The Role of Noise Valuation in Assessing Infrastructure Investment and Management: A Case Study of Pearson International Airport

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Abstract

This paper examines the modelling that was undertaken to establish both a value for noise or quiet as well as measure the economic costs of a runway expansion project at Pearson International Airport. The valuation was based on the use of the hedonic technique, which was used in developing measures of the changes in the cost of noise exposure with expansion of the airport. The valuations were a key input in the benefit-cost analysis of the runway expansion, which was one component of the environmental assessment of the project. In the modelling the impact of differences in the functional form and variable input were examined as well as the components of the analysis. The paper provides a survey of the different valuation techniques, an explanation of the underlying basis for the hedonic method and a case study of the application of the hedonic technique. It also illustrates where the noise valuation is used in the calculation of benefits and detriments of the airport expansion.

Table of Contents

1. Introduction

The dramatic expansion of low cost carriers into secondary airports has resulted in a significant increase in traffic and hence noise generation and [to a lesser extant] noise exposure around these airports.[1] In other cases where runway expansion is going forward or has been proposed, the new runway would increase the number of people exposed to noise and may result in higher [or lower] amounts of noise falling on those currently experiencing noise from airport operations. This is happening at a time when externalities are being included in pricing airport [and other transportation] infrastructure services. The impacts of such externalities are also included in environmental assessments to be part of any benefit-cost analysis of runway expansion and should be part of any proposed noise management strategy at the airport or in the region.

Within this context, the EU had issued a directive in 2000 on the Assessment and Management of Environmental Noise which required member states to produce 'strategic noise maps, using specific noise indicators.[2] The noise maps were intended to be used to assess the number of people affected by noise, inform the public of the extent of noise exposure and its affects, to serve as a basis for developing some action plans and to establish benchmarks for noise quality and measuring the impact of different noise strategies. Such noise maps would provide some of the basic information needed to undertake any environmental assessment and/or benefit-cost study of an infrastructure investment program or change in airport strategy in which full social costing was the basis of any calculation.

In any appraisal of a strategy or investment the objective is to develop an approach to create measures of the noise costs associated with each considered mode of transportation, the emphasis here being on aviation. Noise costs are a product of two factors, the quantity of noise and the economic valuation of the noise.[3] It is the latter which is the primary focus of this paper. The amount of an externality produced by transportation is the result of the technology of the transportation, as well as the amount of defense and abatement measures undertaken.

One of the first questions asked is, "is the noise an externality to users or to those outside of the system?" In some cases, congestion, for example, all users may internalize an externality in the system but not users outside of the system. In the situation of noise, users of the system internalize nothing while those outside the system internalize everything. This is true for air, auto, rail and truck while it may be less true for public transit.[4] Therefore, the full costs of noise should be included in the calculations of full social costs because the noise externality is generated by the

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1 I say to a lesser extent since many cases the secondary airports used by Low Cost carriers are located in rural or semi-rural settings with relatively low population density.

2 There are a number of different noise metrics, some single event and others cumulative. The EC indicated Lden (day-evening-night indicator) and Lnight (evening-noise indicator) be used. These were defined in an Annex to the Directive.

3 In measuring noise generation we need to understand the linkages between economics and externalities? Pricing, financing, investment, regulations and policing are the principal underlying drivers for economic activity. These lead to physical transportation activity including vehicle kilometers of travel (people and cargo), infrastructure, vehicle stock, vehicle composition, use patterns and vehicle design. Not each of these physical characteristics affects output volume and quality and hence the amount of the externality. Measuring the externality, and hence pricing it, will be contingent on given technologies. The physical outputs and features give rise to externalities, in our case measures of noise exposure. Thus the linkage is from economic conditions to physical output to externalities.

4 I am thinking here of buses where the suppliers of transit services do not consider the external noise costs in choosing capital or operations management.

components of the transportation system but paid for (through a loss of consumer surplus and the expenditure of real resources) by agents outside the system.

In section 2 we summarize the approaches to valuation noise, distinguishing primarily revealed and stated preference methods. Section 3 provides a brief description of the theory underlying the hedonic approach while section 4, describes an application and pitfalls in creating the application. Section 5 describes how the information from the hedonic study is actually used in the benefit-cost analysis and how it fits into the broader methodology. Section 6 presents an illustration of the application to Pearson International Airport in Toronto Canada while section 7 contains the summary.

2. Economic Valuation of Noise

Noise valuation as with any economic evaluation is the sum of market and non-market resource costs. The former is the opportunity costs and the latter any loss in utility and transactions costs which is not reflected in market prices. Broadly speaking revealed and stated preference techniques are the methods used to establish these values. Interestingly, the revealed preference approach uses indirect market data to establish values whereas the stated preference methods use a direct approach. The majority of the revealed preference methods use the hedonic method on market based housing sales data. The strength of this method is its wide application over time and markets. It uses real data as distinct from synthetic data.

There have been some criticisms of the approach claiming the hedonic method, yields a wide array of noise discount valuations. A recent paper by Nelson (2004)[5] dispels many of these criticisms where he shows a remarkable consistency. He found the weighted-mean noise discount is 0.58% per decibel. He used a meta-regression analysis to examine 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 has 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.

The other two revealed approaches are expert assessment and avoidance costs. The former have a limited number of studies, are generally highly localized to a few properties and rarely have one individual assessing over a number of different markets or time periods. The avoidance cost method is not until a willingness to accept measure. However, the main weakness of this method is, as in all applications, that only in certain circumstances the results can be interpreted as a proxy of welfare loss /gains from increased/decreased noise levels.

The stated preference methods are principally Contingent Valuation (CV) and conjoint models (CE). Navrud (2002) provides an excellent assessment of the different methods.[6] Choice experiments using conjoint are viewed as superior than the CV models in that individuals are asked to select from alternative bundles of attributes instead of ranking or rating them. In this choice the

5 See Jon Nelson (2004), Meta-Analysis of Airport Noise and Hedonic Property Values: Problems and Prospects, Journal of Transport Economics & Policy, January 2004.
6. See Stale Navrud (2002), The State of the Art in the Economic Valuation of Noise (Department of Economics and Social Sciences, Agricultural University of Norway, February 2002)

individual is forced to make tradeoffs, that is, incur an opportunity cost. Thus the values elicited are more likely to reflect true WTP.[7] Because CEs are carefully constructed to control for context and to force trade-offs across a number of attributes, they allow the researcher to value attributes as well as situational changes. This approach can provide substantially more information about a range of possible alternative policies as well as reduce the sample size needed compared to CV. As Navrud (2202) argues, the CE approach allows for simultaneous valuation of several characteristics/goods that naturally belong together, and thus has the potential of avoiding aggregation biases. However, survey design issues with the CE approach are often much more complex due to the number of goods that must be described and the statistical methods that must be employed.

A reason for the relatively few Contingent Valuation (CV) studies on noise could be the difficulties in constructing a good survey for valuing noise level reductions. Respondents need to understand the context and also what a particular noise reduction means. In the US for example, airports use simulated noise of aircraft takeoff and landings to convey differences in airport traffic levels or the expected impact of a new runway. A good CV survey would, among other things, set the general context for the decision to be made as well as provide a detailed description of the good to be offered. Furthermore, the institutional setting in which the good will be provided and the manner in which it will be paid for must be carefully articulated. Problems can arise particularly if changes in noise levels are not understandable. Also people must understand the governance and institutional arrangements that makes respondents accept willingness-to-pay (WTP) questions and the payment vehicle must be considered fair and reasonable with minimal transactions costs.

3. Hedonic Technique

The essence of the property value approach to valuing "quiet" is that individuals can select the amount of quiet by choosing a location that is more or less noisy. If noise is regarded as undesirable, less noisy areas will, ceteris paribus, cost more. Thus observing the behavior of people who are more or less noise sensitive with respect to their location choice should enable us to estimate the implicit value of quiet. This approach requires four assumptions: (1) individuals are fully mobile; (2) noise is not ubiquitous; (3) "noise value" can be quantified; and (4) the effects of noise can be isolated in the house price differential.[8]

The basis of much of the applied hedonic method is Rosen's (1974) study of a commodity with multiple characteristics. As a starting point, Rosen observed that the hedonic price function is a market phenomenon common to both buyers and sellers, and represented the minimum price for any bundle of characteristics or attributes. Consumers select goods according to the attributes they possess so as to maximize their utility subject to their budget constraint. Rosen defines a value function for the consumer as being the maximum amount that the consumer would be willing to pay for alternative goods (bundles of characteristics) such that the level of utility and expenditure are held constant.

The buyer's value function is an indifference curve for the consumer as well as an iso-expenditure curve that defines the various bundles of characteristics the individual is willing to purchase. The first order partial derivative of the value function with respect to any characteristic depicts the

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7. Under the CE approach respondents are asked to pick their most favoured out of a set of three or more alternatives, and are typically given multiple sets of choice questions.
8. Airport noise and the housing market would seem to satisfy all of these assumptions.

marginal valuation the consumer places on the characteristic at a fixed income and utility level. This reveals the individual's reservation demand price for the attribute which is a decreasing function of the amount of the characteristic. Therefore, this function defines the inverse of the ordinary income-compensated demand function for the attribute.

In a similar manner, firms produce goods which possess various characteristic bundles in order to maximize profit. The seller's offer function defines the bundle of characteristics the firm is willing to produce. The first order partial derivative of the offer function with respect to any attribute reveals the marginal value the firm places on the characteristic at a fixed profit level. This is the firm's reservation supply price for the attribute and is an increasing function of the amount of the characteristic. It, therefore, defines the inverse of the firm's ordinary profit compensated supply function for the characteristic. Rosen placed the characteristics approach in the familiar demand and supply framework.[9] He also suggested a two-step estimation method to estimate the demand and supply functions for the characteristic.[10]

A number of objections were raised to this and other similar work. The literature focused on three issues: first, the condition under which property values can be used to predict the effect of a change in environmental amenity on equilibrium property values; second, the relation between the change in aggregate property values and willingness to pay; and finally the necessary assumptions to estimate both of the above.

The consensus was that if rents (prices) extract all benefits, and the "market" is small and open (to insure mobility), hedonic functions can provide accurate measurements, however further conditions should be included (Harris, 1981). If there is less than full information, if search or transactions costs are greater than zero, and if demand and supply do not adjust instantaneously, some bias may be introduced. It is necessary to assume that this will be random and not systematic bias. Second, we must assume the market offers the opportunity of an interior solution. This means there are no discontinuities in the supply of characteristic bundles.

Even though the implicit prices of each of the characteristics are not observable in the market, they can be estimated using the techniques of hedonic price estimation. This technique, and its implications, can best be examined within the framework of a model of consumer choice and environmental quality.

Consider a house is a composite of a number of characteristics including size, number of bathrooms, lot size, garage space, number of bedrooms, nature of the neighborhood, and so on. The consumption of housing services can therefore be written as

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[9] The measurement of the damages or costs caused by aircraft noise creates problems because the demand for quiet cannot be observed as an explicit price-quantity relationship. There is no readily observable market demand because quiet is produced jointly with other housing services at any given location. If there were explicit market demand curves for quiet and these measured marginal willingness to pay, the total willingness to pay for any level of quiet could be measured as the area under the compensated demand curve corresponding to that level. Thus, the costs of increased aircraft noise could be simply determined as the differences in total willingness to pay between different amounts of noise at least from a partial equilibrium model.

10 Brown and Rosen (1982) have shown that Rosen's (1974) estimation procedure to identify structural demand and supply functions had difficulties. In particular the procedure yielded nonsense estimates of demand and supply functions since the estimated coefficients were simply functions of the coefficients of the equilibrium price function and do not have any more information than that provided in the individual price function. They point to two ways of circumventing this difficulty. First, to use data from spatially separate markets or a panel data set and second, and the one used in this study, to impose a priori restrictions on the functional form.

$$h_c = f(c_1, c_2, \ldots c_n) \qquad (1)$$

where h_C is the consumption of housing services and the c_i's are the various characteristics.

Each individual or household can be assumed to have a utility function as

$$U = u_j(X, h_c, L) \qquad (2)$$

where U is utility, j indexes the individual, X is a vector containing all goods and services other than housing, h_C is housing services and L is location. The consumer has a budget constraint given by the flow of income from his wealth. It can be represented as

$$Y = X + p_c(L) \bullet h_c + C_T \qquad (3)$$

where Y is income, p_C is the price of a characteristic some of which depends on location and CT is the cost of travel to work.[11]

The term p_C (L). hc is the cost of housing characteristics, essentially price times quantity, and can be divided into two segments to indicate which characteristic's prices are contingent on distance and those which are independent of distance.[12] The maximization problem of the individual or household can be represented as:

$$Max\, U = u_j(X, h_c, L) \qquad (4)$$

subject to

$$Y = X + \sum_j p_j c_j + p_n(L) \bullet c_n + C_T \qquad (5)$$

where those characteristics indexed j are independent of location. Thus, p_j, is the price of the jth service and is the 'implicit or hedonic' price. These prices reflect the valuation of the characteristics that comprise the commodity bundle. Equation (4) reflects the fundamental assumption of hedonic models set out earlier, namely, individuals or households are fully mobile and respond to changes in the magnitude of characteristics, including noise.

This model provides the foundation for empirical estimation. In order to determine a value for "quiet", quiet (or noise) can be included in the maximization problem as simply another characteristic, c_k, for example. Allowing for the fact that the sales price of the house is the discounted future value of services into the future and that the prices of characteristics would, in the above equations, be annual values, one can annualize the expenditures on housing services as

$$H = Y - X - C_T = \sum_j p_j c_j + p_n(L) \bullet c_n \qquad (6)$$

Equation (6) can be translated into present value terms by dividing the right side by the discount rate or going rate if interest. It would be represented as

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11 One could include other travel costs here such as to school, shopping and entertainment but it would not change the substance of the model.

12 Nelson (1976) makes noise independent of distance along with other characteristics other than land services.

$$PV(H) = sales\ price\ of\ house = 1 \Big/ r \left\{ \sum_j p_j c_j + p_n(L) \cdot c_n \right\} \quad (7)$$

This price function is an "hedonic relationship" that is established by the equilibrating processes in the market. The hedonic estimation technique attempts to use multiple regression analysis to determine both the functional form of the price relationship and to estimate the parameters associated with any particular function. The empirical expression of (7) would be represented as the regression of house sales price (the dependent variable) on measures of various characteristics as the independent variables.

An hedonic estimation technique, in which the values of a group of properties are regressed against a vector of characteristics that determine those values, can be used to calculate the marginal prices associated with any of those characteristics, quiet included. The regression analysis would generate estimates of the various parameters, and the estimated function could be used to calculate the marginal prices of each of the housing characteristics.

The measurement of willingness to pay from the hedonic price function is sensible since it represents a household expenditure function that connects observed differentiated product prices to quantities of various embodied attributes and associated implicit or hedonic prices. The marginal hedonic prices merely connect equilibrium reservation bid and offer prices and attributes for both consumers and producers and reveal little about the underlying demand and supply schedules. From the consumer's perspective estimation of a hedonic price function serves only to determine the marginal cost or tariff schedules confronting consumers and does not by itself identify the bid price schedule for air quality or any other housing attributes.

Nelson (1976) used a log-linear form of the regression to investigate the impact of noise on property values. It was :

$$PV(H) = b_0 C^{b_1} N^{b_2} u_1 \quad (8)$$

where b_i's are parameter estimates, C is the set of characteristics other than noise, N is a measure of noise and u_1 is an error term. N is measured as

$$N = a_0 e^{a_1(Ldn)} u_2 \quad (9)$$

where a_0 and a_1 are constants, e is the natural logarithm and u_2 is a random error term. Ldn is the 'noise exposure' measure.[13] Substituting (9) into (8) yields the estimating equation.

$$PV(H) = d_0 x^{d_1} e^{d_2(Ldn)} u_3 \quad (10)$$

where $d_0 = b_0 a_2$, $d_1 = b_1$, $d_2 = a_1 b_2$ and $u_3 = u_1.u_2 b_2$

Nelson (1976) argues that d_2 can be interpreted as the <u>constant percentage marginal damage cost per unit of noise exposure;</u> ie, the partial derivative of PV(H) with respect to Ldn is equal to d_2(V).[14]

13 See David W. Gillen and Terrence J. Levesque (1989) for a complete description and explanation of this measure as well as other noise impact measures.

14 This specification makes the marginal damage cost rise proportionately with property value. It does however keep the price of a unit of noise constant regardless of the level of noise.

4. Application of the Hedonic Methodology to Noise Valuation

There have been numerous applications of the hedonic method to the problem of noise abatement benefit measurement. These are summarized very well in Navrud (2002) and Nelson (2004). In Nelson's recent meta analysis examines 33 different airport studies in Canada and the US. The results of the studies are presented in terms of a 'noise depreciation index' to place the results of the various studies in a common metric.

The NDI (noise depreciation index) is defined as:

$$NDI = {difference\,in\,total\,\%\,depreciation} \Big/ {difference\,in\,noise\;exposure}$$

A meta-regression analysis examines the variability in the noise discounts for exposed properties 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.

4.1 Hedonic Model for Pearson International Airport: Areas of Debate

In the hedonic regression technique the market value is regressed against housing characteristics in an attempt to determine the price function and the parameters associated with each of the attributes. From the estimated equation one can derive the implicit marginal price of a housing characteristic. This value may be constant or may vary depending on the nature of the functional form used. There are four areas of debate regarding the application of hedonic models; the choice of how to characterize the noise variable, the functional form of the hedonic regression, the measure of noise exposure and the segmentation of the data by housing type. Each is considered in turn below.

4.1.1 FORM OF NOISE VARIABLE

One of the alternative functional forms to estimate would be one that related the market value to the characteristics in a log-linear way. Such an equation would be represented as:

$$\ln V = \alpha_0 + \sum_i \alpha_i \ln h_i + \sum_j \alpha_j \ln h_j + f(q) + \varepsilon \qquad (11)$$

where h_j refers to housing characteristics which are treated as dummy variables such as the presence of a swimming pool or a double garage. f(q) represents a general function for quiet to be related to ln V.

Before selecting the form of f(q) to represent noise exposure in the hedonic price function, several alternative specifications of the discount factor were estimated and compared. The functions estimated were exactly like eq(11) except for the term in NEF which had the general form

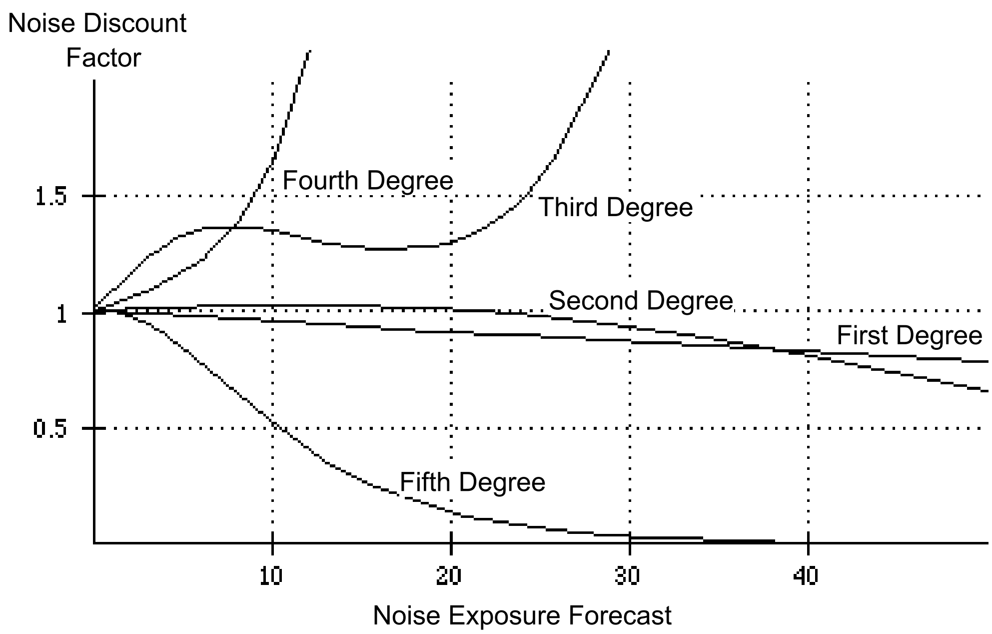
$$f(NEF) = \sum_{k=1}^{n} \beta_k NEF^k \qquad (12)$$

The term n in the summation was varied from 1, giving a linear discount rate, to 5, giving a discount rate represented by a fifth degree polynomial function. Figure 1 shows the results of the five hedonic estimations in terms of the implied discount associated with various values of NEF.

The evidence from the estimates of the discount factor shows that only the first and second-degree polynomial models of the discount factor are reasonable. The first-degree model is chosen for simplicity and because it is consistent with the models used in numerous other studies.

Figure 1

Estimated Discount Factors



In the estimation of this function on Toronto data the form d_2(NEF) was utilized. The reason this form is used is it makes housing depreciation with respect to noise a function of the level of noise. The percent change in housing value as a function of changes in the level of noise will vary with the level of noise and the house value. Thus, a given change in noise will affect a more expensive property relatively more than a less expensive property. Also housing currently not exposed to noise and suffering an x unit increase in NEF will experience a greater impact than the same NEF increase impacting housing already exposed to noise.

4.1.1 FUNCTIONAL FORM OF HEDONIC EQUATION

Virtually all applications of the hedonic technique result in either linear or log-linear models being estimated empirically. As an alterative to imposing a functional form it is possible to use a technique termed 'flexible functional forms' in which a general function is estimated and various restrictive forms are tested which are special cases of the more general flexible form; including linear and log-linear.[15]

The most general function is a quadratic Box-Cox model.[16] It can be represented as:

$$V^{\lambda_1} = \beta_0 + \sum_i^n \beta_i h_i^{\lambda_2} + \frac{1}{2}\sum_i^n \sum_j^m \beta_{ij} h_i^{\lambda_2} h_j^{\lambda_2} + \varepsilon \qquad (12)$$

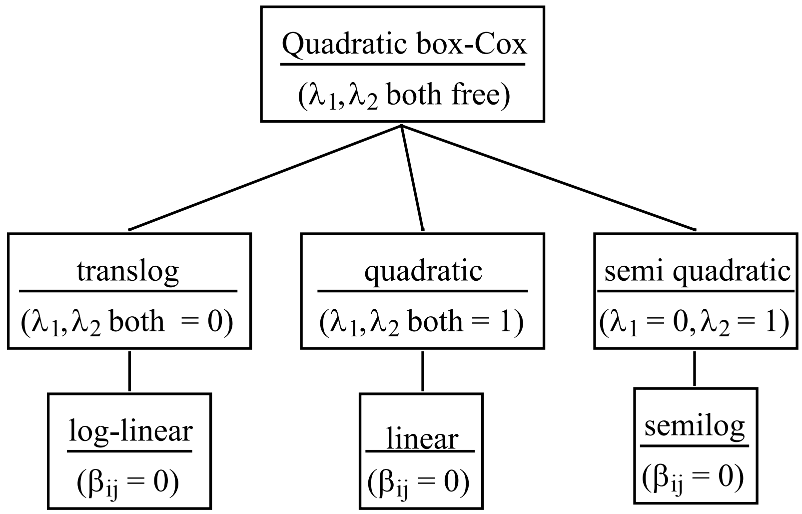
where V and h are defined as before and q is assumed to be included in h. The Box-Cox is a power transformation of the type

$$X^{\lambda_i} = \begin{bmatrix} (X^{\lambda_i} - 1) / \lambda_i & \text{for all } \lambda_i > 0 \\ \ln X & \text{for all } \lambda_i = 0 \end{bmatrix}$$

where X refers to either V or h. The estimation of the λ_i let the data determine the functional form and with particular values of the λ_i's, certain types of functional forms emerge. These functional forms can be estimated using maximum likelihood techniques and the hypothesis tested using asymptotic statistics.

Parameter[17]			Functional Form
λ_1	λ_2	β_{ij}	
*	*	*	Quadratic Box-Cox
0	0	*	Translogarithmic
0	0	0	log-linear
1	1	*	quadratic
1	1	0	linear
2	1	*	generalized square
0	1	0	semilog

15 See Oum and Gillen (1982) for an application of the flexible functional forms to the transportation literature.
16 Berndt and Kaled (1979) generalized the translog by employing a Box-Cox transformation. Halvorsen and Pollakowski (1981) introduced the Box-Cox transformation to the implicit or hedonic market literature.
17 * means the parameter is unrestricted



There are compelling reasons to at least attempt the use of "flexible functions". It allows homotheticity and homogeneity conditions to be tested. These are important in calculating aggregate welfare measures across individuals (Willig, 1978). A second reason for using flexible forms is that the prices of characteristics are no longer constant as in the linear or log-linear model but depend on other characteristics. This may in fact be correct but without testing the functions it is a maintained hypothesis.

In previous research Gillen and Levesque (1989)[18] found that the semi-log and log-log functional forms performed as well as the complex translog function and better than the simple arithmetic function on the Toronto housing data which is reported elsewhere in this paper.

4.1.1 MEASURING NOISE EXPOSURE

There are a number of different noise measures varying by a number of different parameters. The most important difference is between single event and cumulative noise metrics; the latter are used almost exclusively in hedonic studies. An important question that arises is what is most important to recipients of noise the loudness or the length of time exposed. Clearly depending on the answer different mitigation strategies are called for.

Previous hedonic studies rely exclusively on cumulative noise measures, especially the Noise Exposure Forecast, to represent noise at the locations studied. The Noise Exposure Forecast aggregates the noise produced by individual events over a day NEF(i,j) is the NEF value produced by aircraft i using flight path j. These values are calculated as

$$NEF(i,j) = EPNL(i,j) + 10\log[N_d + 16.67N_n] - 88$$

where EPNL(i,j) is the Effective Perceived Noise Level at the location produced by aircraft i using flight path j, N_d is the number of daytime flights (0700-2200) involving this combination and N_n is the number of nighttime flights (2200-0700). EPNL measures loudness in terms of sound pressure levels, the duration of the event, and the presence of pure tones like the whine of a jet engine (Raney and Cawthorn, 1991). It is particularly suited to measure the human response to aircraft

18 David W. Gillen and Terrence J. Levesque (1989),

noise. As a result the Noise Exposure Forecast provides a good correlate of responses to the question "How annoyed are you by aircraft noise?"

The goal of hedonic price analysis of airport noise is, however, not to calibrate dose response functions of the annoyance reaction rather it attempts to measure the contributions of a variety of location characteristics to real estate price differences. In a housing market, buyers react to the number of "loud" events at a location and the level of the noise from these events. Combining these characteristics in a particular formula like the NEF calculation imposes *a priori* restrictions on the way that loudness and frequency can affect prices. It is appropriate to test these against more general specifications of the effects.

In spite of this, there is only one published account of any attempt to decompose the separate effects of loudness and number of events in the literature that examines the relationship between market prices and airport noise; see Levesque (1994) and Gillen and Levesque (1989). This is attributable to two features of previous studies. Generally, hedonic studies have not accounted for the research on noise annoyance, and hence do not recognize the variety of issues surrounding the representation of noise, *including the separation of loudness and number of events*. Besides, they tend to rely exclusively on noise contour maps to estimate noise at a housing location. These maps only depict the cumulative noise measure, conveying no information about the variability of the loudness of individual events or their number.

Houses exposed to higher numbers of events exceeding 75 EPNL sell at a discount to those exposed to lower numbers. Houses in high average EPNL areas sell at a discount to similar houses in low average EPNL levels. Both findings are consistent with expectations.

The coefficient on noise variability form the Gillen and Levesque (1989) and Levesque (1994) studies suggests that *houses sell at a premium in areas affected by the same number of events, the same average EPNL level, but with a larger variation in the individual event noise levels. If it is a valid and reliable finding, this is an interesting result as it implies that variability in the loudness of events compensates for the number of events and their average loudness.*

One way to describe the results of this hedonic estimation involves deriving the percentage price discount per unit increase in each noise characteristic. This extends the Noise Depreciation Index to the separate features of noise. For noise characteristic z_k, the percentage change in price arising from a unit increase in the z_k is denoted NDI_k.

Consider a "standard" house comprising a 35-year-old three-bedroom bungalow with one bathroom, a fireplace, and garage space for one car and the house is a half-kilometer from the nearest school, and is located on a property of average dimensions. The NDI for average EPNL is about -1.3 over the range 78 to 92; increasing the average EPNL by one decibel reduces predicted house prices by about 1.3 percent. In contrast, the NDI for the number of events is much smaller as would be expected. Adding one more landing or takeoff is less noticeable than raising average loudness. The NDI for the number of events varies from -0.2 to -0.1 as the number of events increases from 80 to 400. The NDI for the variability of the EPNL shows the percentage change in the predicted price arising from a one-decibel decrease in the standard deviation.[19]

There appears to be significant evidence that decomposing the contributions of loudness and event frequency provides a better model of housing prices than using the Noise Exposure Forecast. This

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[19] For more detail on this issue see Appendix 1.

result suggests that decomposition is an effective approach. However, the information requirements to undertake this disaggregation are non-trivial.

4.1.1 SEGMENTING HOUSING BY TYPE

A final yet equally important issue is to consider different types of housing may result in noise being capitalized at different rates. The vast majority of hedonic applications either has only single family detached homes in their data set or do not distinguish among housing types. There are a few exceptions; for example, Uyeno and Hamilton (1993) and Gillen and Levesque (1989, 1992). The differences can be quite significant. Based on analysis by Gillen and Levesque (1989), separate estimates were prepared for 2015 transactions involving single or semi-detached houses, and 1361 transactions involving condominiums. The data used for the two estimations included a comprehensive set of housing, lot, neighbourhood and location characteristics.[20]

Two important findings about the impact of noise emerge from this study. The noise coefficient for the single and semi-detached houses falls well within the range reported in other studies. The NDI for single and semi-detached houses is about 0.5, at the lower end of the range. These findings are consistent with previous evidence on the effect of noise and they lend credibility to the noise cost calculations on which they are based.

The consistency with previous evidence of the results for single and semi-detached houses contrasts with the results for condominiums. The much lower impact of noise on condominiums (the NDI is less than half that for single and semi-detached houses) indicates a difference in the markets for the two types of housing that ought to be reflected in the calculation of the impact of noise on households living in them.

There are a number of factors that might explain these results. For example, self-selection may be working where single-family units would not be built in areas that are or are likely to be exposed to high noise levels. Condominiums also reflect a different life style choice than single-family homes, people in a different point in the life cycle, no children and people who may travel more.

The results show that segmenting property by type can be important for both planning as well as public policy. To the extent a neighbourhood is composed of a mix of housing the expected noise cost of an investment in airport capacity or a change in noise or airport management strategy would be overestimated using a NDI of .5 or .6, consistent with Nelson's (2004) findings.

5. Measuring the Total Costs of Changes in Noise Exposure

To this point the emphasis has been on developing measures of the value of noise (quiet). These are then combined with measures of the magnitude of the noise change to provide estimates of the economic costs (or benefits) of changes in noise exposure. However, these costs are not the full costs of a noise exposure but reflect only property depreciation.

Once a $ valuation has been attached to noise it is necessary to use this 'price' and determine the quantities of people affected and the nature of the affect. Two groups emerge. those who stay in the area and those who move away due to increased noise or for other reasons. Within these two groups there are different components of costs.

[20] I do not report the empirical findings from the Pearson study in this paper since it is not the focus of the paper. Copies of the study are available through the author.

Economic theory would predict that an externality such as noise would impose an economic cost on people in several different ways. First, **property depreciation**, assets such as homes would become less valuable in the marketplace because the asset now has a lower quality of services flowing from it. Equivalently, in order to enjoy the same level of services such as outdoor relaxation, sleeping or conversation resources would have to be invested. Second, the **transactions cost** associated with moving to another location impose an economic loss on those who decide to move. Third, people who decide to move will face a cost of lost utility in the form of attachment to their home. This would be captured in a measure of **lost consumer surplus**. Fourth, people who remain in the area, for whatever reason, face **increased nuisance noise** and, therefore, a reduction in the flow of services from their homes. The magnitude will depend upon a number of factors including sensitivity to noise and activities that are perceived affected by noise such as sleep, recreation or solitude. Below a conceptual framework is presented which provides empirical measures of each of these components.

5.2 Conceptual Framework for Calculating Noise Costs

Two variables represent a composite of sub-components that must be disaggregated. There are three different types of housing, which must be considered; detached single-family homes, condominiums and apartments. There are also three groups of people; those who move to an adjacent community as a consequence of the increase of airport activity, those who move naturally regardless of what happens with airport operations and those who remain in the community.

Expressions for each of the four components that make up total noise costs are:

1. Asset Depreciation Costs

$$\sum_{i=1}^{2}\sum_{j=1}^{3}\sum_{t=1}^{k}\left[\left(V_{ijt}\right)\bullet\left(P_{ij}\right)\bullet\left(d_t\right)\left(\Delta N_{ijt}\right)\bullet\left(M_{ijt}\right)\right]\bullet\left(\frac{1}{1+i}\right)^{t+5}$$

2. Lost Householder Surplus

$$\sum_{i=1}^{2}\sum_{j=1}^{3}\sum_{t=1}^{k}\left[\left(V_{ijt}^{*}-V_{ijt}\right)\bullet\left(\Delta N_{ijt}\right)\bullet\left(\hat{M}_{ijt}\right)\right]\bullet\left(\frac{1}{1+i}\right)^{t+5}$$

3. Transactions Costs

$$\sum_{i=1}^{2}\sum_{j=1}^{3}\sum_{t=1}^{k}\left[\left(\Delta N_{ijt}\right)\bullet\left(\hat{M}_{ijt}\right)\bullet tc\right]\bullet\left(\frac{1}{1+i}\right)^{t+5}$$

4. Noise Nuisance

$$\sum_{i=1}^{2}\sum_{j=1}^{3}\sum_{t=1}^{k}\left[\left(V_{ijt}\right)\bullet\left(P_{ij}\right)\bullet\left(\Delta N_{ijt}\right)\bullet\left(NM_{ijt}\right)\right]\bullet\left(\frac{1}{1+i}\right)^{t+5}$$

where:

V_{ijt} is the weighted average market value of house type i in noise exposure contour j at time t.

P_{ij} is the property depreciation or price of noise.

ΔN_{ijt} is the increase in the number of houses of each type in a noise exposure contour as a result of a shift in noise contours with the new runway alternatives.

M_{ijt} is a measure of the 'movers'; those who leave the area for reasons other than noise as well as because of increase in noise exposure.

$\widehat{M}_{ijt}$ is the number of households who are induced to move as a result of the increase in noise exposure.

NM_{ijt} is the number of people who remain in the neighbourhood even with the change in airport operations

V^*_{ijt} is the valuation of the average house by the homeowner reflecting the utility, consumption and investment value of the house.

$\mathbf{d_t}$ is the duration cost to the homeowner and is a measure of the discounted present value of forgone income as a result of houses in noisy neighbourhoods being on the market for a longer period of time.

There are four elements common to each calculation; in principle, the impact on the three different types of housing, the division between those who move out of the environment and those who choose not to do so, the impact of noise as measured from an existing base case developed from current runway usage and the discounting of all measured costs over a time horizon which reflects when the new infrastructure or new traffic strategy (such as a new runway option) will be completed.[21]

The *base case* from which all measurements are made is established as the 1996 noise exposure contours (based on a NEF measure) and hence traffic levels and composition. This level of airport activity will have imposed property depreciation and noise annoyance costs upon the airport environs and it is from this level that the 'incremental costs' of the alternative runway configurations are calculated.

Each component of Total Noise Costs must also be taken forward in time as well as discounted to place the measurement in constant dollars (Euros). By 'taking forward in time' we mean that with the moving propensity with respect to noise, the community will turn over or will be entirely replaced in approximately 30 years. This means that the noise externality applies only to those residents who remain in each year. Those who move into the community are assumed to be fully aware of the noise and airport operations, now and into the future, and thus suffer no externality. The costs of these externalities that occur over thirty years are discounted using a 5% real discount rate.

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[21] The empirical example presented later in the section is based on an assessment of runway alternatives for Toronto International airport.

5.2.1 MEASURING THE PROPENSITY TO MOVE: THE MOBILITY MODEL

The model of noise costs requires estimates of the long run equilibrium rate of emigration from neighbourhoods and the short run rate at which those who are most annoyed by increased noise move away.

Theoretical Background

If the annual rate of emigration from a neighbourhood is constant, it can be simply calculated from the five-year rate. The technical relationship between the five-year rate, denoted Y_k for Enumeration Area k, and the annual immigration rate, denoted g_k, is based on the following formula:

$$g_k = 1 + (Y_k - 1)^{1/5}$$

A useful way to interpret the annual rate g_k is as an index of the long run equilibrium turnover of homes in a neighbourhood. Figure 2 represents this view. Panel (a) shows long run demand and supply curves for a resale housing market; by assuming that the housing stock of a neighbourhood is relatively fixed, it is possible to represent the quantity demanded and offered as a fraction of the housing available. The levels of supply and demand are assumed to reflect the effects of an NEF value of 25.

The equilibrium "quantity" is also the rate at which new households will replace incumbent households in the neighbourhood. That is the equilibrium quantity is the annual rate of emigration from a neighbourhood with a fixed housing stock. It is, of course also the annual rate of immigration; however, the former interpretation is more useful for the purpose of this study.

Panel (b) shows the demand and supply effects of an increase in noise levels to NEF = 30. Demand drops at all positive price levels, because noise is a negative externality, reducing the consumer surplus enjoyed by homeowners. The supply price of housing decreases for every quantity, because houses affected by the negative externality are worth less to homeowners, and therefore, their reservation prices fall.

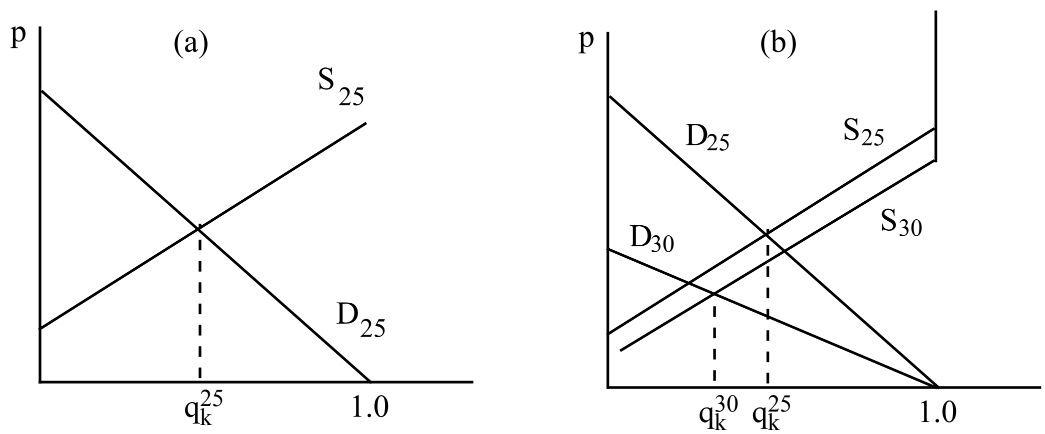
Panel (b) depicts a reduction in the long run equilibrium rate of emigration from a neighbourhood. This coincides with empirical results discussed below, which suggests that q_k is a decreasing function of noise, when it is estimated from five-year rates according to the above expression. In theory, the effect of the demand and supply shifts on the long run value of q_k depends on the elasticities of demand and supply with respect to noise. If additional noise causes demand to shift relatively more (less) than supply, then q_k will fall (rise).

The path from the old equilibrium in panel (b) to the new equilibrium is of central concern in the development of a mobility model that represents the effects of increased noise on moving rates. The deviation from long run equilibrium supply is the measure of noise-induced mobility that is required in the noise cost models. Unfortunately, there is no information available to guide the analyst to a model of this short run process. Ideal data consists of observations on housing market activity before and after a large and permanent change in noise.

In the absence of a behavioural model of the mobility effects of noise, it is necessary to determine what can be learned from the facts and theory available. In the short run, the supply of housing will increase, as current market prices begin to exceed the reservation prices of homeowners, newly affected by the negative externality. For some time, then, the moving rate among incumbents will exceed g_k^{25}.

Figure 2

The Housing Market in a Neighbourhood



5.2.1 ESTIMATING THE EQUILIBRIUM MOBILITY RATE

An empirical model of the equilibrium mobility rate is required to calculate the moving rates of those who are not immediately induced to move because of increased noise. When this model is combined with that describing the short run effects of noise on mobility, an annual profile of each Enumeration Area can be calculated that shows the expected proportion of the households originally exposed to an increase in noise that remain.

The model hypothesizes that annual emigration rates depend on aviation noise levels in the Enumeration Area and neighbourhood characteristics. The model is based on the following expectations about aviation noise and equilibrium neighbourhood turnover. Emigration rates are expected to fall as normal noise levels rise; that is, the higher the measured NEF value in an area the higher g_k is expected to be, all else equal. If there is any measurable noise effect on emigration rates from quiet EA's (NEF < 20), it is expected to have a much smaller than the effect in noisy EA's (NEF = 20).

Emigration rates from a neighbourhood are also expected to reflect neighbourhood characteristics. For example, the age of the EA as measured by the average age of its' housing, and the percent of the homes in the EA that are single detached homes are hypothesized to affect emigration rates. It is expected that emigration is lower in older neighbourhoods, and in neighbourhoods with high proportions of single detached homes. Both variables suggest the idea of neighbourhood stability.

The model that is estimated is:

$$g_k = \alpha + \beta_0 \delta_k + \beta_1 NEF_k + \beta_2 (1 - \delta_k) NEF_k + \frac{\gamma_1}{Age_k} + \gamma_2 \%\text{single}_k + \varepsilon_k$$

$$g_k = \left\langle \begin{matrix} 1 \; if \; NEF_k \geq 20 \\ 0 \; if \; NEF_k \end{matrix} \right\rangle$$

This model tests the difference in emigration rates between quiet and noisy neighbourhoods in two ways. In a quiet neighbourhood, the intercept term of the model is just the constant α; in noisy neighbourhoods the intercept term is $\alpha + \beta_0\delta_k$. The term $\beta_0\delta_k$ is a "noise shift" parameter. If δ_k is negative and significantly less than β_2, then noise has a greater impact on long-term emigration rates in noisy neighbourhoods than quiet neighbourhoods.

Investigation of the data suggested that the emigration rate was probably related more closely to the inverse of average age of the housing in an EA (Age). Table 1 presents the results of least squares estimation of the coefficients of model. All of the coefficient estimates are significant at the 5 percent level of significance. Turnover is statistically lower in noisy neighbourhoods than in quiet

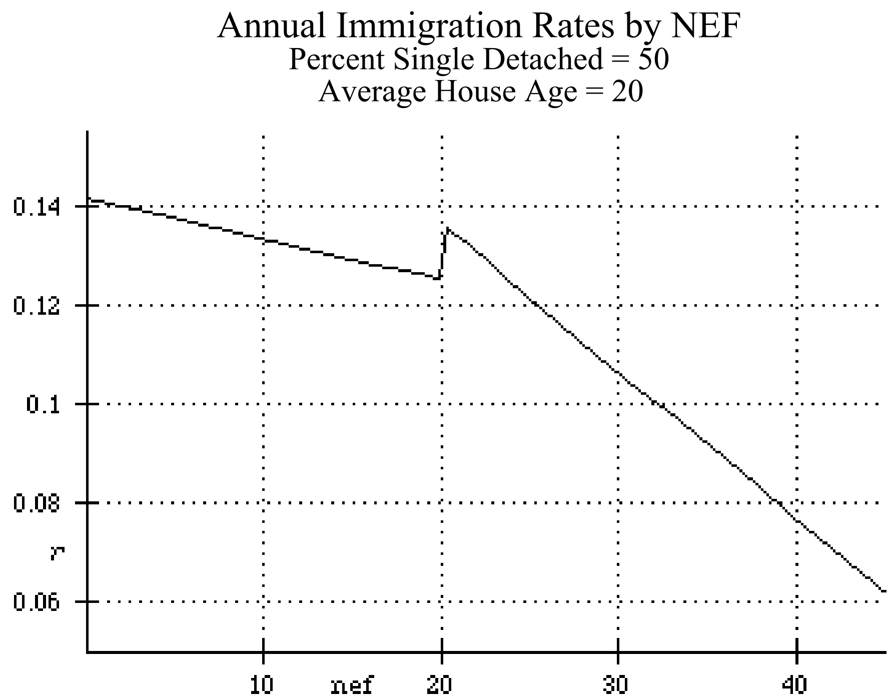
Table 1

Coefficient Estimates of Mobility Model

Variable	Coefficient Estimate (Standard Error)
NEF: Noisy	-0.00298 [0.00069]
NEF: Quiet	-0.00081 [0.00018]
Inverse Age	1.19460 [0.02323]
Percent Residential	-0.00067 [0.00003]
Constant	0.11132 [0.00236]
Noise Shift	0.05470 [0.01711]
Sample Size	4353
Adjusted R-square	0.4311

neighbourhoods. Figure 3 shows the turnover rate in an EA as NEF increases for given values of Age and %Single Family homes. The hypotheses about the effects of noise on equilibrium emigration rates are evident in the relationship. The results in Table 1 also indicate that emigration rates fall as the percent of single detached homes increases, and that emigration falls as the average housing age rises.

Figure 3



The results of the mobility model estimation are used to construct emigration rates for all EA's <u>net of the contribution of NEF</u> according to the function:

$$g_k^{net} = 0.11132 + 0.0547\delta_k + \frac{1.1946}{Age_k} - 0.00067 \bullet \%\text{single}_k$$

The base case and alternative runway NEF values are then used to produce separate long-term emigration predictions by adding the noise contribution

$$g_k = -0.00298\delta_k NEF_k - -.00081\delta_k NEF_k$$

to obtain gross emigration rates for each scenario.

5.3 Modelling the Short Run Effects of Increased Noise on Mobility

One approach to estimating the short run noise induced mobility rate consists of linking mobility to noise annoyance. A considerable literature exists that describes the relationship between noise levels and responses to scale questions about degree of annoyance.

Suppose that the rate q_k^{30} reflects the behaviour of incumbents who find that they become "highly annoyed" by noise when NEF increases from 25 to 30. Empirical analysis based on survey responses suggests that approximately 27 percent of the population would describe themselves as highly annoyed by noise measured at NEF 25. If noise levels increase to NEF 30, the percent highly annoyed increases to about 46.

A sensible condition of long-term equilibrium in a competitive neighbourhood housing market is that all households for whom the costs of noise exceed costs of relocating actually move to some quieter location. At the equilibrium in panel (a), no households remain who move because of noise if the equilibrium exhibits the preceding characteristic.

When noise increases, some proportion of all the households who were not highly annoyed at NEF 25 will become so at NEF 30. They become candidates for noise-induced relocation. A certain fraction of these, g_k^{25}, will already be in the process of moving for reasons other than noise. Suppose that φ(25,30) is the fraction of the population that becomes highly annoyed when noise is initially NEF 25, and increases to NEF 30. Then the proportion of the population that is induced to consider a move because of noise is:

$$\varphi(25,30) \bullet \left(1 - g_k^{25}\right)$$

Empirical evidence suggests that φ(25,30) = 19, and g_k^{25} = .12 in neighbourhoods that are about 20 years old and for which 50 percent of their dwellings are single detached homes. Therefore, noise increases from NEF 25 to NEF 30 could induce as much as 16 percent of the households in such a neighbourhood to move.

Lacking a model of how rapidly these noise-induced movers enter the market, it is assumed that they leave within the first year. Hence, long run equilibrium is re-established after one year.

The method for calculating the components of noise-induced mobility is:

1. Calculate the impact of a noise increase on the percent "highly annoyed." The function

   $$\%HA = -40.2 + .003129(NEF + 35)^3$$

   is described as fitting noise annoyance survey data from neighbourhoods bordering Pearson International Airport very well. It is used to calculate the difference in the percent highly annoyed before and after an increase in noise.

2. Estimate g_k^{NEF}

3. Calculate the induced emigration rate.

5.3.1 LOST HOUSEHOLD SURPLUS

The 'consumer surplus' represents the dollar value of utility associated with the current location that the household must give up if they move. It is the difference between the subjective valuation of the house and the market valuation of the house.

The lost consumer surplus is calculated by estimating the difference between the homeowners valuation of their home including 'value' over and above market price and the market price of the home. It can be determined by examining the difference between the valuation reported in the Census data by enumeration area and the market data, aggregated by Enumeration Area, contained in the home sales data. This difference fits the definition of 'lost householder surplus' of the difference between the market price of a house and the price at which a householder would sell. It is assumed that anyone moving into the area is fully aware of the presence and level of activity now, and in the future, at the airport. Therefore, the lost householder surplus for immigrants is assumed to be zero.

5.4 Calculation of the Costs of Increased Noise

Calculation of the four costs of increased aircraft noise requires formulae for total depreciation, moving costs, and the lost household surplus experienced by those moving. The mobility model of noise induced and equilibrium emigration is also required.

5.4.1 TOTAL NOISE COSTS

The total noise annoyance costs associated with each runway investment option is the sum of the discounted values of each of the four components described above and summed over all noise exposure areas. They are compiled in Table 2 below.

These results are dependent upon two key calculations. First, in the calculations by housing type there are different depreciation rates from noise; single detached housing differs from owner flats and condominiums.

The second key measure is the propensity to move as a consequence of noise exposure. The analysis indicates a low propensity to move with changes in the level of noise. This 'household moving model' reflects the state of the larger urban housing market and, as we argue in the text, is corroborated by evidence from Chicago. Two forces are at work. First, market prices, in this period, had been increasing rapidly far outstripping the rate of increase in wages. This meant that first time buyers had to move further from the city centre to purchase and that existing owners may be reluctant to attempt to filter up to a newer home. This 'macro' effect creates immobility. Second, a relatively large number of people living in the airport community are employed by the airport or airport derivative (or related) businesses. This proximity to place of employment would also make existing residents reluctant to move.[22]

Information was received for essentially three alternative runway investment alternatives. There were in fact 16 alternative runway alignments and locations but these can, for the noise externality analysis, be reduced to three alternatives.

Noise contours were also constructed for two years 1996 and 2001. The differences between these two were for the most part, the impact of Stage III aircraft. These newer generation quiet aircraft, introduced in greater abundance in 2001, have the impact of reducing the size of the noise contour. This was taken account of in our calculations by including only those EA's (the geostatistical unit used) that experienced a noise increase from the base case. A common occurrence was to observe an increase in noise to 1996 and a decrease in 2001 lower than 1996 but above the base case. We, therefore, based calculations in two stages; EA's affected to 2001 by ΔNEF = x and EA's affected by ΔNEF = y after 2001. The change, Δ, was always measured relative to the base case. For example, an EA could experience a noise exposure increase from 30 to 38 NEF to 2001; ΔNEF = 8. In 2001 noise decreases to 35NEF. Now ΔNEF = 5. Calculations made for the period after 2001 would therefore use 5 rather than 8 as the change in NEF.

In the analysis that considers the changes between 1996 and 2001, technological effects were separated from runway investment effects. This means, for example, that we are interested in the net impact of the runway investment after 2001 excluding the technological effect of quieter Stage III aircraft since this would have occurred regardless of the decision to invest in a runway. If fact this entire issue led to calculate **two sets of values** for Total Noise Costs. One can take two views of the world. One view holds that it will take 30 years for the 'system' - meaning airport and community - to get back into full equilibrium. Therefore, the impact of changes to the airport infrastructure is taken over 30 years. An alternative view of the world is that after 2001 quieter Stage III aircraft will result in a significant shrinkage of the noise contours and hence measured impact. Since we are concerned only with increases in noise, from the base case, and not decreases, the impact of the runway investment(s) take place between completion and 2001. After this period noise actually goes down. The impact, therefore, is considered only until 2001.

The total environmental costs generated by the investment options are contained in the following Table. There are three cases considered; the 6 Runway option, 5 Runway Option A and 4 Runway Option B. Both the 30-year and 5 year 'state of the world' are illustrated. In all options the largest cost associated with the noise externality is 'noise nuisance'. This is because in the Toronto case relatively few people move as a consequence of changes in the exposure to noise. The propensity to move drives the values of depreciation, transactions cost and lost householder surplus.

[22] The hedonic analysis corroborates this argument. The sign on the coefficient measuring 'distance from runway threshold' is negative. For single-family homes the elasticity of house price with respect to distance is -.09. The same figure for condominiums is -.04. Thus, for example, a ten percent increase in distance from the airport leads to a .9% decrease in house price for single-family homes.

Table 2

Total Noise Costs of Alternative Investment Options[23]

Category	$ Value			% of Total		
	6 Runway case	5 Runway Option A	4 Runway Option B	6 Runway case	5 Runway Option A	4 Runway Option B
1. Depreciation						
assuming 5 year impact	$20,565,609	$4,318,221	$5,790,090	5.58	5.53	5.59
assuming 30 year impact	$52,793,964	$11,079,432	$14,870,403	5.55	5.45	5.57
2. Lost Householder Surplus						
assuming 5 year impact	$1,381,261	$940,970	$298,183	0.37	1.21	0.29
assuming 30 year impact	$3,543,490	$2,413,258	$764,701	0.37	1.19	0.29
3. Transactions Cost						
assuming 5 year impact	$789,199	$341,839	$108,915	0.30	0.44	0.11
assuming 30 year impact	$8,052,532	$3,870,560	$1,233,353	0.85	1.9	0.46
4. Noise Nuisance						
assuming 5 year impact	$345,632,493	$72,431,182	$97,472,071	93.75	92.82	94.02
assuming 30 year impact	$887,276,009	$185,840,255	$250,333,451	93.23	91.46	93.69
Totals						
assuming 5 year impact	$368,668,163	$78,032,213	$103,669,259	100	100	100
assuming 30 year impact	$951,665,995	$203,203,505	$267,201,908	100	100	100

Option A refers to the addition of 2 runways, includes 1996 & 2001
Option B refers to the addition of 1 runway, includes 1996 & 2001

The analysis of the propensity to move showed that, on average, approximately 4% of households in an EA move independent of the level of noise. Noise exposure, as measured by NEF, does have a positive affect upon the number of movers. A unit increase in NEF from the current mean value (20.91 in the sample used) will increase out-migration by .045%. Therefore, when noise exposure changes it is more likely that Pearson will be faced with increased complaints and pressures to reduce or reorient airport operations than to have a significant out-migration of noise sensitive households and an in-migration of noise tolerant households.

6. Summary and Conclusions

This paper has focused on the *practice* of including the assessment of externalities in investment and strategic management decisions, focusing specifically on noise externalities. It is increasingly important that the full [social] costs of an activity be considered in any choice of pricing, investment or operational strategy. In order to accomplish this it is necessary to measure both the value and the amount (quantity) of noise. For noise there are several methods of establishing values or willingness to pay for less of it. A popular and well-researched method is the hedonic technique

[23] See Appendix 2 for the underlying costs measured by noise contour.

that uses the differences in property values bundled with different amount of noise exposure to establish a noise depreciation index. The paper provides a background to the underlying theory as well as a description of four important factors that can affect the estimated value of the noise deprecation index. This index provides the basis of the measure of costs associated with changes in noise exposure.

The bulk of the paper dealt with implementation of the noise valuation in evaluating different runway investment options. Pearson International Airport in Toronto Canada was used as the empirical example. The quantification of changes to noise exposure is not simply a matter of measuring what the [new] value of the noise contour would be under the different investment options. Rather it is determining who receives the noise and who avoids it. The avoidance costs are to be included in the noise costs assessment as are the costs of noise exposure if one does not avoid the noise. Therefore, the total costs of noise are the sum of property depreciation; assets such as homes would become less valuable in the marketplace because the asset now has a lower quality of services flowing from it. Equivalently, in order to enjoy the same level of services such as outdoor relaxation, sleeping or conversation resources would have to be invested. Second, the transactions cost associated with moving to another location impose an economic loss on those who decide to move. Third, people who decide to move will face a cost of lost utility in the form of attachment to their home. This would be captured in a measure of lost consumer surplus. Fourth, people who remain in the area, for whatever reason, face increased nuisance noise and, therefore, a reduction in the flow of services from their homes. The magnitude will depend upon a number of factors including sensitivity to noise and activities that are perceived affected by noise such as sleep, recreation or solitude.

In undertaking the noise cost evaluation management and policy makers will be provided with additional information. For example, one conclusion that can draw from the analysis is that noise management strategies will be more important in a city in which there is less turnover of houses (less mobility) than in a community in which people move a good deal. In the Vancouver market , for example, the community turns over in a comparatively short period of time and [relatively] noise insensitive residents filter into the community. In the Toronto market this does not occur. A second important piece of information is seeing which component of total noise cost is most important. The largest cost in the Toronto case is nuisance and one can expect significant pressures from community residents to reduce operations or noise or both. In order to realize the benefits of the investment, airport management will have to develop noise management strategies. These strategies if effective will have a significant return. It also suggests that the output planned for any investment might have a contingent value since realized output (aircraft operations per time period) may differ from planned output due to restrictions resulting from political action.

7. Appendix 1- Alternative Noise Measures and the Impact of Frequency

The traditional noise measures used in these types of studies are NEF or Ldn . These two measures of noise exposure take into account such things as the noise energy level and source of noise, frequency of flights and the timing of the flight. The NEF or Noise Exposure Forecast is used in Canada to measure and assess noise due to aircraft around Canadian airports. It is a composite measure of the effective perceived noise level (Epnl) by aircraft type and runway and the frequency and timing of the flights. Values are generally not reported below 25 NEF. This measure was calculated for each house in our sample by matching the location with respect to the noise contours associated with Pearson International Airport. We did not, however, stop at NEF = 25 but rather used a spline interpolation program to attach NEF values as low as 1 and the NEF gradient was treated as continuous rather than as a step function.

The NEF measure can be criticized on a number of grounds. First, there is an assumed linear relationship with flight frequency so the impact of the 100th flight is the same as that of the first flight. Second, it aggregates frequency, sound level and time of day of flight in an ad hoc manner. A more desirable method is to be able to decompose the NEF measure and present the elements separately. The rationale is that the magnitude of the changes in the value of NEF depends upon which component changes and, second, it can be determined empirically whether the market capitalizes each component of NEF in the same way. The decomposition also provides more information, from a policy perspective, since if frequency, for example, is less important than flight timing, it suggests a different set of tools or strategies should be used to handle the noise problem. Finding a significant effect of the NEF variable does not direct one to an appropriate strategy to manage noise annoyance.[24]

The relationship between the components of the NEF measure and between NEF and Ldn (used predominantly in the U.S.) are presented in the table below. Sel and Epnl are similar measures of the single event noise level and are measured in decibels. The N_d, N_e and N_n are the number of day (0700-1900), evening (1900-2200) and night (2200-0700) flights respectively. The formulas for NEF and Ldn place different weights on each type of flight. Night flights are weighted at 16 times day flights, for example. The formulas for the two measures are:

$$\mathrm{NEF} = \mathrm{Epnl} + 10 \log (n_d + n_d + 16.67\ n_n) - 88$$

$$\mathrm{Ldn} = \mathrm{Sel} + 10 \log (n_d + n_d + 10\ n_n) - 49.4$$

The first thing one notes upon examining the table is the close correspondence between the two measures, however, it is also evident that the variance in the two measures differs according to the source. In the first six rows, the number of flights is held constant as are the proportions between day, night and evening flights. Only the level of sound is allowed to vary. An increase in the sound level from 80 to 108 decibels (a 35% increase) results in a more than doubling of the NEF measure (a 132% increase) and a 47.42% increase in the Ldn measure. The remaining three parts of the table illustrate changes in Ldn and NEF with changes in the frequency of flights.

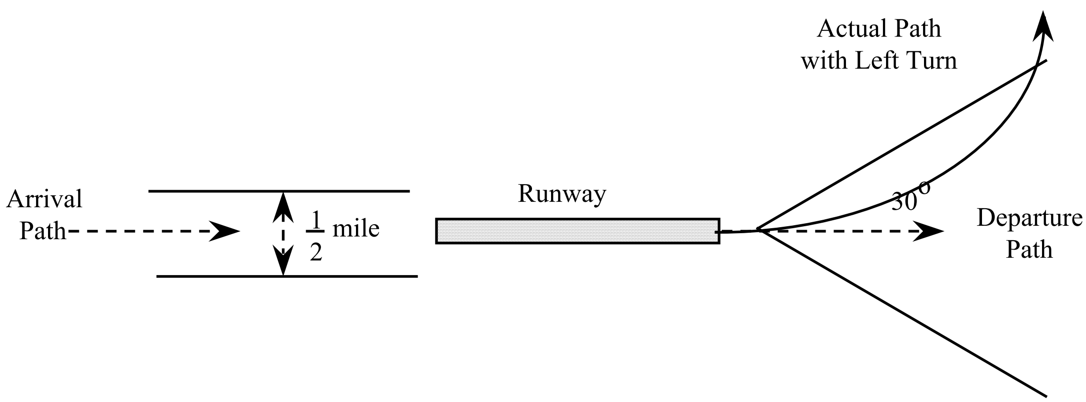
It is evident that increasing (doubling) the number of day or evening flights has little impact on the value of Ldn or NEF. There is some marginal increase in the value of the two measures when the

24 This is not unsurprising since the NEF measure is a planning measure rather than a policy measure.

frequency of night flights is doubled which is a consequence of the weighting scheme. The important point, however, is that the value of NEF is a composite of two factors which may be annoying; sound and the visual presence of aircraft. The NEF is a better measure of the former than the latter as illustrated above but it may be that visual presence is important to noise management. Therefore, some alternative set of variables may be required.

Awareness of an aircraft movement depends on the individual's location relative to the flight path. Our raw data consists of the annual arrival and departure movements from the six runway thresholds at Pearson International with no flight path information. Lack of the flight paths represents a potentially serious limitation on our ability to detect any contribution to the depreciation of property values by event frequency. Nevertheless, we attempted the following simple model of the relationship between location and event frequencies. This is illustrated in

Flight Path Exposure Zones



Any location within a half-mile corridor centered on the extension of the runway is assumed to be exposed to the arrival frequencies for that runway. Any location within a 60-degree zone centered on the extension of the runway, and originating at its threshold is assumed to be exposed to the departure frequencies for that runway. Our departure zone attempts to account for the left and right turns that characterize departures on all of the airports runways.

8. Appendix 2; Total Noise Costs for Investment Options segmented by Noise Contour

Table 3

4 Runway Option

Present Value $1990

4 runways		Low	Mean	High
Nuisance cost	20-25	$5,105,092	$7,765,072	$10,237,078
	25-30	$231,008	$363,728	$485,072
	30-35	$0	$0	$0
	35-40	$0	$0	$0
	40+	$0	$0	$0
Capital loss	20-25	$666,307	$1,037,239	$1,381,342
	25-30	$21,338	$34,616	$46,733
	30-35	$0	$0	$0
	35-40	$0	$0	$0
	40+	$0	$0	$0
Surplus	20-25	$1,614,398	$1,614,398	$1,614,398
	25-30	$81,472	$81,472	$81,472
	30-35	$0	$0	$0
	35-40	$0	$0	$0
	40+	$0	$0	$0
Moving costs	20-25	$1,181,012	$1,181,012	$1,181,012
	25-30	$62,833	$62,833	$62,833
	30-35	$0	$0	$0
	35-40	$0	$0	$0
	40+	$0	$0	$0
TOTAL	20-25	$8,566,809	$11,597,721	$14,413,830
	25-30	$396,651	$542,649	$676,110
	30-35	$0	$0	$0
	35-40	$0	$0	$0
	40+	$0	$0	$0

Table 4

5 Runway Option

Value $1990

5 runways		Low	Mean	High
Nuisance cost	20-25	$8,071,543	$12,732,462	$17,051,070
	25-30	$2,835,417	$5,344,018	$7,622,610
	30-35	$2,729,760	$3,761,040	$4,694,160
	35-40	$0	$0	$0
	40+	$0	$0	$0
Capital loss	20-25	$1,110,103	$1,779,590	$2,399,023
	25-30	$383,825	$765,160	$1,111,385
	30-35	$146,232	$207,074	$261,960
	35-40	$0	$0	$0
	40+	$0	$0	$0
Surplus	20-25	$2,972,909	$2,972,909	$2,972,909
	25-30	$2,055,219	$2,055,219	$2,055,219
	30-35	$593,568	$593,568	$593,568
	35-40	$0	$0	$0
	40+	$0	$0	$0
Moving costs	20-25	$2,235,529	$2,235,529	$2,235,529
	25-30	$1,284,839	$1,284,839	$1,284,839
	30-35	$526,992	$526,992	$526,992
	35-40	$0	$0	$0
	40+	$0	$0	$0
TOTAL	20-25	$14,390,084	$19,720,490	$24,658,531
	25-30	$6,559,300	$9,449,236	$12,074,053
	30-35	$3,996,552	$5,088,674	$6,076,680
	35-40	$0	$0	$0
	40+	$0	$0	$0

Table 5

6 Runway Option

Present Value $1990

6 runways		Low	Mean	High
Nuisance cost	20-25	$12,834,737	$19,983,030	$26,612,180
	25-30	$2,986,280	$5,583,900	$7,943,740
	30-35	$2,729,760	$3,761,040	$4,694,160
	35-40	$0	$0	$0
	40+	$0	$0	$0
Capital loss	20-25	$1,746,854	$2,770,095	$3,718,128
	25-30	$394,704	$783,454	$1,136,360
	30-35	$146,232	$207,074	$261,960
	35-40	$0	$0	$0
	40+	$0	$0	$0
Surplus	20-25	$4,502,239	$4,502,239	$4,502,239
	25-30	$2,105,942	$2,105,942	$2,105,942
	30-35	$593,568	$593,568	$593,568
	35-40	$0	$0	$0
	40+	$0	$0	$0
Moving costs	20-25	$3,355,617	$3,355,617	$3,355,617
	25-30	$1,326,288	$1,326,288	$1,326,288
	30-35	$526,992	$526,992	$526,992
	35-40	$0	$0	$0
	40+	$0	$0	$0
TOTAL	20-25	$22,439,447	$30,610,981	$38,188,164
	25-30	$6,813,214	$9,799,584	$12,512,330
	30-35	$3,996,552	$5,088,674	$6,076,680
	35-40	$0	$0	$0
	40+	$0	$0	$0

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