A Hedonic Model of the Impact of Localized Aircraft Noise on Housing Values

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ABSTRACT

The market becomes inefficient when externalities cause market failure. However, an externality does not entrain inefficiency if a market other than the one that generates it accounts for it in some way. Airports are a well-known source of the negative externality noise; and housing markets are commonly thought to be affected by airport noise. A hedonic model was applied to airport noise and the housing market, together. It was found that the housing market of the West Island of Montreal *did* account implicitly for the noise annoyance from Dorval Airport, hence that the noise was a *pecuniary* externality. Moreover, each additional unit of noise annoyance (NEFdB) was found to cause an average depreciation in housing price (NDSI) of 0.76%. Finally, the linguistic predominance (French- or English-speaking) of a neighbourhood's residents may be an appropriate Canadian analogue for the racial variables that have been specified in some hedonic property models in the U.S..

RESUME

Le marché devient inefficace quand les externalités causent la faillite du marché. Pourtant, une externalité n'entraine pas de l'inefficacité si un marché autre que celui dont elle provient en tient compte de quelque façon. Or, les aéroports répresentent une source bien connue de l'externalité negative du bruit. Les marchés immobiliers sont considérés comme étant susceptibles d'être influencés par le bruit aéroportuaire. Un modèle hédonique a été appliqué au bruit aéroportuaire et au marché immobilier conjointement. On a constaté que le marché immobilier de l'Ouest de l'Ile de Montréal a bien tenu compte de la nuisibilité bruyante de l'Aéroport Dorval. Donc, on pourrait conclure que ce bruit a été une externalité *pécuniaire*. De plus, on a constaté que chaque unité additionnelle de la nuisibilité bruyante (NEFdB) aurait entrainé une dévalorisation moyenne dans la valeur des maisons (NDSI) de 0.76 pour cent. Enfin, la prédominance linguistique (anglophone ou francophone) des habitants d'un quartier pourrait être analogue pour le Canada aux variables raciaux qui ont été specifiés dans des modèles hédoniques immobiliers aux Etats-Unis

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CHAPTER I. INTRODUCTION

I. Externalities and Airport Noise

Economic activity in a given market can have external ramifications, either positive or negative, for people who do not participate in that market. When the latter are not involved in that particular market, and the impact that they experience is not the direct object of a market transaction, the effect is called an externality. Externalities represent a productive or destructive activity which is not explicitly embraced by the market institution. When the market does not account for them in any way, its putative efficiency is undermined.

However, the external impacts may have an induced effect on the prices in a second market, so that the latter contains what amounts to two sub-markets: an explicit market for its own good, and an implicit market for the externality. When such is the case, the externality is termed "pecuniary", and the market institution, through its implicit reflection of the particular externality, does not lose its property of efficiency because of it.

One interesting example of a negative externality is airport noise, the local noise emanated by aircraft operating at a given airport. As a pollutant, its effects are well-documented (Beattie, 1983; DWG, 1990; Harvey *et al.*, 1979; Muskin and Sorrentino, 1977; Tietenberg, 1988; and Walters, 1975 and 1978). Because aircraft contribute the largest component of airport noise, it will be assumed that aircraft noise and airport noise can be considered to be more or less synonymous [1]. However, it is not just the high level of localized noise that is relevant, but also the fact that most airports are located near urban centres which are the origins or destinations of most of their clientele. Indeed, the problem of airport noise lies in the coincidence of locally high levels of noise and local concentrations of

1 Nevertheless, ground traffic may contribute to airport noise (DWG, 1990), and aircraft noise may have an impact away from airports.

population.

Although the fact that commercial airports are usually sited in or around urban areas makes airport noise problematic, it is fortunate for the analysis of the airport noise externality. Because housing markets also happen to be located in urban or suburban areas, they provide an excellent opportunity for analyzing the impact of the airport noise externality through its capitalization in housing prices.

There is no explicit market for airport noise, but the general capitalization of airport noise effects in housing prices makes it most certain that there is an implicit market for airport noise (Nelson, 1979; Pennington *et al.*, 1990; and Walters, 1975). Consequently, airport noise is most probably a so-called *pecuniary* externality, one that induces effects in another market and which may thereby preserve the efficiency of the market as a whole. If this capitalization effect can be measured around a given airport, and it is found to be significant, then the airport noise externality can be deemed pecuniary, or locally so, and one can conclude that the market has not failed in this respect.

II. Research Questions and Hypotheses

II.A. Problem Statement

The research problem for this thesis is to determine whether the market accounts for the negative externality of airport noise. More specifically, the housing market was the part of the economy which was being considered, and Dorval airport was the locus of the airport noise. This may also be the first economic study pertaining to the airport noise emanating from Dorval airport. Measures of the relative importance of noise effects on housing prices are calculated and compared with previous work.

II.B. Research Questions

The first question to be dealt with in this thesis is whether airport noise is a pecuniary or non-pecuniary externality. If it is the former, its effects should be incorporated into the prices of the housing market. Thus, this question amounts to one of whether the market works despite the existence of external effects. The second question is contingent upon the first. It asks how much of an effect does airport noise have on housing prices, supposing that there is an effect.

II.C. Hypotheses and Questions

The primary hypothesis concerns whether there is a statistically significant relationship between house prices and noise. It maintains that at least one, if not all, such coefficients are significant and negative or, in other words, that aircraft noise at Dorval Airport does have a significant, negative effect on local housing prices. Besides the hypothesis, a question is posed: how large is the impact, if any, of airport noise on housing prices, relative to those prices?

III. Structure of the Thesis

This chapter has introduced the research problem; and presented the research questions and hypotheses. Chapter II reviews the literature on the nature of externalities, as a departure from Pareto-optimality and market efficiency. Moreover, it discusses pecuniary externalities, which preserve market efficiency; and hedonics: theory, application, assumptions, and alternatives. Chapter III deals with how to specify hedonic models, in terms of both functional form and which variables to include; and covers the sources of data and variables that were actually used. It goes on to explain the Box-Cox transformation, a method of using the data to determine the appropriate functional form.

Chapter IV deals with the method. It covers the empirical techniques used, including ordinary least squares (OLS) and maximum likelihood estimation (ML). The fifth chapter treats of the results of the various estimations and hypothesis tests and their limitations. Moreover, it shows calculations of the relative importance of noise as a determinant of housing prices, and discusses the importance of neighbours' linguistic affiliation.

Chapter VI concludes the thesis with a summary, a discussion of potential limitations and an idea for refining the method that was used to maximize the likelihood function, as well as recommendations for further research. Finally, Appendix A presents the model specifications retained and corresponding econometric results.

CHAPTER II. LITERATURE REVIEW

This chapter summarizes the literature on Pareto-optimality and externalities, and reviews the nature and impact of airport noise. It then surveys the main theoretical aspects of the hedonic method: specifically, the nature of amenities or characteristics, implicit prices, the hedonic price function, hedonic equilibrium, and marginal bid and offer curves. It also deals briefly with the method's assumptions and with the question of whether one should estimate demand functions from hedonic results, and, if so, under what conditions. Finally, there is a brief evaluation of alternatives to the hedonic method.

I. The Market, Efficiency, Pareto-Optimality, and Market Failure

I.A. The Market and Market Efficiency

A perfectly competitive economy is defined to have certain characteristics, which real markets may be assumed to satisfy. These are that it encompasses all welfare-relevant inputs, goods, and services, and that transactions are effected and ownership established without cost. It is also presupposed that every commodity has a price and that this price is identical for both consumers and producers [1]. Although the distribution of resources and profits is assumed to be completely specified; a different distribution would not detract from the essential nature of the market's characteristics (Hjalte *et al.*, 1977).

Although a market economy's price system distributes information about resource abundance throughout the economy, the market is not complete. It excludes some natural resources and man-made products, so that the price system divulges incomplete information about the opportunity

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1 Each of these major assumptions depends on other, lesser assumptions and qualifications, which will not be discussed here.

cost of resources or the impact of unpriced outputs. This, as will be seen below, contributes to the persistence of environmental problems (Hjalte *et al.*, 1977).

A perfectly competitive economy will tend to move to a long run equilibrium, where a unique price system equates supply and demand for each positively-priced good (Hjalte *et al.*, 1977). Moreover, it is economically efficient, which subsumes efficiency in production, in consumption, and in exchange. All of these happen to be necessary conditions for Pareto-optimality (Asimakopulos, 1978; Layard and Walters, 1978; Randall, 1981; Varian, 1984; and Weimer and Vining, 1989). Thus, having a perfectly competitive economy in long run equilibrium is equivalent to achieving Pareto-optimality. However, the concept of economic efficiency is not a total criterion for evaluating the workings of a market, neglecting as it does the equally important question of distributional equity (Asimakopulos, 1978; Varian, 1984; and Weimer and Vining, 1989) [2].

I.B. Pareto-Optimality

Effectively, economic efficiency and Pareto-optimality are coincident (Asimakopulos, 1978; Layard and Walters, 1978; Tietenberg, 1988; and Varian, 1984). But, whereas economic efficiency is explained in terms of the marginal conditions facing each producer and consumer, Pareto-optimality is defined in terms of the superiority of the situation in question for all concerned. Pareto-optimality holds that: "There is no feasible allocation where everyone is at least as well off and at least one agent is strictly better off." (Varian, 1984, p.198).

However, Pareto-optimality is only a necessary but not sufficient

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2 For more complete expositions, please see Asimakopulos (1978, pp.421-423) and Layard & Walters (1978, pp.7-17).

condition for maximum welfare; and Pareto-optimal positions are not unique, as there is an infinite number of output and price combinations that are Pareto-optimal, each of which corresponds to a certain distribution of resources (Asimakopulos, 1978; and Varian, 1984). Finally, Pareto-improvements do no more than present a potential for improvement. There is no guarantee that the gainers will compensate the losers for whatever loss they may incur through a policy change (Tietenberg, 1988; and Weimer and Vining, 1989).

I.C. Market Failure

There are situations, known as market failure, where some of the assumptions that are basic to the competitive model are not met, hence where Pareto-optimality is absent (Weimer and Vining, 1989). An imperfection in the market for just one commodity is enough to preclude Pareto-optimality in the entire economy (Tietenberg, 1988). As an exception to the functioning of a pure market economy, externalities constitute a major case of market failure, along with the three cases of public goods, natural monopolies, and informational asymmetry (Asimakopulos, 1978; Hjalte *et al.*, 1977; Layard and Walters, 1978; and Weimer and Vining, 1989).

II. Externalities and Pareto-Relevant Externalities

II.A. Definition and Nature

An externality results from a decision-maker's actions, when there is an impact on other agents who are not considered in the decision. There can be positive and negative externalities; both of which can emanate from the same source (Hjalte *et al.*, 1977; Johnson and Ragas, 1987; Layard and Walters, 1978; Li and Brown, 1980; Randall, 1981; Thibodeau, 1990; Tietenberg, 1988; Varian, 1984; and Weimer and Vining, 1989). Respectively, these externalities entail economic benefits or damages to the affected party. The decision maker can be a producer or a consumer; and the effect can be had upon a producer's production (a production externality), or a consumer's utility (a consumption externality). The decision maker may disregard the impact because it does not arise from a market transaction with the afflicted party, or, in any event, because there is no mediation by prices (Asimakopulos, 1978; Hjalte *et al.*, 1977; Layard and Walters, 1978; Tietenberg, 1988; Varian, 1984; Walters, 1978; and Weimer and Vining, 1989).

An important distinction is drawn between externalities that do entrain inefficiency in the absence of Coasian solutions, and those that may not (Layard and Walters, 1978; Randall, 1981; Tietenberg, 1988; and Weimer and Vining, 1989). The former are called technological (Layard and Walters, 1978) or Pareto-relevant (Randall, 1981) externalities. The latter, variously described as pecuniary or non Pareto-relevant externalities, are accounted for by the price system through their induced effects on markets other than their market of origin. An obvious example is the capitalization of an external effect in local property prices (Tietenberg, 1988).

Although pecuniary externalities are held to preserve market efficiency under certain conditions, there is some disagreement over what these conditions are. Tietenberg (1988) argues that prices in the afflicted market provide an unconditional feedback mechanism to the polluter, but this supposes that the polluter will be a participant in the afflicted market, which may not be true in the case of an industrial polluter and a housing market. Layard and Walters (1978), on the other hand, suggest that there need only be small induced price changes and a lack of distortion in the economy; whereas Weimer and Vining (1989) present more sophisticated and exacting linkages.

According to Weimer and Vining (1989), efficient outcomes can be attained when: property rights are established by custom; an externality effect is capitalized into property values; those originally affected by the introduction of the externality are no longer involved, and the level of the externality is stable. For example, the negative effects associated with an established, local pollution source may be capitalized into housing values, and a new generation of homeowners will not bear any Pareto-relevant externality. Customary property rights (to pollute) discourage any initial legal challenges, leading to acquiescence and capitalization. Moreover, unlike the original generation, the new generation of owners need not experience any loss. Finally, instability in the level of the externality is equivalent to the receipt of windfall gains in the case of reduced pollution, or to further impacts in the case of increased pollution (Weimer and Vining, 1989).

Coasian solutions hold out the theoretical possibility of private resolution of Pareto-relevant externalities between the concerned parties. Economically efficient solutions may be achieved if there are no transaction costs, rights are nonattenuated, and the negotiated redistribution would not affect marginal values. Nonattenuated property rights refer to a structure, where the rights are: completely specified, exclusive, transferable, and enforceable (Randall, 1981). However, negotiations could well be ineffectual: first, when there are many parties, because of the free rider problem; or, second, because of positive transaction costs and income effects. These are all likely situations which limit the applicability of Coasian solutions (Layard and Walters, 1978; Randall, 1981; and Weimer and Vining, 1989). Indeed, Walters (1975) points to the large number of affected parties as an obstacle to negotiated levels of airport noise.

II.B. Some Implications of Externalities

The chief, theoretical consequence of a *Pareto-relevant* externality in production or consumption is that long run equilibrium in a perfectly competitive economy will no longer guarantee either Pareto-optimality or efficiency (Asimakopulos, 1978; Varian, 1984; Weimer and Vining, 1989). In other words, market failure will occur (Varian, 1984).

There are more practical or specific implications. The above consequences may be obviated in the case of non Pareto-relevant externalities or where Coasian solutions are feasible. First, the presence of an externality associated with a production process indicates that the produced good is not optimally priced. That is to say that the good's marginal private cost and marginal social cost differ, by an amount that is related to the external cost imposed upon others ("society") by the producer. Second, when a negative externality is associated with a production process, firms will produce too much of the good in question. This occurs because the firms only perceive the lower marginal private costs of their activity, rather than the higher marginal social costs. Likewise, too much of the externality will be produced; and third, incentives for reducing the pollution per unit of output are absent (Hjalte *et al.*, 1977; Layard and Walters, 1978; and Tietenberg, 1988). Finally, where an externality does affect behaviour in some other markets, such behaviour ought to be reflected in the afflicted markets' prices (Layard and Walters, 1978; Tietenberg, 1988; and Weimer and Vining, 1989).

III. Aircraft or Airport Noise - Pollution and Externality

III.A. Airport Noise as an Externality

Aircraft noise bears all of the hallmarks of a negative externality. First, it is perceived as causing injury, or of having the potential to do so. Those who experience the noise on the ground are being affected by the actions of others (Beattie, 1983; DWG, 1990; Harvey *et al.*, 1979; and

Walters, 1978)[3]. As a by-product of economic activity, aircraft noise meets the classic definition of an *economic* externality, above (Muskin and Sorrentino, 1977).

Not only is airport noise a negative externality, but it can also be classified as a public bad. As such, it is indivisible in consumption and fully accessible to all. Indivisibility means that one person's "consumption" of a bad (or good) neither depletes it nor excludes another from consuming it[4] Moreover, the private sector or market cannot be relied upon to produce an efficient amount of a public bad (or good) (DWG, 1990; and Tietenberg, 1988). A more-than-efficient amount of a public bad is likely to be provided, and can be traced to an improperly defined property rights system

Finally, airport noise is particularly interesting as an externality because commercial airports are usually sited in or around urban areas, in close proximity to housing markets. This geographic coincidence between the zone afflicted by airport noise and a housing market provides an excellent opportunity for measuring the capitalization of airport noise in housing prices, hence the extent to which it can be considered to be a pecuniary as opposed to technical externality.

III.B. The Nature and Impact of Airport Noise

Most definitions of noise suggest that it is both a physical concept, and a psychological or physiological one. For example, DWG (1990, 33) define noise as "... a sound of any kind which is especially loud, discordant,

3 This distributional factor is problematic because the absence of property rights precludes compensation between the two groups (DWG, 1990).

4 Parsons (1990), however, argues that there is some congestion in the consumption of locational (dis)amenities, a result of the spatial dispersion of housing on lots.

harsh, or disagreeable ... noise is sound and noise is subjective."; and Beattie (1983) and Harvey *et al.* (1979) define it as unwanted sound. As the definition of noise refers to both physical and subjective aspects, noise itself has both physical and perceived effects.

In terms of its effects, noise causes: psychological and sociological stress, physiological effects, effects on job performance, on property values, and on the ecosystem (The U.S. Office of Science and Technology, cited in Harvey *et al.*, 1979). As an example, Harvey *et al.* (1979) reported frequent complaints about airport noise at Buffalo, New York concerning the impact of noise on: educational activities, hearing, emotional problems, communications, sleep, and property values. Because it has physiological, psychological, social, and economic impacts, there can be no doubt that noise is an environmental pollutant (Beattie, 1983, citing Alberta's Environment Council [*Noise in Alberta*, Publication No. ECA80-16/1B4, Edmonton, Alberta, 1980]).

The subjectivity of reactions to noise implies that different people will have different cognition of noise, its sources, and its effects. Therefore, noise cannot simply be measured as sound. Moreover, the locational and demographic attributes of households are related to the cognition of airport noise, including perceptions of: stress, adjustment, property devaluation, and health hazards. These attributes include social status, place of work, age of household head, household location, and length of residence (Harvey *et al.*, 1979). It has been argued that people may be able to adjust successfully to airport noise (Whitbread, 1978), but Harvey *et al.*'s findings (1979) suggest otherwise.

Apart from subjective perceptions, the effect of airport noise can be moderated or worsened by both physical and circumstantial factors. The propagation or diffusion of aircraft noise from its source depends upon atmospheric factors like temperature, wind, air pressure, and humidity; distance; and the presence of natural barriers such as woodlands or hills

(Beattie, 1983). Likewise, circumstantial factors act to increase noise sensitivity around airports (DWG, 1990). These are residential encroachment, changes in operations, and increased awareness of noise's impact.

III.C. Airport Externalities in General

Although it is the most important one, noise is not the sole externality generated by airports. There are other externalities, both positive and negative. The chief positive externality is the airport's proximity as a centre of employment or a point of departure. Airports also provide advantages to services and industries that depend on them for their business. The other negative externalities include air pollution and local traffic congestion (Beattie, 1983; De Vany, 1976; DWG, 1990; Gautrin, 1975; Nelson, 1979 and 1980; Pennington *et al.*, 1990; and Walters, 1978).

These other externalities may complicate the analysis of airport noise when they can be accounted for, and may introduce error when they cannot. However, they are only important insofar as their measurement would provide a more accurate accounting of the costs and benefits of alternative airport policies, or as they would be the sources of multicollinearity or bias in a distance proxy for noise. Both positive and negative externalities are more or less inversely correlated with distance, thus with each other. If the positive ones are relevant, this may pose a problem.

Though several authors consider the distance to an airport to be important, such variables are likely to be insignificant when included in specifications with noise variables (Bender and Hwang, 1985; Jud and Watts, 1981; and Palmquist, 1984). Moreover, Nelson (1979) concluded that accessibility to an airport has little influence on estimated noise coefficients.

III.D. Why Evaluate the Impact of Airport Noise

Airport congestion is already a widespread problem in Canada. Moreover, the demand for air travel has grown throughout the early 1980's and there are forecasts of a continuation of past growth. Likewise, airport capacities are expected to grow to accomodate increased demand for air transport services, thereby increasing annoyances like noise and air pollution. Residential encroachment has increased the number of people who are close to Dorval airport's flight paths, and are therefore exposed to its noise. Such trends have been measured and are expected to continue through to the year 2000 (DWG, 1990). Passengers were forecast to increase at a rate of 4.2 percent annually until 1996, and at 2.8 percent thereafter, whereas aircraft movements were forecast to increase at annual rates of 3.9 percent and 2.3 percent over the same periods (Table 1.4. in DWG, 1990, p.8).

IV. Hedonics

Hedonics have a theoretico-empirical nature, being at once a theoretical framework and an empirical method or modelling strategy (Bartik and Smith, 1987; Brookshire *et al.*, 1982; Freeman, 1979; and Triplett, 1986). Essentially, hedonic *theory* attempts to explain the interactive equilibrium between consumers' preferences for the attributes that comprise heterogenous goods, and the producers' supply of them. The theory also explains the results of this equilibrium in terms of the combinations of attributes that are exchanged, and the associated prices, both for the constituent attributes, and for the good as a whole (Bartik and Smith, 1987). The hedonic *method*, on the other hand, pertains to how a researcher may use observations on the prices and characteristics of heterogenous goods sold in the market, regress the characteristics against the prices, and then arrive at implicit prices for the attributes that make up the goods (Triplett, 1986).

IV.A.1. The Hedonic Nature of Goods and Amenities

The hedonic method involves considering heterogenous goods and services in a different light, where the object of an economic transaction and utility is not so much the good itself, but the characteristics or attributes of which it is composed. Each good is considered to be a bundle or package of such attributes, and can be described by a vector of them (Bartik and Smith, 1987; Garrod and Willis, 1992; and Triplett, 1986).

Characteristics have three definitional aspects: (i) they are homogenous components of heterogenous goods, "packaged" or "bundled" into the latter; (ii) they have value to buyers and sellers; and (iii) though the characteristics may not have explicit or separate prices, a model's price reflects the amount and value of each characteristic of which it is composed (Triplett, 1986). Moreover, goods can be shaped by producers, by externalities, and by nature. For housing, the latter two means pertain to amenities, which are location-specific characteristics of the immediate environment. These can make positive or negative contributions to utility (Bartik and Smith, 1987; Nelson, 1980; and Triplett, 1987).

Amenities can be classified along the lines of their geographic extent, permanence, and physical tangibility. They are supplied in various ways, some are provided by the public sector, but are only indirectly related to what is ultimately valued by households. Others are supplied through private sector activity, modified by public sector regulations or incentives (Bartik and Smith, 1987).

The notion of a heterogenous good as a bundle of characteristics is fundamental to the interpretation of hedonic functions. Because of this idea, the price of a heterogenous good can be broken down into prices and quantities of characteristics, an operation that is made explicit by a hedonic function. A good's characteristics are the objects of economic transactions, and the associated implicit prices are economic variables which have supply and demand side market interpretations (Triplett, 1986). For the sake of clarity, the discussion of implicit prices follows that of the hedonic price function, immediately below.

IV.A.2. The Hedonic Price Function, and the Bid and Offer Functions

The hedonic price function relates the quantities of a good's attributes, and their implicit prices, to the good's overall price at equilibrium. As such, it is also what is estimated empirically, with data on the total prices and levels of characteristics of different designs of a good. As an equilibrium function, its existence and continuity over attribute space must be assumed (Bartik and Smith, 1987; Brookshire *et al.*, 1982; Freeman, 1979; Palmquist, 1984; Rosen, 1974; Thibodeau, 1990; and Triplett, 1986). It can be defined thus, where $\mathbf{h}_j$ are the attributes of the good:

$$P = P(\underline{h}) = P(h_1, h_2, h_3, \quad , h_j, \quad , h_k) .$$

The hedonic function is a joint envelope of a set of convex consumers' bid functions and another of concave producers' offer functions (Anderson, 1985; Rosen, 1974). The bid or value function (**B**) is the function **B(h;V,D)** that solves **U(h,y-B;D)** = **V**; where **V** is some utility level, **D** is a vector of buyer's attributes that determine its preferences, and **y** is income (Bartik and Smith, 1987). The bid function measures the consumers' willingness to pay (bid) for different designs of housing, at a given level of utility and income; and can be described as a family of indifference surfaces relating characteristic "j" and money (Rosen, 1974).

The offer function (**O**) is, on the other hand, the function **O(h,π,S)** that solves **O•N - C(h,N;S)** = **π**; where **S** is a vector of supplier attributes that determine its cost function, **N** is the scalar number of housing units to offer, and **C** is the particular firm's cost function (Bartik and Smith, 1987). The offer function gives the unit price per model, or the firm's willingness to accept payment for various designs at a constant profit when the quantities of the individual variants are optimally chosen (Rosen, 1974).

The hedonic price function is determined by the distributions of consumer tastes and producer costs which underly the bid and offer functions (Rosen, 1974). A related property of the hedonic price function is that it acts as a budget constraint, along with income or profits, respectively, on consumption and production decisions (Anderson, 1985; Bartik and Smith, 1987; and Triplett, 1987). Even though producers and consumers can affect marginal implicit prices through their choices of specific variants of a differentiated product, they are "price-schedule-takers". Consumers do not arrive at a willingness to pay based on the characteristics of a good, but choose a combination of attributes, given the price schedule and their preferences (Palmquist, 1988).

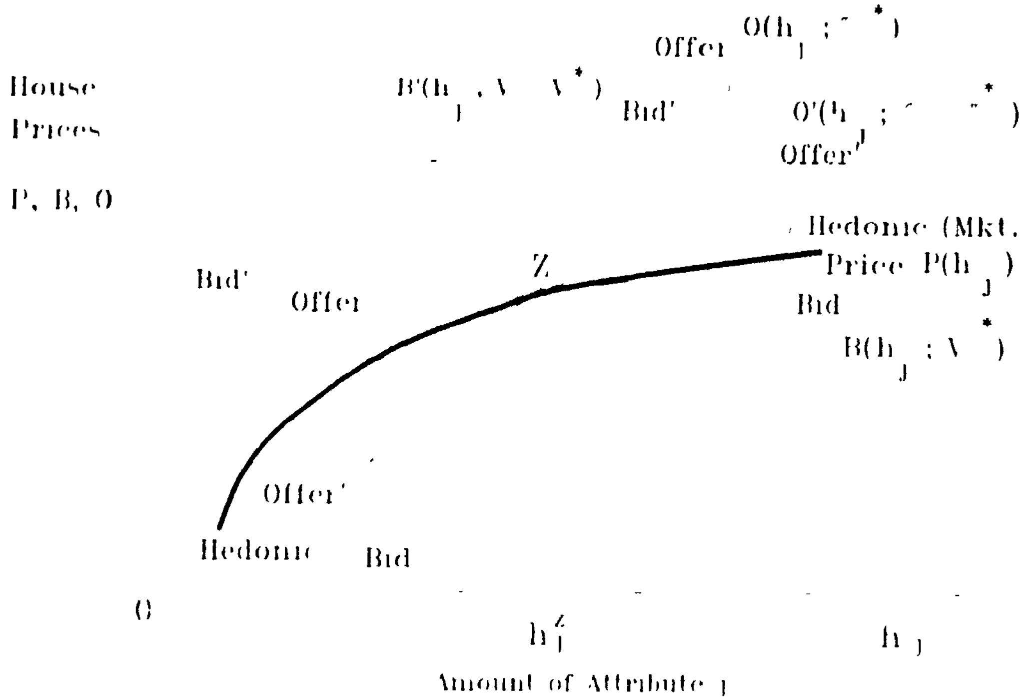
Although the equilibrium equality is (k+1)-dimensional for each optimal bundle, optima can be depicted in a two-dimensional cross-section, with total bids and offers as functions of one characteristic at a time (Bartik and Smith, 1987). Figure 2.1. shows an equilibrium equality for a house containing amount $\mathbf{h}^{z}$ of attribute j.

All bids, offers, and prices are for entire houses with some of attribute j. Lower bid curves imply higher utility, whereas higher offer curves imply greater profits. There will be similar matchings of bid and offer curves along the entire hedonic price function, for the full continuum of the amount of each characteristic. Each such pair matches at the quantity of an attribute contained in a housing design that is mutually suitable to the corresponding buyer(s) and seller(s). Moreover, there could be many different house styles, hence many buyers and sellers, that correspond to each such point. The houses would be identical in terms of characteristic j, but could differ in terms of all or some of the other characteristics.

Consumers try to minimize their bid for a house, while suppliers try to maximize the offer price; and both are subject to the constraint of the exogenous price function $\mathbf{p(h)}$. The point of tangency $(\mathbf{h}')$ of the bid, offer, and price curves is where *a* household and *a* supplier reach their mutual optimum (Bartik and Smith, 1987).

Figure 2.1.

Hedonic Price, Bid and Offer Functions for a House with Attribute j; Given Optimal Amounts of Other Attributes



[After Bartik and Smith's (1987) Fig.1, p.1215]

The hedonic price function is usually assumed to be non-linear, because attributes are assumed only to be available in tied sales such that consumers cannot "arbitrage" among variants by undoing and then repackaging their attributes without cost (Anderson, 1985; Bartik and Smith, 1987; Nelson, 1979; Palmquist, 1988; and Rosen, 1974). For example, two 10,000 square foot houses are not equivalent to one 20,000 square foot house, since only one house can be lived in at a time. Similarly, one 20,000 square foot house for half a year and one 10,000 square foot house for the other half are not equivalent to one 15,000 square foot house for the whole year (Example after Rosen, 1974). Such arbitrage is especially improbable for housing, because of its durability and the jointness of its structural and locational characteristics.

Non-linearity implies that those who buy bundles containing different amounts of a certain characteristic will pay different (implicit) prices for it, and that the implicit price function, too, will be non-linear (Triplett, 1986). This is since a characteristic's implicit price function is the first partial differential of the hedonic price function with respect to the quantity of that characteristic. And, a non-linear or even non-horizontal, but linear implicit price function means that implicit prices and the quantities of attributes will be endogenous, as each will depend on the other (Bartik, 1987a; Diamond and Smith, 1985; Garrod and Willis, 1992; Ohsfeldt and Smith, 1988; Nelson, 1978; and Palmquist, 1984 and 1988). Implicit prices are discussed at more length below.

IV.A.3. Implicit Prices

The implicit prices of characteristics have been described as "... the most important empirical results from a hedonic function." (Triplett, 1986, p.37). These correspond to the attributes of a good, and are the amount of money that is implicitly offered and accepted for each unit of a particular attribute when the good in question is bought and sold. Implicit prices reflect the net present value of the enjoyment of the corresponding attribute, since its durability tends to preclude its immediate and instantaneous consumption (DWG, 1990; Gautrin, 1975; and Goodman, 1978). They are both similar to and dissimilar from ordinary prices. Three similarities are that: (1) they measure the payment made and received for the characteristic; (2) they are proportional to both marginal valuations by consumers and marginal costs to producers only, however, when the respective side of the market is competitive; (3) their values are a reflection of market supply of and demand for the relevant characteristics which, in the long run, will push the characteristics' prices to the level of their costs. Thus, they are economic variables that have supply and demand side market interpretations (Triplett, 1986).

Implicit prices are different in that they are rarely directly observable, and are normally estimated; and because the bundling of their associated characteristics gives rise to complicated interdependencies among them. As an example of the latter, non-linear hedonic functions mean that even in competitive markets, buyers and sellers of different product designs do not pay or receive the same prices for the same characteristics (Triplett, 1986).

Implicit (marginal) prices are found by evaluating the first partial derivative of the hedonic price function with respect to the quantity of the corresponding attribute (Blomquist and Worley, 1981; Butler, 1982; Freeman, 1979; Nelson, 1980; Palmquist, 1984; Rosen, 1974; and Triplett, 1986). Depending on the hedonic price function's form, the implicit prices may be equal to its estimated coefficients, or they may have to be calculated by evaluating the implicit price function at a house's or sample's level of attributes. The implicit price function for attribute $\mathbf{h}_j$ that corresponds with the hedonic price function above would be defined thus:

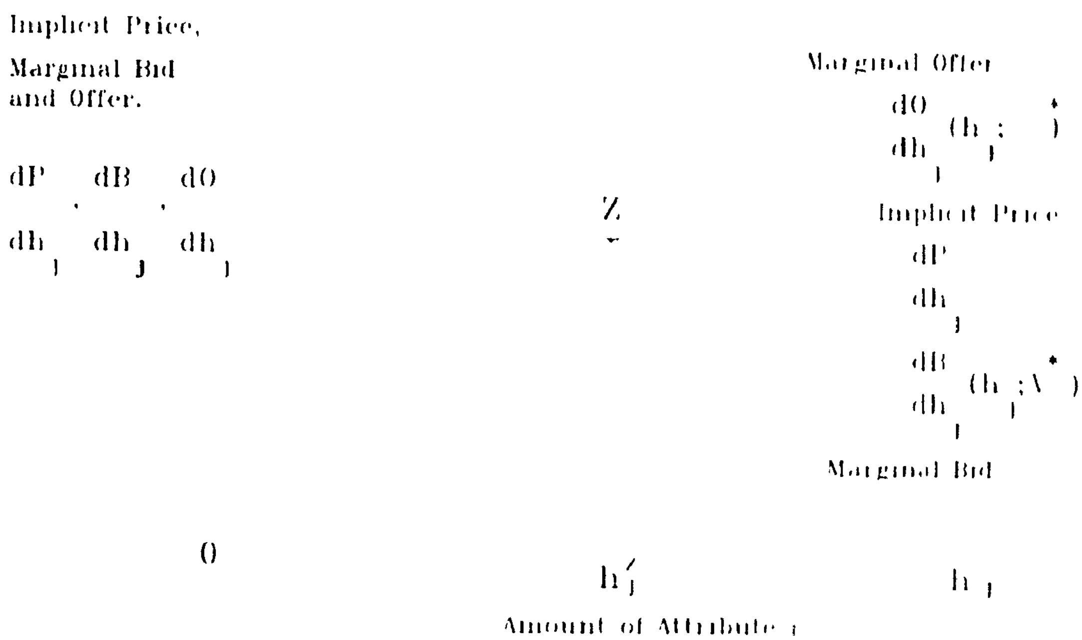
$$p(h_j) = \frac{\partial P(h)}{\partial h_j}$$

An estimated implicit price for noise exposure estimates the capitalized damage, specifically psychic costs, per decibel increase of noise exposure or per decibel avoided. The measure also happens to reflect discounted expectations of future levels of noise (Habuda O'Byrne *et al.*, 1985; Nelson, 1982; and Walters, 1975).

IV.A.4. The Marginal Bid and Offer Functions

The endogeneity of implicit prices and quantities of characteristics worsens an identification problem: that of distinguishing demand (marginal bid) and/or marginal offer curves from the implicit price function (Bartik and Smith, 1987; and Palmquist, 1988). It implies that marginal implicit prices cannot be used to predict consumer responses to shifts in their budget constraint (Bartik and Smith, 1987; and Cassel and Mendelsohn, 1985). It is illustrated in Figure 2.2. The intersection in this diagram corresponds to only one point, at quantity z of attribute j, along the hedonic price function in Figure 2.1. Different buyers and sellers will have different marginal bid and offer functions, respectively, which will intersect at different points along the implicit price function.

Figure 2.2.
Implicit Price, Bid and Offer Functions for Attribute j, at the Optimum "Z" in Figure 2.1.



[After Bartik and Smith's (1987) Fig. 2, p.1216]

The marginal bid function is the first partial differential of the bid function with respect to the quantity of characteristic j, and is equivalent to the marginal rate of substitution between characteristic j and money, or the implicit marginal valuation of or reservation demand price for j, given a utility index and income. In other words, it is a compensated demand function (Rosen, 1974). The marginal offer function is found in a similar way from the offer function, but it represents the marginal reservation supply price for characteristic **j**, at constant profit, for a unit increase in the quantity of **j** (Rosen, 1974).

Assuming that the equilibrium price function can be specified and estimated, the hedonic model implies that the points where the marginal bid, offer, and price functions for each characteristic intersect can be found. But, because the hedonic price function is the only price function for the bundle that can be known, its derivative with respect to each characteristic $\mathbf{h}_i$, the implicit price function, is the only one of these marginal curves that can be known directly. Neither the marginal bid nor the marginal offer curve can readily be identified (Bartik and Smith, 1987).

IV.A.5. A Simple Hedonic Model

This section presents a simple hedonic model of household choice, after Bartik and Smith (1987). Assume that households and firms, respectively demanders and suppliers of housing, are both price-takers. It is also assumed that the choice of housing and collateral locational amenities is conditional upon prior employment decisions. A household would maximize utility over the choice vector **h**, subject to its budget and the set of actual prices for housing types. This is represented by:

$$\max_{\mathbf{h},\mathbf{x}} \mathbf{U(h,x;D)}$$
$$\text{subject to: } \mathbf{P(h) + x < y}$$

where:

h is a vector of quantities of the dwelling's attributes and associated amenities;

P(•) is the relevant hedonic price function;

y is income;

x is a numeraire non-housing commodity; and

D is a vector of the buyer's preference-determining attributes.

On the supply side, profit is maximized over the vector **h**, and the scalar number of housing units to offer (**N**):

$$\max_{h,N} N \bullet (P(h)) - C(N,h;S);$$

where:

$C(\bullet)$ is the particular firm's cost function; and

S is a vector of supplier attributes that determine its cost function.

A supply-demand equilibrium is assured by the existence of the hedonic price function. This function maps characteristics to price so that the distributions of bundles demanded and offered, which depend on the distributions of **D** and **S**, respectively, will correspond to each other (Bartik and Smith, 1987). The existence of hedonic equilibrium, and other, subsidiary assumptions are discussed below, at greater length.

The marginal or equilibrium conditions for the previous two maximization problems are such that: the implicit price $\delta P(h')/\delta h_j$, the marginal bid $(\delta U/\delta h_j)/(\delta U/\delta x)$, and the marginal offer $(\delta C/\delta h_j)/N$ are equal, for each characteristic element h_j of each vector bundle of attributes **h'**, and this for all market participants buying or selling the bundle **h'**. The bundle **h'** represents an optimum for those who have marginal bid and offer functions such that it suits them to trade that particular variant of the good.

The marginal equilibrium conditions are:

$$\frac{\frac{\partial U}{\partial h_j}}{\frac{\partial U}{\partial x}} = \frac{\partial P}{\partial h_j}(h^z) = \frac{\frac{\partial C}{\partial h_j}}{N}$$

This equilibrium condition does not imply the simultaneity of supply and demand or the endogeneity of the implicit price schedule at the level of the individual. Nevertheless, the hedonic price function is the result of interaction between all suppliers and all demanders (Bartik and Smith, 1987).

IV.B. Applying Hedonics

IV.B.1. Appropriateness of Hedonics as a Method

For several reasons, the hedonic method is appropriate for evaluating airport noise and other externalities. First, housing is traded on a well-integrated market, and most consumers will purchase but one of many different patterns. Second, airport noise varies spatially across those urban areas that are affected, thereby yielding variation in the attribute noise. Third, and most important, airport noise has been found to have a demonstrable, negative effect on housing prices (Bartik and Smith, 1987; Brookshire *et al.*, 1982; DWG, 1990; Ellickson, 1981; Nelson, 1980; and Palmquist, 1982, 1984 and 1988).

Indeed, the method is a well-established tool for work in land and environmental economics in general; and have been the theoretical basis for most empirical studies of airport noise as of 1980 (Brookshire *et al.*, 1982; Milon *et al.*, 1984; Nelson, 1980; Palmquist, 1988; and Poon, 1978). For example, the method has been applied to problems of: climate, air pollution, social infrastructure, noise level, and ethnic composition (Brookshire *et al.*, 1982); as well as the capitalization into housing values of fuel savings from investments to improve energy efficiency (Dinan and Miranowski, 1989). The fundamental rationale for using the hedonic approach in such applications is that if people are aware of the effects of pollution on themselves and their property, and can ascribe a monetary value to the damages, they will pay more for residential property which is less subject to the effects of pollution (Brookshire *et al.*, 1982; DWG, 1990; and Poon, 1978).

Not only does the method yield an indication of whether or not an externality is capitalized, but the implicit price for the externality can be used to arrive at an estimate for households' willingness to pay (WTP) for a reduction in a negative externality, or an increase in a positive one Hence, the method is appropriate for measuring the welfare costs or benefits associated with an environmental amenity (Garrod and Willis, 1992, Palmquist, 1988; and Poon, 1978).

IV.B.2. Identification, Endogeneity, and Demand

Having estimated a hedonic price function, many researchers have proceeded to use Rosen's second stage (Rosen, 1974) to estimate the demand curves for one amenity or another. Nevertheless, this practice is erroneous, and gives biased results, except in certain special circumstances (Bartik, 1987a; Bartik and Smith, 1987; Blomquist and Worley, 1981, Brown and Rosen, 1982; Butler, 1982; Freeman, 1979, Kanemoto and Nakamura, 1986; McConnell, 1990; Mäler, 1977; Marks, 1984, and Palmquist, 1984). This is because of the well-documented, but often-ignored problem of endogeneity of the marginal bid function, which makes it hard to distinguish from the implicit price function. The problem is that the consumer can endogenously choose the quantities and marginal prices of characteristics (Bartik, 1987a; and Bartik and Smith, 1987; and Dubin and Sung, 1990)

Two commonly-suggested remedies are to restrict the form of the hedonic price .function, and to use single-market instrumental variables, whether for suppliers or otherwise. These have been found to be inappropriate (Bartik, 1987a; Bartik and Smith, 1987; Diamond and Smith, 1985; Epple, 1987; Horowitz, 1987; Mendelsohn, 1984; Ohsfeldt and Smith, 1985, and Palmquist, 1984).

However, exogenous, multiple-market instruments that shift the hedonic price function to identify demand curves are more credible. Still controversial, their use amounts to estimating separate hedonic functions, one for each distinct market (Bartik, 1987a and 1987b; Bartik and Smith, 1987; Diamond and Smith, 1985; Mendelsohn, 1984; Ohsfeldt and Smith, 1988; and Palmquist, 1984 and 1988). Three appropriate kinds of instrument include the buyers' social groups, separate markets in space, and separate markets in time (Bartik, 1987a; Brown and Rosen, 1982; Diamond and Smith, 1985; and Kanemoto and Nakamura, 1986; and Palmquist, 1984).

Finally, Rosen's second stage of estimating demand and supply curves may not even be necessary, since implicit marginal prices are quite sufficient for any policy analysis, whether the changes in ambient noise are marginal or gross (Bartik, 1988). For this thesis, a lack of both multiple market data and *a priori* evidence for the necessary assumptions precluded any attempt at using multiple-market instruments to estimate the marginal bid function.

IV.C. Theoretical and Empirical Limitations

There has been much criticism of the hedonic method. Its limitations arise in going from the theoretical to the empirical, when trying to apply the technique to a given market for which the assumptions may not be appropriate. Most of the other, so-called "empirical problems" (Mäler, 1977) of the method are not unique to hedonics. Nevertheless, Bartik and Smith (1987) and Brookshire *et al.* (1982) do note possible limitations of the method which would not arise from inappropriate assumptions.

These are, first, that it yields only "... point estimates of the marginal rates of substitution (slopes of indifference curves) between pollution and other goods (money) ..." (Brookshire *et al.*, 1982, p.169). Second, most theoretical treatments of hedonic functions have ignored the dynamic, expectational aspects of home ownership: consideration of the future, and resale of the dwelling. Third, the effects of uncertainty have been ignored in most models of household behaviour. Here, uncertainty subsumes both imperfect knowledge about housing characteristics and risks due to the proximity of disamenities (Bartik and Smith, 1987).

Theoretical and empirical evidence is insufficient to evaluate these issues of uncertainty, expectations, and informational asymmetry to be evaluated. Nevertheless, as these issues are relevant to most empirical models in economics, hedonic models are not materially worse. Moreover, in spite of their limitations, hedonic models have been providing increasingly consistent indications of the relative importance of attributes and amenities to households and are appropriate (Bartik and Smith, 1987; and Palmquist, 1988).

As mentioned above, and discussed below, many of the hedonic method's limitations arise in a lack of correspondence between its assumptions and the market being studied (Bartik and Smith, 1987). Further limitations occur when hedonic results are used to evaluate policies and measure externalities. First, intertemporal changes in hedonic price functions may undermine the use of a hedonic model estimated from the data of one time period to measure impacts in another. Second, the composition of the sample will affect the implicit price for noise. For example, the relative number of noisy and quiet houses may have an effect, as could the fact that the gradation of noise over distance means that relatively fewer people will be severely affected, and many will be less affected (Edmonds, 1985; Walters, 1975; and Whitbread, 1978).

Third, estimated implicit prices for an externality, when used to evaluate the impact of the externality's *source*, may not reflect all of the latter's effects. There may be non-residential noise costs, such as may be inflicted on schools and hospitals, among other institutions, or borne by visitors staying at hotels or using local parks. In addition, if noise-tolerant people locate closer to airports, the estimated noise discount may under-estimate the typical person's aversion to noise (Mieszkowski and Saper, 1985; Nelson, 1982; and Walters, 1975). Fourth, as mentioned in Chapter VI, the actual aggregation over properties or households to arrive at a measure of total costs or benefits is also problematic. This depends on the affected population, and how one measures the population that is distributed among different noise levels (Borins, 1981; and Mieszkowski and Saper, 1978).

Despite these limitations, hedonic theory and practice are such that the importance of amenities to households can be clearly identified. Moreover, estimated hedonic prices constitute the best tool available; and, to the extent that it can isolate the magnitude of the causal relationship between environmental quality and housing prices, hedonic analysis is successful (Bartik and Smith, 1987; and Cassel and Mendelsohn, 1985).

IV.D. Hedonic Assumptions

Most critiques of the theory of hedonics arise in the assumptions (Mäler, 1977; and Nelson, 1982). There are two categories of assumption: those which are relevant to the hedonic method in general; and those which arise when the method is applied to evaluate the economic impact of a local amenity or externality. The general assumptions pertain to first, the capitalization of attributes in general and, second, the existence of hedonic equilibrium. This, in turn, subsumes the existence of a variety of housing, full information, and no transaction costs. The second group of assumptions deals with the capitalization of a specific externality's effects. Hence, it subsumes the full mobility of consumers, exogenously-supplied amenities, and external effects in the market of interest alone.

IV.D.1. Capitalization in General - The Hedonic Hypothesis

The hedonic hypothesis, that heterogenous goods are available as many bundles of fewer attributes, implies that since market transactions involve the exchange of such bundles, the price of a house is actually an aggregation of its characteristics and their prices (Dinan and Miranowski, 1989; and Triplett, 1987). This presupposes that the values of the attributes are capitalized into the housing price. For there to be *full* capitalization, there must be, in turn, market equilibrium, hence full information and zero transaction and moving costs; and, second, a wide enough variety of housing designs for the price function to be continuous (Freeman, 1979).

IV.D.1.a. Equilibrium

The existence of market equilibrium for the good in question is a central assumption of the hedonic technique. However, it is controversial in the case of housing, since it has been argued that the housing market is not in equilibrium (Anas and Eum, 1984; Bartik and Smith, 1987; Brookshire *et al.*, 1982; Freeman, 1979; Goodman, 1977; Mäler, 1977; and Marks, 1984). Disequilibrium may stem from the presence of transaction costs, and informational asymmetry in the housing market. The former are exemplified by moving expenses and real estate commissions. Nevertheless, the costs and asymmetry may be assumed to be insignificant relative to the price of a house, hence not terribly important, and the latter may be mitigated by the presence of real estate agents and the Multiple Listing Service (Bartik and Smith, 1987; Mäler, 1977; Michaels and Smith, 1990; Palmquist, 1988; Walters, 1975; and Weimer and Vining, 1989). Hedonic models that assume equilibrium can do fairly well (Anas and Eum, 1984).

IV.D.1.b. Variety of Housing

Yet another assumption is that houses are available in sufficient variety for there to be a continuous price function. This ensures that a household's optimally desired house design will be available, so that the household will be able to maximize its utility such that the first order hedonic conditions are equalities. Consequently, there will be equilibrium between each individual's tastes and the supply of a particular version of a good at a certain price (Freeman, 1979; Michaels and Smith, 1990; and Nelson, 1979). However, only a limited range of alternative house models may be available in a given market (Freeman, 1979).

IV.D.2. Capitalization of an Amenity's Effects

For the hedonic method to be used at all to evaluate a public good (bad), there must be spatial variation in that good. This must be assumed to be reflected in housing values (Brookshire *et al.*, 1982; DWG, 1990; and Mäler, 1977). This assumption requires, in turn, the assumptions of full residential mobility, exogenously-supplied amenities, and effects that are restricted to the housing market.

IV.D.2.a. Full Residential Mobility

For one to evaluate the capitalization of local amenities or public goods, consumers must be able to move between locations of differing amenity levels (DWG, 1990; Kanemoto, 1988; and Nelson, 1982). This "cross-sectional capitalization hypothesis" (Kanemoto, 1988), is supposed to reflect consumers' ability to trade off the level of an amenity, as a housing characteristic, against its implicit price, the overall price of a house, or both. Although DWG (1990) maintain that this assumption is satisfied by airport noise and the housing market, transaction costs relating to moving, and to buying or selling houses, may limit the mobility of consumers (Nelson, 1982; and Palmquist, 1988).

IV.D.2.b. Exogenously Supplied Amenities, and Expectations

To apply hedonics to the evaluation of an amenity, three assumptions about the supply of amenities are also necessary. The first is that amenities are exogenously supplied. Second, it should be assumed that the supply of amenities is fixed over the period relevant to the hedonic market equilibrium. The third assumption is that housing supply and demand decisions are subject to existing patterns of urban amenities though they will, eventually, affect the latter (Bartik and Smith, 1987).

It is also assumed that there are no *expected* changes in the level of an amenity. Otherwise, housing prices and marginal implicit prices may be independent of actual pollution, since the market prices of assets like housing include the present value of expected future (dis) services (Bartik and Smith, 1987; Freeman, 1979; Goodman, 1978; Habuda O'Byrne *et al.*, 1985; and Walters, 1978).

IV.D.2.c. Effects Limited to the Housing Market

Finally, it must be assumed that the effects of airport noise are restricted to that market and are not captured at all in other markets such as wage or labour markets (Bartik and Smith, 1987; Brookshire *et al.*, 1982; and Mäler, 1977). This does ignore non-housing market considerations which may determine a household's choice of city (Bartik and Smith, 1987). Even if the real estate market does capture the impact of an environmental commodity, it may not be the only market to do so. To the extent that prices of goods other than housing respond to differences in environmental quality, housing rents will not fully reflect such differences (Mäler, 1977).

IV.E. Alternatives to Hedonics

The hedonic method has been described as one of a trinity of indirect methods for valuing pollution that depend on observed choices. The other two are the averting behaviour approach and the weak complementarity approach (Cropper and Oates, 1992). There are also other, less directly appropriate methods, which include residential mobility and contingent valuation models.

The averting behaviour approach looks at the costs of mitigating or avoiding the pollution and its impacts. Thus, it considers the substitution of other production inputs for pollution. In the case of airport noise, substitutes might include sound insulation, ear plugs, medicine, and cottages. The weak complementarity approach, on the other hand, examines how pollution affects the purchase of complementary goods. It subsumes the travel cost approach and discrete choice models (Cropper and Oates, 1992). The first would be difficult to apply to problems of airport noise because data on averting behaviour are scarce and complex; whereas the second approach is by its very nature more appropriate to pollution sites which are removed from residential areas.

Similar to the above methods, residential mobility models and locational models of discrete choice are an alternative to the hedonic method (Bartik and Smith, 1987; Brookshire *et al.*, 1982; and Whitbread, 1978). However, amenities have been found to have had minimal effect on residential mobility, and data on housing turnover may be difficult to obtain (Bartik and Smith, 1987).

Contingent valuation or bid-rent models form another alternative to the hedonic method (Bartik and Smith, 1987; Brookshire *et al.*, 1982; Lerman and Kern, 1983; and Whitbread, 1978). Contingent valuation involves the use of surveys or experiments to find respondents' willingness to pay to maintain or improve some aspect of the environment (Tietenberg, 1988).

Cropper and Oates (1992) suggest that the contingent valuation method is to be used in the absence of appropriate averting or mitigating behaviour, or in the presence of nonuse values. Brookshire *et al.* (1982) add that survey techniques are especially useful where market data are insufficient or unavailable for hedonic analysis.

However, the hypothetical nature of survey questions constitutes a serious drawback. Other limitations include the possibility of strategic behaviour in answering the questions, unfamiliarity with the (dis)commodity being evaluated, and significant differences between willingness to pay (WTP) and willingness to accept compensation (WTA) (Cropper and Oates, 1992). These create a high potential for biased responses which can, nevertheless, be limited through proper survey design (Tietenberg, 1988).

CHAPTER III SPECIFICATION, VARIABLES, and DATA

This chapter consists of three main parts. The first deals with the two chief aspects of specifying the hedonic regression model - variable choice (inclusion) and functional form. The second part considers the specifics of which variables may appear in a hedonic regression, why or why not, and what their inclusion implies. The last part of this chapter reports the sources and treatment of the data.

I. Specification

The specification of a hedonic model is an important empirical problem which subsumes both the choice of variables and functional form. It is important because the degree of misspecification and the use of proxies may have a critical effect on a hedonic price function's performance (Butler, 1982; Cropper *et al.*, 1988; Freeman, 1979; Mäler, 1977; and Milon *et al.*, 1984).

I.A. Choice (Inclusion)

Although the choice of variables to include is seen as being critical (Coelli *et al.*, 1991; Garrod and Willis, 1992; and Graves *et al.*, 1988), there are few clear indications of exactly which of the many attributes of housing ought to be included as explanatory variables in a hedonic model. All attributes are potentially relevant, yet not all can or should be included in a hedonic model. Having too many variables in a specification can reduce the precision of parameter estimates, because multicollinearity becomes more likely. Multicollinearity is worsened by the fact that housing characteristics show little variation across a sample and are clustered into a limited range of house designs. That is, there are only so many ways in which the attributes of houses are combined (Butler, 1982; Cassel and Mendelsohn, 1985; Kamath and Yantek, 1979; and Nelson, 1979). By the same token, any hedonic equation is necessarily misspecified since some relevant variables must be omitted, either for lack of data or to reduce multicollinearity (Butler, 1982).

There are certain, recognized categories of housing attributes which have been shown by previous work to be relevant. These pertain to the structure of the dwelling itself and the lot upon which it is built; neighbourhood characteristics, including local public services; location, proximities, and accessibility to the central business district; and micro-neighbourhood (dis)amenities such as aesthetics and pollution (Brookshire *et al.*, 1982; Freeman, 1979; Li and Brown, 1980; Nelson, 1979; and Palmquist, 1984).

I.B. Form

Along with variable choice, functional form is an equally important aspect of hedonic model specification. Failure to use the appropriate functional form will give rise to misspecification bias, hence errors in measuring marginal characteristic prices and erroneous conclusions (Anderson, 1985; Cropper *et al.*, 1988; Graves *et al.*, 1988; and Halvorsen and Pollakowski, 1981).

However, there is little solid theoretical support or unambiguous prior empirical evidence for any functional form in particular (Bartik and Smith, 1987; Cassel and Mendelsohn, 1985; Freeman, 1979; Goodman, 1978; Halvorsen and Pollakowski, 1981; and Milon *et al.*, 1984). For instance, the hedonic function's form is not derivable from, and rarely depends on, the form of the utility function. Instead, it depends on the distribution of consumers across characteristic space (Triplett, 1987), which is similarly unknowable. Consequently, functional form is often chosen out of convenience, with the semi-logarithmic form being one of the most prevalent (Dinan and Miranowski, 1989; and Halvorsen and Pollakowski, 1981).

There are two approaches to specifying functional form: first, choosing it *a priori*; and second, choosing it empirically, given the information contained in the data at hand. The former approach is relatively more restrictive and may obscure behavioural information (Milon *et al.*, 1984). The latter, on the other hand, increases the number of parameters to be estimated, and entails higher computational costs and some difficulties in hypothesis testing (Bartik and Smith, 1987; and Marks, 1984).

I.B.1. *A priori* Specification of Form

Although many forms are possible *a priori*, hedonic theory suggests that non-linear forms are more plausible and less restrictive. This is because arbitrage through the costless division and recombination of housing attributes is unlikely implying that non-linear specifications may be more appropriate than linear ones. There are few available combinations of housing attributes, housing is durable, hence not easily repackaged, and its structural and neighbourhood services are jointly supplied. Non-linearity implies that marginal implicit prices may not be constant; they may depend on the quantities of their own or other characteristics, and that they, but not the overall price schedules, can be influenced by consumers and producers (Freeman, 1979; Nelson, 1978, 1979 and 1980; and Rosen, 1974).

The linear form is held to be unrealistic, overly restrictive and likely to bias the estimated coefficients. This is because the form implies that a characteristic's implicit price is independent of both that characteristics' own quantity and those of others, hence that it is constant (Freeman, 1979; and Rosen, 1974).

The semi-logarithmic form is generally regarded as an appropriate non-linear specification for owner-occupied housing, on the grounds of not being ruled out by hedonic theory and of being superior in terms of goodness-of-fit (Brookshire *et al.*, 1982; Dubin and Sung, 1990; Goodman, 1978; Nelson, 1982; and Triplett, 1987). In the semi-logarithmic form, the housing price is held to be a linear function of the natural logarithms of the characteristics (Bartik and Smith, 1987).

Nevertheless, even semi-logarithmic forms may be restrictive as the true hedonic relationships may be much more complicated and less uniform than the form would imply (Butler, 1982; and Halvorsen and Pollakowski, 1981). For example, Anderson (1985) notes that the hedonic price function could have both convex and concave segments. This may occur because the hedonic price function is a joint envelope of many different consumers' bid functions on one side, and producers' or sellers' offer functions on the other. Depending on where mutually tangent functions meet, and on how they are distributed across the amount of each attribute, the hedonic price function could assume many, complex, but curvilinear shapes. Also, the interpretation of parameter estimates for dummy variables becomes difficult in the case of semilog forms (Marks, 1984).

I.B.2. Flexible (Box-Cox) Functional Form

Using the Box-Cox transformation procedure to allow for flexible functional form is another approach (See: Graves *et al.*, 1988; and Palmquist, 1982; among others). This has been based on the argument that even the semi-logarithmic form may not be adequate for describing the possible complexity of the true relationship between the quantity of characteristics and price (Butler, 1982; Cassel and Mendelsohn, 1985; Dinan and Miranowski, 1989; and Halvorsen and Pollakowski, 1981). However, despite its advantages, the Box-Cox method has not supplanted the semi-logarithmic form (See: Coelli *et al.*, 1991; and Michaels and Smith, 1990). A variable Z's Box-Cox transformation is:

$$Z^{\Omega} = (Z^{\Omega} - 1)/\Omega \quad \text{if } \Omega \neq 0;$$
$$= \ln Z \qquad \text{if } \Omega = 0.$$

Any or all of the hedonic function's variables can be so transformed. This approach brings generality as to functional form, encompassing as it does the linear, log-linear, semilog, quadratic, and translog forms (Griliches, 1967).

I.B.3. Conclusion about Form

The most appropriate form for the hedonic price function is the one that yields the most accurate estimates of marginal amenity prices (Cropper *et al.*, 1988). Thus, although one form may fit the data more closely, another might better measure the effect of the explanatory variable of interest on the dependent variable. Since there is no theoretical guidance for the appropriate functional form of hedonic price functions, choosing the best form according to empirical performance is reasonable (Cassel and Mendelsohn, 1985).

Although a data set may provide little empirical support for any of the conventional functional forms used in economics, these simpler forms may be sufficient if hedonic prices are relatively insensitive to functional form (Graves *et al.*, 1988). Moreover, forms such as the semi-logarithmic enable easier interpretation of results and greater comparability with other studies than do Box-Cox transformations (Marks, 1984). Finally, data with a restricted sample range may mean that only a small segment of the hedonic price function can be estimated, and the actual form cannot be distinguished (Butler, 1982, citing Dhrymes, 1971). They may also result in parameter estimates with large standard errors. In this thesis, semi-log, linear, inverse semi-log, and log-log functional forms were estimated. The Box-Cox transformation was also used in a linear Box-Cox model, but the chosen algorithms did not converge.

II. Variables and Data

This section deals with the kinds of variables that appeared in the hedonic specifications that were estimated, as well as the sources and treatment of the data.

II.A. Specification Summary

A conventional hedonic specification could include housing characteristics, neighbourhood characteristics, proxies for local public goods, access to the central business district, and variables describing the externality of interest as explanatory variables. Conventional housing characteristics are: lot size, age, living area, the number of baths, condition, building materials, the presence of a swimming pool, the number of fireplaces, covered parking, and the heating system. Neighbourhood characteristics may include ethnicity, crime rate, and population density (Brookshire *et al.*, 1982; and Michaels and Smith, 1990). Local public goods can be described in various ways.

II.B. Price, and Temporal, Structural, and Lot Size Variables

II.B.1. Price

This project used actual transaction prices, since it is generally recognized that these data are preferable to average prices or evaluations (Ball, 1973; Freeman, 1979; and Palmquist, 1984). Parson's partial weighting (1990) by lot size was used to reflect congestion in the consumption of urban (dis) amenities. Price was not divided by lot size to correct for heteroskedasticity or to arrive at a price per area (e.g. Coelli *et al.*, 1991; Jud and Watts, 1981; and Li and Brown, 1980), since this would be tantamount to weighting all variables by lot size.

Finally, the price variable was indexed to give a real price for June 1991, using the monthly housing price index for Montréal. For more details about time and indexation, please refer to the next section, below.

II.B.2. Time and Price Indexation

Specifying a time variable or using a price index can be justified when estimating a hedonic model, since the model is meant to be cross-sectional in nature: it is supposed to explain the effects of characteristics on housing prices. They may account for otherwise unexplained variance in housing prices and isolate the effects of a dwellings' actual attributes (Anas and Eum, 1984) One can then deal with the question: "Given that people do buy houses, what is it about each house that contributes to its price?" Changes in housing market activity or in the general price level of housing within the sampling period, due to macroeconomic events or market disequilibrium, must be accounted for to allow one to pool a time series/cross sectional sample (Bartik and Smith, 1987; Michaels and Smith, 1990; and Walters, 1975).

Temporal phenomena were apparent in data published by the Greater Montreal Real Estate Board (GMREB; 1990-1991). For example, both the number of sales of residential units per period and their average sale value changed in a non-monotonic way from month to month and from year to year (GMREB, 1990-1991). Such market activity is held to be influenced by interest rates and recessional expectations or perceptions (GMREB, Jan.15, 1990). Indeed, housing starts, a measure of activity both in the housing market and in the economy, had also varied greatly in 1989 and 1990 (Statistics Canada, *Canadian Economic Observer*, 1990-1991)

Indexation should account for the month-to-month price levels in the housing market, ones that are held to be external to the structural and locational characteristics of each dwelling In parallel with arguments for separable utility, conditional demand, and multiple stage consumption decisions, a housing price index is thought to be more appropriate than a general, consumer price index. This is because hedonic analysis takes the fact that each particular house has been purchased as given, and since housing transactions constitute a very distinct kind of purchase Moreover, a housing price index is more accurate, since it accounts for what had been most relevant to the housing market up to the time of purchase. Nevertheless, a time variable is also useful as a proxy for market signals, disequilibrium, or activity in the housing market which may not be captured in a housing price index.

Real house prices were calculated for the month of June 1991. This month was chosen since it was a summer month, hence it was likely to have included the albeit fictitious peak planning day for which the 1991 NEF forecast was prepared. Statistics Canada's monthly index of Housing-Owned Accommodation for Montréal was used (Statistics Canada, 1991, Series P486137) [1]. It was assumed that the Montréal area was already the intended place of residence, and that decisions about housing followed those about employment. A monthly time trend was also used. Both time trends and price indexation have been used before (See, for example: Michaels and Smith, 1990; among many others).

Initially, some models did not include indexed housing prices, and some did not include a monthly time trend. Thus, there were four basic kinds of specification with respect to price and time. They differed in two basic dimensions: whether the price variable was real (indexed) or nominal, and whether or not a monthly time trend variable was included. Eventually, only specifications with both real prices and the monthly time trends were retained.

An annual or long-period dummy variable was also tried, along with the monthly time trends (After: Johnson and Ragas, 1987; Kowalski and Paraskevopulos, 1990; and Mieszkowski and Saper, 1978). This was done to account for a gap in the sample, and for the fact that it was split between 1989 and 1990. However, the introduction of the year dummy led to problems of near singularity in OLS estimation, hence they were abandoned.

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1 Data for this index had been collected monthly and were not treated for seasonality, according to a personal communication with Statistics Canada's Consumer Prices Section, 19 June 1992.

II.B.3. Structural Variables

In general, a wide range of data on properties' structural characteristics is desireable so that remaining price variation can be attributed to external factors (Freeman, 1979). However, this must be balanced against model concision and the need to limit multicollinearity (Butler, 1982; Cassel and Mendelsohn, 1985; and Kamath and Yantek, 1979).

Certain structural variables have been considered by previous authors and found to have had quadratic effects on housing prices. Thus, both the variables themselves and their squares have been specified for: living area; age of structure; number of rooms; number of bathrooms; and land area (Li and Brown, 1980; Palmquist, 1984; Pennington *et al.*, 1990; and Poon, 1978). Palmquist (1984) cites a phenomenon, long known to appraisers, whereby the price per unit of living area changes with a house's size; whereas Li and Brown (1980) observe that housing value declines with age until the age approaches historical significance.

Here, living area, dwelling age, the number of rooms, the number of bathrooms, and lot size were all specified with either linear and quadratic terms, or logarithmic, after Li and Brown's suggestion (1980). The coefficient for age was expected to be negative, whereas the square of age was expected to have a small, positive coefficient. The logarithm of age was expected to have a negative coefficient. It should be noted that the logarithmic transformations of these variables are, in effect, present in the inverse semi-logarithmic specifications.

II.B.4. Lot Size

Lot size was specified both as a separate variable, and used to weight environmental and locational (dis)amenities. As a weight for environmental and locational (dis)amenities, it accounted for how residential density leads to congestion in experiencing or consuming local (dis)amenities.

Residential density does affect how amenities are capitalized into land prices, and this means that they can be considered as quasi-public goods instead of public goods (Correll *et al.*, 1978; Diamond, 1980; and Parsons, 1990). Parsons (1990) adduces this locally congested, hence quasi-public nature of certain amenities to justify the weighting of a property's locational, as opposed to structural, attributes by its lot size in the framework of a hedonic model. This is not, however, to suggest that actual consumption increases with lot size, only that the number of those who can have access to the amenities decreases. Neglecting to weight by lot size when it is appropriate will bias estimated implicit prices for both structural and locational attributes. Other authors have also advocated a similar weighting (Li and Brown, 1980).

Weighting by lot size should be less strict than otherwise to the extent that newer or to-be-built houses are less substitutable for old ones, or when the degree of substitutability between old and new houses is unknown or may vary with the design of new houses. In these cases, Parsons (1990) recommends the use of a *partial* weighting function such as $P = X_1\alpha + WX_2\beta + X_2\Gamma$. Here, X_1 represents the structural attributes; X_2 denotes locational ones; and W is the lot size as a weight. Correct signs on β and Γ make $\delta P_{X_i}/\delta W > 0$ and $\delta P^2_{X_i}/\delta^2 W < 0$; where P_{X_i} is the implicit price of characteristic Xi. Here, a partial weighting function was used, where lot size was tried as a weight for the noise (NEF) variable, yielding "NEFW", and/or was used as an explanatory variable in its own right.

II.B.5. MLS Data

Disaggregated market transaction and price data were obtained from the Multiple Listing Service (MLS) on houses, as well as duplexes, triplexes, and condominiums (Greater Montreal Real Estate Board, 1989-1990; hereinafter: GMREBb, 1989-1990). Apartments, however, were excluded. Differences in structure and ownership suggest that measures of externalities derived from data on owner-occupied houses may not apply to high-rise apartments. Part of the reason also lies in the relatively short period of occupancy in the latter. Condominiums, however, should provide as good an indication as do houses (Poon, 1978; and Beattie, 1983) Moreover, this would also reflect the hypothesis that the two kinds of housing represent different lifestyles and preferences (DWG, 1990; and Beattie, 1983). The present sample consists of 427 observations. Samples of MLS data have ranged from as few as 234 observations (Dinan and Miranowski, 1989) to as many as 4331 (Thibodeau, 1990).

As only certain MLS books were available to the researcher, the data cover a time period from June 1989 to December 1990, with a gap of eight months from December 1989 to July 1990 inclusive. 95% of the 1989 observations were from October and November 1989. Hence, there are what amount to two sub-samples, containing 179 and 248 observations. Requests for further data were denied by the Greater Montreal Real Estate Board. The market was defined to include all West Island municipalities for which MLS data were available.

It is important to note that the MLS data do not cover all housing transactions. Hence, the MLS share of the housing market may not be representative of the entire housing market in either behaviour (Fidelman and Riga, 1991; and GMREB, 1990-1991) or goods. It is unknown whether there are significant differences between residential properties listed on MLS and those not so listed [2].

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2 Poon (1978, p.219) cited P. Chinloy of the Department of Economics of the University of Western Ontario as having reported the absence of significant differences between MLS and non-MLS sales.

II.C. Neighbourhood and Locational Variables

II.C.1. Introduction

Many authors, either explicitly [3] or through their specifications, reveal the importance of including variables for neighbourhood quality, location, and community in a hedonic specification. Indeed, there is a strong precedent for specifying neighbourhood variables in a hedonic equation. Nevertheless, there is little concensus on how to measure neighbourhood quality or, more specifically, on whether certain variables are direct measures or proxies (Bartik and Smith, 1987; and Dubin and Sung, 1990). Since consumers tend to choose communities which satisfy their preferences for public goods and neighbours, such variables should be included in specifications (Brookshire *et al.*, 1982; Dubin and Sung, 1990; Graves *et al.*, 1988; and Tiebout, 1956).

Dubin and Sung (1990) provide the basis of a useful taxonomy of neighbourhood variables: municipal or public services, socio-economic status, and racial composition. The last two can be combined into one category, since both describe the residents of a neighbourhood. Public services include schools and police protection or crime, its converse. Socio-economic variables describe the neighbours in each area; their education, kind of employment, and age (Dubin and Sung, 1990; Freeman, 1979; and Tiebout, 1956).

One other class of neighbourhood variable should be added to account for a dwelling's proximity to natural amenities and to specific private or public sector sources of positive or negative externalities, besides the one of interest. Examples include places of employment and shopping, highways, and railways, as well as scenic views, and parks. Although some of these

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3 See, for example, Brookshire *et al*, 1982; Freeman, 1979; Graves *et al*, 1988; Nelson, 1979; Pennington *et al*, 1990; Poon, 1978; and Tiebout, 1956.

are, strictly speaking, public services, their specificity and tangibility distinguish them from other (dis)services.

II.C.2. Public Services

Public service measures can be of two kinds: per capita expenditure (or taxation) and output. The former may be correlated with the quality of service, despite economies of scale and bureaucratic inefficiency. Output measures, on the other hand, are of more direct interest to households, and may entail a lower level of aggregation, since they are more neighbourhood-specific. However, output measures entail the difficulties of obtaining data and of choosing which variables to include (Dubin and Sung, 1990).

Relevant public services may include facilities and services like beaches, parks, police protection, roads, parking facilities, and schools (Tiebout, 1956). However, no such variable was specified here, since data on public service outputs in the West Island were either not collected or not available, and could not be collected by the researcher. Instead, dummy variables were used for cities or groups of similar cities to represent possible differences in tax rates and in the quality of public services, as well as locational differences (Dubin and Sung, 1990; Jud and Watts, 1981; and Thibodeau, 1990) [4].

II.C.3. The Neighbours

Hedonic price equations commonly include variables for neighbourhood socioeconomic characteristics (Goodman, 1977; and Li and Brown, 1980). These can be divided into descriptors of "race" or ethnicity; and measures of socioeconomic status (Dubin and Sung, 1990). Here,

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4 Alternatively, by concentrating on one area, one can control for tax rates, levels of local expenditure, and public services in general (Pennington *et al*, 1990).

language was used as a counterpart to race, and unemployment was used as a measure of socio-economic status.

Unlike the areas considered in other hedonic studies, the dichotomy of language (French or English) may be more relevant than "race" in a West Island neighbourhood. There are several reasons why this is so. On one hand, there is no single, predominant visible minority. On the other hand, there has been a well-known and longstanding distinction between Canada's two main language groups. As no one else has, to the knowledge of the researcher, specified a variable for language in the context of a hedonic model, this should prove to be of interest. Thus, the proportions of an enumeration area's population that speak French or English are introduced as neighbourhood variables.

The language variable is defined as the apparent proportion of an enumeration area's population that has affiliations with one language or the other. %French.Sp. measures the francophone and bilingual proportion, whereas %Engl.Sp. measures the anglophone and bilingual proportion. These are based on 20% samples of each enumeration area. Those who speak neither language are only counted in the denominators, as part of the total population. In spite of the overlap and the exclusion of non-French, non-English speakers, the variables for the two languages may be highly negatively correlated.

There are two theoretical explanations for a linguistic variable. The most plausible is that the members of one linguistic group prefer to live in neighbourhoods with others of the same group. The alternate, interpretation holds that sellers and/or real estate agents discriminate against the members of one group or the other (After discussions of "race" variables in: Bender and Hwang, 1985; King and Mieszkowski, 1973; and Lapham, 1971). If the first explanation holds, prices should be higher in neighbourhoods where more of either group is present, because of their presumed desireability. The quadratic form of a language variable should represent this. Although a household may prefer to locate in a neighbourhood where English or French is the predominant language, the presence of the other linguistic group would not be expected to lower housing values, *ceteris paribus*. As is the case for race variables, there is no clear indication of what sign is to be expected for the language coefficients (Dubin and Sung, 1990).

Finally, a measure of the local unemployment rate was specified, to reflect the prevalence of unemployed people. Given the high unemployment rate in and around Montreal, this variable seemed to be more relevant than other neighbourhood measures such as poverty, education, and transience.

II.C.3.a. Census Data

An enumeration area is the lowest level of aggregation for Canadian socioeconomic census data, and was equated in this study with the notion of neighbourhood. To describe the neighbourhoods, 1986 census data were obtained for all of the enumeration areas in municipalities covered by the MLS books for the West Island. Each dwelling's address was assigned to an enumeration area from the 1981 census, which was then converted into the equivalent one for the 1986 census. Addresses that either did not exist in 1981, or that were located in 1981 enumeration areas with many-to-many correspondences to 1986 ones, were assigned to 1986 enumeration areas according to their apparent locations on maps of the 1986 enumeration areas.

II.C.4. Proximity Variables

Distance to central business district (CBD) variables are commonly specified in hedonic regressions, as proxies for travel time and access to places of employment (McConnell, 1990). However, no distance variable was used in the empirical model. The presence of multiple employment centres and a dispersed pattern of employment, as on the West Island of

Montreal, was problematic. These factors have been found to make it difficult, first, to identify subsidiary employment centres, second, to determine their relative importance to the inhabitants of each neighbourhood or dwelling, and third, to specify variables representing the centres' impact (Bender and Hwang, 1985; Kowalski and Paraskevopoulos, 1990; Jud and Watts, 1981; and Palmquist, 1984). Moreover, the differential in distance between any pair of houses around the airport was small relative to the distance between any of them and the CBD of Montreal.

II.D. Airport Noise

II.D.1. Introduction

There is fairly extensive and consistent evidence of the negative impact of airport noise on property values. This has been observed despite both the diversity of noise measures and methods used, and suggestions that strong demand for housing, lack of information on the part of buyers, and noise imperturbable persons would prevent any observed effect of noise on housing prices (Gautrin, 1975; Nelson, 1980; Pennington *et al.*, 1990; and Walters, 1975 and 1978).

II.D.2. Measuring Airport Noise

Choosing a measure of noise is one of two key issues in specifying a hedonic model for the study of noise (Nelson, 1982). Barring actual, continuous physiological measures of human reactions to local noise, the most ideal measure would be a continuous recording of local noise, at several frequencies, for each house. However, this is highly impractical, so that the noise's impact must be estimated. For this, noise indices represent a superior alternative to measures of the proximity to a noise source or the frequency and intensity of complaints about noise (DWG, 1990). Noise indices are based on recordings from various directions and distances of the noise intensity generated by individual, benchmark noise events such as a particular type of aircraft's take-off, overflight, or landing. Future aircraft movements are predicted in time, and estimates of their aggregate noise are projected (predicted in space) for various points about an airport. Noise contours are then drawn among the points.

To do otherwise, comparing the price of quiet houses with that of noisy houses without accounting for the other attributes that give value to a house, for example, will reveal the expenditure on quiet, but will not indicate the quantity or price of quiet. Indeed, this value can only be considered as the price of quiet if it is unrealistically assumed that noise can be in two amounts: some or none. Because noise is a continuum as opposed to an "attribute" (something that can be present or absent, but which does not vary in its amount), it is better to use a measure of noise that reflects this fact. Noise indices do, whereas dummy variables or "noisy" versus "quiet" controls cannot (Walters, 1975).

Finally, there are, in turn, three main, noise indices: the Noise Exposure Forecast (NEF), the Composite Noise Rating System (CNR), and the Noise and Number Index (NNI) (Walters, 1975). Nevertheless, since only one measure will usually be available for a given airport, the question of which is superior (See: Bartik and Smith, 1987) becomes somewhat irrelevant. In the case of Dorval Airport, this measure happens to be the the NEF.

II.D.3. Measuring Noise: the Noise Exposure Forecast (NEF)

II.D.3.a. The NEF and its Calculation

The NEF, currently used to estimate airport noise in Canada, does reflect the fact that noise is a continuum. It also accounts for the fact that noise annoyance is a function of the noise's duration, loudness, sound frequency mix, and of how often noisy events occur (Beattie, 1983; and Walters, 1975). Although it is not a perfect measure of the noise annoyance originating from Dorval or other airports, it is the best and only one available. Essentially, the NEF estimates what the cumulative noise annoyance from air traffic on a notional busiest day of the year would be for a particular geographic point.

The NEF at a given point is arrived at in the following way. First, the physical accoustic pressure (sound) propagated during the take-off or landing of a given type of aircraft is measured at various distances and angles relative to its flight path. These recordings are weighted at various frequencies, to reflect the relative annoyance induced by certain parts of the sound spectrum. The weighted measures are then plotted versus elapsed overflight time, for each type of aircraft, and for both take-off and landing. For each curve, the global maximum is determined. Next, a factor which corrects for the duration of the noisy event is added to each maximum, to represent one of the most distressing aspects of noise. The resultant measure is called the effective perceived noise level (EPNL) (Transport Canada, March 1989). The EPNL measures the noise from single noise events, and is determined for each type of aircraft, as a function of the shortest distance from the aircraft's flight path, for each kind of operation: taking-off, landing, or flying. Because it does not measure sound *per se*, but only effective perceived noise *annoyance*, its units are distinguished from true dB with the prefix EPN (Transport Canada, March 1989).

The NEF, in turn, is an aggregation, for given reference points on the ground, of the EPNL calculated from the closest points of all flight paths, followed by all types of aircraft, to each destination, on a notional "peak planning day" (Transport Canada, March 1989 and June 1990). The NEF also incorporates weighting to emphasize the relatively greater annoyance caused by nightime flights (Muskin and Sorrentino, 1977). It is measured in NEFdB, which are identical to perceived noise units (EPNdB). The logarithmic nature of this summed noise measure, combined with the large sample sizes used to calculate noise and aircraft performance data, allows one to ignore variations due to relatively less important factors such as weather, wind, and pilot habits (Transport Canada, March 1989 and June 1990).

II.D.3.b. Empirical Support for the NEF

A rough correlation can be drawn between NEF zones and the kinds of reactions that the administrators of an airport can expect from the residents of those zones. In addition, the severity of health effects have been related to increasing NEF levels (Beattie, 1983; Muskin and Sorrentino, 1977; Nelson, 1979; Transport Canada, March 1989; and Walters, 1975). Both the Canada Mortgage and Housing Corporation (C.M.H.C.) and the Ontario Ministry of Housing have referred to NEF levels in, respectively, a lending policy fo residential housing around airports, and guidelines for residential land use (Beattie, 1983).

II.D.3.c. Inherent or Definitional Limitations

Measurement error in pollution variables such as those for noise has been found to have a much greater effect on their own coefficients than did potential measurement error in other explanatory variables. Thus, the measurement of noise variables is critical (Graves *et al.*, 1988).

The NEF does have certain inherent or definitional limitations. They imply that it may not be an entirely accurate measure of the noise annoyance, hence the externality, that is actually experienced on the ground when the buyers and sellers of houses, or their agents, appraise a dwelling to decide on a price. These limitations pertain to: calculating the NEF for a peak planning day, instead of a more typical day; using forecasts of aircraft movements to arrive at both the number of noise events to be aggregated and their distribution among aircraft types and flight paths; not calibrating the NEF with actual measurements from the ground; and ignoring the local effects of topography, building design and orientation, and vegetation on noise annoyance. Two other limitations are that the NEF ignores the noise annoyance that is generated when aircraft use reverse thrust, after they touch down; and that the NEF may not adequately account for the number of events, even though this enters into the aggregation (DWG, 1990; Hornblower, 1991; and Transport Canada, March 1989, Feb. 1990, June 1990, and May 1991).

II.D.3.d. Problems in Usage

Beyond the definitional limitations of the NEF or other noise indices, there are two problems which arise when they are used. The first is the existence of multiple airport externalities; and the second is the presence of multiple sources of externalities which, consequently, overlap.

There are other, lesser externalities which emanate from the airport, both positive and negative (See, for example: De Vany, 1976; Gautrin, 1975; Nelson, 1979; Pennington *et al.*, 1990; and Walters, 1975 and 1978). The chief positive externality is the airport's proximity as a centre of employment or a point of departure. The former may pertain to the airport itself or to air transport-related businesses. The latter may refer to the convenience of passengers or to shippers. To the degree of its relevance to local inhabitants, an airport's proximity may bias estimates of noise coefficients towards zero (Beattie, 1983; De Vany, 1976; Nelson, 1980; and Pennington *et al.*, 1990; and Walters, 1975). This follows from the positive correlation of noise and proximity. Finally, the other, lesser negative externalities include air pollution and traffic congestion (Walters, 1978).

Although one could specify a distance to airport variable, in whatever fashion, to control for accessibility (Walters, 1975); the dispersion of local employment centres would pose the same problem as it does for distance to CBD variables. Also, the empirical evidence for the usefulness of distance proxies is weak. For example, Nelson (1979) concluded that NEF coefficients were stable at different distances from airports. Because of the dispersed nature of employment in the West Island of Montréal, and the above finding, the possible existence of multiple externalities emanating from Dorval Airport is recognized, but has not been dealt with in this thesis.

Not only are there multiple externalities from a single source, but there may also be multiple sources of externalities which affect a given property. Thus, housing price may also reflect the impact of non-airport externalities, such as air, noise, and visual pollution from nearby highways and railways (Poon, 1978; and Whitbread, 1978). Nevertheless, the possible effect of other externality sources on housing prices was not considered here. Airport noise would seem to be more noticeable, hence have the greatest impact.

II.D.4. Contour Data and Sampling

Noise data were obtained from Transport Canada's Map *Airport Montréal International (Dorval): Noise Exposure Forecast 1991*. Ref.No. QR1, Sheet No.1/1, March 1986. Since the noise data used in this thesis were forecast circa 1984, and the sales data pertain to 1989 and 1990, estimated coefficients may be inaccurate. Nevertheless, it may be reasonable to use noise readings from one point in time to represent the noise level over a longer period if there is not much variation in the traffic that produces the noise (Palmquist, 1982). Noise contour data were converted into secondary data by relating the positions of housing observations to the appropriate NEF zones or contours. Houses located near the NEF contours themselves were given integer noise values equal to the contours' values. Those located near the middle of a noise zone (between two contours) were assigned noise values equal to the level at the lower contour. Moreover, linear interpolation was not attempted, owing to the likely complexity of the NEF surface (Levesque, 1991).

Since the NEF index has a non-zero origin, assigning zero noise levels to houses located beyond the outer contour creates measurement error (Nelson, 1980, and 1982; and Palmquist *et al.*, 1990). This study followed the majority of authors in specifying a background noise level (minimum annoyance threshold) of NEF 20 instead of NEF 25 (Abelson, 1979; and Nelson, 1978, 1980, and 1982). This was in keeping with the West Island's relatively quiet suburban nature, and there already is an NEF = 25 contour for Dorval Airport. The erroneous practice of excluding observations that are adjacent to NEF contour lines was not followed.

As mentioned above, noise data have some possible limitations. They are collected during or forecast for relatively brief periods, to which housing sales data should correspond. Instability in airport traffic or usage, hence noise, may render the use of previous-period samples inappropriate (Mieszkowski and Saper, 1978; and Nelson, 1982). A similar problem may arise when the noise sampling or forecasting period and the sales sample are separated by a noticeable lag.

Subjective annoyance has been found to be proportional to e^{NII}, which would suggest a semi-log specification for the hedonic model (Nelson, 1979 and 1982). Brookshire *et al.* (1982) found some empirical support for this in their study of the relationship between their pollution variable and housing price.

II.E. Specified Variables

The variables considered in various specifications for this thesis, and their units, definitions, and sources are presented in Table IV.1., below. Their expected signs, means, sample standard deviations, minima, and maxima appear in Table IV.2.. Most all of these variables, or similar ones, have been previously found to be significant by many researchers (Dubin and Sung, 1990; Goodman, 1977; Palmquist, 1984; and Poon, 1978). Some structural variables for which data were available, but which were not used in the empirical models include the number of floors, the basement's finish, hardwood floors, and central air conditioning. Nevertheless, whether houses were detached or semi-detached was specified.

Four zonal variables were specified, grouping similar cities together. The adjacent cities in Zone 3 are all exposed to airport noise, and are located on the (southern) Lakeshore of the Island of Montréal. Likewise, the cities in Zone 4 are similar, adjacent towns, but are located on the northern shore of the island. Thirdly, Zone 1 subsumes cities that are all located away from Dorval Airport, whose citizens may, in general, be similarly well-off, and which have similar-looking streets and suburban patterns. Finally, the Zone 2 dummy variable is identified with the town of Dollard-des-Ormeaux, which, although exposed to airport noise, contains many more recent housing developments than do Pointe-Claire, Dorval, or Lachine.

Table III.1. Variables: Units, Brief Definitions, and Sources.

Variable	Units	Brief Definition	Source
Real Price	$(June 1991)	Real house price.	a
Detachment	Yes/No	Fully- or semi-detached, vs. attached.	a
Age	Years	Age, since construction or last renovation.	a
Rooms	Units	Total number of rooms of any kind.	a
Bathrooms	Units	Number of bathrooms.	a
Floor Area	ft^{2}*	Living space in structure.	a
Fireplace	Yes/No	Presence of fireplaces.	a
Central Heat.	Yes/No	Presence of central heating.	a
Heat Pump	Yes/No	Presence of a heat pump.	a
Brick	Yes/No	Presence of substantial brick facing.	a
Stone	Yes/No	Presence of substantial stone facing.	a
Lot Size	'000s of ft^{2}†	Size of the lot.	a
Garages	Units	Number of garages.	a
Pool	-	No or above- or in-ground swimming pool.	a
Noise (NEF)	[NEFdB]	NEF noise annoyance level.	c
Noise (NEFW)	NEFdB·'000s of ft^{2}.	NEF times lot size.	(a,c)
% French Sp.	100ths of pop.	Proportion of francophone or bilingual pop.	b
% English Sp.	100ths of pop.	Proportion of anglophone or bilingual pop.	b
% Unemployed	100ths of pop.	Proportion of neighbours unemployed.	b
Zone 1	Yes/No	Kirkland, Beaconsfield, Baie d'Urfé or Senneville	(a)
Zone 2	Yes/No	Dollard-des-Ormeaux	(a)
Zone 3	Yes/No	Pointe-Claire, Lachine or Dorval.	(a)
Zone 4	Yes/No	Pierrefonds, Ste-Genevieve or Roxboro.	(a)
Month	Months	Sample month of sale.	(a)

Notes for Table III.1.:

a : MLS , various books (GMREBb, 1989-1990).

b : Statistics Canada (1990), 1986 Census.

c : Transport Canada (1986).

(•) : Calculated from indicated sources' data.

*,+ : 1 ft^2 = 0.093 m^2; square feet are the conventional unit of measurement for lot sizes and floor areas.

N.A.: Not Applicable.

Table III.2. The Variables: Expected Signs, Means, Sample Standard Deviations, Minima and Maxima.

The variables below appear in the set of retained specifications. Variables which were only included in eventually rejected specifications are not listed.

Number of Observations: 427

Variable	Expected Sign	Mean	Std. Dev.	Minimum	Maximum
Real Price		148525	65271	19866	610695
ln(Real Price)		11.84	0.35	9.90	13.32
Detachment	(+)	0.81	0.39	0	1
Age	(-)	21.19	16.88	1	240
ln(Age)	(-)	2.66	1.08	0.00	5.48
Age^2	(+)	733	2830	1	57600
Rooms	(+)	7.67	1.39	4	13
ln(Rooms)	(+)	2.02	0.18	1.39	2.56
Bathrooms	(+)	1.79	0.61	1.00	3.50
ln(Bathrooms)	(+)	0.52	0.34	0.00	1.25
Floor Area	(+)	1544	602	482	5620
ln(Floor Area)	(+)	7.28	0.35	6.18	8.63
Fireplace	(+)	0.65	0.48	0	1
Central Heating	?	0.66	0.47	0	1
Heat Pump	(+)	0.08	0.27	0	1
Brick	(+)	0.88	0.32	0	1
Stone	(+)	0.03	0.16	0	1

Table III.2. (continued):

The Variables: Expected Signs, Means, Sample Standard Deviations, Minima and Maxima.

Variable	Expected Sign	Mean	Std. Dev.	Minimum	Maximum
Lot Size	(+)	6.75	3.40	0	31.72
ln(Lot Size)[5]	(+)	8.68	0.88	-6.91	13.44
Garages	(+)	0.95	0.70	0	2
Pool	?	0.26	0.60	0	2
Noise (NEF)	(-)	22.68	4.43	20	35
Noise (ln(NEF))	(-)	3.10	0.18	3.00	3.56
Noise (NEFW)	(-)	151.71	81.50	0.00	685.44
Noise (ln(NEFW))	(-)	11.78	1.02	-6.91	13.44
% French Sp.	?	0.68	0.08	0.51	0.98
% English Sp.	?	0.90	0.08	0.46	1.00
ln(% English Sp.)	?	-0.11	0.09	-0.78	0.00
% Unemployed	(-)	0.06	0.03	0.00	0.18
Zone 1	?	0.12	0.32	0	1
Zone 2	?	0.18	0.38	0	1
Zone 3	?	0.02	0.15	0	1
Zone 4	?	0.24	0.43	0	1
Month	(-)	12.31	5.80	1	18

N.A.: Not Applicable.

5 The log of lot size is in ft^2, not (000) ft^2.

CHAPTER IV. METHOD

I. Introduction

The method used to estimate a hedonic function is crucial, since it can have a great effect on the marginal valuations of environmental commodities (Graves *et al.*, 1988). Although the Box-Cox method is often used in hedonic modelling, efforts to apply it to the data set at hand were not successful. This was so even when different initial parameter values and optimization algorithms were used. Consequently, the discussion about Box-Cox estimation is brief. Hence, OLS, with functional form specified *a priori*, was used to estimate hedonic functions of various forms (linear, ln-ln, inverse semi-ln, and semi-ln). OLS models are still used to estimate hedonic functions (Michaels and Smith, 1990, for example). However, little space is devoted to a discussion of this well-known method.

The first part of this chapter discusses the OLS estimation strategy that was used, including model selection and variable evaluation, how multicollinearity was dealt with, as well as testing for stability and heteroskedasticity. The second part considers the Box-Cox method and its application to hedonic analysis, and reports briefly on the Box-Cox work that was done for this thesis.

II. OLS Estimation

II.A. Considerations

This section presents three considerations in estimating, selecting, and retaining OLS models: general criteria, individual variable significance, and multicollinearity. The next section (II.B.) deals with the strategy that was followed and how it involved these considerations.

II.A.1. Model Selection Criteria

Hedonic models may be evaluated in light of Harvey's five criteria (1981) of what constitutes a "good" model: parsimony, identifiability, goodness of fit, theoretical consistency, and predictive power. First, a parsimonious model is one that contains few parameters, yet which brings out the essential features of the processes under examination. Simplicity entails subsuming certain factors under the disturbance term. Parsimony is relevant to the extent that it justifies dropping individually insignificant variables from the model. Identifiability, the second property, tends to be related to parsimony, and means that only one set of parameters is consistent with the data set (Harvey, 1981). Since no non-nested tests were used here to evaluate alternative specifications, identifiability has, to some degree, been ignored.

The third criterion, goodness of fit, is especially relevant to predicting movements in the dependent variable, but not to hedonic analyses, since they have the goal of estimating specific regression coefficients, rather than simply explaining the variation in the dependent variable (Harvey, 1981). Thus, although goodness of fit can be characterized by measures such as R^2, these are not useful criteria for evaluating alternative specifications (Ridker and Henning, 1967).

Theoretical consistency means that a model is consistent with *a priori* knowledge, whether from economic theory or common knowledge The accuracy of a model's predictions is a final criterion, which may be more relevant than goodness of fit, particularly when it is measured against a new sample (Harvey, 1981). However, since hedonic models are not intended for forecasting, this criterion is only relevant to the significance of individual parameter estimates.

II.A.2. Multicollinearity

Multicollinearity is a common empirical problem in hedonic work (Butler, 1982; and Garrod and Willis, 1992). Examples include dimensional housing characteristics, such as the number of bedrooms, bathrooms, and garages, and floor area and lotsize; distance to CBD variables and neighbourhood characteristics; and structural characteristics or town and age (Butler, 1982; Correll *et al.*, 1978; Dinan and Miranowski, 1989; Li and Brown, 1980; and Pennington *et al.*, 1990).

Multicollinearity reduces the reliability of estimated coefficients (Ozanne and Malrezi, 1986, cited by Garrod and Willis, 1992), yet its seriousness in an application is not easily judged in an objective way. Researchers must resort to their own judgment and to empirical tests (Maddala, 1977, cited by Garrod and Willis, 1992; and Ridker and Henning, 1967). Moreover, there is a trade-off between multicollinearity and misspecification (Butler, 1982). Omitting a relevant variable will entrain bias in the estimates of coefficients for the variables with which it is correlated, whereas retaining the variable may entrain inefficiency through multicollinearity (Ridker and Henning, 1967). Provided that such problematic variables have adequate t-ratios and that their inclusion is strongly justified *a priori*, they should be retained (Coelli *et al.*, 1991).

II.B. Estimation Strategy

The objective was to estimate the coefficients of the hedonic price function, especially those corresponding with noise and neighbourhood variables. In preliminary regessions, some multicollinearity was evidenced by incorrect coefficient signs and insignificant coefficients for variables. Hence, the matrix of correlation coefficients between the variables was computed, and special attention was paid to pairs of variables which had coefficients of approximately 0.60 and greater in magnitude. Each variable that had such coefficients with two or more other variables that measured roughly the same thing, size, for example, was treated as being problematic and was dropped from all specifications. Pairs of similar variables with coefficients greater than about 0.90, such as the English and French linguistic variables, were treated as alternates. New, alternate specifications were set, which differed only in which member of each pair was included.

Thus, the number of specifications was doubled for each such pair. All other variables were organized into several combinations of similar, yet compatible variables. These combinations were, in turn, combined with dissimilar, but compatible combinations to arrive at a new set of specifications as to inclusion.

III. Error, and General Limitations

III.A. Error

Hedonic price equations can present the usual econometric problems of measurement error, misspecification error, autocorrelation, multicollinearity, heteroskedasticity, and multicollinearity. However, these problems are not necessarily more severe in hedonic analysis than in any other kind of analysis that uses econometrics.

III.A.1. Measurement Error

Measurement error, of the price or the characteristics of a property, may result from their misrepresentation with proxies or from the non-measurement of certain attributes. Fairly strong assumptions must be made about unmeasured characteristics, ones which are only met when the attributes are fairly particular. Such attributes may include the colour of paint or carpets, for example (Epple, 1987). Except where alternative measures are available, such error is generally beyond the control of the researcher [1].

This problem is especially relevant to amenities. In general, crude, aggregate and controversial proxies are used to analyze amenities. Such measures do not account for distributions of perceptions More

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1 Another explanation of residuals, besides measurement error, is that they are caused by agents' erroneous perceptions of price or characteristics (Epple, 1987).

fundamentally, the perceptions themselves are poorly understood, as is their formation. It follows that the use of resultant estimates in policy analysis is fraught with uncertainty (Bartik and Smith, 1987).

III.A.2. Misspecification Error

Misspecification error, whether due to the omission of measured variables, or the exclusion of unmeasured ones, involves the presence of unobserved or unaccounted-for characteristics. Its extent has a critical effect on a hedonic price function's performance. The omission of relevant variables may reduce a model's degree of explanation, since their effects may be included in the intercept or other terms (Cropper *et al.*, 1988; Epple, 1987; and Garrod and Willis, 1992). However, omitting certain variables such as those describing a neighbourhood may be justified if the resultant misspecification error is small enough (Butler, 1982; and Garrod and Willis, 1992). Likewise, although both the linear and quadratic Box-Cox transformations are the best forms to use when there is minimal misspecification, only the former is appropriate in other circumstances (Cropper *et al.*, 1988).

III.A.3. Autocorrelation and Multicollinearity

Autocorrelation, both spatial and temporal, may be an important problem in connection with hedonic analyses, but the structure of the data used makes both kinds very difficult to test for and deal with (Anas and Eum, 1984; Ball, 1973; and Coelli *et al.*, 1991). The irregular distribution of sales over time is one chief example of the structural problems (Coelli *et al.*, 1991). Multicollinearity is discussed at length in a previous section of this chapter, since its presence was influential in determining the estimation strategy used here.

III.A.4. Heteroskedasticity

The spatial nature of hedonic data indicates that heteroskedasticity should be tested for, but there is a lack of theoretical support for a relationship between variance in price and location (Correll *et al.*, 1978). Nevertheless, Coelli *et al.* (1991) did encounter heteroskedasticity with respect to lot size.

IV. Diagnostic Tests

IV.A. Tests of Stability

Because the overall sample comprised 179 observations from 1989 and 248 from 1990, with an eight-month gap in the middle, the models' stability was tested using the F-test variant of the Chow test. This entailed running separate OLS regressions for the overall sample and for each of the sub-samples. Since the periods' estimated standard errors, hence the σ^2's, were very similar, a Wald test for stability was unnecessary. The Chow test was constructed for each of the 34 most promising specifications that had been arrived at for the overall sample, including ones for each of the inverse semilog, true semilog, log-log, and linear functional forms.

A conclusion that could be drawn from all of these Chow tests is that there may have been a significant structural change between the two periods, implying that the two periods should, perhaps, have been considered separately. However, the Chow tests did not really test the specifications that had been retained, but ones which differed from them in the exclusion of the variable Month. This variable had been highly significant in all previous specifications, but problems of near-singularity with the sub-samples meant that the variable had to be dropped in order to perform the Chow tests. Thus, any conclusions drawn from the Chow tests performed are relevant to the specifications that were tested without Month, but may not be relevant to the specifications that were actually retained and that *did* include the variable Month. In other words, the Chow tests were only performed on similar, but not identical specifications to those retained. Moreover, the apparent significance of the Chow tests for all functional forms could still be attributed to the sample's discontinuity.

Nevertheless, *a priori* information suggests that there was a change which affected the housing market between 1989 and 1990, namely the beginning of a recession. This resulted in weakened demand for housing, manifested in sharply falling housing starts and building permit expenditures, starting in the second quarter of 1990, and continuing, with some minor reversals, throughout that year (Statistics Canada, *Canadian Economic Observer*, 1990-1991).

IV.B. Tests of Heteroskedasticity

The presence of heteroskedasticity is likely to bias the variance estimator, hence the standard errors of the regression coefficients. Moreover, some misspecification tests based on OLS theory may be weakened (Godfrey, 1988; and and Judge *et al.*, 1982). Therefore, it is important to test for heteroskedasticity. A Breusch-Pagan test for heteroskedasticity was constructed for each of the specifications retained after the preliminary selections for significant, individual t-tests and absence of apparent multicollinearity. Hence, it was applied to 11 fully linear, four semi-ln, 11 ln-ln, and two inverse semi-ln specifications.

The Breusch-Pagan test is a general Lagrange Multiplier (LM) test for hypotheses that the estimated disturbance is some function of the regressors. It is versatile since it can be applied without prior knowledge of the functional form of the heteroskedastic relationship, although given such knowledge, other, more specific tests are stronger (Kennedy, 1985; Judge *et al.*, 1982; and Studenmund, 1992).

Although the Breusch-Pagan test does allow one to test several factors at once, the factors and the form of heteroskedasticity must be specified, and the sample should be large (Studenmund, 1992). In small samples, the test may be sensitive to non-normal error distributions Where this is of concern, the test may be modified by regressing the square of the OLS residual, less the sample variance, on the variables in question The Breusch-Pagan statistic would then be calculated as the product of this second regression's R^2 and the sample size (Koenker, 1981, cited by Kennedy, 1985). As well, Judge *et al.* (1982) caution that in finite samples, this test entails a lower frequency of Type I error than the chosen significance level would suggest. In other words, the level of significance may be more stringent than that indicated by (α), or the chosen level may be less strictly applied.

All of the fully linear and semi-ln specifications were found to be afflicted by some heteroskedasticity with respect to the variables Rooms, Bathrooms, Floor Area, and Lot Size. Weighted least squares (WLS), where each non-dummy variable is divided by the most influential factor (Studenmund, 1992), can be used in an attempt to correct for heteroskedasticity. This was used to estimate a representative, fully linear specification (TL60). Since its Breusch-Pagan test statistic was on the order of 5×10^{14}, it was apparent that the resultant model was even more prone to heteroskedasticity than the original, uncorrected one. Because the other linear specifications were not very different from TL60, and because their heteroskedasticity seemed to be related to the same size variables, it was decided that weighted least squares would not prove fruitful Hence, the absence of apparent heteroskedasticity was adopted as an additional criterion for retaining specifications. Consequently, whereas all of the linear and semi-ln specifications were rejected, both of the inverse semi-ln, and all 12 of the ln-ln specifications were retained

IV.C. Functional Form

The Durbin-Watson test may be used to detect an incorrect functional form in cross-sectional data, although it may not be the most appropriate test for this purpose (Kennedy, 1985). Rejecting Ho implies that the specified functional form may be erroneous.

V. The Box-Cox Technique

V.A. Introduction and Appropriateness

Hedonic theory suggests that the hedonic price function may be non-linear instead of linear, but does not provide any definite conclusions. This is precisely the kind of situation for which Box-Cox transformations are appropriate (Bender *et al.*, 1980; Butler, 1982; Cassel and Mendelsohn, 1985; Milon *et al.*, 1984; and Zarembka, 1974).

The Box-Cox technique estimates the most appropriate values of the transformation parameters, hence the most appropiiate functional form, for the data set at hand. These, and restrictions that describe other, recognized forms can be tested against one another with likelihood ratio tests (Coelli *et al.*, 1991; Kmenta, 1986; and Milon *et al.*, 1984).

V.B. The Box-Cox Transformation and Model

The Box-Cox power transformation of a variable Z is defined to be:

$$Z_i(\lambda) = (Z_i^{\lambda} - 1)/\lambda, \qquad \text{for } 0 < \lambda \leq 1,$$

$$= \ln Z_i, \qquad \text{for } \lambda = 0;$$

where $Z_i > 0$[2], $i=1,\dots,N$.

The transformation can be applied to the dependent and independent variables, but must be strictly positive, since the logarithmic transformation

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2 See, for example: Amemiya, 1985; Beauchamp and Kane, 1984; Box and Cox, 1964; Carroll, 1982; Draper and Cox, 1969; Fomby *et al*, 1984; Godfrey, 1988; Harvey, 1981; Kennedy, 1985 and 1992; Kmenta, 1986; Maddala, 1977; Pindyck and Rubinfeld, 1991; Schlesselman, 1971; Seaks and Layson, 1983; Spitzer, 1982a, 1982b, 1984; Tse, 1984; and Zarembka, 1974.

of zero or negative values will be undefined. Moreover, the transformation parameter need not be the same for all variables, and not all variables need be transformed [3]. In general, as the number of transformation parameters increases, the overall model will become more flexible; but its complexity and, with it, the computational costs, will increase as well (Blomquist and Worley, 1981; Dinan and Miranowski, 1989; Fomby *et al.*, 1984; and Judge *et al.*, 1980).

The unknown parameter λ is unrestricted within the range of $0 < \lambda \leq 1$ (Cox, 1990; Palmquist and Danielson, 1989). λ is assumed to be non-zero for convenience in deriving the log-likelihood function (Zarembka, 1974). Moreover, Box-Cox models must include a constant term, so that the estimated transformation parameter for the dependent variable is invariant to changes in the units of measurement of the dependent variable (Cassel and Mendelsohn, 1985; and Zarembka, 1974 and 1987).

Here, the regressors in the linear Box-Cox model were entered in linear versus quadratic form. This has the advantage of being relatively simple, and results are easier to use and interpret. It is also more robust to misspecification and the use of proxies in hedonic work (Cropper *et al.*, 1988).

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3 See: Amemiya, 1985; Box and Cox, 1964, Cox, 1990; Draper and Cox, 1969; Fomby *et al*, 1984; Judge *et al*, 1980, Maddala, 1977; Seaks and Layson, 1983; Spitzer, 1982a; and Zarembka, 1974 and 1987.

The linear Box-Cox hedonic model with dummy variables is:

$$P(\Theta) = \alpha_0 + \Sigma_j \alpha_j X_j(\lambda) + \Sigma_k \beta_k D_k + \epsilon;$$

Where: $j = 1,...,m;$

$k = 1,...,p;$

$$P_i(\Theta) = (P_i^{\Theta} - 1)/\Theta, \quad \text{for } \Theta \neq 0,$$

$$= \ln P_i, \quad \text{for } \Theta = 0; \text{ and}$$

$$X_j(\lambda) = (X_j^{\lambda} - 1)/\lambda, \quad \text{for } \lambda \neq 0,$$

$$= \ln X_j, \quad \text{for } \lambda = 0;$$

$P_i(\Theta) \in P(\Theta)$, and $X_j(\lambda) \in X(\lambda)$.

(After: Bender and Hwang, 1980).

This formulation includes a transformation parameter (θ) for the dependent variable (**P**), and (λ) for each of the independent variables (X_j). The dummy variables (D_k) are not transformed.

Applications of the Box-Cox transformation require that the transformed dependent variable be strictly positive, since logarithmic transformations (when $\Theta = 0$) of negative numbers or zero are undefined. This implies that the distribution of ϵ is necessarily truncated, and cannot be exactly normal. However, normality happens to be a basis for the maximum likelihood method (Amemiya, 1985; Fomby *et al.*, 1984; and Zarembka, 1987).

Nevertheless, this conflict can be reconciled by assuming either normality, with a very small probability of large, negative values for ϵ_i; or *approximate* normality [4]. Finally, no matter what is assumed, the Box-Cox procedure, including maximum likelihood estimation, is robust to non-normality, hence is consistent, provided that the error distribution is reasonably symmetric or that $P_i(\Theta)$ is relatively unskewed (Draper and Cox,

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4 See: Beauchamp and Kane, 1984; Fomby *et al*, 1984; Lahiri and Egy, 1981; Maddala, 1977; Seaks and Layson, 1983; Spitzer, 1982b and 1984; Tse, 1984; and Zarembka, 1987.

1969; Seaks and Layson, 1983; and Zarembka, 1974).

The Box-Cox method is particularly sensitive to the presence of heteroskedasticity when not allowed for in the log-likelihood function's specification. Unaccounted-for heteroskedasticity will bias the estimate of Θ towards a value (0) that stabilizes σ_i^2 towards apparent homoskedasticity (σ^2), giving the false impression of non-linearity (See: Kmenta, 1986, Judge *et al.*, 1980; Lahiri and Egy, 1981; Seaks and Layson, 1983; and Zarembka, 1974, 1987). Moreover, this bias will, consequently, extend to other parameters (Zarembka, 1987). Hence, the Box-Cox model should be generalized to account for both functional form and possible heteroskedasticity, so that they can be tested simultaneously and their effects isolated (Lahiri and Egy, 1981; and Tse, 1984). This was done here.

V.C. The Box-Cox Likelihood Function

The Box-Cox model was devised with maximum likelihood estimation in mind (Harvey, 1981; Maddala, 1977; and Pindyck and Rubinfeld, 1991) Because the maximum likelihood (ML) technique was used, a density function had to be assumed, from which a likelihood function was specified. The joint density or likelihood for the elements of the vector of original, untransformed observations, $\mathbf{P}_{N x b}$ was assumed to have a multivariate, approximately normal yet possibly heteroskedastic distribution, after Harvey (1981):

$$L \equiv (2\pi)^{-\left(\frac{427}{2}\right)} |V|^{-1/2} \cdot e^{-1/2[P(\theta) \quad X(\lambda) \quad \alpha \quad D \quad \beta]' V \quad [P(\theta) \quad X(\lambda) \quad \alpha \quad D \quad \beta]} J(\theta)$$

(1)

The positive definite (variance-) covariance matrix, with some allowance for heteroskedasticity, is:

$$V^{-1} \equiv \begin{bmatrix} e^{W_1\delta} & & & \bigcirc \\ & e^{W_2\delta} & & \\ & & e^{W_i\delta} & \\ \bigcirc & & & e^{W_N\delta} \end{bmatrix}^{-1}_{N \times N}$$

(2)

Here, J(O) is the Jacobian of the transformation from P(Θ) to **P**, after Harvey (1981) and Zarembka (1974):

$$J(\theta) = \Pi_{i=1}^{N} \left| \frac{\partial P_i(\theta)}{\partial P_i} \right| = \Pi_{i=1}^{N} P_i^{\theta - 1}$$

(3)

The likelihood function is equal to the product of the normal densities, times J, the Jacobian of the transformation from the transformed dependent variable, **P**(Θ), back to its original, untransformed value, **P**. The Jacobian reflects the change of variables that occurs in moving from ϵ's distribution function to that for **P**; and is equal to $|(\Theta - 1)\Sigma_i \ln P_i|$ (Harvey, 1981; Judge *et al.*, 1980; Pindyck and Rubinfeld, 1991; Schlesselman, 1971; Seaks and Layson, 1983; and Zarembka, 1974).

Tse's approach (1984) to allow for the possible presence of multiplicative heteroskedasticity was used above. This entailed specifying: $\sigma_i^2 \quad \sigma^2 \bullet h(\mathbf{W}' \bullet \boldsymbol{\delta})$, where **W** was an mx1 vector of non-stochastic variables with respect to which there could be heteroskedasticity, $\boldsymbol{\delta}$ was an mx1 vector of heteroskedasticity parameters, $\boldsymbol{\delta} = 0$ when there is homoskedasticity, and h(•) was a positive function for which h(o) = 1. Here, h(•) was defined to be the constant e to the power of $\mathbf{W}' \bullet \boldsymbol{\delta}$, after Harvey (1981). Thus, $\boldsymbol{\delta}$ was treated as an additional unknown parameter vector to be estimated, and the whole term was substituted for σ_i^2 in the likelihood function. The necessary assumptions were that: ϵ_i was normal, and that the probability of large, negative values of ϵ_i was so small that the problem of truncation could be ignored (Tse, 1984). ϵ_i was the disturbance term of the Box-Cox hedonic model.

The first convenient transformation of the likelihood function was to take its logarithm. Since the logarithmic transformation is monotonic, and the likelihood function is always non-negative, this operation was not problematic (Pindyck and Rubinfeld, 1991). The resultant ln-likelihood function was as overleaf:

$$\ln L = -\frac{1}{2}\left[\begin{array}{l} 427\ln 2\pi + 427\ln\sigma^2 + 1'W\delta \\ + \frac{1}{\sigma^2}[P(\theta) - \alpha X(\lambda) - \beta D]'V^{-1}[P(\theta) - \alpha X(\lambda) - \beta D] \end{array}\right] + (\theta - 1)\,1'\ln P$$

(4)

But, specified in notation which reflected the requirements of GAUSSX, the ln-likelihood function was:

$$\ln L = -\frac{1}{2}\left[427\ln 2\pi + 427\ln\sigma^2 + W\boldsymbol{\delta} + \frac{[P(\theta) - X(\lambda)\boldsymbol{\alpha} - D\boldsymbol{\beta}]^2}{[\sigma^2 e^{W\delta}]}\right] + \theta\ln P - \ln P$$

(5)

Please note that the matrices W, X, and D had to be split into vectors, and the parameter vectors **δ**, **α**, and **β** had to be split into scalars so that GAUSSX could handle the ln-likelihood function. The definitions of the matrices and parameter vectors, in terms of the individual variables, and scalar parameters, respectively, are:

$W_{Nx3} \equiv$ (Rooms|Bathrooms|LotSize)

$X_{Nx7} \equiv$ (Age|Rooms|Bathrooms|FloorArea|LotSize|NEF|%Engl Sp)

$D_{Nx11} \equiv$ (1|Detachment|Fireplace|..|Zone01|..|Zone04|Month)

$\boldsymbol{\delta}_{3x1} \equiv (\delta_1|\delta_2|\delta_3)'$

$\boldsymbol{\alpha}_{7x1} \equiv (\alpha_1|\alpha_2|\alpha_2|\alpha_3|\alpha_4|\alpha_5|\alpha_6|\alpha_7)'$

$\boldsymbol{\beta}_{11x1} \equiv (\beta_1|\beta_2|\beta_3|\beta_4|\beta_5|\beta_6|\beta_7|\beta_8|\beta_9|\beta_{10}|\beta_{11})'$

Two more convenient changes that could have been made to the likelihood function would have been to concentrate it so that it would have depended on fewer variables, and to scale it so that the Jacobian term would have dropped out[5]. Here, however, concentration was not used because the first partial differentials of the likelihood function could be evaluated, but solutions for the parameters were intractable. Scaling was not done either, because the heteroskedasticity-encompassing specification would have complicated it.

V.D. Maximizing the Likelihood Function

Once the likelihood function has been specified, it must be maximized. The method of maximum likelihood (ML) could be used for this purpose (Kmenta, 1986), although other techniques have been proposed, such as Iterated Ordinary Least Squares (IOLS). IOLS maximizes a likelihood function with an Ordinary Least Squares (OLS) grid search (Cassel and Mendelsohn, 1985; Graves *et al.*, 1988; Halvorsen and Pollakowski, 1981; and Zarembka, 1974). However, it has a severe drawback, because it will underestimate the covariance matrix and, therefore, bias estimated standard errors and give misleading individual t-values (Fomby *et al.*, 1984; Milon *et al.*, 1984; and Spitzer, 1982a and 1984). IOLS was not used for this project.

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5 See: Bassman, 1987; Fomby *et al*, 1984; Harvey, 1981 and 1990; Judge *et al*, 1980; Kmenta, 1986; Maddala, 1977; Pindyck and Rubinfeld, 1991; Spitzer, 1982a, 1982b and 1984; and Zarembka, 1974 and 1987.

V.D.1. Numerical Optimization

If analytic derivatives can be found fairly easily, they are usually preferable to numerical derivatives, which can be subject to inaccuracies However, in general, iterative or numeric procedures must be used for maximum likelihood estimation, especially when the ML estimators are non-linear (Harvey, 1981 and 1990; Maddala, 1977; and Pindyck and Rubinfeld, 1991). A given procedural rule is used to obtain successive estimates until convergence is achieved (Harvey, 1990).

Several algorithms exist for maximizing the likelihood function, including the Newton-Raphson (Newton's) method, quasi-Newton methods such as the Davidon-Fletcher-Powell (DFP) algorithm, the Gauss-Newton (GN) method, and the Berndt, Hall, Hall, and Hausman (BHHH) algorithm. These methods differ in whether they involve the calculation of first derivatives alone, or of second derivatives; in whether the Hessian matrix itself or an approximation is used; and in how the direction vector is defined (Harvey, 1990).

V.E. Box-Cox (ML) Estimation Strategy

Initially, the maximum likelihood estimation of various Box-Cox models was attempted so as not to restrict functional form with theoretically unjustified assumptions. However, the relatively large number of parameters, up to 48, and the relatively small number (427) of observations resulted in failure to converge, even when only one transformation parameter was applied to all variables. Thus, it was decided to use OLS as a more feasible method and to arrive at a more concise specification

OLS was used to arrive at a starting value for σ^2, and the ln-likelihood function was specified to allow for possible heteroskedasticity with respect to: the number of rooms, the number of bathrooms, and lot size. The non-transformation parameters associated with individual variables were given initial values roughly mid-way in their possible orders of magnitude as determined from prior OLS regressions. The ln-likelihood function itself was defined for the two transformation parameters. Combinations of various optimization algorithms, including BFGS, DFP (Davidon-Fletcher-Powell), and NR (Newton-Raphson), were used to maximize the ln-likelihood function, however, these attempts failed to produce satisfactory results.

CHAPTER V. RESULTS

I. The Regression Models

The variables that appeared in the retained specifications are described in Tables III.1. and III.2., pp.56 and 58, in Chapter III. For all regressions mentioned below, the sample consisted of all 427 observations for 1989 and 1990. The discussion of results is organized according to the form of the estimated hedonic functions. Within each specification as to form, the equations differ according to which regressors were used. Since no nested hypothesis tests of functional form were performed, the forms can be considered to be equally valid. Thus, specifications were retained for each. Nevertheless, some forms seemed to be more prone to problems of heteroskedasticity than others, so some choices can be made among the specifications. As well, adjusted R^2's were not used as model-selection criteria. Finally, multicollinearity was not apparent in any of these specifications, as it had already been dealt with in arriving at them from the initial specifications.

I.A. Inverse Semi-ln (Appendix A.I.)

For the inverse semi-ln specifications, the natural logarithm of the real housing price was specified as the dependent variable. Two models were retained, ISL126 and ISL127. With the possible exception of Central Heating, all independent variables have the expected coefficient signs Most parameter estimates are highly significant (below 1% or 3%), although some, Heat Pump, Noise (NEF), and Zone 1, are of dubious or border-line significance (10-20%). Lastly, the intercepts are extremely significant.

The two equations have adjusted R^2 values which, at 0.70 and 0.72, are in the range which is considered to be adequate for this kind of cross-sectional analysis (Mark and Goldberg, 1986). The joint F-tests of all independent variables were significant at the 0% level. Finally, Breusch-Pagan tests suggest that severe heteroskedasticity is not present, and that there is probably less than in the linear and semi-ln specifications. Durbin-Watson tests were used as proxies for tests of functional form. The results suggested that Ho ["no autocorrelation"] should not be rejected at the 5% level of significance, hence that the inverse semi-ln functional form may not be aberrant.

I.B. Linear (Appendix A.II.)

The real housing price was specified as the dependent variable for all of the linear specifications. Of these, the following specifications were retained: TL60, TL61, TL76, TL77, TL78, TL79, TL86, TL87, TL88, and TL89. See Appendix A.II. for the full specifications of TL60, TL61, TL88 and TL89, as examples. The TL equations were all found to be afflicted by significant heteroskedasticity, according to Breusch-Pagan tests. However, another heteroskedasticity test [hereinafter "Heteroskedasticity Test No.2"], based on the slope of a regression of squared residuals on squared fitted values, suggested that the problem may have been somewhat less severe. The models have adjusted R^2 values of between 0.64 and 0.68. and F-tests were significant at the 0% level. All parameters had the expected signs in all models. With the notable exception of the intercept coefficients, most parameter estimates were highly significant at or around the 1% and 5% levels. Some others, such as %English speaking in TL78 and TL79, and Heat pump in TL78 and TL88, were significant, but at about the 10% level. The Durbin-Watson proxy-tests for functional form implied that the fully linear functional form may have been incorrect for all specifications but TL60, TL61, TL78, and TL79. For these, the proxy-test was inconclusive at the 5% level of significance.

I.C. Ln-Ln (Appendix A.III.)

The natural logarithm of the real housing price was specified as the dependent variable for the ln-ln specifications. Since they include dummy variables, these specifications are not fully logarithmic. In the end, twelve were retained: LL21, LL25, LL30, LL31, LL32, LL33, LL34, LL35, LL36, LL37, LL38, and LL39. Three of these: LL21, LL30 and LL38, for example, appear in Appendix A.III., p.123. All LL equations had adjusted R^2's in the range of 0.76 to 0.80, and F-tests were highly significant. Both the Breusch Pagan and Heteroskedasticity Test No.2 suggested that it was insignificant or of only marginal importance in all cases. Moreover, since the test statistics are much lower than those obtained for the linear and semi-ln functional forms, more credence can be put in these results. All parameters had the expected signs, in all models. With some exceptions, all parameter estimates were individually significant at or around the 1% or 5% levels. The exceptions were: Fireplace in LL31 (10.5%); the intercept in LL32, LL33, LL38, and LL39 (not significant at all); and Zone 3 in LL34 and LL36 (9.6% and 10.1%). Some houses had no lots or were less than one year old, or were located in unilingual neighbourhoods. The corresponding observations that had some variables with zero values had the zeroes replaced with .001 or 1, depending on the order of magnitude of the variables' non-zero values. This was done to enable taking the variables' natural logarithms. Finally, the Durbin-Watson proxy-test for functional form was inconclusive about possible misspecification as to form for all ln-ln specifications, at the 5% level of significance.

I.D. Ln-Linear (Semi-ln) (Appendix A.IV.)

For the semi-ln specifications, the real house price is the dependent variable. Four specifications were eventually retained: SL18, SL22, SL27, and SL28. Refer to Appendix A.IV., p.126, for SL18 and SL27. Dummy variables were specified, but their natural logarithms were not. Thus, these models are not fully semi-logarithmic. These semi-ln specifications were all found to be afflicted by significant heteroskedasticity, according to Breusch-Pagan tests. Again, as for the linear specifications, the results of the

Heteroskedasticity Test No.2 suggested that the problem was less severe. In general, all coefficient signs were as expected. All parameter estimates, with the exceptions of ln(Lot size) in SL18 and Zone 3 in SL27 and SL28, were highly significant at or around the 5% or 1% levels. The adjusted R^2 values were only slightly below the 0.7 to 0.9 range that Mark and Goldberg (1986) report as adequate for the micro housing data used in hedonic studies. Moreover, the F-tests of overall model significance supported the rejection of the null hypothesis. Finally, the Durbin-Watson proxy-test of functional form was inconclusive for all semi-ln specifications but SL28, for which the null hypothesis of no apparent misspecification was rejected at the 5% level of significance. These results do not materially contradict Nelson's finding (1979 and 1982) that a semi-logarithmic relationship between price and the noise variable, as found in the semi-logarithmic form, gives the best results.

II. Estimated Noise Coefficients

With the notable exception of those from the linear models, the hedonic regressions' estimated coefficients for noise exposure do not themselves measure the implicit price of airport noise. Rather, they measure the extent to which the corresponding variable, however defined, NEF or NEFW, influences the dependent variable. These appear in Table V.1., below. To know the implicit price of noise for the non-linear functional forms, the first partial differential of the hedonic price function with respect to the NEF must be evaluated. These calculations involve the mean values of certain variables in a specification, as well as certain of the parameter estimates. Consequently, the implicit prices for noise are affected by error in the coefficient for noise, as well as error in the other coefficients. Since the resultant implicit prices are evaluated at the sample means, they may not represent the full distribution of implicit prices for noise.

The results for the various retained specifications are presented in Table V.1. Based on individual t-tests, the most credence can be put in the estimates obtained for all functional forms but the inverse semi-ln The magnitudes of the implicit prices for noise are fairly consistent among the specifications for each functional form. The average for the inverse-semi ln form is $510/dBNEF, and the ln-ln ones is $1121/dBNEF. The semi-ln ones are somewhat higher, at $1895/dBNEF, whereas those for the linear form are comparable with those for the ln-ln form, at $965/dBNEF.

Although the specifications were not designed to capture this effect, noise discount sensitivity indices have been found to increase exponentially with NEF levels, and linearly with housing prices (Beattie, 1983; Gautrin, 1975; and Nelson, 1979 and 1980). Moreover, because the implicit prices themselves are highly sample specific, they cannot be readily compared with the results obtained in different studies.

Nevertheless, the noise depreciation (sensitivity) index (NDSI or NDI) is a convenient measure of the impact of noise which facilitates comparisons among samples. It measures the percent depreciation due to a unit (NEFdB) increase in the noise level and is defined to be the ratio of the dollar impact of noise on housing prices to the value of a typical (median or average) housing property, expressed as a percentage. In practice, it is calculated as the implicit price of noise (D), multiplied by one hundred, and divided by the sample's average property value (Beattie, 1983; Nelson, 1980 and 1982; Pennington *et al*, 1990; and Walters, 1975). Again, these appear in Table V.1.

Differences between the NDSI's for the various functional forms may be explained by the fact that the means of different variables entered into their calculations. Despite all of the possible sources of error, the NDSI's for this sample are comparable with the results found by other researchers, presented in Table V.2.

Table V.1. Noise Coefficients, Implicit Prices for Noise and Noise Depreciation Sensitivity Indices

Model	Noise Coefficient	Significance	Implicit Price for Noise ($\partial RP/\partial NEF$)	$NDSI_*$
$ISL126_a$	-0.0035	0.20	-525.59	0.35
$ISL127_a$	-0.0033	0.22	-493.67	0.33
ISL Ave.	-0.0034	N.A.	-509.63	0.34
$LL21_b$	-0.1840	0.00	-1201.96	0.81
$LL25_a$	-0.2034	0.00	-1250.38	0.84
$LL30_c$	-0.1665	0.00	-1022.55	0.69
$LL31_a$	-0.1883	0.00	-115[illegible].94	0.78
$LL32_c$	-0.1907	0.00	-1151.08	0.78
$LL33_a$	-0.2122	0.00	-1284.28	0.86
$LL34_c$	-0.1710	0.00	-1054.0	0.71
$LL35_a$	-0.1903	0.00	-1034.05	0.70
$LL36_c$	-0.1510	0.00	-931.04	0.63
$LL37_c$	-0.1726	0.00	-1066.65	0.72
$LL38_c$	-0.1775	0.00	-1075.45	0.72
$LL39_d$	-0.1990	0.00	-1209.53	0.81
LL Ave.	N.A.	N.A.	-1120.16	0.75

Table V.1. (Continued) Noise Coefficients, Implicit Prices for Noise and Noise Depreciation Sensitivity Indices.

Model	Noise Coefficient	Significance	Implicit Price for Noise ($\delta RP/\delta NEF$)	NDSI*
$SL18_b$	-39120.05	0.00	-1724.76	1.16%
$SL22_d$	-48979.59	0.00	-2159.45	1.45%
$SL27_b$	-36926.27	0.00	-1628.03	1.10%
$SL28_d$	-46732.83	0.00	-2060.39	1.39%
SL Ave.	N.A.	N.A.	-1893.16	1.56%
$TL60_a$	-912.34	0.06	-912.34	0.61%
$TL61_c$	-0.1388	0.02	-936.88	0.63%
$TL75_a$	-910.73	0.05	-910.73	0.61%
$TL77_c$	-0.1553	0.01	-1048.26	0.70%
$TL78_a$	-957.86	0.05	-957.86	0.64%
$TL79_c$	-0.1509	0.01	-1018.56	0.69%
$TL86_a$	-867.38	0.06	-867.38	0.58%
$TL87_c$	-0.1547	0.01	-1044.21	0.70
$TL88_d$	-916.99	0.06	-916.99	0.62%
$TL89_c$	-0.1504	0.01	-1015.18	0.68%
TL Ave.	N.A.	N.A.	-962.84	0.65%
Overall Average	N.A.	N.A.	-1130.79	0.76%

N.A. Not Applicable

* Noise Depreciation Sensitivity Index

a : The noise variable is specified as the NEF measure

b : The noise variable is specified as the natural logarithm of the NEF measure

c : The noise variable is specified as the product of the NEF measure and the property's lot size

d : The noise variable is specified as the natural logarithm of the product of the NEF measure and the property's lot size.

II.B. NDSI Results from Other Studies

NDSI results from other studies are presented below, in Table V.2 Similar to that found by Nelson (1980) in his review of thirteen studies, a wide range of noise discounts is evident in the table Nevertheless, about half of the NDSI values lie within the 0.5% to 0.6% range

Table V.2. Noise Depreciation Sensitivity Indices from Other Studies.

Study	NDSI+
Abelson (1979)-City	0.40
Abelson (1979)-Suburb	0.50
De Vary (1976)*	0.80
Dygert (1973)*	0.50
Dygert (1973)*	0.70
Emerson (1972)*	0.58
Gautrin (1975)*	0.56
Gautrin (1975)*	0.68
Habuda O'Byrne et al (1985)	0.67
McMillan et al (1978)*	0.50
Maser et al (1977)*	0.55
Maser et al (1977)*	0.68
Nelson (1978b)	1.10
Nelson (1980)	1.30
Nelson (1980)	0.50
Nelson (1980)	0.50
Paik (1972)*	2.20
Price (1974)*	0.83

*: Calculated by Nelson (1980)

+: Noise Depreciation Sensitivity Index

II.C. Linguistic Results

The results for the linguistic variable that measures the proportion of English-speaking people in a neighbourhood are presented in Table V.3. The counterpart that measures the proportion of French-speakers had already been dropped from all specifications as insignificant. All of the language coefficients had positive effects that were significant at about the 10% level, and most were thus at the 1% level.

These results should be interpreted with care, however, for reasons discussed in Chapter III, above. Briefly, the members of one linguistic group may prefer to live in areas where that group predominates or, less plausibly, there may be discrimination against that group by sellers and/or real estate agents.

Since it has a positive coefficient, the variable in question could be picking up the effects of income and education. Finally, it is worth noting that although English speakers form a minority in Québec as a whole, they are in the majority for the area under study. Consequently, these results may not be comparable with those for % Black population variables in the United States, unless the latter form similar local majorities.

Table V.3. Linguistic Results: Coefficients, Significance, and Implicit Price

Model	Language Coefficient	Significance	Implicit Price for Language (∂RP ∂%Engl.)
$ISL127_a$	0.5582	0.00	467.28
$LL21_b$	0.4701	0.00	724.96
$LL25_b$	0.4802	0.00	742.97
$LL30_b$	0.4501	0.00	694.43
$LL31_b$	0.4621	0.00	715.10
$LL32_b$	0.4771	0.00	723.46
$LL33_b$	0.4879	0.00	743.25
$SL18_b$	79231.7839	0.01	877.43
$SL22_b$	82555.7720	0.01	914.24
$TL60_a$	63893.2835	0.06	638.93
$TL61_a$	60602.0239	0.08	606.02
$TL76_a$	61402.3719	0.06	614.02
$TL77_a$	58629.3325	0.07	586.29
$TL78_a$	57578.8383	0.09	575.79
$TL79_a$	54594.0507	0.11	545.94
Average	N.A.	N.A.	678.01

a The language variable is specified as the proportion of English speakers in the neighbourhood

b: The language variable is specified as the natural logarithm of the proportion of English speakers in the neighbourhood

II.D. Miscellaneous Results and Observations

First, the expectations as to sign, presented in Table III.2, Chapter III, were all borne out, and this for all specifications. Secondly, the significances and signs of all retained variables' coefficients were found to be independent of functional form or specification, hence robust to it. Third, many observations can be made about different variables' signs, and other findings.

Using Price indexation and a Month variable was found both to be appropriate and superior to using either or neither. The Month coefficient's consistently negative sign reflected the deepening recession. No expectation was made for Pool's sign, since some potential buyers of a house are dissuaded by the prospect of maintaining a swimming pool, whereas others find that the enjoyment of the pool is worth the maintenance. This variable was found to have significant and positive, but small coefficients in those specifications in which it appeared, for both log-log (LL) and log-linear (SL) functional forms. Similarly, no expectation was made for Central Heating. Unlike Pool, this variable was found to have significant and *negative* signs for both specifications in which it appeared (ISL126 and ISL127). This may reflect buyers' preferences for electrical baseboard heaters. The square of the Age variable was found to have significant, positive coefficients in all linear specifications, the only ones where it appeared. This bears out the supposition that price decreases with increasing age until a near-historic age is approached.

Moreover, the variable for neighbours' unemployment had a significant and negative coefficient, as expected. As well, the weighted noise variable was highly significant in all specifications where it appeared. This implies that weighting by lot size to reflect congested enjoyment may be appropriate for local quasi-public goods or, at least, that it does not detract from the significance of relevant local (dis)amenities. Surprisingly, little if any multicollinearity was evident among variables that measured the size of a property, for example, Rooms, Bathrooms, and Lot Size Nevertheless, some heteroskedasticity with respect to these variables was evident Finally, the Zone variables had consistently-signed parameter estimates for all specifications as to inclusion and functional form However, because the Zone variables include several cities, little can be concluded about them Nevertheless, extensive multicollinearity as manifested by insignificant coefficients was evident among the separate cities that were later subsumed by the Zone variables

The fact that many parameter estimates were significant and had consistent signs, and that most of the specifications as to variable inclusion do not differ by much across functional forms implies that functional form may not be so critical when one wishes to explain the total variation in the dependent variable Nevertheless, that certain variables were significant for some functional forms, but not for others implies that functional form is relevant when a particular variable's relevance is of interest

CHAPTER VI. CONCLUSIONS

I. Conclusions

I.A. Specific Conclusions

This study was intended to determine whether the market accounts for the negative externality of airport noise, specifically through the housing market's pricing around Dorval Airport. Supposing that the market does account for the externality, i.e. if airport noise is a *pecuniary* externality, a subsidiary question concerned the size of the impact relative to housing prices.

It can be concluded from the results as a whole that airport noise is a negative, pecuniary externality, since the housing market of the West Island of Montreal does seem to account for it in the transaction prices of houses. This conclusion holds for the many different specifications as to variable inclusion, for each of the linear, semi-ln, ln-ln, and inverse semi-ln functional forms.

Moreover, the estimated average effect of airport noise on housing prices, expressed as an NDSI (Noise Depreciation Sensitivity Indices) of 0.78%, does seem to be close to the values found by other researchers. This would suggest that each decibel of aircraft noise annoyance generated by Dorval Airport causes a percent depreciation in housing prices which is comparable with what can be expected from previous work.

Such a capitalization effect of noise on housing prices does not necessarily imply that the actual occupants have suffered economic damages. Those who owned housing before they could have anticipated the establishment of the noise source, and sold it after, would suffer a Pareto externality in the form of a loss upon selling. However, as the pollution's effect will already have been capitalized into house prices, new purchasers will not suffer such externalities. Nevertheless, the lower values of their property will provide a monetary measure of the disutility caused by the pollution (Weimer and Vining, 1989).

Estimates of the implicit price for noise, in $/NEFdB, as well as of the NDSI are presented for each of four functional forms, in Table VI.1, below. The estimated implicit prices were evaluated at the sample mean for each specification as to inclusion subsumed by each form. The averages, maxima, and minima for each functional form are presented in the table. Estimates of the NDSI are presented in like fashion.

Table VI.1. Average, Minimum, and Maximum Implicit Prices for Noise and Noise Depreciation Sensitivity Indices; for Four Functional Forms.

Form	Implicit Price for Noise *			NDSI +		
	Ave	Min	Max	Ave	Min	Max
Inv.Semi-ln	-509.63	-493.67	-525.59	0.34 %	0.33 %	0.35 %
Linear	-962.84	-867.38	1044.21	0.65 %	0.58 %	0.70 %
Ln-ln	-1113.89	-931.04	-1284.28	0.75 %	0.63 %	0.86 %
Semi-ln	-1893.16	-1628.03	-2060.39	1.56 %	1.10 %	1.45 %
All	-1128.10	-493.67	-2060.39	0.76 %	0.33 %	1.45 %

* : $\delta P/\delta NEF$; $ Cdn (June 1991)/NEFdB

\+ : Noise Depreciation Sensitivity Index

The linguistic variable which measured the proportion of the local population that was English-speaking (anglophone or bilingual) had a significant and positive coefficient in all of the retained specifications in which it appeared. The magnitudes of the coefficient appear to be somewhat large, until one realizes that the variable was expressed as a decimal and not in percentage points. When the variable is multiplied by 100 so that it is measured in percentage points, the coefficients in the linear models are divided by 100. The coefficient then implies that a property price appreciates by about $680 per additional percentage point. Similar logic applies to the coefficients in the other functional forms.

As mentioned in Chapter III, this result can be interpreted as implying that anglophones (English speakers) may prefer to reside near other anglophones, or, less plausibly, that the positive coefficient reflects the absence of francophones. Another, more likely interpretation is that the variable is correlated with income and education, hence the ability to pay for larger houses which are advantageously located with respect to other amenities. Many of the anglophone residents of the West Island are relatively well-paid professionals. Not much else can be read into this except that language does, superficially, seem to be an appropriate counterpart to the race variables that have been specified in hedonic analyses in the United States. Potential limitations are discussed in Chapter V.

The four functional forms differed in terms of their susceptibility to heteroskedasticity, the possibility that they were incorrect specifications, according to the Durbin-Watson proxy test, the significance of their parameter estimates for noise, and their tendencies to yield high-, low-, or middling- magnitude implicit prices for noise and language. The ln-ln models, like the inverse semi-ln ones, seemed to be the least-afflicted by heteroskedasticity, according to the Breusch-Pagan tests. Nevertheless, these two forms were not equivalent since the former had significant parameter estimates for noise, whereas the latter did not. On the other hand, the inverse semi-ln specifications did not seem to entail any misspecification as to functional form, whereas the ln ln ones may have

Although the semi-ln models were, apparently, affected by heteroskedasticity, they did not entail any obvious misspecification as to form, according to the Durbin-Watson "d" statistic, and they did have significant noise parameter estimates On the other hand, the linear models seemed to be prone to heteroskedasticity and to represent some misspecification as to functional form Nevertheless, the linear models did have significant parameter estimates for the noise variable

Certain patterns were also evident in the magnitudes of the implicit prices, both for noise and English-speaking neighbours, yielded by the different forms The semi-ln specifications yielded higher estimates of both, compared to the other forms, whereas the inverse semi ln form gave lower estimates The ln-ln and linear forms provided middling estimates

No functional form was clearly superior to all others, in all respects The ln-ln and inverse semi-ln forms were the best in terms of heteroskedasticity For incorrect specification as to form, the linear form may have been the worst, and the inverse semi-ln the best Significant parameter estimates for the noise variable were yielded by all but the ln ln forms. However, it can be concluded that the non linear forms as a group may have been superior to the linear form All of this points out the appropriateness of using a Box-Cox model specified to allow for testing both functional form and heteroskedasticity, provided that it can be estimated

Likewise, no particular specification as to inclusion was clearly superior to all others However, it can be concluded that the following parts of a specification are relevant, regardless of the functional form Detachment, Age, Rooms, Bathrooms, Garages, Lot Size, Noise (NEF), Zonal or municipal variables, and Month

I.B. General Conclusions

More general conclusions and observations can be drawn about the use of hedonics to evaluate local externalities First, proxies were used to analyze (dis)amenities, including the noise externality Households' perceptions of urban amenities are poorly understood, as is how they obtain such information It follows that the use of resultant estimates in policy analysis is fraught with uncertainty (Bartik and Smith, 1987)

Second, although the true benefits of an amenity change can never be known, and despite their limitations, hedonic models are probably the best tools available for analyzing such changes They give measures that are within an order of magnitude of those obtained from surveys, which is at least as good as can be obtained in other fields of applied economics (Bartik and Smith, 1987) As well, estimates of marginal willingness to pay are by far the least uncertain inputs into policy analysis, compared with the politico-legislative elements Indeed, Bartik and Smith (1987, p 1246) write that " our ability to value amenities has clearly outpaced our understanding of the process that delivers amenities to households and particularly the role of the public sector in that delivery process"

II. Ideas and Further Research

II.A. Changing Optimization Algorithms to Enable Box-Cox Estimation

Box-Cox methods are often used to estimate hedonic models The Box-Cox equations themselves are estimated with the maximum likelihood (ML) technique, hence some iterative optimization algorithm However, even with a few parameters to be estimated, such methods can be problematic and may fail to achieve convergence Upon considering the estimates of non-transformation parameters obtained from *a priori* linear or logarithmic models, one cause becomes obvious The latter estimates can differ by several orders of magnitude, while stepsizes increase only incrementally, if at all, and estimated parameter vectors change just as slowly For example, the transformation parameter in a Box Cox model may be changed from its minimum of 0 to its maximum of 1 in one step, whereas the other parameters may only change by eight units on their way from some figure like 270 to a possible convergence value of 34,567

Since this seems to be a likely limiting or critical factor, it may be desirable to use an optimization algorithm which, for the non transformation parameters, optimizes over steps of higher and variable orders of magnitude first, then over lower ones, until convergence is reached Thus, a solution may be to optimize over an exponential domain, base 10 or base e, where the iterated parameters are the exponents, and the powers of the bases are the actual parameters to be estimated Likewise, the tolerances and stepsizes could become progressively smaller For example, the first iterations could be over an integer domain, until the appropriate order of magnitude is identified Then, the next iterations could take place over the first decimal place, and so forth The minima and maxima for the coefficients could be transformed into exponents by taking their natural or base 10 logarithms

II.B. Other Ideas for Further Research

First, most hedonic studies involve the use of housing data from MLS (Multiple Listing Service) listings An important question that should be investigated is how representative the MLS listings and the MLS part of the market are of the entire housing market in a given geographic area The motivations for participating in the MLS market are analysed by Frew (1987)

Second, it can be expected that air traffic will continue to increase at Dorval Airport (DWG, 1990, and Transport Canada, TP 7960E, 1990), after the recession of the past few years ends A less gradual and more distinct change may result instead, from a proposed change in the usage of Montreal's two airports Presently, international flights use Mirabel Airport, whereas domestic and U.S flights use Dorval Airport The proposal, aimed at centralizing operations at a hub, would have all charter and cargo flights go through Mirabel, and all regular international and domestic flights go through the more centrally-located Dorval Airport (McGovern, 1993) Based on Transport Canada figures (TP 7960E, 1990) for existing patterns of usage, the number of passengers passing through Dorval per year may increase by about 40%, and the tonnage of cargo going through Mirabel could increase by a similar proportion. Since aircraft departing on international flights must go for longer ranges, they will carry more fuel, hence will use more thrust when taking off Increased thrust will increase the noise generated by each aircraft, and tend to increase the total noise emanating from the airport However, the absence of presumably heavily-laden cargo flights would offset this increase, so that the net change in noise annoyance, and whether it would be positive or negative, may be indeterminate An economic evaluation of the changed airport noise externality would complete a policy analysis of the above proposal.

Provided that it would be made available, Transport Canada's forecasting software could be used to predict the changes in the composition of aircraft movements These results could then be used with Transport Canada's software for projecting the NEF, to predict the resultant NEF contours or values at each house. These latter estimates would yield the new values of the noise variable Because the area around Dorval Airport does not seem to include distinct sub-markets, the demand for quiet probably could not be estimated, and explicit welfare analysis would not be possible Nevertheless, implicit prices can be used directly to measure local residents' willingness to pay (WTP) for changes in the level of the externality in question (Bartik, 1988; Kanemoto, 1988; McConnell, 1990; and Nelson, 1980).

Depending on the re-evaluated NEF estimates, the change in the airport noise externality could be minor or major, but would be likely to affect a large area If the changes were minor, but affected a large area, there would be a move along the hedonic price function and a shift in the implicit price function. However, the induced household and market adjustments would be pecuniary in nature and *ex ante* evaluation would remain feasible (Bartik, 1988, and Bartik and Smith, 1987)

In the case of a major change in the noise level, one must account for the fact that the hedonic price function, hence consumer utility, would be affected by the change This shift would occur through adjustments in consumers' location, therefore housing demand, and producers' supply decisions, in response to a decrease in the supply of quiet properties and a simultaneous increase in the implicit price for quiet Bartik (1988) works out the four stages of adjustment in detail for the converse case, an amenity improvement

Assuming that there is no shift of the hedonic price function may overestimate the true costs, since these would be mitigated by the demand and supply adjustments Nevertheless, the unadjusted hedonic price function can be used alone to predict *ex ante* an upper bound measure of the total costs of a large, non-marginal amenity deterioration (Bartik, 1988, and Bartik and Smith, 1987) The upper bound yielded by this approach should be close to the actual cost of an increase in noise, since an excessive degree of error between them would imply an improbably large change in the amenity supply (Bartik, 1988). Finally, even order-of-magnitude estimates or estimates of bounds to the costs of increased noise levels are acknowledged as possibly being adequate for making broad policy decisions (Nelson, 1980)

One could also use the noise depreciation sensitivity index as the basis for somewhat inferior estimates of the economic costs resulting from an increase in airport noise. More specifically, the total impact on all residents in a given noise zone could be calculated as the product of the total population residing in detached houses, the average value of detached houses, the percent noise discount (NDSI), and the change in the noise index (NEF), all divided by the population per detached house (Beattie, 1983; Borins, 1981, and Mieszkowski and Saper, 1978) The product of the average value, the NDSI, and the change in the NEF yields the cost per house Dividing by the average number of occupants in each detached house gives a per person figure which, multiplied by the population, measures the total zonal impact

Whichever of the above three methods is used, other information would be required It would include the population in each NEF zone, the proportion of detached and semi-detached houses in each, the occupation density of each kind of housing, and information about the representativity of the sample (Borins, 1981, and Mieszkowski and Saper, 1978)

Moreover, there are two problems of representativity when hedonic results with respect to a noise variable are used to estimate the economic benefits of an amenity improvement. These are, first, that of the sample with respect to the overall population of housing transactions, and second, that of the resultant single estimate of noise's impact with respect to the many, different people who experience that impact (Kanemoto, 1988, Mäler, 1977; and Nelson, 1982) Assumptions can be made to deal with these problems, however For the former, one can assume that the sample is representative For the latter problem, one can assume that individuals are identical More realistically, but less simply, one can assume the existence of a continuum of individuals which allocates itself among the areas exposed to noise so that each area is homogenous (Mäler, 1977).

Should the researcher then try to measure the overall impact of an externality, the willingness to pay measure must be related to the size of the afflicted population (Mieszkowski and Saper, 1978, and Walters, 1978). Indeed, a crude way of using hedonic price differentials due to noise, which are not willingness to pay measures as such, is to multiply them by the number of affected households to yield a measure of the noise externality. However, differing personal tolerance of noise may limit this method's accuracy, as more noise-tolerant people may tend to live in noisier areas (Walters, 1978)

If compensation is a possibility, it is important to identify who would or has borne the brunt of an externality change Indiscriminate compensation of those who move in after the change is made would result in windfall gains, since they should already have paid a lower price for their properties (Nelson, 1981, and Weimer and Vining, 1989) In other words, if any compensation were to be paid for the effects of an externality after the externality's effect had already been capitalized into property values, the newer owners would be compensated for a loss which they did not suffer, whereas the original owners would remain uncompensated

Thirdly and finally, it may be worthwhile to do a comparative study of contingent valuation (CV) or experimental (auction) methods versus a hedonic model This could be applied to the possible policy change above or to current airport noise at Dorval These methods are plausible alternatives to the hedonic method, although Brookshire *et al* (1982) and Cropper and Oates (1992) suggest that they may be redundant in urban situations, since these are already amenable to the implicitly superior hedonic analysis Nevertheless, Brookshire *et al* (1982) found that they yielded results that were consistent with those given by hedonics

A CV study or an experimental one would require that airport noise and its effects be described to the respondents, and that methods of payment and eliciting values be specified (Brookshire and Coursey, 1987, and Cropper and Oates, 1992) The survey could be designed to evaluate residents' willingness to accept compensation (WTA) for enduring an increased noise level or their willingness to pay (WTP) for quiet These would likely differ, and the former would probably be greater than the latter (Cropper and Oates, 1992) Whether to evaluate WTA or WTP would depend on where the balance of rights to quiet or to make noise would seem to lie

Another interesting sample of respondents would consist of air passengers They could be asked how much they would be willing to pay to compensate those who are affected by the externalities generated by their consumption of air travel Nevertheless, this would not elicit the external costs of moving air cargo A sample of respondents from airlines, air carriers, and companies that use airport facilities may not be large enough. Moreover, the respondents may not feel enough personal responsibility for the airport noise that is generated by their economic activity.

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APPENDIX A. RETAINED MODELS.

The sample consisted of 427 observations for all of the regressions. Only selected specifications are presented in full for each functional form, as examples. These are fairly typical, as they differ only in the inclusion or exclusion of one or two variables. The remainder are very similar.

Appendix A.I. Inverse Semi-ln Specifications.

Dependent Variable: the natural logarithm of the real housing price.
Sample: House sales on the West Island of Montréal, 1989-1990.

Inverse Semi-ln Equation 1 (ISL126)

Degrees of freedom = 409
Std. error of est. = 0.19 Log-Likelihood = 107.59
Adjusted R^2 = 0.70 $F_{18,409}$ = 56.85; prob. = 0.00

Durbin-Watson "d" = 1.986; Do not reject Ho (5% level)
Heteroskedasticity: χ^2_4 = 20.44; prob. = 0.00
(Breusch-Pagan)
Heteroskedasticity: χ^2_1 = 5.44; prob. = 0.02
(Test No.2)

Variable	Coefficient	Standard Error	t-Stat.	Prob. Value
Intercept	11.028	0.091	120.95	0.00
Detachment	0.114	0.031	3.71	0.00
Age	-0.003	0.001	-4.21	0.00
Rooms	0.045	0.010	4.65	0.00
Bathrooms	0.186	0.023	8.21	0.00
Fireplace	0.077	0.022	3.44	0.00
Central heat.	-0.051	0.023	-2.19	0.03
Heat Pump	0.058	0.036	1.60	0.11
Brick	0.086	0.036	2.41	0.02
Stone	0.227	0.066	3.42	0.00
Lot size	0.022	0.004	6.29	0.00
Garages	0.088	0.017	5.17	0.00
Noise (NEF)	-0.003	0.002	-1.29	0.20
Zone 1	-0.055	0.035	-1.56	0.12
Zone 2	-0.105	0.029	-3.65	0.00
Zone 3	0.174	0.071	2.45	0.01
Zone 4	-0.156	0.028	-5.66	0.00
Month	-0.008	0.002	-5.09	0.00

Inverse Semi-ln Equation 2 (ISL127)

Degrees of freedom = 407
Std. error of est. = 0.19 Log-Likelihood 119.16
Adjusted R^2 = 0.72 $F_{20,407}$ 54.88; prob. 0.00

Durbin-Watson "d" 1.98; Do not reject Ho (5% level)
Heteroskedasticity: χ^2_4 = 32.81; prob. 0.00
(Breusch-Pagan)
Heteroskedasticity: χ^2_1 = 8.97; prob. 0.00
(Test No.2)

Variable	Coefficient	Standard Error	t-Stat.	Prob. Value
Intercept	10.626	0.166	64.23	0.00
Detachment	0.122	0.030	4.04	0.00
Age	-0.003	0.001	-4.45	0.00
Rooms	0.044	0.010	4.64	0.00
Bathrooms	0.181	0.022	8.17	0.00
Fireplace	0.066	0.022	3.01	0.00
Central heat.	-0.064	0.023	-2.80	0.01
Heat Pump	0.057	0.035	1.63	0.10
Brick	0.063	0.035	1.78	0.08
Stone	0.218	0.065	3.36	0.00
Lot size	0.021	0.004	5.84	0.00
Garages	0.079	0.017	4.72	0.00
Noise (NEF)	-0.003	0.002	-1.23	0.22
%English sp.	0.558	0.172	3.25	0.00
%Unemployed	-0.840	0.317	-2.65	0.01
Zone 1	-0.055	0.034	-1.60	0.11
Zone 2	-0.104	0.028	-3.70	0.00
Zone 3	0.250	0.071	3.51	0.00
Zone 4	-0.099	0.031	-3.16	0.00
Month	-0.009	0.002	-5.36	0.00

Appendix A.II. Linear Specifications.

Dependent Variable: the real housing price.
Sample: House sales on the West Island of Montréal, 1989-1990.

Linear Equation 1 (TL60)

Degrees of freedom 410
Std. error of est. 39165.51 Log-Likelihood = -5112.97
Adjusted R^2 0.64 $F_{17,410}$ = 45.48; prob. = 0.00

Durbin-Watson "d" - 1.61; Inconclusive (5% level)
Heteroskedasticity: χ^2_4 - 419.45; prob. = 0.00
(Breusch-Pagan)
Heteroskedasticity: χ^2_1 106.42; prob. = 0.00
(Test No.2)

Variable	Coefficient	Standard Error	t-Stat.	Prob. Value
Intercept	-12840.57	32931.67	-0.39	0.70
Detachment	17608.75	6224.52	2.83	0.00
Age	-1876.49	232.48	-8.07	0.00
Age^2	7.45	1.22	6.11	0.00
Rooms	10112.74	1989.54	5.08	0.00
Bathrooms	34128.61	4554.93	7.49	0.00
Heatpump	13410.42	7299.14	1.84	0.07
Stone	26765.30	12402.48	2.16	0.03
Lot size	4.17	0.73	5.69	0.00
Garages	8363.58	3523.98	2.37	0.02
Noise (NEF)	-912.34	482.02	-1.89	0.06
%English sp.	63893.28	34058.67	1.88	0.06
Zone 1	-26138.42	7321.61	-3.57	0.00
Zone 2	-23919.51	5758.03	-4.15	0.00
Zone 3	39357.62	14739.19	2.67	0.01
Zone 4	-28007.18	6365.65	-4.40	0.00
Month	-1532.80	337.55	-4.54	0.00

Linear Equation 2 (TL61)

Degrees of freedom	410		
Std. error of est.	39086.29	Log-Likelihood	-5112.11
Adjusted R^2	0.64	$F_{17,410}$	45.76; prob. 0.00

Durbin-Watson "d" 1.62; Inconclusive (5% level)
Heteroskedasticity: χ^2_4 418.81; prob. 0.00
(Breusch-Pagan)
Heteroskedasticity: χ^2_1 109.66; prob. 0.00
(Test No.2)

Variable	Coefficient	Standard Error	t-Stat.	Prob. Value
Intercept	-32658.31	30930.73	-1.06	0.29
Detachment	17448.73	6210.63	2.81	0.00
Age	-1855.91	232.50	7.98	0.00
Age^2	7.39	1.22	6.07	0.00
Rooms	10346.45	1991.29	5.20	0.00
Bathrooms	33501.47	4570.57	7.33	0.00
Heatpump	13983.48	7291.86	1.92	0.06
Stone	24964.57	12426.86	2.01	0.04
Lot size	7.34	1.47	5.00	0.00
Garages	8412.87	3506.97	2.40	0.02
Noise (NEFW)	-0.14	0.06	-2.29	0.02
%English sp.	60602.02	33954.05	1.78	0.08
Zone 1	-25493.39	7244.29	-3.52	0.00
Zone 2	-23551.33	5746 44	-4.10	0.00
Zone 3	39991.40	14617.17	2.74	0.01
Zone 4	-27461.04	6240.37	-4.40	0.00
Month	-1493.15	337.63	-4.42	0.00

Linear Equation 9 (TL88)

Degrees of freedom 412
Std. error of est. 39427.79 Log-Likelihood = -5116.86
Adjusted R^2 0.64 $F_{15,412}$ = 50.37; prob. = 0.00

Durbin-Watson "d" 1.61; Reject Ho (5% level)
Heteroskedasticity: χ^2_4 = 449.83; prob. = 0.00
(Breusch-Pagan)
Heteroskedasticity: χ^2_1 92.65; prob. = 0.00
(Test No.2)

Variable	Coefficient	Standard Error	t-Stat.	Prob. Value
Intercept	40352.02	17987.34	2.24	0.02
Detachment	17120.67	6262.58	2.73	0.01
Age	-1842.16	232.86	-7.91	0.00
Age^2	7.86	1.20	6.53	0.00
Rooms	10481.50	1996.64	5.25	0.00
Bathrooms	34453.42	4565.86	7.54	0.00
Heatpump	12506.25	7333.99	1.70	0.09
Lot size	4.63	0.72	6.44	0.00
Garages	8676.14	3527.82	2.46	0.01
Noise (NEF)	-916.99	484.18	-1.89	0.06
Zone 1	-26245.15	7369.77	-3.56	0.00
Zone 2	-23170.64	5789.84	-4.00	0.00
Zone 3	31051.92	14323.53	2.17	0.03
Zone 4	-34341.95	5606.94	-6.12	0.00
Month	-1563.17	338.77	-4.61	0.00

Linear Equation 10 (TL89)

Degrees of freedom	412		
Std. error of est.	39305.83	Log-Likelihood	5115.54
Adjusted R^2	0.64	$F_{15,412}$	50.85; prob. 0.00

Durbin-Watson "d" 1.62; Reject Ho (5% level)
Heteroskedasticity: χ^2_4 447.26; prob 0.00
(Breusch-Pagan)
Heteroskedasticity: χ^2_1 97.29; prob. 0.00
(Test No.2)

Variable	Coefficient	Standard Error	t-Stat.	Prob. Value
Intercept	17761.78	12904.14	1.38	0.17
Detachment	16995.68	6242.08	2.72	0.01
Age	-1819.25	232.58	-7.82	0.00
Age^2	7.76	1.20	6.46	0.00
Rooms	10726.98	1995.59	5.38	0.00
Bathrooms	33684.85	4576.87	7.36	0.00
Heatpump	13216.68	7320.70	1.80	0.07
Lot size	8.02	1.45	5.52	0.00
Garages	8658.06	3508.23	2.47	0.01
Noise (NEFW)	-0.15	0.06	-2.48	0.01
Zone 1	-25722.17	7283.11	3.53	0.00
Zone 2	-22832.15	5771.77	3.96	0.00
Zone 3	31847.64	14148.91	2.25	0.02
Zone 4	-33651.89	5411.08	-6.22	0.00
Month	-1516.10	338.63	-4.48	0.00

Appendix A.III. Ln-ln Specifications.

Dependent Variable: the natural logarithm of the real housing price.
Sample: House sales on the West Island of Montréal, 1989-1990.

Ln-ln Equation 1 (LL21)

Degrees of freedom	= 409		
Std. error of est.	= 0.16	Log-Likelihood	= 181.59
Adjusted R^2	0.79	$F_{18,409}$	= 70.29; prob. = 0.00

Durbin-Watson "d" = 1.89; Inconclusive (5% level)
Heteroskedasticity: χ^2_4 = 84.27; prob. = 0.00
(Breusch-Pagan)
Heteroskedasticity: χ^2_1 = 25.16; prob. = 0.00
(Test No.2)

Variable	Coefficient	Standard Error	t-Stat.	Prob. Value
Intercept	9.574	0.292	32.76	0.00
Detachment	0.1906	0.024	7.81	0.00
Ln(Age)	-0.095	0.010	-9.71	0.00
Ln(Rooms)	0.258	0.065	3.97	0.00
Ln(Bathrooms)	0.206	0.035	5.90	0.00
Ln(Floor area)	0.237	0.033	7.23	0.00
Heatpump	0.066	0.030	2.22	0.03
Stone	0.113	0.049	2.30	0.02
Ln(Lotsize)	0.087	0.011	8.01	0.00
Garages	0.054	0.015	3.71	0.00
Pool	0.032	0.013	2.39	0.02
Ln(NEF)	-0.184	0.049	-3.72	0.00
Ln(%Engl.sp.)	0.470	0.123	3.83	0.00
Zone 1	-0.134	0.029	-4.59	0.00
Zone 2	-0.128	0.023	-5.60	0.00
Zone 3	0.152	0.056	2.69	0.01
Zone 4	-0.149	0.026	-5.83	0.00
Month	-0.010	0.001	-7.11	0.00

Ln-ln Equation 2 (LL30)

Degrees of freedom = 408
Std. error of est. = 0.16 Log-Likelihood 183.34
Adjusted R^2 = 0.79 $F_{19,408}$ 85.75; prob. 0.00

Durbin-Watson "d" 1.88; Inconclusive (5% level)
Heteroskedasticity: χ^2_4 = 85.53; prob. 0.00
(Breusch-Pagan)
Heteroskedasticity: χ^2_1 = 25.28; prob. 0.00
(Test No.2)

Variable	Coefficient	Standard Error	t-Stat.	Prob. Value
Intercept	9.553	0.292	32.75	0.00
Detachment	0.185	0.024	7.56	0.00
Ln(Age)	-0.093	0.010	-9.55	0.00
Ln(Rooms)	0.262	0.064	4.05	0.00
Ln(Bathrooms)	0.199	0.035	5.70	0.00
Ln(Floor area)	0.229	0.033	6.93	0.00
Fireplace	0.035	0.019	1.83	0.07
Heatpump	0.065	0.030	2.18	0.03
Stone	0.112	0.049	2.28	0.02
Ln(Lotsize)	0.086	0.011	7.99	0.00
Garages	0.053	0.015	3.63	0.00
Pool	0.030	0.013	2.21	0.03
Ln(NEF)	-0.166	0.050	-3.32	0.00
Ln(%Engl.sp.)	0.450	0.123	3.66	0.00
Zone 1	-0.134	0.029	-4.59	0.00
Zone 2	-0.122	0.023	-5.26	0.00
Zone 3	0.148	0.056	2.63	0.01
Zone 4	-0.144	0.026	-5.62	0.00
Month	-0.010	0.001	-7.19	0.00

Ln-ln Equation 11 (LL38)

Degrees of freedom	411		
Std. error of est.	0.17	Log-Likelihood	= 149.06
Adjusted R^2	0.76	$F_{16,411}$	= 83.56; prob. = 0.00

Durbin-Watson "d" = 1.88; Inconclusive (5% level)
Heteroskedasticity: χ^2_4 = 87.27; prob. = 0.00
(Breusch-Pagan)
Heteroskedasticity: χ^2_1 = 32.50; prob. = 0.00
(Test No.2)

Variable	Coefficient	Standard Error	t-Stat.	Prob. Value
Intercept	10.750	0.218	49.40	0.00
Detachment	0.201	0.026	7.69	0.00
Ln(Age)	-0.111	0.010	-11.32	0.00
Ln(Rooms)	0.405	0.067	6.08	0.00
Ln(Bathrooms)	0.300	0.035	8.47	0.00
Heat Pump	0.064	0.032	2.00	0.05
Stone	0.160	0.052	3.08	0.00
Ln(Lot size)	0.106	0.011	9.91	0.00
Garages	0.066	0.016	4.24	0.00
Pool	0.030	0.014	2.08	0.04
Ln(NEF)	-0.178	0.053	-3.35	0.00
Zone 1	-0.142	0.031	-4.51	0.00
Zone 2	-0.130	0.025	-5.27	0.00
Zone 3	0.111	0.058	1.91	0.06
Zone 4	-0.226	0.024	-9.41	0.00
Month	-0.009	0.002	-5.86	0.00

Appendix A.IV. Semi-ln Specifications.

Dependent Variable: the real housing price.
Sample: House sales on the West Island of Montréal, 1989-1990.

Semi-ln Equation 1 (SL18)

Degrees of freedom = 409
Std. error of est. = 39361.76 Log-Likelihood -5114.59
Adjusted R^2 = 0.64 $F_{18,409}$ 42.36; prob. 0.00

Durbin-Watson "d" = 1.63; Inconclusive (5% level)
Heteroskedasticity: χ^2_4 = 455.39; prob. 0.00
(Breusch-Pagan)
Heteroskedasticity: χ^2_1 = 73.04; prob. 0.00
(Test No.2)

Variable	Coefficient	Standard Error	t-Stat.	Prob. Value
Intercept	-158125.43	71194.16	-2.22	0.03
Detachment	30891.52	5943.98	5.20	0.00
Ln(Age)	-17835.48	2375.49	-7.51	0.00
Ln(Rooms)	62664.40	15817.71	3.96	0.00
Ln(Bathrooms)	35773.87	8496.39	4.21	0.00
Ln(Floor area)	42586.45	8004.44	5.32	0.00
Heat Pump	19946.37	7296.25	2.73	0.01
Stone	31292.81	11979.98	2.61	0.01
Ln(Lot size)	3103.20	2636.66	1.18	0.24
Garages	7807.08	3566.70	2.19	0.03
Pool	7613.92	3266.38	2.33	0.02
Ln(NEF)	-39120.05	12038.52	-3.25	0.00
Ln(%Engl.sp.)	79231.78	29904.27	2.65	0.01
Zone 1	-34808.67	7113.11	-4.89	0.00
Zone 2	-26834.88	5589.88	-4.80	0.00
Zone 3	25171.78	13734.24	1.83	0.07
Zone 4	-31156.98	6234.66	-5.00	0.00
Month	-1579.75	339.65	-4.65	0.00

Semi-ln Equation 4 (SL27)

Degrees of freedom = 410
Std. error of est. = 39649.68 | Log-Likelihood = -5118.22
Adjusted R^2 0.63 | $F_{17,410}$ = 43.79; prob. = 0.00

Durbin-Watson "d" = 1.60; Inconclusive (5% level)
Heteroskedasticity: χ^2_4 = 457.48; prob. = 0.00
(Breusch-Pagan)
Heteroskedasticity: χ^2_1 = 73.70; prob. = 0.00
(Test No.2)

Variable	Coefficient	Standard Error	t-Stat.	Prob. Value
Intercept	-203433.35	69615.45	-2.92	0.00
Detachment	29804.41	5973.17	4.99	0.00
Ln(Age)	-16731.87	2355.79	-7.10	0.00
Ln(Rooms)	63649.18	15929.02	4.00	0.00
Ln(Bathrooms)	38525.73	8494.35	4.54	0.00
Ln(Floor area)	42754.39	8062.74	5.30	0.00
Heat Pump	19809.16	7349.43	2.69	0.01
Stone	29247.31	12042.52	2.43	0.02
Ln(Lot size)	5925.19	2429.60	2.44	0.02
Garages	8554.38	3581.54	2.39	0.02
Pool	7122.10	3284.96	2.17	0.03
Ln(NEF)	36926.27	12097.86	-3.05	0.00
Zone 1	-34635.53	7164.84	-4.83	0.00
Zone 2	-26093.58	5623.71	-4.64	0.00
Zone 3	15059.92	13289.82	1.13	0.26
Zone 4	-38701.26	5587.02	-6.93	0.00
Month	-1556.59	342.02	-4.55	0.00