a meta-analysis of 33 estimates of the noise discount for 23 airports in Canada and the US. Using a variety of meta-analytical techniques, the NDI was between 0.50 and 0.70% per dB, with a weighted-effect size of about 0.67%.

The HP literature on road traffic noise has been reviewed by Bateman et al. (2001), Bertrand (1997), Navrud (2002), Nelson (1978, 1982), and Tinch (1995). Nelson (1982) reviewed nine empirical studies covering fourteen different housing markets in Canada and the US. The mean NDI was 0.40% per dB. Using a formal meta-analysis, Bertrand (1997) compared 16 estimates from nine different HP studies. His work suggests an NDI for traffic noise as high as 0.64%. An empirical issue to be explored in the present survey is the extent to which more recent studies have altered the NDIs for aircraft and traffic noise. With this in mind, selected NDI values are reported for various studies and summarized at the end of the survey.

2.3 Research Outline

Following Rosen (1974), Freeman (1993), and Palmquist (2005), consumer preferences and the variety of available houses combine to produce an equilibrium hedonic price function. This function may be linear or non-linear. Individuals affect the price they pay for a house by choosing a different bundle of characteristics. However, as price-takers in a competitive market, they cannot affect equilibrium price schedules for characteristics. Thus, the heterogeneous nature of housing does not destroy the basic notion of a competitive price, and as a first approximation, estimation of the hedonic price function does not require socioeconomic data on the individuals residing in each house.

Empirically, there are two functions that are of interest. First, the hedonic price schedule can be estimated using data on prices of houses and their characteristics, including neighborhood attributes, accessibility, and environmental variables. From this schedule, marginal prices are calculated. Second, marginal prices can be combined with data on occupants' income and other socioeconomic variables to estimate an inverse demand or willingness to pay function. Ideally, inverse demands for all N characteristics are estimated jointly as a system of demand functions. Only a few HP studies for noise have estimated second-stage demand functions; see Day et al. (2007), McMillan (1979), Pommerehne (1988), and Wilhelmsson (2002). However, welfare measurements are possible using only marginal prices if the environmental change affects a small number of houses relative to the size of the market (Palmquist 1992a, 1992b). This is the case of a localized externality. Further, transaction and moving costs must be small enough so that the welfare gains are not offset by costs. If these costs are prohibitive, this places an upper-bound on the welfare change. In this paper, I assume that noise is a localized externality, but transaction and moving costs are discussed below in Sect. 6. Noise mitigation projects that affect large areas add complexity to the problem of welfare measurement using either HP or SP methods (Palmquist 2005).

Given this stylized model, five empirical issues are identified for additional discussion: spatial heterogeneity and housing market segmentation; spatial autoregression and autocorrelation; housing market adjustment models; alternative noise indices and community annoyance; and stated preference methods and hedonic prices.

2.4 Spatial Heterogeneity: Housing Market Segmentation

A housing market can be identified by a uniform hedonic price schedule, which is determined by the housing stock that makes up the market and characteristics of the occupants and neighborhood. An old issue in real estate economics is the existence and measurement of housing submarkets or market segmentation. A metropolitan housing market might be segmented according to structure type, structural characteristics, neighborhood amenities and disamenities, age of occupants, income, occupational or social class, and ethnic or racial identity (Goodman and Thibodeau 1998). Unlike many consumer products, houses are durable, infrequently traded, and short-run supplies are relatively fixed. Furthermore, alterations of physical features ("repackaging") is only possible within certain limits and many neighborhood attributes are either fixed or change slowly and infrequently over time. Spatial heterogeneity for hedonic prices is more likely to occur when households' demand for a particular characteristic is price inelastic and this preference is shared by a relatively large number of potential homeowners or renters (Day 2003). Early HP studies often used small samples that covered limited geographic areas, such as residential areas in close proximity to a major airport or busy highway. In these settings, segmentation is less likely to arise due to homogeneity of the sample of houses, neighborhood attributes, and occupants. However, the advent of GIS methods and computer-based data sets has resulted in study samples that cover entire metropolitan areas and include thousands of housing sales and numerous locational variables. Empirical researchers are no longer faced with problems of a paucity of data and lack of variation, but instead must try to identify order amongst an abundance of sample observations.

The standard econometric test for homogeneity is the Chow F-test, but this test assumes that the model is correctly specified with regard to variables and functional form. Palmquist (2005) argues that an F-test will almost always reject homogeneity, given a large sample size. He suggests that investigators think about the types of transactions that are crucial to the environmental issue being addressed, and this might mean focusing on smaller areas or some subset of the sample. Similarly, a few noise studies have involved individuals from the real estate industry as a source of information about housing submarkets (Day et al. 2004; Feitelson et al. 1996). Also, rejection of the null for the overall regression need not imply a lack of uniformity for individual coefficients for submarkets. For individual coefficients, a Tiao-Goldberger F-test can be used (see Nelson 1979, 1981; Palmquist 1992a).

Baranzini and Ramirez (2005) examine the economic impact of noise in the Geneva market for apartments. A special feature of the Swiss housing market is the high proportion of renter-occupied housing (about 60-65%). They study the effects of road traffic noise on apartment rents using a sample of 13034 apartments covering more than 7000 buildings for the canton of Geneva. They also study the effects of airport noise for a restricted sample of 1847 apartments. For the larger sample, there are 10394 apartments in the private sector and 2640 "public" apartments, which are subject to government regulation in the form of subsidized construction grants, rent controls, and occupant restrictions. The traffic noise data contains information on the day-night sound level

(L_{DN}) at each building's facade, peak noise intrusiveness measured by (L_{10} - L_{90}), and an EU-version of the day-night metric, L_{DEN} , which includes a 5-dB penalty for evening noise. The background noise level is 50 dB. Baranzini and Ramirez estimate semilog regressions for the two full samples and separate regressions for private and public submarkets. A Chow test confirms that there are statistical differences between the two submarkets. The regressions account for eight structural variables (number of rooms, floor level, age of building, etc.), four access variables, air pollution, and noise. For traffic noise, an increase in the mean noise level by one dB reduces private sector rents by 0.63% and public sector rents by 0.65%, which suggests that private and public apartments are in the same market for noise avoidance. However, the full sample NDI is substantially different, which supports the use of submarkets. The impact of airport noise is 0.66% and 0.79% per dB in the private and public submarkets. These NDI values agree substantially with prior studies.

A similar exercise for traffic noise is found in Rich and Nielsen (2004). Their initial sample covers 845 houses and 906 apartments in Copenhagen (40% of Danes live in apartments), but a 50 dB cutoff for background noise reduces the final samples to 238 houses and 472 apartments. The noise measure is the Danish equivalent of L_{DEN}. Rich and Nielsen argue that houses and apartments appeal to different consumer segments and statistical results show that the two markets are different. A non-linear Box-Cox function is used for the regressions, with two structural variables for each structure type, eight accessibility variables, seven neighborhood dummy variables, and traffic noise. Accounting for the non-linear relationship, the NDIs are 0.47% for apartments and 0.54% per dB for houses. A similar study by Grue et al. (1997) for Oslo obtains comparable results. The estimated NDIs are 0.24% for public apartments, 0.48% for private apartments, and 0.54% per dB for houses.

A more sophisticated approach to market segmentation is found in a series of papers by Day (2003) and Day et al. (2006) for Glasgow, Scotland, and Bateman et al. (2004) and Day et al. (2007) for Birmingham, England. The Glasgow sample covers 3544 houses sold in 1986 and the Birmingham sample covers 10889 residential dwelling sales in 1997. The environmental data include noise from aircraft, road traffic, and railroads. The background noise level is 55 dB. Due to the large number of socioeconomic and neighborhood variables, these studies use factor analysis to reduce the number of data dimensions. In order to identify submarkets that are similar structurally or locationally, the studies also use cluster analysis. For Glasgow, there are four clusters: tenements occupied by ethnically Scottish residents; tenements occupied by ethnic minorities; larger urban properties occupied by upwardly-mobile young professionals; and larger properties in affluent suburban areas. For Birmingham, there are eight clusters defined by ethnic identity, age of occupants, wealth (affluent, poor), size of property (standard, large), and geographic location (north, south, west).

Using a semilog model, separate OLS regressions are estimated for each submarket and the full sample. For Glasgow, a Chow test rejects the null and indicates the HP estimates are significantly different for each cluster. The traffic noise coefficients yield NDI values of -0.23, -0.46, -0.57, and a positive value of 0.38% per dB. A Tiao-Goldberger F-test rejects the null of uniform noise coefficients, even when the positive coefficient is excluded. A second set of estimates accounts for spatial autocorrelation and is obtained by using a generalized method of moments (GMM) estimator. Traffic noise coefficients are significantly negative for three of the four submarkets, with NDIs of -0.30, -0.47, -0.58, and 0.31% per dB. These values are quite close to the OLS estimates, except that significance levels increase. Aircraft noise is statistically negative for only one submarket, with a negative NDI of 0.40% per dB. For Birmingham, the regressions are based on a semiparametric model that accounts for spatial autocorrelation. Traffic and rail noise is significantly negative for five of eight submarkets and airport noise is significantly negative for only two submarkets. The traffic noise NDIs for Birmingham are in the range 0.18 to 0.55% per dB, which agrees generally with the estimates for Glasgow. The airport noise NDIs are 1.60% and 0.63% per dB.

Some of the results in these studies suggest that market segmentation is an important empirical issue for future researchers. However, the long list of locational and neighborhood variables are somewhat at a variance with the objectives of spatial modeling. Further, the non-linear nature of the hedonic price function will complicate tests for market segmentation. Advanced methods, such as those employed for Glasgow and Birmingham, are necessary to provide a convincing case for a segmented market.

2.5 Spatial Models: Autoregression and Autocorrelation

Econometric estimation of HP models by OLS requires, among other assumptions, the independence of residual errors. However, residuals in hedonic models are frequently spatially correlated or nonspherical, which means the OLS estimator is unbiased but inefficient and estimates of standard errors are biased. The most likely outcome is that residuals are positively correlated, which biases standard errors downward. Hence, confidence levels (t-statistics) for the coefficients are overstated, and confidence intervals and predicted values are understated. Spatially dependent errors can arise because (1) houses in close proximity to each other share common structural and neighborhood characteristics, so that disturbances are transmitted over space, and (2) the residuals contain systematic spatial information that is not captured by the regression model. For example, residences in the same geographic space share common environmental amenities and disamenities or houses may occupy similar locations in characteristics space, leading to a spatial-lag dependence (SLD) model.

Furthermore, it is unlikely that all locational features and other relevant spatial variables are observed and quantified, which leads to an omitted variables problem. This results in a spatial-error dependence (SED) model. A similar argument applies if locational variables are measured with error. Finally, "adjacency effects" are spatial spillovers that are capitalized into housing prices, such as maintenance decisions by neighbors (Can 1992). In this case, spatial-lag dependence is endogenous and OLS coefficients are biased and inefficient.

Some of these problems can be overcome by increasing the number of locational variables, but this is not necessarily an efficient solution due to attendant collinearity problems. Some empirical applications omit all neighborhood-accessibility variables, and model the resulting autocorrelation in the error term (Dubin 1992). In general, it is expected that residual correlations decline as separation distance increases, reflecting a process of distance decay (Tobler's first law of geography). Hence, one simple econometric solution is to include a polynomial term for the latitude and longitude of each property. Alternatively, in the SLD model, neighboring observations are combined in the form of a spatially-weighted regressor, which is a distance-weighted average of the prices of other properties in the neighborhood. The definition of neighbors is typically based on the notion of distance decay as determined by empirical methods, such as the inverse of the square of distance with an arbitrary cutoff distance. Finally, in the SED model, residuals from neighboring properties are combined using a spatial-weights matrix. The SED model is more appropriate when the researcher is interested in removing bias due to interdependence and the SLD model is used when the concern is with structural interaction. Use of these models has increased due in part to the ease of estimation using GMM procedures suggested by Kelejian and Prucha (1999).

Salvi (2003) applies spatial econometrics to measure the impact of aircraft noise on prices of single-family residences near the Zurich airport. He estimates a general spatial model using GMM techniques. The data set contains 675 housing sales during 1995 to 2002 and fourteen structural features for each house. Noise exposure is measured by the L_{EQ} metric over a 16-hour period and the background noise level is 50 dB. For the OLS model, the NDI is 0.74% per dB. Semi-variogram graphs of the sales prices and OLS residuals indicate that residual correlations decline rapidly with distance. The cutoff for the weighting matrix is set at distances of 300 or 600 meters (656 yards). Moran's I test and a nonparametric test rejects the absence of spatial autocorrelation for both cutoff distances. The spatial model includes the spatial error and a weighted lag of five continuous structural characteristics, but excludes the neighborhood variables. The GMM model is estimated with noise in a continuous form and, alternatively, with five dummy variables for noise increments of 3 to 5 dB. The continuous metric yields an NDI of 0.75% per dB. This result suggests that the spatial error component is small, both statistically and economically. For the semilog model with dummies for noise exposure, the effect of an additional dB in percentage terms can be approximated by NDI = 100(exp[*B* – 0.5•V(*B*)] - 1), where *B* is the noise coefficient and V(*B*) is its variance (van Garderen and Shah 2002). With a background noise level of 50 dB, the five dummies yield NDIs of 0.48, 0.49, 0.63, 1.05, and 1.26% per dB. Hence, using dummy variables, damages rise sharply for the Zurich Airport at sound levels in excess of 65 dB. These estimates are within the range of values provided by previous studies, but demonstrate the importance of using dummy variables for each noise zone.

Theebe (2004) estimates the effects of traffic noise using a SED model, but some of the details are incompletely reported. His full data set contains more than 160 000 property sales in the western part of the Netherlands during 1997-1999, including abundant information on structural characteristics. The data set is split into five smaller samples by political jurisdictions, which are further divided into submarkets according to income, density, date of sale, and property type. Noise exposure is obtained for small areas using the L_{EQ} metric. The background noise level is 55 dB. In order to capture a non-linear relationship, noise exposure data are represented by nine dummy variables. Correcting for spatial autocorrelation, Theebe finds that traffic noise has little effect on house prices at sound levels below 65 dB. Above 65 dB, the NDI varies from 0.3 to 0.5% per dB. At the submarket level, the NDIs are somewhat larger, although less precisely estimated.

A third application of spatial econometrics is found in Cohen and Coughlin (2006). They study housing values in the vicinity of Atlanta's Hartsfield–Jackson International Airport, which is the world's busiest. The data set contains 508 housing sales during 2003, but only four structural variables (number of stories, bedrooms, bathrooms, fireplaces). Soundproofing of houses is an unobserved structural variable. Accessibility is measured by straight-line distance to the airport and neighborhood attributes are captured by dummies for each of six political jurisdictions. Noise exposure is represented by two dummy variables for L_{DN} values of 65 and 70 dB, with a background level of about 55-60 dB. Approximately 67% of observations are outside the 65 dB zone, 29% are in the 65-70 dB zone, and only 4% are in the 70-75 dB zone. This is less than satisfactory as only 19 houses in the sample are exposed to substantial noise levels. OLS estimates yield a negative, but insignificant, coefficient for the 65 dB zone and a significantly negative coefficient for the 70 dB zone. The NDI for the 70 dB zone is about 1.63 to 2.44% per dB, which is substantially larger than most prior estimates including other estimates for Atlanta. Next, Cohen and Coughlin incorporate spatial effects. They consider a general model with both a spatially-lagged dependent variable and spatial-error dependence. GMM estimates for the general model produce empirical results that are similar to the OLS model, but slightly smaller. Houses in the 70 dB zone sell for 20.8% less than houses in the buffer zone, so the NDI is about 1.39 to 2.08% per dB. Access to the airport also enhances housing prices after accounting for the effects of aircraft noise. The coefficient for the spatially-lagged dependent variable is significantly positive. The parameter estimate indicates that if all neighboring housing prices were to rise by 1%, the sale price of an individual house will rise on average by 0.54%.

2.6 Housing Market Adjustment Models

Cross-sectional hedonic models are designed to capture long-run relationships, but policymakers and practitioners often express skepticism about this claim. Suppose, for example, that a new runway is being constructed at a major airport. This might be accompanied by an initial reduction of property values, followed by a slow recovery as new residents move into the area and capture the locational rents associated with access to the airport. If the increased noise adversely affects a large number of houses, the long-run price discount might increase as households move and bid for quieter houses (Walters 1975). This adjustment process is complicated by moving costs, transaction costs, and asymmetric information associated with the purchase of a house. Future noise levels are not known with certainty, but sellers might have more accurate information about present and future environmental problems relative to potential buyers. This section examines several recent papers that account for housing market adjustment processes and associated events.[2]

Jud and Winkler (2006) study the expansion of the Greensboro–Winston Salem airport in North Carolina to accommodate a regional air-cargo hub for Federal Express. Announcement of the expansion took place in early 1998, and between 1998 and 2004 there were 508 news stories and 582 opinion and editorial pieces in the local newspaper related to the hub. For example, it was reported that the expansion would initially add 20 nighttime flights, which would be expanded to 126 flights per night by 2009. Local opposition groups and legal filings added to the publicity about the expansion. An environmental impact assessment was conducted by the Federal Aviation Administration and the final version was released to the public in late 2001. Among other things, it recorded the number of houses that were anticipated to be affected adversely by the expansion of the 65 dB and 70 dB zones. Hence, this is a setting with abundant public information about the event, and it seems likely the housing market would anticipate the expansion. Jud and Winkler measure the change in housing values for pre- and post-announcement time periods, but before the actual construction of the new airport facility. They estimate a HP model for a

[2] Other HP studies of airport expansions are Cohen and Coughlin (2003), Konda (2004), and McMillen (2004a, 2004b). Poulos and Smith (2002) is a repeat-sales analysis of a new US interstate highway, while Julien and Lanoie (2002) and Wilhelmsson (2005) are repeat-sales analyses of traffic noise barriers and property values.

two-year period before the announcement and a five-year period after the announcement, where the important variables are two dummies for distance bands measuring proximity to the airport. A date-of-sale variable captures the effects of inflation and other housing market changes, including the 2001 recession and local plant closures. The pre-announcement sample covers 8957 housing sales and the post-announcement sample covers 20657 sales. Using a SLD model to correct for spatial dependence, they report that housing prices increased by 1.2% per year in the pre-announcement period, but declined by 0.84% per year in the post-announcement period. Properties closest to the airport (within 2.5 miles) sold at a discount of 0.2% before the announcement and a discount of 9.4% after the announcement. More distant properties (2.5 to 4.0 miles) sold at a discount of 2.7% before the event and a discount of 8.3% after the event. Both of the differences are statistically significant based on a Wald test. Using the mean property value and prior estimates of the NDI, the authors also calculate the housing market's anticipated change in aircraft noise levels due to the expansion. In the nearest distance band, the price change suggests an increase in the noise level of 11 to 18 dB. In the second band, the anticipated increase is 7 to 11 dB. Relative to the published noise contours, it appears that the housing market is anticipating a negative effect that exceeds the actual change in the L_{DN} metric. In part, this may indicate the shortcomings of the L_{DN} metric for measurement of community noise exposure and annoyance (Albee et al. 2006; Fidell 2003).

A second event study is found in Pope (2007), except in this case the event occurs in the housing market. In March of 1997, the Raleigh–Durham International Airport (RDU) in North Carolina initiated a legally-binding noise disclosure requirement to reduce liability for imposing noise damages on nearby housing. A North Carolina statute, passed in 1995, required that government agencies and owners of residential real estate provide prospective buyers with a property disclosure statement. RDU used its authority under this statute to develop a notification letter and noise exposure map that was mailed to all homeowners within the 55 to 70 dB noise zones. These materials were sent to real estate agents in the area and a "noise officer" from RDU was appointed to ensure compliance. A web site with "tips for homebuyers" also was developed. In order to model this event, Pope develops a strategic model of a housing market in which the fraction of informed buyers is a function of attentiveness and the benefits and costs of obtaining publicly-available information. A potential seller is assumed to have more accurate information about the house and neighborhood, so there is informational asymmetry about housing quality. When the fraction of informed buyers is below a threshold, the sales price of a house may not reflect its true quality. Hence, information asymmetry produces a setting in which the set of housing attributes that is considered relevant by a buyer is less than the full set, meaning that higher quality houses are underpriced. The testable hypothesis is that as the fraction of informed buyers increases, a high quality seller is able to charge a relatively higher price.

As a test of the model, Pope uses a sample of 16856 single-family houses sold between 1992 and 2000. His data set contains a large number of structural variables, neighborhood variables at the census-block level, fixed-effects for time and location, airport accessibility, and dummy variables for aircraft noise and date of sale. The noise dummies indicate both the noise zone in which the house is located and the date of the disclosure letter. A semilog model is estimated for the full sample and for restricted subsamples according to year of sale. Using OLS, pre-disclosure houses in the 55-65 dB zone sell at a discount of about 2.3% and houses in the 65-70 dB zone sell for 5.1% less compared to houses at 50 dB. Both the SLD and SED models also are considered, with weight-matrices constructed using geographic coordinates. Using the author's preferred SLD model, pre-disclosure houses in the 55-65 dB zone sell at a discount of 1.9% and the 65-70 dB houses sell at a discount of 3.8%. The implied NDIs are about 0.19% and 0.25% per dB, respectively. The disclosure further reduces sales prices in the 65-70 dB zone by 2.1% and the total noise discount for these houses rises to 5.8%. The post-disclosure NDI is about 0.39% per dB, which is an increase of 55%. Pope concludes that conventional HP estimates may be substantially biased if real estate buyers are poorly informed about housing attributes.

An innovative study by Huang and Palmquist (2001) estimates the effects of road traffic noise on property values and selling time on the market (duration). Using a search model borrowed from labor economics, they first present a stylized model of the seller's reservation price conditional on the distribution of potential offers, the probability of receiving an acceptable offer, and selling costs incurred by the owner. Hence, the reservation price will be lower, the lower is the probability of receiving an offer in a period. However, the effect of an environmental disamenity, such as noise, on duration is uncertain. The disamenity will lower the offer prices and the probability of receiving an acceptable offer, but this can lower the seller's reservation price. The lower reservation price results in lower expected time on the market, which makes the net duration uncertain. The empirical model of the seller's reservation price is based on a stochastic frontier production model. The market duration model takes the form of a hazard function for the probability of receiving an acceptable offer, which is modeled as a function of the reservation price and other variables that affect duration (noise level, square footage, season of the year). The model is estimated simultaneously using 499 single-family housing sales in a suburban area near Seattle, Washington. The road traffic noise metric is L_{10} in 2.5 dB increments and the background noise level is 55 dB. Highway noise significantly influences actual and reservation prices, but noise does not significantly affect duration. The NDI is about 0.56% per dB, which agrees closely with many prior estimates. The seller's expected reservation price is estimated to be about 95% of the actual sale price. Overall, duration has a negative effect on the reservation price, which implies that sellers lower their reservation prices as duration time increases.

Wilhelmsson (2000) examines the effects of road traffic noise on housing prices and turnover rates in a suburb of Stockholm. His sample consists of 292 single-family houses sold between 1986 and 1995. Noise levels at each house are estimated using a traffic model and two variables are employed: the L_{EQ} metric and (L_{EQ} - 68 dB), which is interacted with a dummy variable that indicates the house has a view of the road. The second variable captures visual effects of the road at higher noise levels, but simultaneous use of two noise variables may create a collinearity problem in this study. A Chow test indicates that the model parameters are different for 1986-89 and 1990-95, but this is mostly due to the traffic noise coefficients. Wilhelmsson concludes that the average noise discount is 0.6% per dB. He also finds the turnover rate is somewhat higher for houses with a view of the road, but the difference is not statistically significant. Based on this finding, he argues that the existence of symmetric information in this market cannot be rejected. This finding parallels earlier results summarized in Nelson (1982) for other traffic noise studies.

2.7 Alternative Noise Indices and Community Annoyance

In contrast to other environmental areas, scientific measures of noise exposure are designed to correlate with human perceptions of annoying sounds. In 1974, the US EPA adopted the L_{DN} metric as the single best noise index due to its reliable relationship between projected noise and surveyed reaction of people to noises (EPA 1974; FICON 1992). The index is widely used as a guide for acceptable land use in noise-impacted areas and as an indicator of ambient noise levels. The L_{DN} index takes account of the magnitude and frequency of all sound events that occur during an *average* 24-hour period, the number of events, and the increased sensitivity of people to nighttime noise. However, as an average, the index discards potentially important information about the distribution of noises that may be relevant for human annoyance and the economic relationship between noise and property values or rental prices. Albee et al. (2006) observe that noise sensitive individuals often report that an increased number of noise events is more annoying, even if the average noise level per event has fallen. Further, many noise exposure indices are calculated for an average day during a subject year and thus ignore variations due to peak traffic periods, weather-related changes in operations, wind direction, and seasonal differences in living conditions and lifestyle during the year. One alternative is to break L_{DN} into its component parts, with separate measurements for time-above given noise levels and number of events (Albee et al. 2006). A study that illustrates some aspects of this measurement approach is Levesque (1994). He represents noise conditions by three separate variables at each location: (1) number of events that exceed an Effective Perceived Noise Level (EPNL) of 75 dB; (2) mean EPNL; and (3) standard deviation of EPNL for all events exceeding 75 dB. Using a Box-Cox model, Levesque obtains significantly negative effects on property values for the number of events and mean noise level, with a stronger negative effect of the mean level. The noise variance is positive, which may be due to collinearity. Studies using this approach should compare results to L_{DN} and consider more than one peak noise level.

A second approach in the HP literature has been the use of a dummy variable for each noise zone or contour, rather than use of a continuous noise variable such as the L_{EQ} and L_{DN} indices. This approach has the advantage of allowing for non-linear marginal effects due to increased sensitivity at higher noise levels. Cohen and Coughlin (2005) is an important study of the effects of aircraft noise and airport proximity on housing prices in the vicinity of Atlanta's Hartsfield–Jackson International Airport. They obtain a sample of 2370 single-family property sales for the period 1995 to 2002. The data set contains a substantial number of structural variables, neighborhood variables at the census-block level, and public sector dummy variables. Noise contour data are obtained for 1995 and 2003, which permits an examination of changing prices over time. The properties are located in three noise zones: 65-70 L_{DN}; 70-75 L_{DN}; and a zone that is one-half mile outside of the 65 L_{DN} contour, which the authors characterize as a "buffer zone." Note that the properties in the buffer zone are likely to be subject to aircraft noise levels of 55-65 dB, which raises an issue of undercounting of the noise-impacted properties. The choice of a noise threshold depends in part on the importance of noise from non-aircraft sources. Although 65 L_{DN} is the legislated ambient noise level for US airports, researchers should experiment with alternative ambient noise levels.

Cohen and Coughlin calculate the distance between each property and the airport as a measure of proximity or accessibility to air transportation services and airport employment. Due to the elongated shape of noise contours, there generally is a low correlation between aircraft noise and proximity. An important empirical issue is the shrinkage of the noise contours between 1995 and 2003, which can impart bias to the regression coefficients due to systematic measurement error. For example, the number of houses in the 70-75 dB zone declined from 249 in 1995 to 67 in 2003. Cohen and Coughlin address this issue by removing 727 houses from the sample that switched zones between 1995 and 2003. An alternative is to assign a dummy variable to houses that switch zones (see McMillen 2004a, 2004b). Using the reduced sample and a semilog OLS model, they find that houses in the 65 dB zone sell at a discount of 3.7% compared to houses in the buffer zone and houses in the 75 dB zone sell at a discount of 9.1%. The NDIs are about 0.74% and 0.91% per dB, respectively. They also consider the stability of the noise discount over time due, for example, to soundproofing and land purchases by the airport, increasing real incomes of residents, and displacement of noise-sensitive individuals. Adding a time trend for the 65 dB noise zone leads to mixed results, so it is unclear if the noise discount changed over time. In the reduced sample for the semilog model, the time trend is positive, but insignificant.

Another measurement approach is to make use of subjective annoyance relationships reported in the acoustics literature. One method is to use GIS and a noise model to determine the average noise exposure experienced at each house. Next, the exposure data are used to estimate the levels of human annoyance using some version of the nonlinear "Shultz curve," which captures the relationship between noise exposure and community annoyance (Fidell 2003; Fosgerau and Bjørner 2006; Miedema and Oudshoorn 2001; Ouis 2001). Thus, HP regression estimates can be compared for a cumulative metric and an index of annoyance, such as the percent of persons who are "highly annoyed." A second method is illustrated by innovative study by Baranzini et al. (2006). They use data from a Swiss noise perception survey to construct a subjective annoyance index for apartment buildings in Geneva. This index covers annoyance from all forms of noise, including traffic noise. Next, the annoyance index and the inverse of a Schultz curve are used to translate the subjective noise index to a "perceived dB" index. As a result, the researchers can experiment with three noise variables in HP regressions: (1) actual scientific L_{DN} for traffic noise; (2) perceived L_{DN}; and (3) the perceived annoyance index for all sources of noise. A comparison of the actual and perceived noise metrics indicates that survey respondents tend to systematically overestimate noise exposure levels, especially at the lower end of the scale. This may reflect the fact that the Swiss noise survey covers all sources of noise or that survey respondents tend to overestimate low-probability events. The sample of apartment rents covers 2794 observations. The scientific noise metric and the perceived noise metric produce similar values for the NDI. An increase in traffic noise reduces rents by 0.15 to 0.18% per dB. This result is comparable to that obtained in other Swiss studies, but slightly smaller than the NDI of 0.25% reported in Baranzini and Ramirez (2005). The authors conclude that scientific measurements of noise provide a satisfactory representation of individuals' perception of noise exposure, except possibly at the lowest intrusive noise levels.

2.8 Stated Preference Methods and Hedonic Prices

The goal of a stated preference (SP) study is to construct a simulated market for an environmental commodity such that "consumers" will accurately and truthfully state their willingness to pay (WTP) for additional units of the commodity. In real markets for private commodities, consumers reveal their WTP by purchasing (or refusing to purchase) more or fewer units at different relative prices, other things being equal. According to Carson and Hanemann (2005), construction of a simulated market requires: (1) specifying the rules of the market in which the commodity is bought or sold through a bidding game, referendum, or preference ranking; (2) describing the environmental commodity being valued through use of photographs, quality ladders, or tape recordings; and (3) eliciting monetary values or indicators of value for the commodity, including the specification of a payment vehicle such as a tax increase or higher prices for gasoline and travel. Each step in this process can encounter difficulties that might bias the WTP responses, such as the implausibility of the hypothetical payment vehicle or the inability of respondents to understand the specific commodity they are being asked to value. For example, some survey studies have asked respondents to value a complete elimination of noise, which is not an advisable procedure. Because environmental commodities are public goods (locally or globally), there also can be strategic bias in the form of free-riding, which leads a respondent to state a WTP that is different from his or her true WTP. Further, economic theory provides no prediction how people faced with "purely hypothetical" choices will behave, and zero valuations and large WTP outliers are common outcomes in SP surveys. Relative to HP methods, the SP approach has the advantage of focusing more directly on the environmental commodity in question, avoiding imperfections in the housing market, and producing values that might apply in a wider variety of settings and circumstances. Further, in the HP model, it is not clear what aspects of annoyance due to noise and transportation activities are being capitalized in property values (TV interference, sleep disturbance, visual intrusion, air pollution, safety concerns, etc.).[3] An appropriately designed survey could help determine the exact nature of damages that are reflected in property values as well as the omitted damages. Publication of the SP survey questions would aid this determination, although this practice is not often followed. Early SP studies for noise are Plowden (1970) and Thorpe and Holmes (1976), while the recent literature is reviewed in Navrud (2002). A general problem in the SP literature for transportation noise is the wide variation of the WTP estimates.

Several noise studies have compared results from SP and HP models for comparable areas, but the results are mixed.[4] Pommerehne (1988) obtains a sample of 223 dwelling rents in Basel, Switzerland, including dwelling characteristics, accessibility, aircraft noise, traffic noise, and responses to an environmental-quality perception survey. In the CV survey, dwelling occupants were informed that they could reduce noise exposure by 50% by moving to another dwelling. Households were then asked about their current rent and the maximum acceptable rent increase for the quieter dwelling. The survey also obtained information about the respondent's income and family size. This in-

[3] A false issue is the lack of comparability of values from HP and SP methods. A hedonic price is a capitalized value per dB. Treating the house as an annuity and using an appropriate discount rate, a hedonic price can be expressed as an annual or monthly value per dB; see Bjørner (2004a) and Saelensminde and Veisten (2006).

[4] Blomquist (1988) demonstrates that, due to sorting in the housing market, contingent values can be expected to differ systematically from the implicit hedonic values. If quiet houses tend to be occupied by noise-sensitive people, the contingent value will exceed the hedonic price. The opposite will be true for noisy houses occupied by imperturbables. I am indebted to Jean Cavailhès for this point.

formation is used to estimate a survey-based WTP function. In the HP model for aircraft noise, the NDI is only 0.20% per dB. A HP linear model estimated by OLS yields a traffic noise NDI of 1.25% per dB. A non-linear model results in an NDI that increases in the noise level, rising from about 1.0% per dB for traffic noise at 40 dB to 1.50% at 75 dB. The nonlinear marginal prices also are used to estimate a second-stage WTP function for noise avoidance. Comparing the two sets of results, Pommerehne concludes that the WTP functions for traffic noise are similar, but the survey-based WTPs are somewhat lower than those derived from housing market data. However, for aircraft noise, the differences are more pronounced and the survey-based WTPs are higher at all noise levels. This may reflect survey response bias, since aircraft noise was not a serious problem in Basel (the airport is 10 miles from the city).

A second Swiss study was conducted by Soguel (1996) for the city of Neuchâtel. The CV survey asked 200 households to value a 50% reduction in traffic noise exposure. The payment vehicle was a hypothetical increase in the household's monthly rent. Respondents were divided into several categories based on the value of the WTP and other survey responses: indifferents (n = 59 respondents); free riders (30); insolvents (25); and receptive solvents (86). The WTP analysis is confined to 111 respondents who did not engage in strategic behavior and 86 of these individuals had a positive non-zero WTP for noise reduction. A Box-Cox regression model is used to estimate the WTP function, which reduces the influence of large bids. This model is estimated by OLS and by weighted least-squares in order to correct for a heteroscedasticity problem. The SP analysis yields an average monthly bid of about 70 SFr. The results from the survey-based WTP analysis are compared to a HP analysis for the same city. The HP analysis produced an NDI of 0.91% per dB, which results in a monthly WTP of 60 SFr for a 50% reduction in noise exposure. The author concludes that the SP and HP estimates are similar.[5]

A third comparison study using both SP and HP methods was conducted by Bjørner (2004a, 2004b) for Copenhagen. Data for the CV analysis were collected using a mail survey, and the sample consists of 1149 responses (53% response rate). The survey described a new noise-reducing road surface that would lower the noise level so that the respondent would no longer be annoyed (10-20 dB reduction). The WTP of each respondent was obtained using both open-ended bids and referendum-style valuation questions. The survey-based WTP values were analyzed by residence-type (apartments, houses) for five classes of respondents with positive bids: not annoyed (n = 45); slightly annoyed (85); moderately annoyed (198); very annoyed (257); and extremely an-

[5] Navrud (2002) argues that CV questions used by Pommerehne and Soguel are not understandable by respondents. He suggests use of questions based on a reduction of annoyance or other qualitative comparisons, such as reducing daytime traffic noise to levels experienced on a Sunday morning (Barreiro et al. 2005).

noyed (361). The WTP values rise from 45 EUR for the not-annoyed individuals to 361 EUR for the extremely annoyed. The overall mean value is 135 EUR for the road improvement project. A noise annoyance model (Schultz curve) is used to translate the WTP by class to an expected WTP per dB. The WTP per dB increases from 2 EUR at 55 dB to 11 EUR at 75 dB. The HP study uses a sample of sales prices for 2505 apartments for the period 1996 to 2002. Noise exposure levels at each dwelling were calculated using a traffic model for the L_{EQ} metric, with a background level of 55 dB. Three different model specifications result in NDIs of 0.53, 0.54, and 0.58% per dB. The author concludes that the HP results correspond to values found in prior studies. A real discount rate of 2% is used to annualize the mean price in each of six noise zones. The annualized HP differentials are substantially higher than the WTP values calculated from the CV study. At 65 dB, the CV value is 6 EUR per dB per year and the HP value is 14 EUR per dB per year. These results conflict with Pommerehne (1988) and Soguel (1996).[6]

For aircraft noise, CV methods were applied in an innovative study conducted by Feitelson et al. (1997) for the Dallas–Ft. Worth Airport. The authors attempt to value the depreciation of real property due to noise and the loss of utility by residents who remain *in situ*. Using a telephone survey, homeowners near the airport were first asked to state their hypothetical willingness to pay for a standard single-family residence in an area with no aircraft noise and then they were asked to value the same residence with differing levels and types of noise exposure. Using a similar sequence of questions, apartment dwellers were asked how much monthly rent they would be willing to pay for a three-bedroom apartment. The full samples include 3586 observations for homeowners and 2662 for apartment dwellers. In the WTP regressions that omit zero valuations, most of the noise attributes are statistically significant, with larger negative coefficients for severe levels of noise. Noise insulation provides partial relief, but does not fully mitigate the adverse effects of noise. The NDIs are about 1.5% per dB for houses and 0.9% per dB for apartments. The authors note that the zero valuations provide information regarding respondents' unwillingness to tolerate severe aircraft noise, regardless of the noise discount in housing values or apartment rents. The proportion of zero responses rises as noise exposure increases, reaching 45% for homeowners and 35% for apartment dwellers if they were exposed to severe frequent noise from overflights (about 70-75 dB). Alternatively, the zero responses may reflect survey biases. The authors argue that WTP valuations are the outcome of a two-stage decision process. At severe noise levels, many individuals are unwilling to consider the residence, and thus their WTP drops to zero. They con-

[6] Other SP traffic studies are Arsenio et al. (2006), Barreiro et al. (2005), Galilea and Ortúzar (2005), Garrod et al. (2002), Saelensminde (1999), and Wardman and Bristow (2004). Other SP aircraft studies are Bristow and Wardman (2006), Carlsson et al. (2004), van Praag and Baarsma (2005), and Wardman and Bristow (2007).

clude that HP studies understate damages by failing to incorporate the losses to households who would like to relocate.

2.9 Summary and Concluding Remarks

The preceding discussion demonstrates that there is a very active research program for hedonic studies of noise valuation. Interest in the area declined in the 1990s, but it now enjoys a healthy renewal. Researchers have taken advantage of advances in economic theory, newer econometric techniques, large disaggregated data sets, and GIS methods. Novel and innovative studies have appeared that estimate models not considered by earlier researchers. Survey-based studies now provide a useful supplement to the revealed values obtained from real estate data. However, policy applications of results from hedonic studies do not appear to have increased in frequency, especially in the United States. In this concluding section, I first offer summary comments on the use of hedonic models for valuation of transportation noise and then briefly discuss recent policy applications and final results.

The discussion in this paper suggests five issues that researchers need to be aware of when estimating or using hedonic models:

• Market segmentation may be common in large samples of housing data. Researchers should guard against specification errors due to segmentation by appropriate use of Chow tests and other specification tests and by careful thinking about the research issue being addressed. Cluster analysis is another tool that has been used to address segmentation. However, these tools need to be applied carefully given a non-linear hedonic price function.

• Spatially-dependent errors present a major challenge to research on housing markets. This is due to the fact that econometric tools and software were designed for a spaceless world and the practical difficulty of observing all locational characteristics. Careful model specification can in some cases resolve the problem. However, simply adding more locational variables is not necessarily the best solution due to multicollinearity and the limitations of theory. Spatial statistics can be used to keep the hedonic model simple and augment the conventional HP model with models of spatial-error dependence.

• Housing market adjustments present researchers with opportunities to extend the basic hedonic model and test newer propositions from economic theory, such as the effects of asymmetric information, changes in noise valuation over time, and housing market imperfections. More studies in this area are needed to support applications of hedonic valuations.

• Noise measurement is a relatively old area of interest, but some studies have failed to heed past research. For example, quiet residential areas do not have a background sound level of zero decibels. Noise changes of 3 to 5 dB are generally noticeable, but some studies use dummy variables for differences of 10 dB or more, which is excessive. Attention needs to be paid to the appropriate non-linear relationship between noise levels and housing prices or apartment rents. More attention also should be given to use of community annoyance metrics as an alternative to commonly employed noise indices.

• Stated preference surveys represent an alternative method for valuation of noise damages. These studies rely on hypothetical responses, whereas hedonic price studies use observed behavior and market responses. In order to estimate damages using a survey, SP researchers need to frame questions that simulate actual responses and tie these responses to realistic payment vehicles. This would appear easier for road traffic noise compared to aircraft noise, especially for the United States. Some existing studies suggest that SP and HP models yield comparable results, but interesting differences in noise valuations also have been uncovered.

There are three major policy applications for hedonic prices. First, cost-benefit analyses of specific noise mitigation and abatement projects, including airport expansions, curfews, quieter aircraft, traffic noise barriers, and improved roads and highways. Representative studies in this area include Bateman et al. (2005); De Vany et al. (1977); Morrison et al. (1999); Nellthorp et al. (2007); Nelson (1978); Nijland et al. (2003); Saelensminde and Veisten (2006); and Wilhelmsson (2005). Second, overall evaluations of the full social costs of transportation, which are studies of the "paid" and "unpaid" costs of motor vehicle and aircraft operations. Representative full-cost studies include Delucchi and Hsu (1998); Greene et al. (1997); Levinson and Gillen (1998); Levinson et al. (1998); Murphy and Delucchi (1998); Parry et al. (2007); Quinet (2004); and Schipper (2004). Third, studies have evaluated alternative policy instruments, such as the calculation of noise and congestion taxes. Representative studies of noise-congestion taxes are Brueckner and Girvin (2007); Hsu and Lin (2005); Newberry (2005); and Pearce and Pearce (2000).

Continued refinement of HP and SP estimates of noise damage valuation will aid these policy applications. In particular, HP estimates of noise damages are more useful if marginal prices are stable over time and space, and therefore can be applied to welfare changes in similar environmental settings. Absent this stability, each HP estimate is useful for only its designed purposes. A general problem in environmental economics is the use of a WTP value or function from a given study area (or mode of transport) for a policy evaluation of another location or mode, which is referred to as the "benefit transfer" problem (Brookshire and Neill 1992; Rosenberger and Loomis 2003). Both unit value transfers and function transfers are possible. Several European countries have adopted standardized noise valuations for policy purposes, but many of these values are old or based on only a few studies (Saelensmine and Veisten 2006). These values could be improved through benefit transfer methods.

Earlier reviews reported mean NDI values of 0.50 to 0.70% per dB for aircraft noise and 0.40 to 0.60% per dB for traffic noise (Bertrand 1997; Nelson 1980, 1982, 2004). For rough comparisons, the NDI values reported in this survey can be combined to yield more recent estimates of noise valuations. For aircraft noise, the 24 estimates yield an unweighted mean value of 0.92% and a median value of 0.74% per dB. The interquartile mean for aircraft noise is 0.80% per dB. For traffic noise, the 25 estimates yield an unweighted mean value of 0.57% and a median value of 0.54% per dB. The interquartile mean for traffic noise is 0.53% per dB. The average values for aircraft noise are slightly higher than prior estimates, which may reflect rising real incomes as well as differences in econometric techniques. The average values for traffic noise also are slightly higher than prior estimates, although the differences are perhaps minor. Hence, a review of recent estimates of the NDI for aircraft and traffic noise suggests that the unit values are stable over time.

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