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AIRCRAFT NOISE AND RESIDENTIAL PROPERTY VALUES: HEDONIC ESTIMATES OF THE COSTS OF AIRCRAFT NOISE IN THE CITY OF EDMONTON

by

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A THESIS

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled AIRCRAFT NOISE AND RESIDENTIAL PROPERTY VALUES: HEDONIC ESTIMATES OF THE COSTS OF AIRCRAFT NOISE IN THE CITY OF EDMONTON submitted by Bradford G. Reid in partial fulfillment of the requirements for the degree of Master of Arts.

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ABSTRACT

In recent years, environmental issues have taken a prominent position among the concerns expressed by many members of society. One such environmental issue is the problem of aircraft noise. As the air transportation industry has increased in size, the frequency and magnitude of noise endured by individuals living in proximity to airports or along aircraft flight paths has also increased.

In the broadest context, aircraft noise can be considered to be an external diseconomy that reduces the utility levels of individuals residing near airports. The existence of an external diseconomy can lead to an inefficient allocation of resources with too much air transport service and too little noise abatement being provided to society. To determine an efficient allocation of resources, or at least what constitutes a movement towards efficiency, requires that it be possible to measure the costs of aircraft noise, or conversely the willingness to pay for quiet. This thesis provides both a theoretical and an empirical framework in which the problem of aircraft noise can be analyzed. Thus, the main emphasis of the thesis is twofold. First, a theoretical model capable of measuring the willingness to pay for quiet is formulated through a review and assessment of previous studies into

the problem of environmental pollution. It is found that an analysis of expected changes in residential property values can be used to determine the willingness to pay for exogenous changes in the level of quiet provided that the area affected by the change is "small and open". Secondly, empirical estimates of the willingness to pay for quiet are derived using data from the Edmonton Industrial Airport and the City of Edmonton. This is accomplished by using the hedonic regression technique. House prices are regressed against a vector of housing characteristics, quiet included, so that the implicit marginal price of quiet is derived. This marginal price is then utilized, *in a manner superior to previously used techniques*, to calculate an estimate of the willingness to pay for changes in the level of quiet. The theoretical and empirical results are then used to assess policies designed to deal with the problem of aircraft noise that are currently in effect in the City of Edmonton.

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CHAPTER I

AIRCRAFT NOISE
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Within the last decade or so, environmental issues have taken a prominent position among the concerns expressed by many members of society. One such environmental issue is the problem of aircraft noise. As the air transportation industry has increased in size, the frequency and magnitude of noise endured by individuals living in proximity to airports or along aircraft flight paths has also increased. The expansion of existing airports and the construction of new ones are often opposed by noise conscious neighbourhoods whose quiet environments are threatened by such activities. Thus, the disutility of noise, or the value of quiet, is an important element in determining the efficient allocation of resources between competing land uses.

The purpose of this thesis is to examine the problem of aircraft noise within the framework of economic analysis. Specifically, an attempt is made to develop an economic model that will provide a measurement of the costs associated with the generation of aircraft noise within the City of Edmonton. Only once the costs of aircraft noise, or conversely the benefits of noise abatement, are established is it possible to determine what constitutes an efficient allocation of resources between the provision of air transport services and quiet environments. Such an analysis will not only allow for an examination of efficiency considerations but also the distributional consequences of unanticipated changes in noise levels.

1.1 Noise Defined

The first major problem confronting any attempt to measure the costs of aircraft noise is to determine what exactly constitutes "noise". As De Vany argues:[1]

> In terms of man's auditory system there is no distinction between sound and noise. Noise is unwanted sound. Values and tastes must, therefore, be introduced to separate noise from other sounds--one person's rock music is another's noise. This is an important point because most noise experienced by persons living near an airport is not of such intensity as to induce pain or other symptoms of psychological stress. The noise is just irritating, perhaps in and of itself, or because of what it interferes with or interrupts.

Thus, to a large extent, the measurement of noise requires a subjective rather than an objective scale of measures. Different individuals may assess the "noise component" of various sounds differently. However, certain characteristics present in any sound will determine its perceived noisiness:[2]

1. *Spectrum content and level.* Generally sounds with high pressure and intense frequencies are noisier.

2. *Spectrum complexity.* Sounds having energy concentrated in narrow frequency bands, or containing pure tones are noisier than sounds having a more level distribution of energy.

3. *Duration.* Sounds are noisier the longer their duration.

4. *Duration of increase.* The more rapid the rise of the sound pressure from ambient to peak, the noisier the sound is. This is the startle effect.

Individuals determine the noisiness of any sound by ranking it with respect to the above four characteristics in relation to other sounds. Each individual, therefore, will have a different evaluation concerning the noisiness of any particular sound. The sound generated by aircraft can generally be viewed as noise because it has a tendency to

> disturb sleep, privacy, rest and communication and in doing so may be considered potentially harmful to health.[3]

Index numbers have been constructed that combine the four characteristics outlined above into a single number. These index numbers attempt to measure the noisiness of neighbourhoods in the vicinity of airports. The higher the index number, the "noisier" is the neighbourhood.

One such indexing system is the Noise Exposure Forecast (NEF) which is currently being used by the Canadian Ministry of Transport to assess the noise levels around Canadian airports.[4] The value of the NEF index at any particular location is calculated as follows:[5]

$$NEF = 10 \log \sum_i \sum_j \text{antilog} \frac{NEF_{ij}}{10}$$

where NEF is the composite Noise Exposure Forecast and NEF_{ij} is the NEF value produced by aircraft of class i on runway j. Thus, the composite NEF s a summation of the noise levels associated with different types of aircraft. The value for NEF_{ij} is calculated as:

$$NEF_{ij} = EPNL_{ij} + 10 \log\left[N(day)_{ij} + 16.67\ N(night)_{ij}\right] - 88$$

where $EPNL_{ij}$ = effective perceived noise level of aircraft i on runway j

N(day) = number of movements between 0700 hours and 2200 hours (day flights)

N(night) = number of movements between 2200 hours and 0700 hours (night flights)

The NEF index associated with any location depends upon the number and type of aircraft utilizing the airport, the number of day and night flights and the effective perceived noise level of the various aircraft. The EPNL is a subjective valuation of such annoying noise effects as pure tones and duration. Thus, the Noise Exposure Forecast system is a composite of the four characteristics that distinguish the noisiness of any sound. The higher the NEF index, the higher is the level of noise.

In this thesis the level of aircraft noise endured by individuals at any particular location will be measured by the NEF indexing system. The reason for this is twofold. First, data about noise levels surrounding

Canadian airports are reported in terms of the NEF system. Second, preliminary statistical evidence supports the NEF system as a reasonable measure of noise annoyance. As the value of the NEF index rises, the number of complaints from individuals about the disburbance created by aircraft noise also rises.[6] If it is assumed that the number of complaints is highly correlated with actual noise annoyance, then the NEF index may provide a reliable measure of that annoyance.

1.2 The Edmonton Industrial Airport

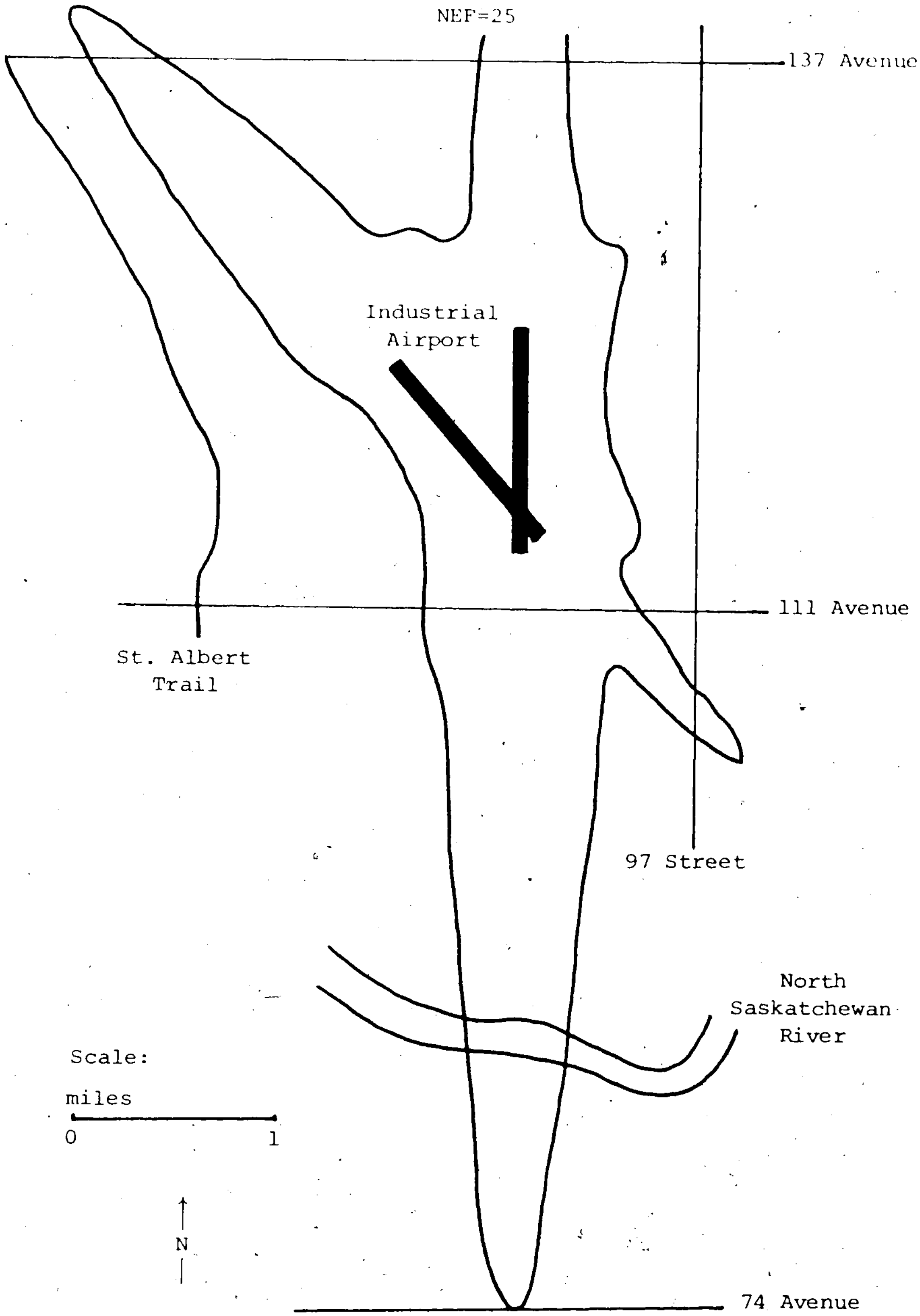
The City of Edmonton is served by three airports: the Industrial Airport, the International Airport and Namao Airport (military). The primary source of aircraft noise in Edmonton is the Industrial Airport as both the International and Namao Airports are located outside of the city limits and aircraft noise generated at those sites does not, for the most part, affect individuals residing within Edmonton. However, the Edmonton Industrial Airport and its flight paths are located within the boundaries of the city and aircraft approaching or departing from this airport generate noise that does affect city residents. Thus, the empirical analysis of the costs of aircraft noise presented in this thesis will concentrate exclusively on the noise created at or near the Industrial Airport.

The Edmonton Industrial Airport is located approximately two miles northwest of the city center and is surrounded by residential development (see Figure 1-1). It is composed of three runways: runway 03-21 extends in a northeast to southwest direction and is 4,446 feet in length; runway 16-34 extends in a north-to-south direction and is 5,700 feet in length; and runway 11-29 extends in a northwest to southeast direction and is 5,868 feet in length. Due to prevailing winds, runway length and availability of lighting and directional equipment, runways 11-29 and 16-34 are used for the vast majority of aircraft movements in and out of the Industrial Airport. Runway 16-34 handles about 70 percent of all such movements and runway 11-29 is utilized for the remaining 30 percent.[7]

The Edmonton Industrial Airport was constructed in 1929 by the City of Edmonton.[8] It was used extensively by military aircraft during World War II and the Korean War. Commercial air traffic grew considerably during the 1950-1960 period when the Industrial Airport was the only airport serving the City of Edmonton. In 1961 construction was completed on the International Airport and the major airlines, such as Air Canada (then Trans Canada Airlines) and Canadian Pacific Airlines, moved their operations from the Industrial to the International Airport.

Since 1961 the Industrial Airport has been the center of operations primarily for privately owned aircraft (both jet and propellor driven) and such regional air carriers as Pacific Western Airlines (PWA) and Time Air. In 1963, PWA instituted an Edmonton to Calgary airbus ser-

Figure 1-1: Edmonton Industrial Airport and the Area Affected by Aircraft Noise



vice utilizing DC-4 aircraft. In 1968, this service was upgraded when the airline converted to Boeing 737 jetliner service between the two cities. Even with the construction of the International Airport, the Edmonton Industrial Airport has remained one of the busiest in Canada, ranking fourth in total aircraft movements in 1974, with total movements of 236,778 that year.[9]

1.3 Previous Research

The only previous research into the problem of aircraft noise in the City of Edmonton was conducted by Hans-Werner Mary in a masters' thesis done at the University of Alberta in 1975.[10] In that thesis, Mary attempts to determine the cost of aircraft noise by establishing the relationship between noise and residential property values. To assess this relationship, a combined cross-section:time-series correlation analysis was used.

In his thesis Mary attempted to standardize for differing neighbourhood, locational and property characteristics among houses by establising a "grid" system over the City of Edmonton. Each grid was represented by an *average* house within that particular area. Closely matching grids (matching with respect to all housing characteristics other than the level of aircraft noise) were then selected and price-time relationships were calculated for these grids between the years 1950 and 1974. These price-time relationships were then compared, using correlation analysis, to determine the variation in property values that could be attributed to different noise levels.

For the most part, Mary's analysis found that a positive correlation existed between noise levels and house prices over time. That is, higher house prices were associated with grids characterized by more, rather than less, aircraft noise. Mary attributes this result to people not minding aircraft noise which, in essence, is to conclude that there was no cost to the aircraft noise generated at the Edmonton Industrial Airport.

This thesis attempts to improve upon Mary's empirical analysis in three ways: by developing a theoretical foundation on which to build and interpret the empirical analysis, by introducing a better data set upon which to determine the relationship between aircraft noise and house prices and by utilizing a superior statistical technique in the analysis. Mary's examination of the relationship between aircraft noise and house prices was constrained by a lack of precise site-specific data about the housing characteristics associated with individual houses. In this thesis, site-specicific information, gathered from the Multiple Listings Service of the Edmonton Real Estate Board, will be utilized to assess the effects that the various housing characteristics, including aircraft noise, have on house prices. At the same time multiple regression analysis, rather than correlation analysis, will be used to determine the statistical relationship that exists between aircraft noise and property values. The results of this empirical investigation are presented in Chapter IV of this thesis.

1.4 Existing Policies

Even though no detailed analysis has been conducted to determine the costs of aircraft noise in Edmonton several government agencies have formulated a set of policies designed to "deal" with the problems created by such noise. These policies are the responsibility of three government agencies operating at the local and federal levels of jurisdiction: the City of Edmonton Assessment Department, the Central Mortgage and Housing Corporation and the federal Ministry of Transport's Air Transportation Administration.

The first policy was instituted by the City of Edmonton in the late 1950's and is designed to provide compensation to those individuals owning houses in areas affected by aircraft noise. This compensation takes the form of reduced property taxes. The Assessment Department of the City of Edmonton reduces the assessed value of any residential property by two to eight percent depending upon the level of aircraft noise associated with that property.[11] The higher the level of noise, the lower is the assessed value of the house and, hence, the lower is the yearly property tax. Thus, individuals owning houses affected by aircraft noise are compensated by reduced property taxes.

The Central Mortgage and Housing Corporation (CMHC) has also adopted a policy designed to reduce the impact of aircraft noise on residential properties. This policy is effected through the Corporation's ability to grant financing for newly constructed housing under the National Housing Act. CMHC divides the area around an airport into an upper noise zone (NEF value greater than 35) and a lower noise zone (NEF value between 25 and 35). Since 1975, it has been the Corporation's policy to deny financing under the National Housing Act to houses built in the upper zone and to grant financing to houses built in the lower zone only if adequate sound insulation is provided.[12] Thus, CMHC is attempting to discourage the construction of housing units in high noise areas. However, this particular policy does not have a great effect on the noise problem around the Edmonton Industrial Airport, as the area surrounding the airport was developed for residential purposes well before 1975.

The third policy consideration is the result of a joint planning effort between the City of Edmonton and the Canadian Air Transportation Administration that attempted to develop a master aviation plan for the City of Edmonton, with particular emphasis on the role of the Edmonton Industrial Airport.[13] This master plan study analyzed various alternatives for the future development of the Edmonton aviation system. One of the key proposals that came out of the study was to reduce the utilization of the Industrial Airport by constructing a "satellite" airport designed to accommodate privately-owned light aircraft. This proposal was partly based upon a desire to reduce the environmental impact of aircraft noise generated at or near the Industrial Airport.[14]

An important point to recognize about all three of the above policies is that they were implemented without a precise evaluation of the costs associated with aircraft noise. Without such an assessment it is not possible to determine whether these policies are economically efficient and actually provide an improved allocation of resources.

1.5 Outline of Thesis

This thesis will attempt to provide a theoretical framework in which the problem of aircraft noise can be analyzed and an empirical estimate of the costs associated with aircraft noise in the City of Edmonton. In Chapter II, the problem of aircraft noise is discussed within the context of the economic theory of external effects. The chapter will emphasize the conditions for attaining a Pareto efficient allocation of resources when externalities (in this case aircraft noise) are present. Chapter III attempts to develop an economic model capable of providing a method of measuring the costs of aircraft noise. The discussion centers around the applicability of using predicted changes in property values as a measure of the willingness to pay for quiet. In Chapter IV, an empirical estimate of the willingness to pay for quiet is derived by applying the models developed in Chapter III to data about noise levels and house prices in the City of Edmonton. The thesis concludes with Chapter V which provides a brief summary as well as a discussion of the policy implications for dealing with aircraft noise inherent in both the theoretical model and the empirical results.

Footnotes

[1]Arthur S. De Vany, "An Economic Model of Airport Noise Pollution in an Urban Enrivonment," in *Theory and Measurement of Economic Externalities*, ed. by Steven A. Y. Lin (New York: Academic Press, Ltd., 1976), p. 206.

[2]*Ibid.*, p. 207.

[3]Central Mortgage and Housing Corporation, *New Housing and Airport Noise* (Ottawa, Ontario: 1975), p. 5.

[4]*Ibid.*, p. 6.

[5]Hans-Werner Mary, "The Influence of Aircraft Noise Annoyance on Single-Family House Prices: A Case Study of Edmonton's Industrial Airport" (unpublished M.A. thesis, University of Alberta, 1975), p. 32.

[6]Central Mortgage and Housing Corporation, *New Housing and Airport Noise*, p. 8.

[7]Canadian Air Transportation Administration and The City of Edmonton, *Edmonton Area Aviation Systems Master Plan Study* (1972), p. 88.

[7]Canadian Air Transportation Administration and The City of Edmonton, *Edmonton Area Aviation Systems Master Plan Study* (1972), p. 88.

[8]Edmonton Industrial Airport, *Annual Report: 1974.*

[9]*Ibid.*, p. 8.

[10]Hans-Werner Mary, "The Influence of Aircraft Noise Annoyance on Single-Family House Prices: A Case Study of Edmonton's Industrial Airport" (unpublished M.A. thesis, University of Alberta, 1975).

[11]Information gathered by personal conversation with the tax assessors in the City of Edmonton Assessment Department.

[12]Central Mortgage and Housing Corporation, *New Housing and Airport Noise*, p. 19.

[13]Canadian Air Transportation Administration and The City of Edmonton, *Edmonton Area Aviation Systems Master Plan Study* (1972).

[14]*Ibid.*, p. 94.

CHAPTER II

AIRCRAFT NOISE AND THE THEORY OF EXTERNALITIES

In recent years, factors which contribute to the "quality of life" have come under the scrutiny of economic analysis. Since many of these factors are not priced by any explicit market, the theory of external economies and diseconomies has proven useful in providing a theoretical framework in which they can be studied. This chapter will examine aircraft noise as an external diseconomy of the producer-consumer variety.

Aircraft noise is an external diseconomy because it adversely affects the utility level achieved by an individual, this effect not being directly priced by the market. More specifically, aircraft noise affects the consumption of housing services by interfering with the individual's enjoyment of a "quiet" environment at any given location, assuming that quiet is a desirable characteristic. In most circumstances, market compensation is not forthcoming from the airline transportation industry for the use of the environment as a factor of production. It is this non-priced aspect of aircraft noise that can lead to distortions in the allocation of resources.

2.1 Externality Defined

The problem of externalities often arises in instances where there has been a failure to establish property rights.[1] The absence of clearly defined property rights can easily lead to the situation in which not all the benefits and costs of an activity are internal to that activity. Aircraft noise is an example of such a situation. The air space has traditionally been treated as a common property resource by the legal institutions of society and, hence, a quiet environment is not a private property right.[2] Because of the common property problem, the air transport industry has been able to use the noise assimilative capacity of the environment without payment for its use. An external cost to the individual consumer of quiet thus arises.

Baumol and Oates state that an externality exists when two conditions have been met:[3]

1. An externality is present whenever some individual's (say A's) utility or production relationships include real (that is, nonmonetary) variables, whose values are chosen by others without particular attention to the effects on A's welfare.

2. The decision maker, whose activity affects others' utility levels or enters their production functions, does not receive (pay) in compensation for this activity an amount equal in value to the resulting (marginal) benefits or costs to others.

Both of these conditions are met by the case of aircraft noise. The noise generated along the flight paths of aircraft enters the utility functions of individuals living along those paths as an external cost (that is, it decreases the utility levels of these individuals). The individual can not, on his own accord, vary the noise level at any given location, but rather it is established by the air transport industry. At the same time, the individual is not compensated by the air transport industry for this reduction in utility. Thus, the full costs of air travel are not borne by the producing industry. The existence of these external costs can lead to a non-optimal allocation of resources, with too little quiet environment being provided and too much aircraft noise being generated.

Buchanan and Stubblebine[4] provide a further delineation of the concept of externality. The authors construct a two-person model[5] in which the activity of one of the individuals enters into the utility function of the other individual, so that:

$$U^A = U^A(X_1, X_2, \ldots X_m, Y_1)$$
$$\text{and } U^B = U^B(Y_1, Y_2, \ldots Y_m)$$

A marginal externality exists when $\frac{\partial U^A}{\partial Y_1} \neq 0$, that is, small changes in B's consumption of Y_1 affects the utility levels of A. An infra-marginal externality exists when $\frac{\partial U^A}{\partial Y_1} = 0$ but $\int_0^{Y_1} \frac{\partial U^A}{\partial Y_1} d\, Y_1 \neq 0$. In this case, the overall level of Y_1 affects A, but small marginal changes do not.

Buchanan and Stubblebine use this simple model to define Pareto relevant and irrelevant externalities. An externality exists whenever an individual's utility function (or a firm's production function) has the form of A's utility function as cited above. The externality is potentially relevent if

> the activity, to the extent that it is performed, generates any desire on the part of the externally benefitted or damaged party (A) to modify the behavior of the party empowered to take action (B).[6]

If this desire is lacking, the externality is irrelevant. If the level of B's activity is denoted by $\overline{Y}_1$, then a potentially relevant marginal externality exists when:

$$\left.\frac{\partial U^A}{\partial Y_1}\right|_{Y_1=\overline{Y}_1} \neq 0$$

It should be noted that infra-marginal externalities are irrelevant for small changes in Y_1. They become potentially relevant only for significantly large changes in Y_1.

The concepts of Pareto relevance and irrelevance follow from the above definition. A Pareto-relevant externality exists when A can be made better off by changing the level of Y_1 without making B worse off, that is, when gains from trade are possible. It is known from the simple process of maximization that B (or A for that matter) reaches a utility maximizing equilibrium when:

$$\frac{U^B_{Y_1}}{U^B_{Y_j}} = \frac{f^B_{Y_1}}{f^B_{Y_j}} \quad \text{where} \quad U^B_{Y_1} = \frac{\partial U^B}{\partial Y_1}$$

This means that individual B maximizes his level of utility when the marginal rate of substitution (right-hand side of above equation) equals the marginal rate of transformation (left-hand side). From this a marginal externality becomes Pareto relevant whenever:

$$(1) \quad -\frac{U^A_{Y_1}}{U^A_{X_j}} > \left[\frac{U^B_{Y_1}}{U^B_{Y_j}} - \frac{f^B_{Y_1}}{f^B_{Y_j}}\right]_{Y_1 = \overline{Y}_1} \qquad \text{for} \quad \frac{U^A_{Y_1}}{U^A_{X_j}} > 0$$

$$\text{or} \quad (2) \quad \frac{U^A_{Y_1}}{U^A_{X_j}} < (-)\left[\frac{U^B_{Y_1}}{U^B_{Y_j}} - \frac{f^B_{Y_1}}{f^B_{Y_j}}\right]_{Y_1 = \overline{Y}_1} \qquad \text{for} \quad \frac{U^A_{Y_1}}{U^A_{X_j}} < 0$$

When this condition does not hold, the externality is Pareto irrelevant. Whenever gains from trade are possible the externality is Pareto relevant, whenever they are not possible the externality is Pareto irrelevant. It should be noted that whenever B is in a utility or output maximizing equilibrium for $Y_1 = \overline{Y}_1$ (that is, the right-hand side of the above equations is zero), gains from trade are always possible and potentially relevant marginal externalities are always Pareto relevant.

It can be seen that the distinction between relevance and irrelevance rests on the fact that an external diseconomy for one individual or firm is an external economy for another individual or firm. There is a basic symmetry to the problem. Thus, the internalization of a Pareto-relevant externality leads to a movement towards Pareto optimality as one individual is able to fully compensate the other out of the gains from trade to be derived from such a move. The internalization or removal of Pareto-irrelevant externalities simply results in a redistribution of income, as there are no gains from trade to be derived.

The implications of Buchanan and Stubblebine's analysis are quite clear. The only type of externalities that can be removed under the justification of increased efficiency is the Pareto relevant externality. The existence of Pareto irrelevant externalities is a problem of distribution, not efficiency. An economy can reach a position of Pareto-efficiency even though irrelevant externalities exist within the system.

2.2 The Coase Theorem

The Buchanan-Stubblebine analysis presented in the previous section has illustrated that if Pareto-relevant externalities are not internalized the resulting production and consumption decisions of individuals and firms will be non-optimal. The first attempt to resolve the problems created by externalities for the attainment of maximum efficiency was made by Pigou.[7] Pigou recognized that the existence of externalities caused private and social costs and benefits to diverge so that the resulting private decisions were non-optimal for society as a whole. To ensure that a Pareto-optimal output is produced (that is, where private and social net products are equal everywhere), Pigou proposed that prices be altered through a tax-subsidy scheme. The Pigouvian tax/subsidy program would tax firms if their output was too high and subsidize them if their output was too low due to the existence of external effects. In this manner private and social costs and benefits would be equal and private consumption and production decisions would correspond to the socially desirable decisions.

In a landmark article[8] which began much of the modern debate concerning externalities, Coase disputed the traditional Pigouvian method of handling the externality problem. Much of his argument is based upon his recognition of the bilateral nature of any externality. As Coase states:[9]

> The traditional approach has tended to obscure the nature of the choice that has been made. The question is commonly thought of as one in which A inflicts harm on B and what has to be decided is: how should we restrain A? But this is wrong. We are dealing with a problem of a reciprocal nature. To avoid the harm to B would inflict harm on A. The real question that has to be decided is: should A be allowed to harm B or should B be allowed to harm A? The problem is to avoid the more serious harm.

The essence of the Coasian argument is based upon this symmetrical aspect of externalities. According to Coase, because all externalities are reciprocal in nature, it is not necessary that any Pigouvian tax/subsidy scheme (or any government involvement for that matter) be instituted because the two parties will always reach a negotiated settlement as long as gains from trade are to be derived. This negotiated settlement will always be Pareto-efficient no matter what the liability rules (or property rights) are within the system. The same level of externality production will occur whether the polluter must bribe the pollutee for the right to pollute or whether the pollutee must pay the polluter to stop polluting. Thus, Coase's conclusion is that the market will always handle the problem of externalities and this market solution will be Pareto-efficient.[10] Liability, and hence the moral and ethical considerations that correspond to the creation of liability rules, is unimportant to the question of efficiency because the externality problem is "allocatively neutral with respect to the assignment of liability."[11] Coase argued that the assignment of liability affects only distribution and not efficiency.

The appeal of the Coasian argument rests in the manner that it dispenses with the "problem" of externalities. If Coase is correct, externalities no longer form an impediment to the achievement of efficiency. At the same time, the Coasian system is completely decentralized as the market, through individual negotiation, realizes all gains from trade resulting from the movement to an optimal level of externality production. Thus, Pareto efficiency is possible without the government intervention required by a Pigouvian tax/subsidy scheme.

2.3 The Coase Theorem Disputed

The Coase theorem has been disputed for several reasons. The two main areas of attack have been to question whether liability rules are allocatively neutral and whether negotiated settlements can be expected to occur. If liability with respect to externality generation is not neutral, changes in liability rules will result in changes in resource allocation and the production of the externality. In this case, any negotiated settlement will depend upon the liability rule and may, or may not be Pareto-efficient. The second area of concern lies with the problem of negotiation. If it is not possible to costlessly negotiate, the Coase theorem could break down and it may only be possible to achieve Pareto-efficiency through government intervention.

Dewees summarizes the argument against allocative neutrality with respect to liability when he states:[12]

> While the bilateral nature of the costs is important to recognize, the argument that the legal assignment of rights is irrelevent to resource allocation goes too far. It ignores income effects by implicitly assuming a constant marginal utility of money, otherwise the income consequences of property right assignment would affect consumption patterns and thereby resource allocation. Much more serious, it neglects the impact of liability rules on profits of the firms. If the polluter is bribed to reduce his emissions he may pollute no more than if he paid an effluent charge, but his profits will be higher. Either he must lower his product price, thereby increasing his sales volume, or other firms will be attracted by the profits, enter the industry, and gather similar bribes while increasing total production . . . . Finally, the argument ignores a pollutee's ability to reduce his damages by protective action that he would have no incentive to pursue if he were fully compensated.

Thus, Dewees argues that allocative neutrality is not to be expected for two main reasons. Depending upon the liability rule (that is, who must pay or bribe whom to achieve the desired level of externality output) different consumption patterns will result if a constant marginal utility of money does not exist among individuals. Secondly, production patterns will depend upon the liability rule because profit levels are indicators for entry and exist in new industries. Unless fairly restrictive assumptions hold within the economic system, Coase's argument concerning the neutrality of liability cannot be accepted.

The Coase theorem can also be criticized for its reliance upon the negotiated settlement of externality problems. Negotiation often fails to be a viable method of resolving the issue of externalities because it

> is only a reasonable solution where very few parties are involved, so that transaction costs of determining pollution quantities, consequences, and compensation are small and problems of public goods and revealed preferences do not arise.[13]

The negotiation approach works best when only two persons are involved in the process. However, as the number of persons affected by some external effect rises, the problems of reaching a satisfactory negotiated solution also rise. The costs of obtaining information on individual preferences, benefits and damages as well as the costs of bargaining may far outweigh the benefits to be derived from achieving the socially desired level of externality output. In many instances, it may be more efficient, because of the costs associated with negotiation, for the government to impose a Pigouvian tax/subsidy scheme (or some other form of externality regulation) to achieve the desired externality output.

The negotiation approach can also be criticized because it implicitly assumes that all individuals affected by the externality are willing to reveal their true preferences. Yet, as Baumol and Oates argue, there are many cases where the control of an externality can be considered to possess public good characteristics.[14] To provide pollution abatement for one individual often means that it must simultaneously be provided for all other affected individuals. The problem of revealed preference in the case of public goods thus arises, creating a situation in which most attempts at reaching a solution to an externality problem through negotiation will fail.

Thus, it can be demonstrated that the Coase theorem, while theoretically correct under a set of idealized conditions, is not particularly useful to the solution of externality problems in actual situations. It has been demonstrated that the liability rule is not allocatively neutral so that the assignment of property rights does affect efficiency. It has also been shown that reliance upon negotiation does not constitute a viable solution to the externality problem in many circumstances.

Since the applicability of the Coase theorem is severely limited, market solutions cannot be expected to provide a Pareto-efficient allocation of resources in many situations where externalities are present. It follows, therefore, that some form of government intervention in the market, either through a Pigouvian tax/subsidy scheme or other forms of regulation (such as standards), is required to achieve the socially desirable level of externality production.

2.4 Pigouvian Tax/Subsidy Schemes

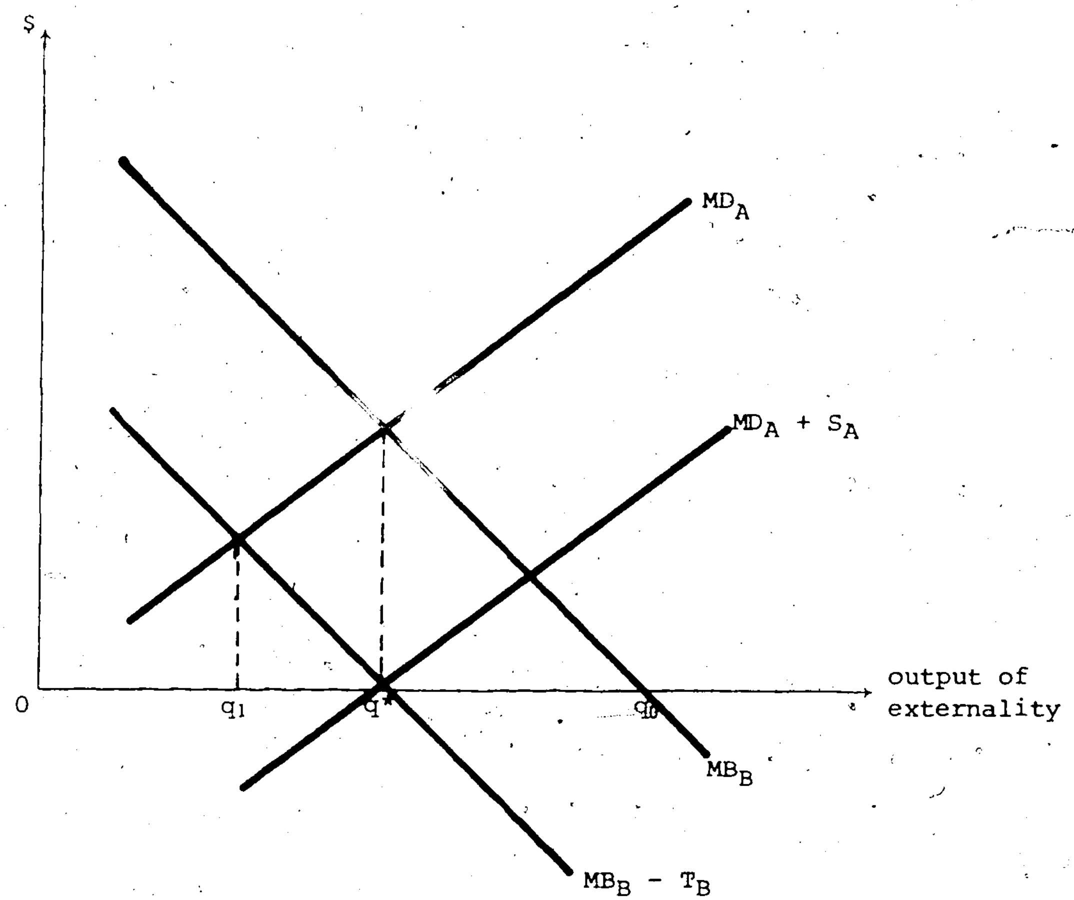
The Pigouvian tax/subsidy scheme is an attempt to reconcile the divergence between private and social costs that arises when externalities are present. If an external diseconomy is present, private cost is less than social cost (as the producer does not consider the damages inflicted by the diseconomy in his cost function) and output of the externality can be greater than is socially desirable. In the case of an external economy, the opposite occurs and output of externality is less than socially desirable. As discussed in Section 2.2, the Pigouvian scheme taxes the producer of an external diseconomy so as to reduce the output of the externality and subsidizes the output of a producer of an external economy.

However, Buchanan and Stubblebine[15] argue that Pigou's system of taxes and subsidies may result in a less-than-Pareto efficient situation because it fails to recognize the bilateral nature of an externality. By concentrating solely on the producer of the externality the Pigouvian scheme can result in an allocation of resources that is not Pareto efficient. The achievement of Pareto optimality requires that taxes or subsidies be applied to *both* of the affected parties and not just one of them.

Figure 2-1 illustrates Buchanan and Stubblebine's argument. In Figure 2-1, individual or firm B would like to produce q_0 units of the externality, that is, produce up to the point where his marginal benefits (MB_B) fall to zero, assuming, for simplicity, that marginal costs for the production of the externality are zero. The socially optimal output is q* which is where the marginal benefits to B are exactly equal to the marginal damages to A (MD_A). If the government institutes a per unit tax on B such that his net marginal benefits fell to zero at q*, B would wish to produce the socially desirable output. Yet, at this point A could bribe B to reduce his production of the externality to q_1 because the absolute value of A's damages exceed B's net marginal benefits ($MB_B - T_B$) between q* and q_1. In order to ensure that the socially optimal output is produced, it is necessary to actually compensate A (S_A) so that he has no incentive to bribe B to reduce output of the externality below q*.[16]

In contrast to the argument given by Buchanan and Stubblebine, Coase argues that not only should the producer be taxed to reduce his output of an external diseconomy, but that the victims of the diseconomy should also possibly be taxed.[17] Coase states that the total amount of

Figure 2-1: Bilateral Nature of an Externality



where: MD_A = marginal damage to A

MB_B = marginal benefit to B

S_A = subsidy for A

T_B = tax on B

an externality present in a community is a fur tion of both the output of the externality-producing firm and the number of persons suffering the external cost. Thus, it might be optimal to have some sort of geographic separation between the firm and the individuals. If the victims of an external diseconomy were fully compensated for their damages, there would be no incentive for them to geographically separate themselves from the producer.

Baumol,[18] however, contends that there is no need to tax the victims of an external diseconomy. It is sufficient to merely refrain from compensating them. Without compensation, each individual bears the full social cost of his location decision and the necessary geographic separation will occur without further government intervention.

This argument against Buchanan and Stubblebine's symmetry cond[illegible]n for the implementation of a Pigouvian tax/subsidy scheme is further strengthened by Baumol and Oates who provide a further delineation of the externality concept. According to them, externalities can be classified as being either depletable or undepletable in nature.[19] A depletable externality can be likened to a "private good" in which its consumption by an individual means that it is not available for consumption by any other individual. An undepletable externality, however, is similar to a "public good" in that one individual's consumption does not diminish the availability of the externality for any other individual. This further delineation strengthens Baumol's original argument concerning the Coase problem, for as Baumol and Oates state:[20]

> No tax upon the victims is necessary; the smoke itself will keep residents away. Because smoke is an undepletable externality, A's inhalation of smoke will affect no one but himself and, so, at a zero price (tax) he will absorb the full social cost of his location decision. The decision that is optimal privately is optimal socially. On the other hand, if he were to be compensated for smoke damage, he would be relieved of the real cost of his decision and then Coase's problem would indeed arise: too many persons would end up living next to the factory.

Thus, the case of undepletable externalities requires that a two-price system be established to achieve Pareto optimality. The Pigouvian tax/subsidy scheme should involve a positive price (tax) to the producer of an external diseconomy and a zero price (no tax or subsidy) to the consumer of the externality.

2.5 Conclusions

The question that remains to be discussed is what implications does the preceding discussion about the theory of externalities have for the problem of aircraft noise? The externality created by aircraft noise has "public good characteristics" and for that reason is an undepletable externality. One individual's consumption of noise in no way diminishes the amount of noise available for consumption by other individuals. Aircraft noise is not an ubiquitous externality but, rather, is a local phenomenon.[21] Thus, individuals do have a choice as to how much noise they wish to consume. They can locate their place of residence close to an airport flight path and consume a great deal of noise or they can locate further away from the airport and consume less or even no noise. These characteristics of aircraft noise pollution create interesting policy implications.

In order for an economic system to achieve a Pareto-efficient allocation of resources, it is necessary that all Pareto-relevant externalities be internalized. It is unlikely that a negotiated settlement, or market solution, will be reached between the airport[22] and the victims of the noise pollution, as the problem of "large numbers" exists. Even though there is only one producer, the airport (at least in an abstract sense), there will likely be a large number of individuals affected by the externality. The transactions costs of achieving a negoti- …ttlement in such a case would weigh heavily against …t solution. Even if these costs were not excessive, it is unlikely that true preferences would be revealed by the victims. Any noise abatement program would have public good characteristics so that any attempt to assess willingness to pay for such a program would be met by the "free-rider" problem on the part of the victims. Each individual would have a tendency to understate his preferences so as to avoid paying his part of the bribe to the airport.

Thus, it appears as though the solution to the problem of aircraft noise must rely on some form of government intervention, possibly by the implementation of a Pigouvian tax/subsidy scheme. Since aircraft noise is an undepletable externality, such a scheme would require that the airport be taxed so as to reduce its output of noise to the socially desirable level. At the same time, the victims of the external diseconomy should be neither taxed nor compensated, as was demonstrated in Section 2.4 of this chapter. In this way, the socially optimal amount of noise is produced (in terms of Pareto efficiency) and individuals locate themselves in an optimal manner.

Footnotes

[1]Harold Demsetz, "Toward a Theory of Property Rights," *American Economic Review: Papers and Proceedings*, 57 (May, 1967), pp. 347-348).

[2]A. A. Walters, *Noise and Prices* (Oxford: Clarendon Press, 1975), p. 1.

[3]W. J. Baumol and W. E. Oates, *The Theory of Environmental Policy* (New Jersey: Prentice-Hall Inc., 1975), pp. 17-18.

[4]J. Buchanan and W. Stubblebine, "Externality," *Economica*, 29 (November, 1962), pp. 371-384.

[5]This model is directly applicable to the case of aircraft noise simply by designating U^A to be a utility function of an individual and U^B to be the production function of the air transport industry. Then, Y^1 would be a variable related to the noise assimilative capacity of the environment (an input in he production function).

[6]Buchanan and Stubblebine, "Externality," p. 374.

[7]A. Randall, "Coaşian Externality Theory is a Policy Context," *Natural Resource Journal*, 15 (January, 1974), p. 36.

[8]R. Coase, "The Problem of Social Cost," *Journal of Law and Economics*, 3 (October, 1960), pp. 1-44.

[9]*Ibid.*, p. 2.

[10]It is obvious from the discussion presented in Section 3.1 that Coase is concerned with Pareto-relevant externalities.

[11]Randall, "Coasian Externality Theory in a Policy Context," p. 37.

[12]D. N. Dewees, *et. al.*, *Economic Analysis of Environmental Policies* (Toronto: University of Toronto Press, 1975), p. 14.

[13]*Ibid.*, p. 14.

[14]Baumol and Oates, *The Theory of Environmental Policy*, p. 19.

[15]Buchanan and Stubblebine, "Externality," pp. 380-382.

[16]It can be seen that the Buchanan-Stubblebine argument is somewhat tenuous. If A has the ability to bribe B, there is no need for a tax/subsidy solution, as the market solution would result in q* units of the externality being produced. If, however, A cannot bribe B, the imposition of a tax on B's production would also result in q* units being produced. Only if the government unilaterally imposes a tax scheme, without regard for the market solution, will Buchanan and Stubblebine's argument hold.

[17]Coase, "The Problem of Social Cost," pp. 33-41.

[18]W. Baumol, "On Taxation and the Control of Externalities," *American Economic Review*, 62 (June, 1972), pp. 312-313.

[19]Baumol and Oates, *The Theory of Environmental Policy*, pp. 19-23.

[20]*Ibid.*, p. 25.

[21]Walters, *Noise and Prices*, p. 2.

[22]The term airport is being used as a composite producer for the airline transportation industry. Since the majority of aircraft noise problems occur in proximity to airports, due to the frequency of landings and takeoffs, it seems reasonable to state that the airport is the externality-producing firm.

CHAPTER III

THE BENEFITS OF NOISE ABATEMENT: THEORETICAL DIMENSIONS

The preceding chapter of this thesis has attempted to establish a theoretical framework within which the problems associated with aircraft noise can be examined. Both the effects of an external cost on the achievement of a Pareto efficient allocation of resources and the implications for household maximizing behavior have been discussed. Yet, this theoretical framework has no practical application unless the costs of aircraft noise (or conversely, the benefits of noise abatement) can be measured. The purpose of this chapter is to present two theoretical models that may possibly provide this measure.

3.1 Compensating and Equivalent Surpluses

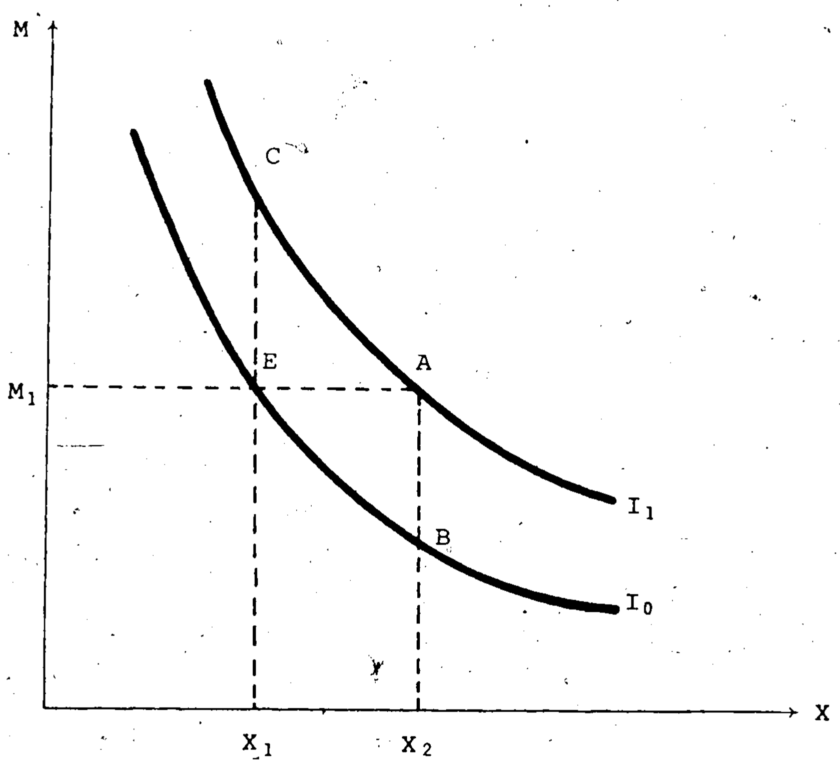
A major problem associated with measuring the damages inflicted on individuals by aircraft noise, or the benefits to be derived by pursuing some noise abatement program, is that there are not one, but two, measures of welfare changes: the compensating surplus and the equivalent surplus. This problem in measuring possible changes in welfare was first identified by Hicks[1] and later developed for the case of externalities by Mishan.[2] The difference in measures arises because each gainer and each loser from an external effect has two subjective valuations of the externality's impact on his welfare. According to Mishan, the benefit that an individual receives from a reduction in an external diseconomy, such as aircraft noise, could be measured:[3]

> . . . either as the maximum amount of money, OM, he would be prepared to pay rather than forego the benefit or as the minimum amount of money, ON, he would be willing to accept in order to abandon it . . . . As for the relationship of these two measures, from the definition of welfare effects we know that for each individual ON exceeds OM whenever the welfare effect with respect to the good in question is positive inasmuch as his level of welfare is higher if he agrees to accept ON instead of the good rather than if he pays OM to retain it. Conversely, a negative welfare effect with respect to the good (the good in question being inferior) entails that OM exceeds ON.

The compensating surplus is the maximum amount of money that the individual would pay to have an external diseconomy removed, while the equivalent surplus is the minimum payment he would accept in order to endure it (assuming a discrete, all-or-nothing case for simplicity of argument). The two measures differ because of the income effect involved in welfare changes. If the good in question, in this case noise pollution abatement, is an income-normal good the equivalent surplus will exceed the compensating surplus. Payment of the compensating surplus leaves the individual at his original level of welfare, while receipt of the equivalent surplus moves the individual to a higher level of welfare.[4]

The difference between the two measures can best be illustrated with a simple diagram. In Figure 3-1, an individual is assumed to be able to form a preference ranking over combinations of a good called "X" (this could be pollution abatement) and money, "M", which is a composite commodity of all other goods. The indifference curves I_0 and I_1 represent the preference ordering, such that the individual is indifferent between all bundles of M and X along I_0 but prefers all bundles on I_1 to those on I_0. Assume that the individual is initially located at point E ~~and is, thus, "consuming" M_1 units of money~~ and X_1 units of X. Now suppose that the amount of X is increased from X_1 to X_2, so that the individual is now located at point A on indifference curve I_1. The compensating surplus would measure the change in welfare arising from this increase in X to be the maximum amount the individual would be willing to pay for the change. This is the amount of money which would leave him on his *original* indifference curve I_0, but consuming X_2 instead of X_1. This amount corresponds to the distance AB in the diagram. The equivalent surplus is the minimum amount of money the individual would accept in lieu of the increase in X, and is measured as the value that would allow him to reach I_1 without any increase in X. This is the distance CE in the diagram. If X is a normal good, then the distance CE will be greater than the distance AB and the equivalent surplus will exceed the compensating

Figure 3-1: Compensating and Equivalent Surpluses



compensating surplus = AB

equivalent surplus = CE

surplus. Since the two surpluses differ in magnitude, it is necessary to determine which one is being used by the theoretical models presented below to measure the costs of noise damage or, conversely, the benefits of noise abatement.

3.2 The Ridker-Henning Approach

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

However, an explicit formulation of the demand for quiet is not available from observed market transactions. The problem, therefore, is to use variables for which data are available to estimate the implicit price-quantity relationship. Ridker and Henning[5] utilized an hedonic regression technique[6] in an attempt to determine the costs associated with air pollution in the city of St. Louis. This study is of particular interest because air and noise pollution are externalities with many similar characteristics, the most important being that both are undepletable externalities, the costs of which are not readily observable through market transactions.

The hedonic estimation procedure is strongly rooted in Lancaster's theory of household consumption.[7] According to this theory, the household consumes goods and services because they provide, either singularly or in combination, certain desirable characteristics. Thus, characteristics and not goods enter directly into the utility function. The relationship between the hedonic technique and Lancaster's theory is emphasized by Meullbauer, who states:[8]

> Roughly speaking, exponents of the hedonic technique take the view that the quality of a good is related to measurable specification variables or characteristics such as size, performance, etc. All empirical applications regress prices or logs of prices of the different varieties or models of a type of good on these characteristics.

The hedonic estimation procedure regresses the price of a good against the characteristics that the good provides to the consumer. From this regression equation the implicit prices of the characteristics can be determined.

The application of the hedonic technique to the determination of the implicit price of quiet is readily apparent. Quiet is a characteristic that is derived by the individual through his consumption of housing services, specifically the location of his house.[9] Thus, to estimate the implicit price of quiet, it is necessary to regress the price of housing services against the various characteristics or attributes that are provided by those services, one of these being the level of quiet.

Ridker and Henning adopt this approach in their attempt to measure the costs of air pollution. They utilize a cross-sectional regression analysis in which the observations correspond to census tracts in the city of St. Louis. Thus, each data point is a median or average value of the parameter being tested.[10] The basis of the analysis, as with any hedonic technique, is that:[11]

> A given residential unit is assumed to consist of a "bundle" of attributes present in varying degrees, each of which has an implicit market price (positive or negative), the market value of this unit being the sum of the values of these attributes.

Ridker and Henning regress the assessed value of housing services in St. Louis against a set of indexes that attempt to measure the various characteristics which determine that value. The independent variables that measure housing characteristics are divided into several broad categories, the most important of these being:

(1) Air pollution--measured as sulfation levels.

(2) Property-specific--includes such variables as median number of rooms, percentage recently built and houses per square mile.

(3) Location--includes accessibility to highways, shopping areas and industrial areas.

(4) Neighbourhood--includes school quality, crime rates, persons per unit and occupancy ratio.

Ridker and Henning conduct regression analyses using various combinations of these characteristics as independent variables.

The results of this analysis are that the estimated coefficient attached to the sulfation level is statistically significant and negative and is estimated by the various regression equations to lie between -$83 and -$245 per sulfation zone. From this, Ridker and Henning conclude that a reduction of sulfation levels of 0.25 100·cm²/day, or about 30% of the mean sulfation value, could be expected to raise house prices in St. Louis by at least $83 and possibly by as much as $245. The total increase in property values resulting from such a reduction is estimated to be about $83 million and this is the amount, according to Ridker and Henning, that the householders of St. Louis should be willing to pay to have air pollution reduced to the levels stated above. It is this amount that should be compared to the costs of air pollution abatement to determine whether such a reduction is economically feasible.[12]

Freeman, in two subsequent notes, vigorously attacks the Ridker-Henning analysis.[13,14] The basis of Freeman's argument is that the coefficients derived from the regression analysis are the result of partial equilibrium calculations and cannot be used to estimate values for total willingness to pay. Only with the application of a general equilibrium model is it possible to determine the relationship between land values and air quality.

The problem arises because the Ridker-Henning model does not separate the supply and demand characteristics that constitute the equilibrium land values. The relationship between air quality and property values in any urban area is the result of an interaction between supply factors, such as the availability of land possessing different amounts of air pollution, and demand factors, such as income, tastes and preferences. According to Freeman, the Ridker-Henning analysis estimates the locus of equilibrium points and not the marginal willingness to pay curve. The air pollution coefficients calculated by the regression analysis measure the difference in property values assuming that air quality does not change over the *entire* system, so that

> the benefits of non-marginal changes in air quality can not in general be determined without more information on the shape of the marginal willingness to pay curve.[15]

Thus, it is invalid to use the coefficients to predict the benefits accruing from an overall change in air quality. Freeman concludes that this type of analysis should be discontinued until a general equilibrium model of land rents has been developed.

Anderson and Crocker[16] reply to Freeman by stating that such a general equilibrium model, as developed by

Lind, does exist. They agree with Freeman that Ridker and Henning have misinterpreted their statistical results, but argue that property value studies are valid because they are consistent with models of land rent determination. Given the existence of such models, it is possible to use the results of hedonic regression techniques to estimate total willingness to pay. According to Anderson and Crocker, Ridker and Henning have misinterpreted the meaning of the regression coefficients derived in their statistical analysis. As they state:[17]

> The equations estimated in the above property value studies therefore explain bids for properties contingent upon bidder income and property characteristics. Hence, derivatives of these equations with respect to any characteristic yield not the change in market equilibrium price (gradient) with respect to a characteristic, but rather a change in bid contingent upon bidder income and other characteristics.

It is necessary to apply the Ridker-Henning analysis to a general equilibrium model. The Lind[18] model of equilibrium property value determination is an assignment model. The equilibrium allocation of land use can be determined by solving for the maximand of the following constrained function:

$$\text{maximize } \sum_i \sum_j a_{ij} \, s_{ij}$$

subject to: (1) $\sum_j s_{ij} \le 1$ j = number of locations

(2) $\sum_i s_{ij} \le 1$ i = number of individuals

where a_{ij} = the maximum rent that individual i would be willing to pay to locate at j

s_{ij} = 1 if individual i is assigned to j

and s_{ij} = 0 if individual i is not assigned to j

Anderson and Crocker state that, for improvements in environmental quality, it is usually assumed that:

$$a^1_{ij} \geq a_{ij}$$

where a^1_{ij} = the maximum rent that individual i would be willing to pay to locate at j, given the environmental improvement

The benefits that accrue from any improvement in environmental quality can be estimated as the difference between the solution to:

$$\text{maximize} \sum_i \sum_j a^1_{ij} s^1_{ij}$$

and the previously indicated maximization problem. Thus, it is possible for Anderson and Crocker to show what is wrong with the Ridker-Henning analysis. Ridker and Henning calculate the benefits of air pollution to be:

$$\sum_i \sum_j (a^1_{ij} - a_{ij}) s_{ij}$$

when the actual total benefits are:

$$\sum_i \sum_j (a^1_{ij} s^1_{ij} - a_{ij} s_{ij})$$

It can be seen that their analysis implicitly assumes that each individual does *not* relocate his place of residence because of the improvement in air quality. The proper calculation of total willingness to pay requires that changes in land values be calculated after the relocation of individuals among sites (that is, to their welfare maximizing locations in the changed environment).[19]

The problem with the Anderson-Crocker attempt to defend Ridker and Henning is that it is based upon a very tenuous assumption. Lind argues that:[20]

> . . . if we assume that rents are established on land directly affected by the project so as to eliminate profits and consumer surplus, then benefits can be measured in terms of the change in the value of that land alone. One does not have to consider changes in land values throughout the system.

Thus, for the Ridker-Henning analysis, which looks at land values only within the area affected by air pollution, to be correct it is necessary to assume that the equilibrium land rents totally exhaust the consumer surplus of each individual household, that is, each household pays its maximum willingness to pay.

Polinsky and Shavell[21] present an alternative model that, under certain conditions, satisfies the Lind assumption concerning the exhaustion of consumer surplus. In their model, individuals are assumed to have identical tastes and incomes[22] so that the individual's residential location decision corresponds to the following maximization problem:

$$\text{maximize } U = U[q,x,a(k)]$$

$$\text{subject to: } y = p(k) \cdot q + p_x \cdot x + T(k)$$

where $U(\cdot)$ = the individual's utility function

q = quantity of housing services

x = quantity of some composite good

$a(k)$ = level of amenities at location k

y = income

$p(k)$ = price of housing services at k

$T(k)$ = transportation costs at k

An alternative formulation[23] of the above utility maximization problem is to utilize the indirect utility function, $V(\cdot)$, so that the individual would choose an optimal location according to the function:

$$V(k) = V[p(k),y-T(k),a(k)]$$

Given free mobility of individuals, the equilibrium pattern of location is defined to be the pattern such that no household can increase its level of welfare by moving. Thus, there exists a level of utility, V^*, that is independent of location:

$$V^* = V[p(k), y - T(k), a(k)]$$

The key to the Polinsky-Shavell model is to determine the value of V* and its relationship to property values. From the above equation it can be shown that p(k) can be defined by the following relationship:

$$p(k) = f[V^*, y - T(k), a(k)]$$

If the area affected by air pollution, or any other external effect, is "small and open", then the equilibrium level of utility is an exogenous value. If the area is open such that mobility of individuals is free and costless, a common level of utility will exist across the entire system because individuals will relocate so as to equalize utility levels. If the area is small, effects such as changes in air quality will have a negligible effect on the system as a whole. Thus, in a small, ope area, the equilibrium value of p(k), the price of housing services, will depend only upon the characteristics available at k because V* is an exogenous variable. In this case, the Ridker-Henning analysis is valid because changes in total willingness to pay can be measured by examining only changes in property values within the affected area.

If, however, the area under consideration is not small and open, the Ridker-Henning partial equilibrium analysis does not apply. In this case, V* cannot be treated as an exogenous variable because what happens within the area will affect the entire system. Thus, p(k) becomes a function of both the characteristics at k *and* the equilibrium level of utility, V*, which changes as the quality of air changes. The solution to this problem requires a general equilibrium model that solves for p(k) and V* simultaneously.

The question that now arises is what implications does the above discussion have for the measurement of the costs associated with aircraft noise or the benefits to be derived from noise abatement? It has been established that the Ridker-Henning approach to environmental quality problems can be applied if one of two conditions is met:

(1) rents extract total willingness to pay so that no surpluses are earned;

or (2) the area under consideration is a "small, open" area.

In a previous chapter of this thesis it was established that aircraft noise is a non-ubiquitous externality, such that its effects are very localized. Hence, it appears as though the conditions outlined by Polinsky and Shavell can be met. Since aircraft noise affects only "neighbourhoods" within a city (and the larger the city, the smaller the relative size of these neighbourhoods becomes), the Ridker-Henning approach can be adopted to measure the costs of noise pollution.

3.3 The Aaron-McGuire Approach

In an article by Aaron and McGuire,[24] a method for imputing the benefits of government expenditures on public goods is discussed. This article provides a theoretical model and some casual empirical results concerning the distributional aspects of public good provision. In a subsequent note, Maital[25] explicitly outlines the Aaron-McGuire approach and provides alternative empirical results. The interesting aspect of the Aaron-McGuire approach to measuring the benefits derived from public goods is that their measurement process explicitly utilizes a utility function that describes individual preferences for public and private goods. Previous studies had merely imputed the benefits of government expenditures in proportion to criterion such as gross income or disposable income. The purpose of section 3.3 is to illustrate how the Aaron-McGuire model can be modified to measure the benefits from noise abatement programs, which have public good characteristics, and to determine how the model can be used for empirical analysis.

If it is assumed that the individual has a homogeneously separable utility function,[26] this function can be expressed in the following form:

$$U = U[u(x), u(H)]$$

where x = a vector of consumption goods

H = housing services.

The nature of the assumed separability is such that the individual first allocates his total income, Y, between expenditures on consumption goods, Y_x, and expenditures on housing services, Y_H. He then allocates his housing budget among purchases of the various housing characteristics so as to

$$\text{maximize } u(H) = u(h,q)$$

subject to $Y_H = p_h \cdot h + p_q \cdot q$

where h = a vector of housing characteristics other than quiet

q = the level of quiet = f (location)

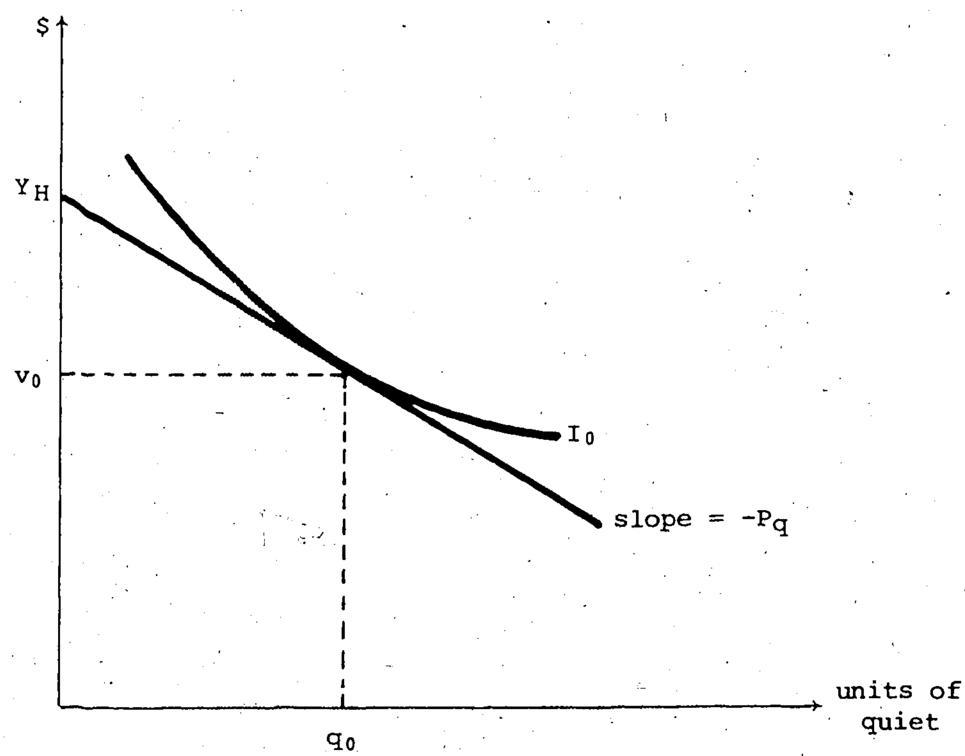
p_h = price vector of the housing characteristics

p_q = price of quiet

and $Y_H = Y - Y_x$

The individual could allocate the whole of his housing budget to the purchase of the housing characteristics other than quiet (that is, reside at the noisiest of locations), or he could allocate part of his budget to the purchase of h and part to the purchase of quiet.[27] This allocative choice depends upon the price of the housing characteristics, the price of quiet, the individual's level of income and his preference schedule. The individual's optimal consumption choice, with respect to housing services, is illustrated in Figure 3-2.

Figure 3-2: Optimal Consumption Choice



As Figure 3-2 indicates, the individual will choose to consume q_0 units of quiet and v_0 dollars worth of housing characteristics other than quiet when he has a housing budget of Y_H, the price of quiet is p_q and his preferences for housing characteristics and quiet are represented by an indifference map containing I_0. If the individual consumes v_0 dollars worth of housing characteristics other than quiet out of a total budget of Y_H dollars, then the value to the individual of the q_0 units of quiet must be $Y_H - v_0$ dollars.

It can now be shown how the modified Aaron-McGuire model can be applied empirically. If the individual spends his entire housing budget on the purchase of housing services, then that budget[28] will equal the purchase price of any property that the individual buys, so that:

$$Y_H = PV$$

where PV = property value (measured as a transactions price)

Thus, if data are available regarding the transaction prices of properties and the level of quiet associated with those properties, it appears as though the Aaron-McGuire model has empirical practicability. The implicit marginal price of quiet can be estimated from an hedonic regression equation of the form:

$$PV = \hat{\beta}_0 + \hat{\beta}_h \cdot h + \hat{\alpha} \cdot q + \hat{e}$$

where $\hat{\beta}_h$ = an estimate of P_h

$\hat{\alpha}$ = an estimate of P_q

This regression equation, illustrated as linear for ease of exposition, is the same as the equation estimated in the Ridker-Henning approach that was discussed in the previous section of this chapter.

The implicit price ratio, $\frac{P_q}{P_h}$, estimated by the regression analysis as $\frac{\hat{\alpha}}{\hat{\beta}_h}$, is determined by the supply and demand characteristics of the market. If the housing market is in equilibrium, the marginal rate of substitution between quiet and the other housing characteristics must be equal to the price ratio, for *all* individuals. The implications of this equilibrium condition can best be discussed within the context of a simple example.

If it is observed that there are two levels of quiet within a community, q_1 and q_2 ($q_1 < q_2$), and that there are two individuals, individual 1 residing at a location associated with q_1 units of quiet and individual 2 with q_2 units of quiet, how can this difference in locations be explained? This difference in choice of location, given that the market price ratio p_q/p_h prevails for all individuals, can occur only if one of three conditions[29] is met:

(1) If the individuals' incomes (by "income" is meant

that portion of total income allocated to the purchase of housing) are identical, such that $Y_{H1} = Y_{H2}$ or $PV_1 = PV_2$, then the difference in location can only arise if preferences are different between the individuals. This case is illustrated in Figure 3-3a, where individual 1 has a stronger preference for housing characteristics than does individual 2, so that he consumes only q_1 units of quiet.

(2) If the individuals' preferences are identical, then differences in location and consumption of quiet arise only because incomes are different. This case is illustrated in Figure 3-3b, in which I_0 and I_1 have the same shape and position as I_0' and I_1', but $Y_{H1} < Y_{H2}$, so that again individual 1 consumes q_1 units of quiet and individual 2 consumes q_2 units. It should be noted that $q_2 > q_1$ only if $Y_{H2} > Y_{H1}$ when preferences are identical.

(3) If both preferences and incomes are different between individuals, different levels of quiet may be purchased. In Figure 3-3c, the individuals have different preferences and incomes, so that individual 1 purchases q_1 units of quiet and individual 2 purchases q_2 units. In this case, it is *not* necessary that $Y_{H2} > Y_{H1}$ for $q_2 > q_1$. This is illustrated in the diagram.

Figure 3-3a: Identical Incomes, Different Preferences

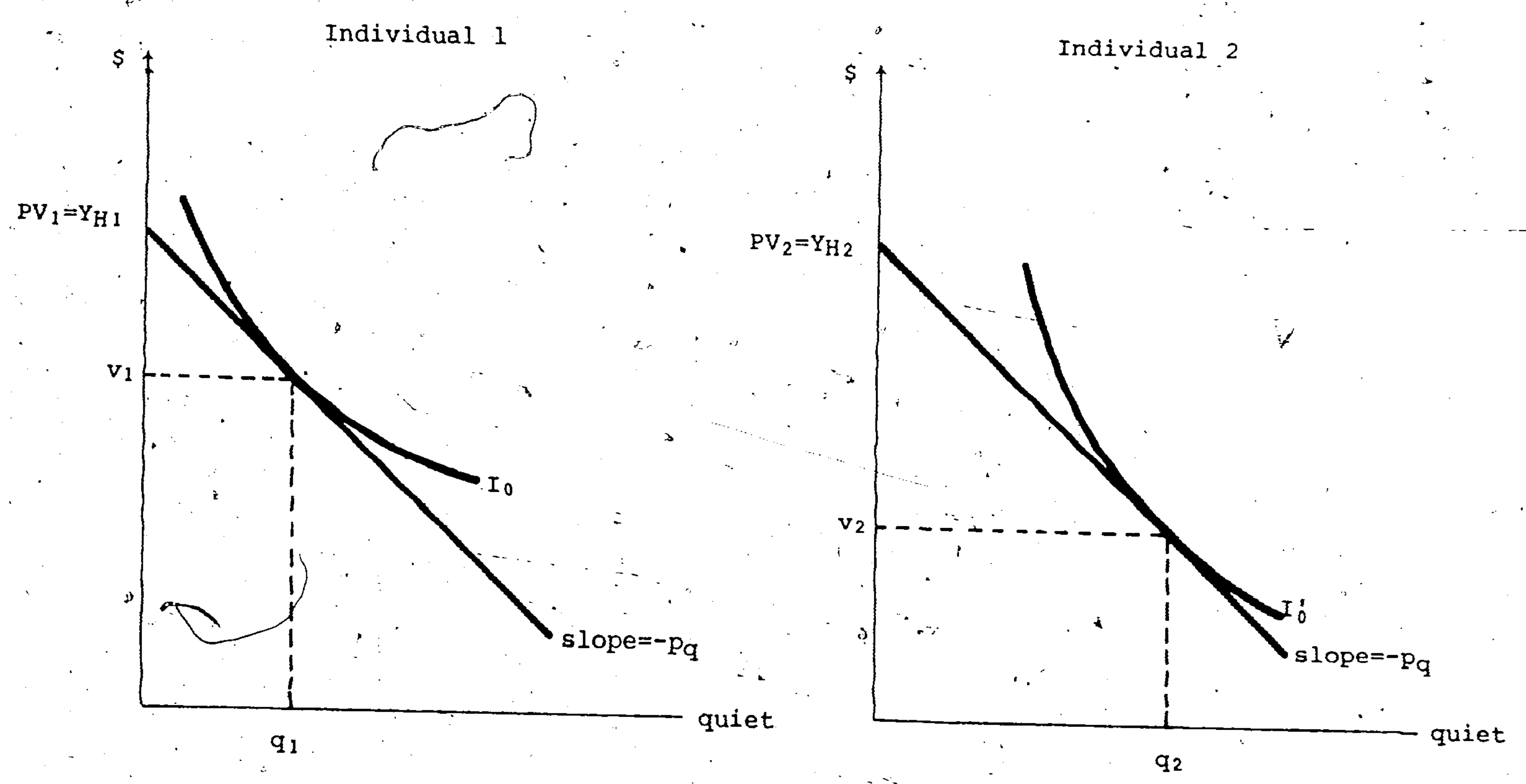


Figure 3-3b: Identical Preferences, Different Incomes

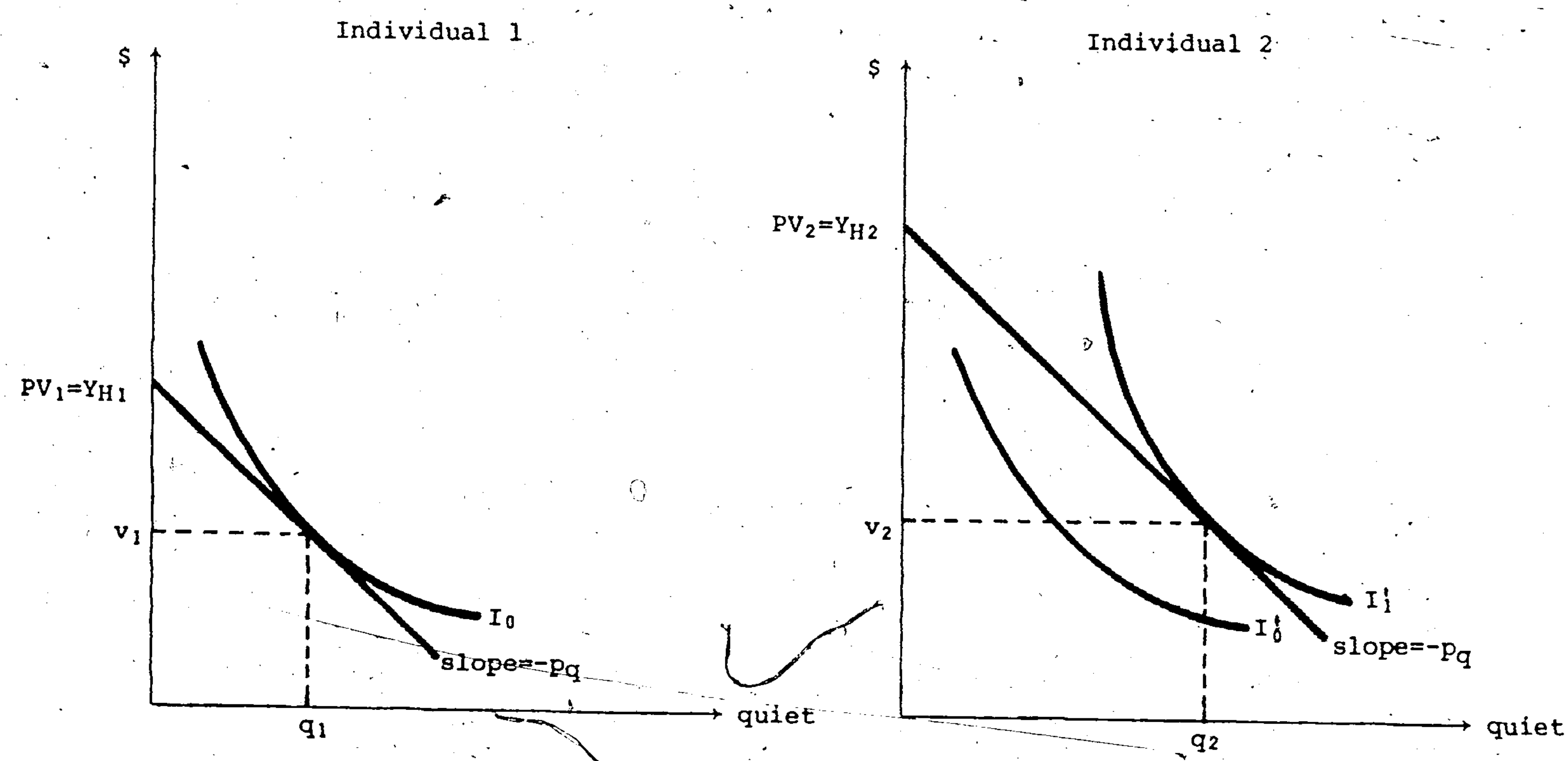
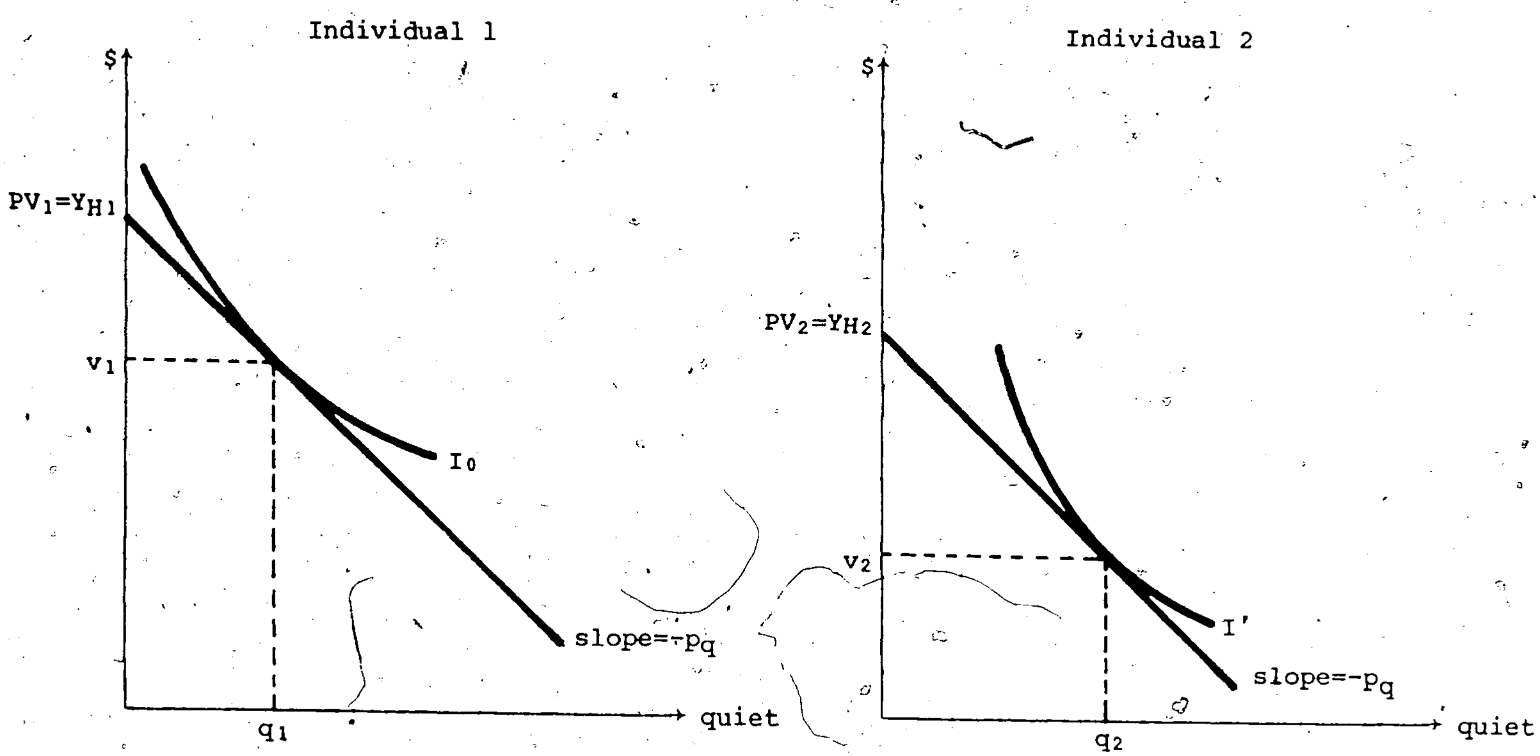


Figure 3-3c: Different Incomes and Preferences



It can now be seen that this modified Aaron-McGuire approach presents a much broader description of the individual's choice of residential location than does the Polinsky-Shavell model. The Polinsky-Shavell model initially assumes identical incomes, identical preferences and homogeneous housing units. The only variable is the level of the amenity so that different price ratios between quiet and other housing characteristics are established for different locations of housing. These different price ratios just compensate the individual for living at any particular location and enduring any particular level of noise. Thus, each individual is indifferent between his location of residence and any other location.

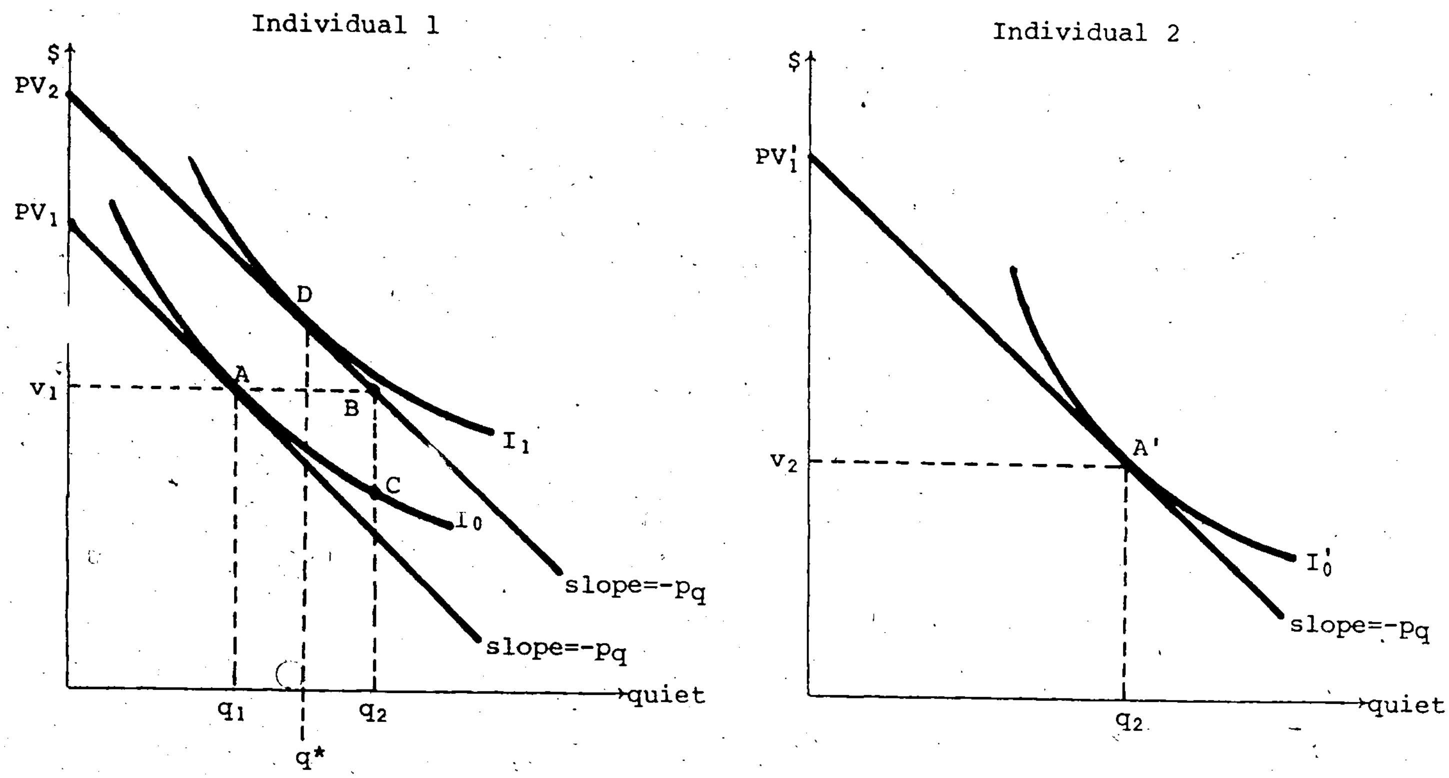
Polinsky and Shavell also briefly examine the case where different "classes" of individuals may reside in the same community (that is, individuals may have different incomes and preferences). In this case, they state:[30]

> The introduction of many classes of households would not change these conclusions in an essential way, although it would complicate the model. There would be a separate locational equilibrium condition and, in general, one would estimate separate regression equations. In the case of a small-open city, the equilibrium level of utility of each class would be determined exogenously, whereas in a closed city these levels would be determined endogenously. The analysis of the questions would remain unchanged except that one would have to take into account the possibility that the class occupying any particular location might change.

The modified Aaron-McGuire analysis supports the above conclusions. This model need not assume identical incomes, identical preferences or homogeneous housing units. Individuals are *not* indifferent between the various possible housing locations, at any existing market price structure. The conclusion of this analysis is that for any arbitrary, exogenous change in the level of quiet, individuals would likely be willing to change location in order to move to an optimal consumption pattern, assuming that mobility is costless.

The problem that must now be considered is how can the modified Aaron-McGuire model be used to determine the benefits, or willingness to pay, arising from a noise abatement program? The method of measuring willingness to pay can be examined most appropriately within the context of a simple example. Again assume that there are two neighbourhoods, one with a level of quiet q_1, and one with a level of quiet q_2, such that $q_1 < q_2$. The initial situation is depicted by Figure 3-4 in which "individual 1" represents individuals located in neighbourhood 1, and "individual 2" represents individuals located in neighbourhood 2. If the price of quiet is p_q, then individuals in neighbourhood 1 would be in equilibrium at a point like A (tangency between budget line and indifference curve, I_0) and own a house that has q_1 units of quiet and v_1 dollars worth of other housing characteristics such that total property value would be PV_1 dollars. Individuals residing in neighbourhood 2 would be in equilibrium at a point like A'

Figure 3-4: Benefits of Noise Abatement



and own a house with q_2 units of quiet and v_2 dollars' worth of other housing characteristics so that total property value would be PV_1' dollars.

Now suppose that the level of quiet is raised from q_1 to q_2 in neighbourhood 1 such that the same level of quiet is available in both neighbourhoods. The question is how much would individuals be willing to pay for this change in the level of quiet?

If it is assumed that the area affected by the change is small relative to the entire community (neighbourhood 1 much smaller than neighbourhood 2), then the price ratio between quiet and the other housing characteristics will not be significantly altered by changes in the level of quiet, provided that all types of noise are perfect substitutes. Thus, the same price ratio will exist both before and after the noise abatement program is enacted (p_q is constant).[31] If this is the situation, there are two cases that have to be considered in measuring willingness to pay:

(1) Individuals are immobile:

The first case to consider is the situation where individuals are constrained to remain at their original locations. From Figure 3-4, it can be seen that individual 2 woul [illegible] be willing to pay anything for the change in the level of quiet because he receives no improvement in his position. Since the price of quiet is assumed to be constant, individual 2 remains in a house having q_2 units of quiet, V_2 dollars worth of other housing characteristics and a property value of V_1'. Thus, individuals in neighbourhood 2 receive no increase in their level of welfare (remain on indifference curve I_0') so their willingness to pay for the change must be zero.

Individual 1, however, does gain from the change in the level of quiet because he now resides in a house having the same value of other housing characteristics (V_1) as before, but with a higher level of quiet (moves from point A to point B in Figure 3-4). Because of this change, individual 1 receives a gain in real income as his location of residence now produces q_2 units of quiet rather than q_1. This increase in income is reflected as an increase in the capitalized value of his property. His new budget line, if the individual owns the property and the change in quiet is made without cost to him, would now be the line passing through the point $B(q_2, v_1)$ and having the slope $-p_q$. With this new budget line, individual 1's optimal consumption pattern occurs where that line is tangent to the indifference curve I_1, at point D. This indicates a consumption of quiet of q^* units, which is less than q_2 but greater than q_1.[32]

Thus, the initial increase in the level of quiet increases individual 1's welfare but leads him to a disequilibrium point at B, given that the price of quiet remains p_q. To realize the full benefit of the increase in quiet, this individual would prefer to trade some of it away to obtain more housing characteristics other than quiet. To effect this type of trade, however, requires that individual 1 change his location of residence as housing is a *tied* bundle of characteristics. If individuals are *immobile* they would be constrained to remain at point B. Thus, given immobility, individuals in neighbourhood 1 would only be willing to pay BC dollars (the distance between points B and C) for the noise abatement program.[33]

(2) Individuals are mobile:

The second case to consider is the situation in which individuals are free to change locations at any time. It should be noted that this condition, combined with the previous assumption of a constant price of quiet, essentially generates the Polinsky-Shavell assumption of "small and open" neighbourhoods. The question is whether the measurement of willingness to pay for changes in the level of quiet under conditions of mobility differs from that under conditions of immobility.

As in the previous case, individuals in neighbourhood 2 should not be willing to pay anything for the increase in the level of quiet in neighbourhood 1. Given that the price of quiet is assumed to be constant, individual 2 remains at the initial equilibrium point A' and does not experience any increase in welfare. Also, as in the situation without mobility, individual 1 initially moves from the equilibrium point A to the disequilibrium point B, as the level of quiet in his neighbourhood is increased from q_1 to q_2. Polinsky and Shavell would argue that if the individuals in neighbourhood 1 are mobile, they would not remain at point B in Figure 3-4. Individual 1 would trade what he considers to be an excess amount of quiet, given his preferences and the price of quiet, for more housing characteristics other than quiet and would move from a house described by point B to one possessing the characteristics described by point D. In other words, there would be a switching of locations to achieve a new equilibrium situation.

Thus, the willingness to pay for the noise abatement program can be measured as the distance between the old budget line and the new budget line, this distance being equal to the value $PV_2 - PV_1$ in Figure 3-4. According to Polinsky and Shavell, willingness to pay when free mobility exists can simply be measured as the expected change in property values due to the change in quiet. If the price of quiet is p_q, this expected change in property values is given by:

$$PV_2 - PV_1 = p_q \cdot (q_2 - q_1)$$

However, there is a fundamental error in this line of reasoning. Even if free mobility exists within the system, it will not be possible for individuals in neighbourhood 1 to move from point B to point D. This is simply because the process of trade requires an exchange between *two* individuals. Thus, if individual 1 wants to trade his house with q_2 units of quiet for one with q^* units, he needs to find someone willing to trade with him. But individuals outside of neighbourhood 1 are in the same type of equilibrium situation as is individual 2 in neighbourhood 2. If the price of quiet remains constant this equilibrium remains in effect both before and after the change in quiet. There is nothing for them to gain through trade if the price of quiet remains at p_q.

Therefore, individuals in neighbourhood 1 are constrained to remain there (at points like B) even if free mobility exists. This means that their willingness to pay for the increase in quiet will not be $PV_2 - PV_1$ but rather BC dollars, the same as in the case of immobility. If the preferences of individuals in neighbourhood 1 can be represented by standard, convex-to-the-origin indifference curves the value BC will always be less than $PV_2 - PV_1$. Thus, the Polinsky-Shavell and Ridker-Henning approaches to measuring the benefits arising from pollution abatement programs will *overestimate* the true willingness to pay for these programs.

3.4 Conclusions

This chapter has presented two approaches to the problem of measuring the benefits associated with the reduction of aircraft noise. If it is assumed that the area affected by any noise abatement program is "small and open" the Ridker-Henning and modified Aaron-McGuire approaches are capable of yielding empirical estimates of willingness to pay for quiet. However, it has been demonstrated that the Ridker-Henning method will yield an estimate that overstates the true willingness to pay.

Given that is is possible to "theoretically" measure the benefits derived from noise abatement, the question arises as to what measure of welfare change is actually being produced. In Section 3.1 of this chapter two such measures, the equivalent surplus and the compensating surplus, were introduced. It was established that the equivalent surplus was the minimum amount an individual would accept in lieu of the level of noise being reduced, while the compensating surplus was the maximum amount the individual would pay to have the level of noise reduced. Since both the Ridker-Henning and modified Aaron-McGuire approaches are measuring willingness to pay, both models must be using the compensating surplus to measure welfare changes resulting from a noise abatement program.

Footnotes

[1]J. R. Hicks, "The Four Consumers' Surpluses," *Review of Economic Studies*, 11 (Winter, 1944), pp. 31-41.

[2]E. J. Mishan, "Welfare Criteria for External Effects," *American Economic Review*, 51 (September, 1961), pp. 594-613.

[3]*Ibid.*, p. 603.

[4]E. J. Mishan, "The Postwar Literature on Externalities: An Interpretative Essay," *Journal of Economic Literature*, 9 (March, 1971), p. 18.

[5]R. G. Ridker and J. A. Henning, "The Determinants of Residential Property Values with Special Reference to Air Pollution," *Review of Economics and Statistics*, 49 (May, 1967), pp. 246-257.

[6]A good overview of this technique is available in: Zvi Griliches (ed.), *Price Indexes and Quality Changes* (Cambridge, Mass.: Harvard University Press, 1971).

[7]K. Lancaster, "A New Approach to Consumer Theory," *Journal of Political Economy*, 74 (April, 1966), pp. 132-157.

[8]John Meullbauer, "Household Production Theory, Quality and the Hedonic Technique," *American Economic Review*, 64 (December, 1974), p. 977.

[9]A. A. Walters, *Noise and Prices* (Oxford: Clarendon Press, 1975), p. 27.

[10]Using average values creates some problems because it suppresses the variance that corresponds to the average. The analysis could be improved by using individual, site-specific data, such as multiple listings data, that would allow the variation over small areas to be included. The use of multiple listing data would also measure the actual market transactions.

[11]Ridker and Henning, "The Determinants of Residential Property Values with Special Reference to Air Pollution," p. 247.

[12]*Ibid.*, pp. 253-254.

[13]A. M. Freeman, "Air Pollution and Property Values: A Methodological Comment," *Review of Economics and Statistics*, 53 (November, 1971), pp. 415-416.

[14]A. M. Freeman, "Air Pollution and Property Values: A Further Comment," *Review of Economics and Statistics*, 56 (November, 1974), pp. 554-556.

[15] *Ibid.*, p. 555.

[16] R. J. Anderson and J. D. Crocker, "Air Pollution and Property Values: A Reply," *Review of Economics and Statistics*, 54 (November, 1972), pp. 470-473.

[17] *Ibid.*, p. 471.

[18] R. C. Lind, "Spatial Equilibrium, The Theory of Rents, and the Measurement of Benefits from Public Programs," *Quarterly Journal of Economics*, 87 (May, 1973), pp. 188-207.

[19] It should be noted that the Anderson-Crocker analysis clearly shows that the Ridker-Henning results provide a lower bound to estimation of the costs of air pollution. Since

$$\sum_i \sum_j a^1_{ij} s_{ij} < \sum_i \sum_j a^1_{ij} s^1_{ij}, \text{ because } s^1_{ij}$$

reflects an optimal location pattern given the environmental improvement, it follows that the Ridker-Henning estimates of the benefits accruing from pollution abatement are less than the actual benefits.

[20] R. C. Lind, "Spatial Equilibrium, The Theory of Rents, and the Measurement of Benefits from Public Programs," p. 202.

[21] A. M. Polinsky and S. Shavell, "The Air Pollution and Property Value Debate," *Review of Economics and Statistics*, 57 (February, 1975), pp. 100-104.

[22] This is for ease of exposition rather than being out of necessity.

[23] This is not just an alternative formulation. It is not possible to use the direct utility approach because there is an equilibrium for each k. Thus, there is a family of functions for each of the i individuals. The indirect utility approach circumvents this problem.

[24] H. Aaron and M. McGuire, "Public Goods and Income Distribution," *Econometrica*, 38 (November, 1970), pp. 907-920.

[25] S. Maital, "Public Goods and Income Distribution: Some Further Results," *Econometrica*, 41 (May, 1973), pp. 561-568.

[26] The assumption of separability is not critical to the analysis. It merely simplifies the theoretical model so that a great number of mathematical calculations are not required. At the same time, it is necessary for the empirical application of the model, due to the limited availability of data. This will become apparent at a further point in the chapter.

[27] The individual consumes a particular level of quiet, q_1, according to the location at which he resides. Thus, the level of quiet can be indexed as a function of location.

[28]In this case, the budget is not an amount of money per period but rather is the present value of all money, present and future, that is to be spent on housing services.

[29]Each of the three cases implicitly assumes that mobility and transaction costs are zero, and that the supply of characteristics is perfectly elastic.

[30]A. M. Polinsky and S. Shavell, "Amenities and Property Values in a Model of an Urban Area," *Journal of Public Economics*, 5 (January-February, 1976), p. 128.

[31]Again, a restrictive assumption is made in the theoretical presentation of the model so that the model can be applied empirically.

[32]Thus, it can be seen what implications the assumption of separability in the utility function has for this analysis. By assuming separability, the entire income effect of changes in quiet are felt only within the housing budget. This makes the analysis considerably simpler. It should be noted, however, that if separability does not actually exist, these estimates of benefits will under-estimate the true benefits because the individual will substitute away from housing services only if the utility gained from doing so exceeds the utility derived from spending the entire increase in real income on housing services alone.

[33]Willingness to pay is measured as that amount which just returns the individual to his original indifference curve after the change.

CHAPTER IV

THE BENEFITS OF NOISE ABATEMENT: EMPIRICAL ESTIMATES

In Chapter III, two theoretical models were developed that provided the methodological basis for the measurement of the willingness to pay for quiet, or the benefits derived from noise abatement programs.[1] Yet, the usefulness of those models is severely limited unless it is possible to apply them to the process of obtaining actual empirical measurement of willingness to pay. The purpose of this chapter is to demonstrate that such a measurement process is possible and to derive an estimate of the willingness to pay for quiet in the City of Edmonton.

4.1 The Hedonic Estimation Technique

The problem that arises in the measurement of the willingness to pay for most environmental amenities, quiet included, is that no explicit market exists for these amenities. Quiet is not bought and sold as a typical private good so that no explicit market price is established for quiet. Thus, the problem of estimating the willingness to pay for quiet can be separated into two distinct sub-problems:

(1) Can a "price" for quiet be estimated?

(2) Under what conditions can this price be used to measure the willingness to pay for quiet?

What can be observed in the market is that individual consumers make purchases of a good called "housing" and pay some market established price for this good. However, it can also be observed that a "house" is not a single commodity but rather is a tied bundle of goods and services, or characteristics, such as size, color, location, etc.[2] The total market value of any particular property should be a composite of the values of each of the characteristics associated with that property. Property value should vary as the quantity and mix of characteristics varies.

Since the level of quiet varies with location (that is, different levels of quiet, or different levels of aircraft noise, exist at different locations within an urban center), one of the characteristics associated with any property is the level of quiet associated with the location of that property. Thus, the purchase of any house involves the simultaneous purchase of some level of quiet. The price of that house should partially depend upon how consumers value quiet. The question that arises is how can the market price of housing be used to derive the implicit prices of each of the characteristics that establish the market price.

Even though the implicit prices of each of the housing characteristics are not observable in the market, they can be estimated using the techniques of hedonic price estimation.[3] This technique, and its implications, can best be examined within the framework of a simple model of consumer choice.[4] If it is assumed that housing is a tied bundle of housing characteristics, including the level of quiet, then the housing commodity, H, purchased by consumers can be characterized as a vector of these characteristics:[5]

$$H = H(h_1,\ h_2,\ \ldots\ h_n,\ q) \tag{1}$$

where h_i = housing characteristics other than quiet;

q = level of quiet associated with a particular housing bundle

For each housing bundle, H, there exists a particular market value that can be observed through market transactions. This value, PV, can be expressed as being some function of the characteristics that are embodied in H, so that:

$$PV = PV(H) = PV(h_1,\ h_2,\ \ldots\ h_n,\ q) \tag{2}$$

This price function is an "hedonic relationship" that is established by the equilibrating processes in the market. The hedonic estimation technique attempts to use multiple regression analysis to determine both the functional form of the price relationship and to estimate the parameters associated with any particular function.[6] From this regression equation, the implicit, or shadow, prices of the housing characteristics can be determined.

The manner in which these implicit prices are derived can be illustrated by taking the partial derivative of the price function with respect to any of the housing characteristics found within that function. This partial derivative measures the rate of change in property value as one of the housing characteristics changes marginally, the value of all other characteristics held constant. Thus, the partial derivative of PV(H) with respect to any of the housing characteristics, say h_i, yields the *marginal* purchase price function for that particular characteristic:

$$\partial PV(H)/\partial h_i = P_i(h_1, h_2, \ldots, h_n, q) \qquad (3)$$

In a like manner, the partial derivative of the price function with respect to the level of quiet will yield the marginal price of quiet, P_q:

$$\frac{\partial PV(H)}{\partial q} = P_q(h_1, h_2, \ldots, h_n, q) \qquad (4)$$

Thus, the first problem involved in estimating the willingness to pay for quiet can be resolved relatively simply. An hedonic estimation technique, in which the values of a group of properties are regressed against a vector of characteristics that determine those values, can be used to calculate the marginal prices associated with any of those characteristics, quiet included. The simplest example of this would be the case where it is postulated that a linear relationship existed between property value and the housing characteristics. This would yield a price function of the form:

$$PV = \beta_0 + \sum_{i=1}^{n} \beta_i h_i + \alpha \cdot q + e \qquad (5)$$

The regression analysis would generate estimates of the various parameters, $\hat{\beta}_0$, $\hat{\beta}_i$ and $\hat{\alpha}$ and the estimated function could be used to calculate the marginal prices of each of the housing characteristics. For this particular functional form, the estimated marginal price of quiet would be calculated as:

$$\frac{\partial PV}{\partial q} = P_q = \hat{\alpha} \qquad (6)$$

Given the fact that these calculations can be made, the problem still remains as to how this estimated price of quiet can be used to determine the willingness to pay for quiet. In one of the initial attempts to measure the benefits derived from changing the level of environmental amenities, Ridker and Henning[7] argued that willingness to pay for increases in these amenities (or decreases in disamenities) could be measured as the increase in property values expected after the change is introduced. If the price of quiet is P_q and there is an exogenous change in the level of quiet of Δq, then, according to Ridker and Henning, the willingess to pay for this change on the part of consumers should be $P_q \cdot \Delta q$. All that need be done to measure willingness to pay is to use the hedonic estimation technique to determine the price of quiet and apply that price to any *marginal* change in the level of quiet.

In the debate[8] that subsequently arose out of the Ridker-Henning article, much attention was devoted to the question of whether this measurement of willingness to pay involved a correct interpretation of the hedonic price function. According to Nelson:[9]

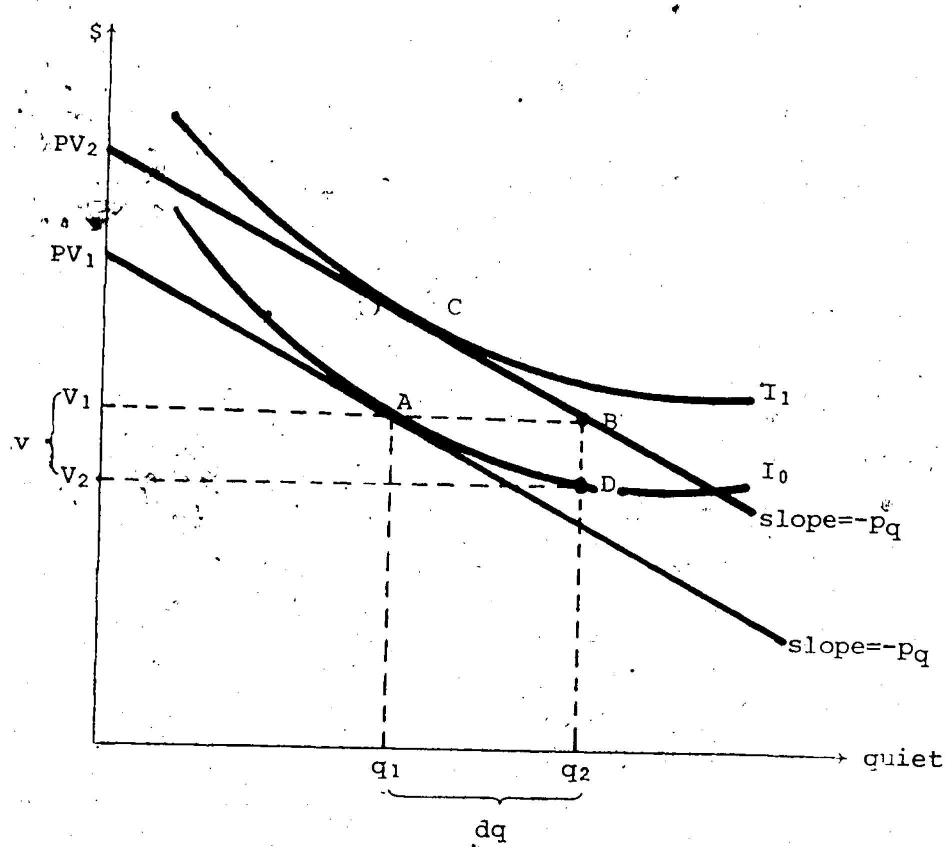
> For a particular good, a hedonic price equation represents a household total cost or expenditure function which connects observed differentiated product prices to quantities of various embodied attributes and associated implicit or hedonic prices. The marginal hedonic prices merely connect equilibrium reservation bid and offer prices and attributes for both consumers and producers and reveal little about the underlying demand and supply schedules. That is, from the consumer's standpoint, estimation of a hedonic price function serves only to determine the marginal cost or tariff schedules confronting consumers and does not by itself identify the bid price schedule for air quality or any other housing attribute.

The hedonic price function is the result of the market process in which supply *and* demand are equilibrated and, thus, represents an opportunity locus of these equilibrium points and cannot be interpreted as a marginal willingness to pay function.[10] This interpretation suggests that a two-stage approach must be taken to estimate the willingness to pay for quiet. Rosen[11] argues that welfare changes can only be measured correctly by a model that incorporates both supply and demand relationships and solves for changes in equilibrium simultaneously. The hedonic price function is just one input into this solution and, thus, the Ridker-Henning approach which utilized only the hedonic prices must be incorrect.

Polinsky and Shavell,[12] however, argue that under a particular set of restrictive conditions concerning the nature of the market the Ridker-Henning approach is correct. If the area being affected by any change in environmental quality is "small and open", then that change will not affect the equilibrium price structure that existed before the change. If the price of quiet does not change, then the willingness to pay for any change in the level of quiet can be measured as $P_q \cdot \Delta q$, and it is not necessary to utilize a two-stage estimation procedure. But, as was demonstrated in section 3.3 of Chapter III, even if the area being affected by some exogenous change in environmental quality is "small and open", the Ridker-Henning approach will *overstate* the willingness to pay for that change on the part of individual households.

Referring to Figure 4-1, assume that the individual is initially in equilibrium at point A, with a total property value of PV_1 and located in a neighbour-

Figure 4-1: Measurement of Willingness to Pay



hood with the level of quiet being q_1. If the price of quiet is P_q, the imputed value of quiet is $P_q \cdot q_1$ which is equal to the value $PV_1 - V_1$. This means that the imputed value of all housing characteristics other than quiet is V_1. Now assume that some exogenous change is made in the level of quiet so that it rises from q_1 to q_2 in this particular neighbourhood. The individual now occupies a house having V_1 dollars worth of housing characteristics other than quiet and q_2 units of quiet (located at point B). If the area was small and open, the market price of quiet would not change from P_q, and Polinsky-Shavell would argue that the individual's willingness to pay for this change would be:

$$\begin{aligned} \text{willingness to pay} &= P_q \cdot (q_2 - q_1) \\ &= P_q \cdot dq \\ &= PV_2 - PV_1 \end{aligned} \qquad (7)$$

However, this is not the willingness to pay for the small and open area case. The above measurement implicitly assumes that the individual can trade his housing unit with the characteristics described by B and move to a housing unit possessing the characteristics described by point C (allows him to reach indifference curve I_1) so that quiet and other housing characteristics are optimally combined. But, if the market price of quiet does not change, no other individual would be willing to trade with this individual (as they would already be in an equilibrium position given the price P_q) and he would be constrained to remain at point B. His willingness to pay for this exogenous change, therefore, would not be $PV_2 - PV_1$ but rather $V_1 - V_2$. Given the standard, convex-to-the-origin indifference curves, $V_1 - V_2$ is always less than $PV_2 - PV_1$ and thus, the Ridker-Henning measure of willingness to pay overstates the true value.

The question that arises is how can the value of $V_1 - V_2$ be measured. I should be noted that the indifference curves presented in Figure 4-1 imply that the individual has a utility function of the form:

$$U = U(v, q) \tag{8}$$

where v is the *value* of housing characteristics other than quiet and q is the level or *quantity* of quiet.[13] A movement from point A to point D reflects a change in v of $dv = V_1 - V_2$ and a change in q of $dq = q_2 - q_1$. However, this movement also entails no change in the level of utility as the individual is indifferent between the housing bundle described by A and the one described by D (on the same indifference curve, I_0). Thus, the value of dv (willingness to pay for the exogenous change in quiet of dq) depends upon how the individual is willing to trade off other housing characteristics against quiet, in other words it depends upon his marginal rate of substitution between v and q.

In Appendix A the mathematical derivation of the value dv is outlined. This derivation indicates that willingness to pay for quiet, as measured by dv, can be calculated as:

$$dv = \sqrt{qv \cdot \sigma \left[\frac{-d^2U(U_q)}{U_v(qU_q + vU_v)} \right]} \qquad (9)$$

where σ is defined to be the elasticity of substitution between quiet and the value of housing characteristics other than quiet. The elasticity of substitution measures the degree of substitutability that exists between q and v, and can take on values between zero (not substitutable) and a positive infinity (perfectly substitutable).

The implications of equation (9) are readily apparent. The elasticity of substitution measures the degree of substitutability that exists between the value of housing characteristics other than quiet and the level of quiet. If the elasticity of substitution is zero, the individual would not be willing to substitute quiet for other housing characteristics (thus generating a set of right-angled indifference curves) and the value dv would be zero. This means that if σ = 0, the individual would not be willing to pay anything for an exogenous increase in the level of quiet. The larger the elasticity of substitution, the greater becomes the value of dv. Thus, the more substitutable quiet is for other housing characteristics the more an individual would be willing to pay for an exogenous increase in the level of quiet.

4.2 Hedonic Price Estimates

The process of deriving actual empirical estimates of the hedonic prices associated with the various housing characteristics involves three fundamental steps:

(1) selection of an appropriate sample of households,

(2) selection of an appropriate set of variables that describe the various housing characteristics, and

(3) selection of an appropriate functional form for the estimated hedonic price function.

This thesis examines the impact that aircraft noise has on property values in the City of Edmonton and concentrates upon the Edmonton Industrial Airport as the primary source of aircraft noise. The reason for this choice of locations is twofold. As has been discussed previously, the Industrial Airport is located within the boundary of the City of Edmonton and is surrounded by residential development. Thus, the damage due to the noise generated by aircraft approaching and leaving the airport should be reflected in these residential property values. At the same time, the effects of this aircraft noise are isolated within relatively small neighbourhoods as only certain areas of the city lie under low level aircraft flight paths. Thus, the damage due to this aircraft noise can be estimated using the Polinsky-Shavell assumption of "small and open" areas.

The primary data used to generate the empirical results came from the multiple listings data gathered by the Edmonton Real Estate Board. The Multiple Listings Service collects information about all properties sold under a multiple listing. This information includes both data about the actual sales transaction (asking price, sale price, date of sale, etc.) as well as data describing the property being transacted (floor area, lot size, house style, etc.). Thus, the multiple listing data provide the basic elements required to generate the hedonic price function. This data source was augmented by various other types of descriptive data, such as distance variables, zoning information, and noise levels, from various other sources. A summary of the variables used in the estimation process, as well as the sources of data, appear in Table 4-1.

It should be noted that the use of the data set, as described above, is a significant departure from most of the previous attempts (for example, Ridker and Henning,[14] de Vany,[15] and Mary [16]) to measure the willingness to pay for environmental amenities. In previous studies, assessed average or median property values have been regressed against a set of average or median housing and neighbourhood characteristics. Thus, for the most part, they do not measure actual market transactions. The use of the

Table 4-1

Description and Sources of Data

Variable Name	Description and Source
PRICE	Sales price in dollars. *Multiple Listing Service* (1975-76)
FLOOR	Floor area in 100's of square feet. *MLS* (1975-76)
LSIZE	Lot size in 100's of square feet. *MLS* (1975-76)
AGE	Number of years since construction. *MLS* (1975-76)
BATH4	Number of 4-piece bathrooms. *MLS* (1975-76)
BROOMS	Number of bedrooms. *MLS* (1975-76).
FIRE	A 0-1 dummy variable equal to one if the property has a fireplace. *MLS* (1975-76)
DGAR	A 0-1 dummy variable equal to one if the property has a garage. *MLS* (1975-76)
TWO	A 0-1 dummy variable equal to one if the property is a two-storey house. *MLS* (1975-76)
DUP	A 0-1 dummy variable equal to one if the property is a duplex. *MLS* (1975-76)
BRICK	A 0-1 dummy variable equal to one if the property has a brick exterior finish. *MLS* (1975-76)
DBASE	A 0-1 dummy variable equal to one if the property has a finished basement. *MLS* (1975-76)
TAX	The effective property tax rate for the tax year prior to sale. *MLS* (1975-76)
DCBD	Distance to the central business district in miles. *City of Edmonton, Transportation Planning Department* (1974)
DZ2	A 0-1 dummy variable equal to one if the property is located in an area zoned for duplexes. *City of Edmonton, Zoning Maps* (1975)
DZ3	A 0-1 dummy variable equal to one if the property is located in an area zoned for apartments. *City of Edmonton, Zoning Maps* (1975)
NOISE	Noise Exposure Forecast (NEF) contour corresponding to location of property. *Ministry of Transport, Canadian Air Transportation Administration* (1976)
QUIET	60-NOISE

Multiple Listing Service data does measure these transactions, as only houses offered for sale and purchased appear in the data set. At the same time, all of information concerning the housing unit is site-spe data that describes the particular unit being transacted. Therefore, use of the multiple listings data should provide a better measure of how the market actually values the various housing characteristics.

The selection of the appropriate functional form for the estimation of the hedonic price function is a problem of determining [illegible] structural form of the equation provides the best fit [illegible] empirical data and yet is consistent with the theoreti[illegible] model. For the purposes of this thesis, a linear functional form was chosen for the estimated hedonic equation for two main reasons: (1) the use of other functional forms provided no increase in the explanatory ability of the equation, and (2) previous property value studies had also used the linear form. Thus, the hedonic price equation was estimated as a function of the form:

$$PV = \beta_0 + \sum_{i=1}^{n} \beta_i h_i + \alpha \cdot q + e \qquad (10)$$

where PV equals property value, the h_i are housing characteristics other than quiet, q is the level of quiet and e is the error term.

The above hedonic equation was empirically estimated cross-sectionally using 352 observations of individual house transactions in the City of Edmonton. These 352 observations corresponded to all the residential, multiple listings transactions that occurred within the areas affected by aircraft noise from the Edmonton Industrial Airport during the one-year period from September, 1975 to September, 1976.[17] The dependent variable in this multiple regression analysis was the actual sale price associated with each multiple listings transaction (the variable PRICE in Table 4-1). The independent variables corresponded to the list of housing characteristics described in Table 4-1; with one exception. Instead of using the level of noise as an independent variable, the hedonic price function was estimated using a measure of the amount of quiet prevailing at a particular location. The advantage of this type of equation is that it yields directly an implicit price for quiet which can be treated as a good, rather than an implicit price for noise which has to be regarded as a "bad".

Since the observations of noise levels in the sample took on values ranging from an NEF contour of 20 to a contour of 40 (quietest to noisiest), it was decided that an appropriate index for quiet would be one that exactly reverse [illegible] se index. Thus, the level of quiet, QUIET, was [illegible] as:

$$QUIET = 60 - NOISE \tag{11}$$

It was found that the regression equation provided the best explanation of the variation in the dependent variable, PRICE, if the square root of QUIET was used as an independent variable rather than QUIET. Thus, a new variable, QUROOT, was generated as:

$$QUROOT = \sqrt{QUIET} \tag{12}$$

and used as the variable measuring the effect of aircraft noise on property values. The ordinary least squares results of this regression analysis appear in Table 4-2.[18]

As can be seen from Table 4-2, some of the housing characteristics are negatively related to property values and some are positively related. Those characteristics that decrease property values include age of the property (AGE), style of house other than bungalow (TWO and DUP), distance to the central business district (DCBD), zoning for uses other than single-family residential (DZ2 and D[illegible]) and the effective tax rate (TAX).[19] Property values [illegible] positively related to floor area (FLOOR), number of bathrooms (BATH4), number of bedrooms (BROOMS), fireplaces (FIRE), garages (DGAR), finished basements (DBASE),

Table 4-2

Estimated Hedonic Price Equation
(Quiet as an Independent Variable)

Dependent Variable: PRICE

Independent Variable	Estimated Coefficient	Standard Error	T-Statistic
CONSTANT	32,553	7,604	4.28*
FLOOR	1,422	231	6.15*
AGE	-538	101	-5.35*
BATH4	5,368	831	6.46*
BROOMS	1,288	726	1.78*
FIRE	5,399	1,508	3.58*
DGAR	5,654	1,103	5.13*
TWO	-5,386	1,235	-4.36*
DUP	-3,346	1,814	-1.84*
DBASE	3,074	811	3.79*
BRICK	6,421	2,913	2.20*
LSIZE	111	36	3.12*
DCBD	-1,339	378	-3.54*
DZ2	-1,157	1,239	-0.93
DZ3	-504	1,482	-0.34
TAX	-1,192,490	171,069	-6.97*
QUROOT	1,470	1,037	1.42**

Number of Observations = 352

R^2 = .6217

* Significant at the 95 percent level of confidence, one-tailed t-test

** Significant at the 90 percent level of confidence, one-tailed t-test brick exterior finish (BRICK) and lot size (LSIZE). All of the coefficients associated with these variables are significantly different from zero at the 95 percent level of confidence except for the zoning variables DZ2 and DZ3. All of the coefficients were of the generally expected signs.

However, for the purpose of this study, the most important coefficient relates to the relationship between property value and the level of quiet. In the regression equation of Table 4-2, a positive relationship is found to exist between PRICE and QUROOT so that, *ceteris paribus*, property values tend to increase as the level of quiet rises. Thus, it is possible to conclude that quiet is an environmental amenity and that the market does place a "value" on quiet, as the coefficient associated with QUROOT is both positive and significantly different from zero at the 90 percent level of confidence.

It is also possible to use the equation generated from the multiple regression analysis to calculate the implicit, or shadow, price of quiet. The regression equation in Table 4-2 is of the form:

$$PV = \hat{\beta}_0 + \sum_{i=1}^{n} \hat{\beta}_i h_i + \hat{\alpha} \cdot q^{\frac{1}{2}} + \hat{e} \qquad (13)$$

where $q^{\frac{1}{2}}$ is noth[illegible]g m[illegible] than the square root of quiet or QUROOT in the re[illegible] [illegible]nalysis. In a linear hedonic equation, the par[illegible] [illegible]rivative of PV with respect to q would yield the price of quiet, so that:

$$\frac{\partial PV}{\partial q} = \hat{P}_q = \tfrac{1}{2}\,\alpha\, q^{-\frac{1}{2}} \qquad (14)$$

Since the coefficient associated with QUROOT has an estimated value of $1,470 (from Table 4-2), the estimatd price of quiet becomes:

$$\hat{P}_q = \tfrac{1}{2}(1470)q^{-\frac{1}{2}} = 735q^{-\frac{1}{2}} \qquad (15)$$

This result indicates that the price of quiet is not constant, but rather changes as the level of quiet, q, changes. Thus, as the level of quiet increases, the price of quiet (or the rate at which the market trades an additional increment of quiet against other housing characteristics) declines. This particular result will prove to be significant in the calculation of the elasticity of substitution that appears in Section 4.3 of this paper.

Further empirical analysis was conducted to determine whether only one price for quiet prevailed in the housing market. Specifically, it was postulated that the price of quiet, or the rate at which individuals were willing to trade quiet against other housing characteristics, might be different for different valued houses. That is, individuals owning expensive houses might value quiet differently than individuals who own cheaper houses so that instead of one homogeneous market for quiet existing for all houses, there might be a series of sub-markets existing. To test this hypothesis an equation of the following form was estimated:

$$PV = \beta_0 + \sum_{i=1}^{n} \beta_i h_i + \alpha_1 D_1 q + \alpha_2 D_2 q + \alpha_3 D_3 q + e \qquad (16)$$

where D_1, D_2, and D_3 were 0-1 dummy variables that were equal to one when the price of a particular house had the following values:

$D_1 = 1$ when PRICE $<$ \$45,000.

$D_2 = 1$ when \$45,000 $\leq$ PRICE $\leq$ \$55,000.

$D_3 = 1$ when PRICE $\geq$ \$55,001.

The sum of the squared residuals from the above regression equation was compared to that of the regression equation found in Table 4-2 to determine whether the inclusion of the dummy variables provided a significantly better explanation of the variation in the dependent variable, PRICE. An F-test was conducted and it was concluded that the dummy variables did *not* improve the explanatory ability of the regression equation. Therefore, it is possible to conclude that a system of sub-markets does not exist and that only one marginal price for quiet prevails throughout the area affected by aircraft noise in the City of Edmonton.

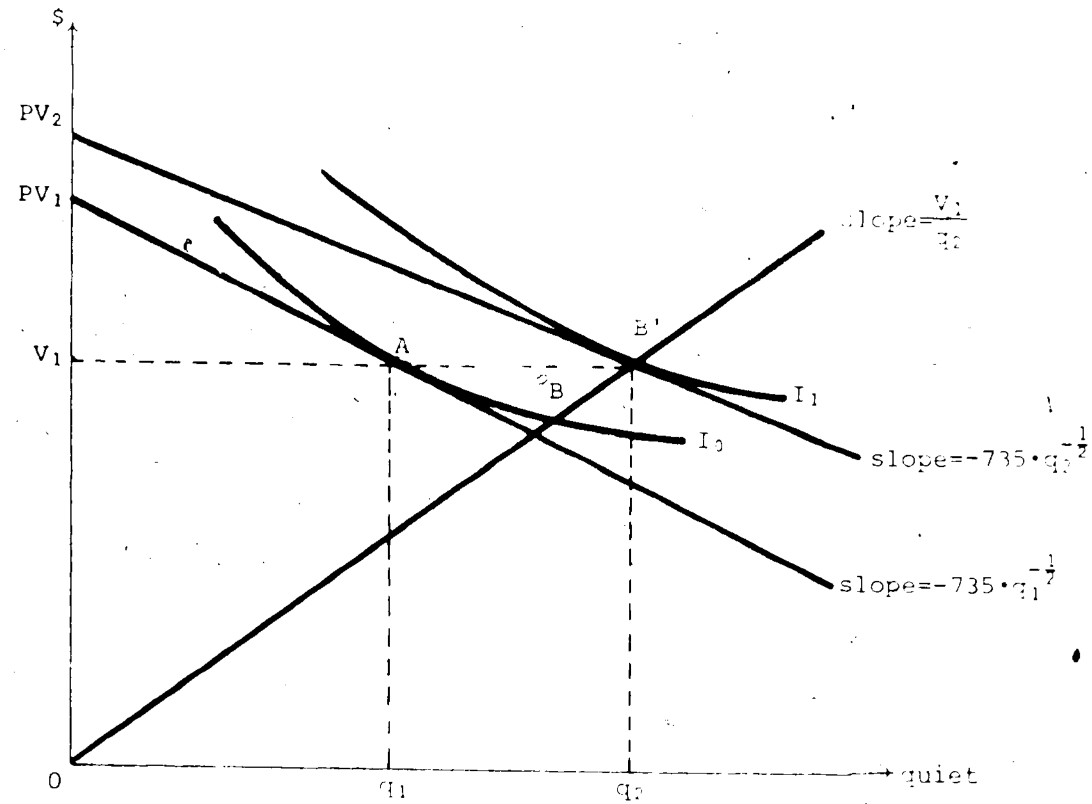
4.3 The Elasticity of Substitution

In the previous section of this chapter, multiple regression analysis was used to calculate the implicit price of quiet. However, it has also been established in Section 4.1 that information about the price of quiet is not sufficient to determine the willingness to pay for an exogenous increase in the level of quiet (that might result, for an example, from an aircraft noise abatement program). Willingness to pay depends not only upon the price of quiet but also upon the elasticity of substitution between quiet and other housing characteristics. Thus, a question arises as to how the elasticity of substitution can be measured, given the limited amount of information available.

Figure 4-2 depicts a situation in which there are two individuals located in different neighbourhoods, each neighbourhood having a different level of quiet. Individual 1 is located in neighbourhood one and owns a house for which the value of housing characteristics other than quiet is V_1 dollars and the level of quiet is q_1. Individual 2 is located in neighbourhood two and owns a house for which the value of housing characteristics other than quiet is V_1 and the level of quiet is q_2. Both individuals 1 and 2 are in an equilibrium position at points A and B', respectively. Individual 2 is located on a higher indifference curve than is individual 1 and owns a house with a higher total property value ($PV_2 > PV_1$) because his house has more quiet associated with it than does the one belonging to individual 1.

If it is assumed that both individuals have *iden-*

Figure 4-2: Measuring the Elasticity of Substitution



tical preferences then the indifference curves I_0 and I_1 reflect the relative preference for housing characteristics and quiet for both individuals. If this is the case, then the only reason why individual 2 is located at point B' and individual 1 at point A, is that individual 2 has a higher income than individual 1. Since both individuals 1 and 2 are in equilibrium positions at their respective locations, the indifference curves I_0 and I_1 must be tangent to the price lines at points A and B' (the marginal rate of substitution between housing characteristics and quiet must be equal to the slope of the price line). This means that the marginal rate of substitution at point A must be equal to the slope of the line PV_1A and the marginal rate of substitution at B' must be equal to the slope of the line PV_2B'. If, however, the price of quiet is the same as that generated by the hedonic regression analysis in Section 4.2 of this chapter (where $P_q = 735\ q^{-1}$), the slope of the price line at A is different from the slope of the price line at B' because the level of quiet is different at these points. Since the empirical analysis indicates that the price of quiet declines as the amount of quiet rises, the marginal rate of substitution at point B' is less than the marginal rate of substitution at A.

If it is assumed that, not only are the individuals' preferences identical, but also "homothetic"[20] then it is possible to relate the marginal rates of substitution found on the indifference curve I_1 to those on indifference curve I_0.

An assumption of homotheticity implies that the marginal rates of substitution along any ray drawn from the origin through the various indifference curves must be equal. Thus, if preferences are homothetic, the marginal rate of substitution at point B must be the same as the marginal rate of substitution at point B'. This means that points B and B' are associated in two ways. The ratio of the value of housing characteristics other than quiet to the level of quiet must be equal because they are both on the ray OBB' (which has a slope V_1/q_2), and the slopes of the two indifference curves must be equal at these two points. Thus, if the assumptions of identical and homothetic preferences are made then it should be possible to derive enough information about the indifference curve I_0, by taking different levels of quiet in combination with the value V_1, to permit the calculation of the elasticity of substitution along that curve.

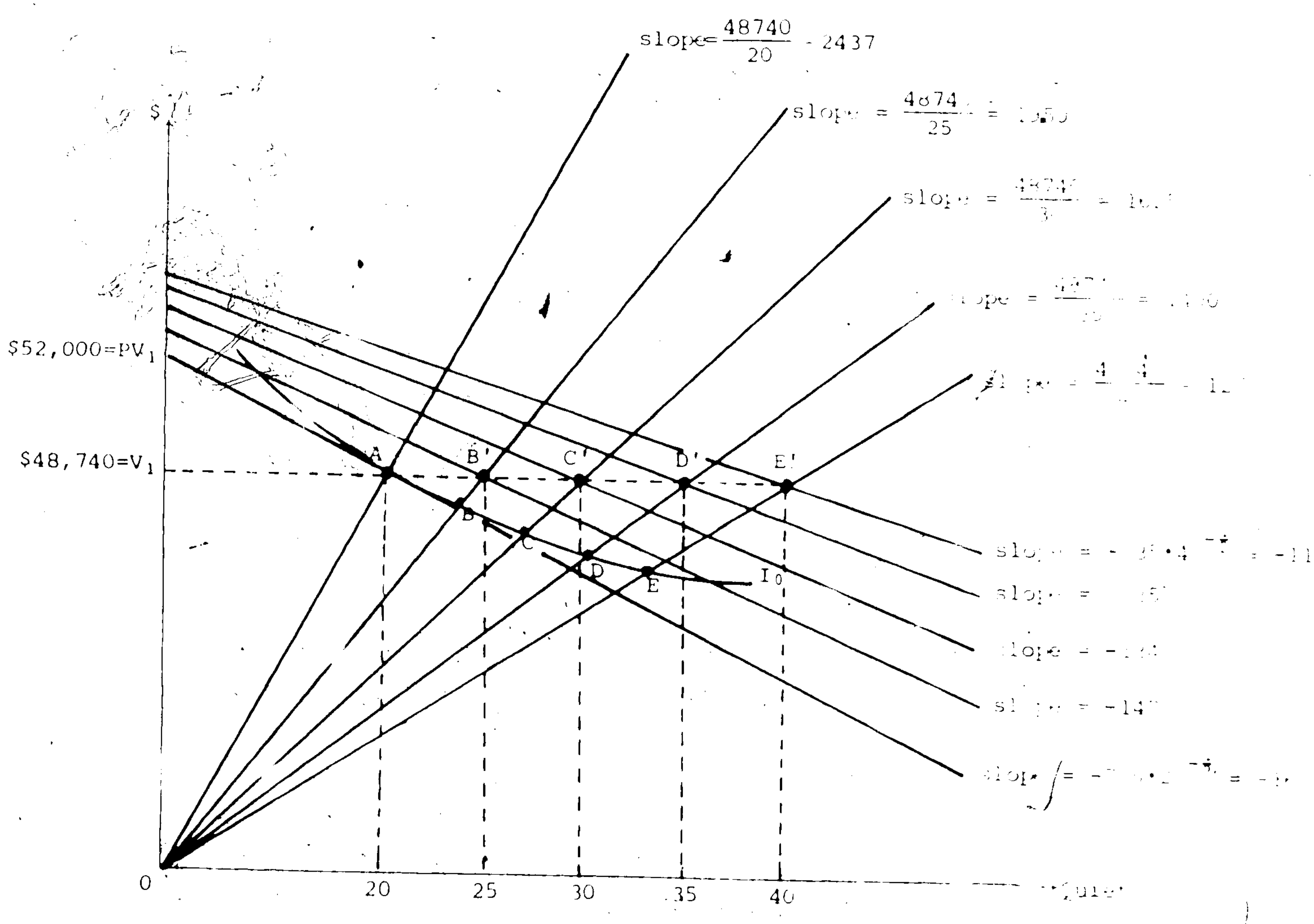
The question that must be asked is whether it is reasonable to make the assumptions of identical and homothetic preferences. The assumption of identical preferences is somewhat arbitrary and, for the most part, cannot be empirically substantiated without a great deal more information concerning the nature of individual preferences. There is, however, some empirical evidence that supports an assumption of homotheticity. A necessary, but not sufficient, condition for the existence of homothetic preferences is that the income elasticity of demand must be unitary. In an analysis of the demand for housing, Muth found that in many instances the income elasticity was estimated to have a value very close to one. Although a unitary elasticity is not sufficient to generate homothetic preferences, it does lend support to an assumption of homotheticity.

If the assumptions of homotheticity and identical preferences are made, it is possible to calculate the elasticity of substitution using the information provided by the hedonic price function. In Figure 4-3 the process of estimating the elasticity of substitution using the estimated hedonic price equation of Section 4.2 is demonstrated. The initial equilibrium point on indifference curve I_0 is at point A. The average priced house in the data sample was \$52,000. If the average house was located at point A, it would have a level of quiet of 20 (the noisiest of areas) and a value of housing characteristics other than quiet of V_1, where:

$$\begin{aligned} V_1 &= \$52{,}000 - \text{value of quiet} \\ &= 52{,}000 - P_q \cdot q \\ &= 52{,}000 - \left[735 \cdot 20^{-\frac{1}{2}}\right] \cdot 20 \\ &= 52{,}000 - 3{,}260 \\ &= \$48{,}740 \end{aligned} \tag{17}$$

Thus, at point A, the marginal rate of substitution (MRS)

Figure 4-3: An Estimate of the Elasticity of Substitution



is the slope of the price line passing through [illegible] in the diagram and the ratio of the value of housing characteristics other than quiet to the level of quiet is the slope of the ray OA (24[illegible] in the diagram). In a like manner, it is possible to determine the MRS and the ratios of goods for the points B, C, D, and E along indifference curve I[illegible] as these values are equal to the ones corresponding to the points B', C', D' and E', if the indifference curves are homothetic.

The elasticity of substitution is defined as the percentage change in the ratio of goods consumed divided by the percentage change in the marginal rate of substitution. Thus, the elasticity of substitution between points A and B, σ_{AB}, on indifference curve I[illegible] in Figure 4-3, can be calculated as:

$$\sigma_{AB} = \frac{V_B/q_B - V_A/q_A}{V_A/q_A} \cdot \frac{MRS_A}{MRS_B - MRS_A} \qquad (18)$$

$$\sigma_{AB} = \frac{1950 - 2437}{2437} \cdot \frac{-163}{-147 - (-163)}$$

$$\sigma_{AB} = 2.04$$

where the subscripts A and B refer the values at the points A and B, respectively. In a similar fashion, the elasticities of substitution between the points B and C (σ_{BC}), C and D (σ_{CD}) and D and E (σ_{DE}) can also be calculated. The results of this procedure are as follows:

Thus it is possible, using the hedonic price equation combined with the assumptions of identical preferences and homotheticity, to generate an estimate of the elasticity of substitution. The interesting thing to note about these estimated elasticities is that no matter where along the indifference curve I the measure is taken, the elasticity of substitution is estimated to be, approximately, two. This would indicate that the individual preferences for housing characteristics other than quiet and for quiet could be described by a CES (constant elasticity of substitution) utility function of the form:

$$U = U(v,q) = \gamma\left[\delta v^{-\rho} + (1-\delta)q^{-\rho}\right]^{-\frac{1}{\rho}} \qquad (21)$$

where the elasticity of substitution is equal to $\frac{1}{1 + \rho}$.

4.4 Measurement of Willingness to Pay

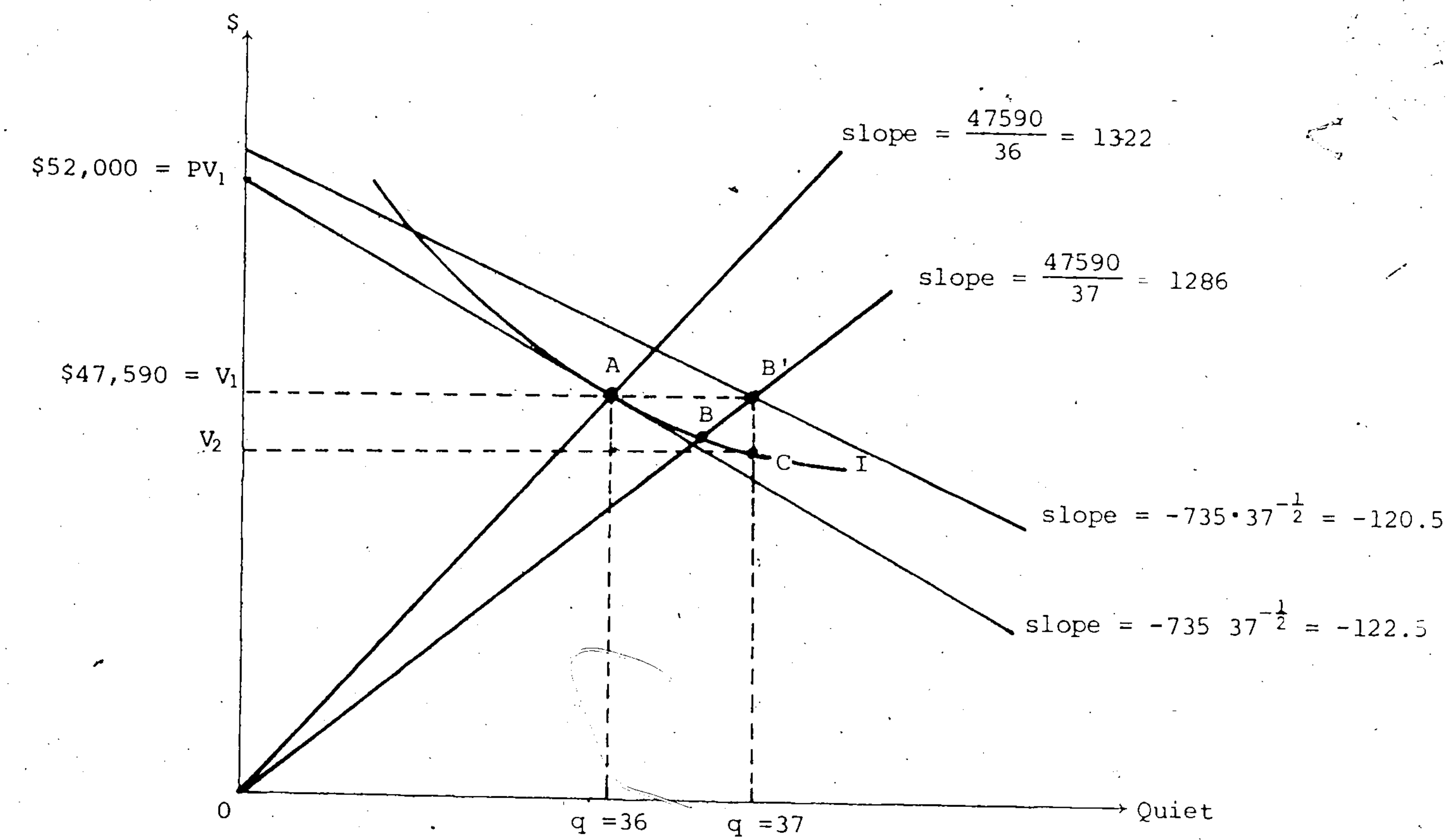
Earlier in this chapter, the problems of using predicted changes in property values to measure the willingness to pay for changes in the level of environmental amenities were discussed in some detail. It was concluded that the estimated hedonic prices of environmental amenities provided insufficient information, *by themselves*, to estimate willingness to pay. In order to derive an estimate of this type, it is also necessary to obtain information about how individuals are willing to substitute environmental amenities for other housing characteristics. In Section 4.3, it was demonstrated that it is possible to use the hedonic price equation, as estimated in the regression analysis described earlier in the chapter, to derive a measure of how substitutable quiet is for other housing characteristics. This measure is the elasticity of substitution. The question now arises as to whether the elasticity of substitution, combined with the hedonic price equation, provides an adequate amount of information to derive accurate estimates of the willingness to pay for quiet.

In Figure 4-4, the equilibrium situation of the "average household" is depicted. In the sample of 352 observations of real estate transactions, the average sale price was approximately $52,000 and the average level of quiet enjoyed by houses in the sample was 36.[25] This means that on average the value of an incremental unit of quiet, $\overline{P}_q$, prevailing in the market can be calculated as:

$$\begin{aligned} \overline{P}_q &= 735 \cdot q^{-\frac{1}{2}} \\ &= 735 \cdot (36)^{-\frac{1}{2}} \\ &= 122.5 \end{aligned} \tag{19}$$

from the hedonic price equation. For the average household

Figure 4-4: An Estimate of Willingness to Pay



to be in equilibrium, it is necessary for its marginal rate of substitution between quiet and other housing characteristics to be equal to the ratio of prices at a level of quiet of 36. This is depicted in Figure 4-4 as the point A, where the indifference curve I_0 is tangent to the price line at $q_1 = 36$. If the average total property value is \$52,000 when $q = 36$, the imputed value of housing characteristics other than quiet must be V_1, where:

$$V_1 = \$52{,}000 - 36(122.5) = \$47{,}590 \tag{20}$$

Now assume that through some noise abatement program the level of quiet associated with the average house increased from $q_1 = = 36$ to $q_2 = 37$, so that the average household moves from point A to point B', in Figure 4-4. The question is how much would the average household be willing to pay for this abatement program and the resulting increase in quiet? The standard Ridker-Henning approach would simply measure the willingness to pay (wtp) for such a change as $dq \cdot \overline{P}_q$ (the change in quiet multiplied by the average price of quiet) so as to derive:

$$\begin{aligned} wtp &= dq \cdot \overline{P}_q \\ &= (37 - 36) \cdot 122.50 \\ &= \$122.50 \end{aligned} \tag{21}$$

However, as has been demonstrated in Section 4.1, the Ridker-Henning measure over-estimates the true willingness to pay. The actual willingness to pay for the increased quiet is the distance B'C, which corresponds to the value $V_1 - V_2$. The calculation of the true willingness to pay depends upon determining the value of V_2, as V_1 is already known.

The elasticity of substitution is defined as the percentage change in the ratio in which the goods are consumed divided by the percentage change in the marginal rate of substitution. This means that the elasticity of substitution between points A and C in Figure 4-4 can be calculated as:

$$\sigma_{AC} = \frac{V_2/q_2 - V_1/q_1}{V_1/q_1} \quad \frac{MRS_A}{MRS_C - MRS_A} \tag{22}$$

where MRS_A and MRS_C correspond to the marginal rates of substitution at points A and C respectively. By rearranging terms, to solve for V_2 using the above equation:

$$V_2 = V_1 \frac{q_2}{q_1}\left[\sigma_{AC} \frac{MRS_C - MRS_A}{MRS_A} + 1\right] \tag{23}$$

The problem with the above equation is that while the values of q_1, q_2, V_1 and MRS_A are known, the values σ_{AC} and MRS_C are unknown. Thus, it is not possible to solve for V_2. If the elasticity of substitution was constant along

I_0, then $\sigma_{AC} = \sigma_{AB}$. Since it is possible to calculate σ_{AB}[26] following the procedure outlined in Section 4.3, a value for σ_{AC} could be derived. But it is not possible, however, to determine the value of the marginal rate of substitution between V and q at point C, without more specific information about the utility function and indifference curve I_0. Thus, the limited amount of information provided by the hedonic price function does not permit the precise calculation of willingness to pay for quiet.

The reason why it is not possible to calculate the exact willingness to pay is that it is impossible to "trace out" the original indifference curve I_0 in Figure 4-4, given the limited amount of information available. The values of v that correspond to the various levels of q along I_0 cannot be determined. However, it is possible to approximate the indifference curve and derive an estimate of the willingness to pay for additional units of quiet.

The estimated hedonic price function indicates that the marginal price of quiet declines as the level of quiet rises *ceteris paribus*, since $P_q = 735 \cdot q^{-\frac{1}{2}}$ is the partial derivative of the price function with respect to quiet.[27] Thus, when the average level of quiet increases from 36 to 37 in Figure 4-4, the "average" marginal price of quiet declines from \$122.50 to \$120.50, which is determined by evaluating the partial derivative at $q_1 = 36$ and $q_2 = 37$. The Ridker-Henning approach to measuring willingness to pay simply extends the original price of quiet over the change in the average level of quiet. In this measurement the marginal rate of substitution between quiet and other housing characteristics at point A is being applied to the entire segment AC of the indifference curve I. Therefore, the measurement is only correct if there is no curvature to the indifference curve (this would occur if the elasticity of substitution was infinitely large in value).

A better measure of the benefits derived from the increase in quiet would be to approximate the curvature that exists between points A and C (approximate the change in the marginal rate of substitution). This approximation could be given by the marginal rate of substitution at point B, which lies between points A and C. If the indifference curves are homothetic, the marginal rate of substitution at B would be equal to that of point B', where the MRS is equal to the price of quiet evaluated at $q_2 = 37$. Thus, an estimate of willingness to pay that is better than the Ridker-Henning estimate which could be derived by valuing the change in the level of quiet in terms of the marginal price of quiet that would prevail at $q_2 = 37$ rather than $q_1 = 36$. This would yield a measure of willingness to pay equal to:

$$\begin{aligned} wtp' &= (37-36) \cdot 735(37)^{-\frac{1}{2}} \\ &= (37-36)(120.5) \\ &= \$120.50 \end{aligned} \tag{24}$$

This measure of willingness to pay for quiet is superior to the Ridker-Henning approach because it recognizes that the marginal rate of substitution between quiet and other housing characteristics will change as the level of quiet changes. However, it does not measure the true willingness to pay for the exogenous change in quiet because it does not take into consideration the full change in the marginal rate of substitution. It is also not possible to say whether it is an over- or an under-estimate.

From equations (21) and (24), it would appear that the Ridker-Henning approach provides an estimate that is fairly close in value to the one provided by the procedure outlined above: \$122.50 versus \$120.50 or a difference of about 1.7%. However, this applies only to a one-unit change in the level of quiet. The error in the Ridker-Henning measurement becomes progressively worse as larger changes in the level of quiet are analyzed.

For example, suppose that a noise abatement program would increase the level of quiet from an average of 36 units to an average of 40 units. Ridker and Henning would measure the willingness to pay for this change as:

$$\begin{aligned} wtp &= (40-36) \cdot 735(36)^{-\frac{1}{2}} \\ &= (40-36) \cdot 122.5 \\ &= \$490.00 \end{aligned} \qquad (25)$$

However, using the modified approach suggested above a better estimate of willingness to pay could be generated by approximating the change in the marginal rate of substitution that would occur in moving from q = 36 to q' = 40. This can be done by valuing the change in quiet in terms of the price of quiet that would have prevailed had the new level been the average level of quiet. In moving from q = 36 to q' = 40, the marginal price of quiet would change as:

$$P_{q_1=36} = 735\cdot(36)^{-\frac{1}{2}} = 122.50$$

$$P_{q_2=37} = 735\cdot(37)^{-\frac{1}{2}} = 120.50$$

$$P_{q_3=38} = 735\cdot(38)^{-\frac{1}{2}} = 118.60$$

$$P_{q_4=39} = 735\cdot(39)^{-\frac{1}{2}} = 117.60$$

$$P_{q_5=40} = 735\cdot(40)^{-\frac{1}{2}} = 116.70 \qquad (26)$$

If the total change in quiet was decomposed into a series of one-unit changes, willingness to pay for each of these changes could be calculated in the same manner as was done in equation (24). The willingness to pay for the total change could then be derived by summing the willingness to pay for each of the one-unit changes, so that:

$$wtp' = (37-36)\cdot 735(37)^{-\frac{1}{2}} + (38-37)\cdot 735(38)^{-\frac{1}{2}} + (39-38)\cdot 735(39)^{-\frac{1}{2}} + (40-39)\cdot 735(40)^{-\frac{1}{2}} \qquad (27)$$

This gives a total willingness to pay of

$$wtp' = \$120.50 + \$118.60 + \$117.60 + \$116.70$$
$$= \$473.40 \qquad (28)$$

It can be seen, by comparing the results of equations (25) and (28), that the difference between the Ridker-Henning estimate and the above measure of willingness to pay has become considerably larger. The error in the Ridker-Henning estimate is now 3.4%. Thus, while the Ridker-Henning approach may provide reasonably accurate estimates of willingness to pay for very small changes in the level of quiet, the size of their error becomes progressively larger as more sizeable changes in the level of quiet are considered. For this reason, the method proposed in this section for measuring the benefits of a noise abatement program is to be considered superior to the standard Ridker-Henning method.[28]

One final extension can be made to this analysis, that being to determine what the *total* willingness to pay would be for a change in the *average* level of quiet. To do this it is necessary to combine the average willingness to pay, as calculated above, with some estimate of the number of households in the area affected by aircraft noise. A crude estimate, obtained from the 1971 Census of Canada data,[29] of the number of households in the area would be about 27,500. If these households have the same marginal valuation of quiet as was derived from the hedonic regression equation and are distributed geographically in the same way as the observations in the sample data, then the total willingness to pay for a change in the average level of quiet can be calculated as:

$$\text{wtp (one unit } \Delta q) = 27{,}500 \times 120.50 = \$3{,}313{,}750$$

$$\text{wtp (four unit } \Delta q) = 27{,}500 \times 473.40 = \$13{,}018{,}500$$

Thus, the total benefits of a noise abatement program designed to increase the average level of quiet by one unit (36 to 37) would be approximately $3,313,750. If the abatement program was designed to raise the average level of quiet to 40 units, the total benefits would rise to $13,018,500. To determine whether either of these programs are economically efficient, it would be necessary to compare the total benefits to the total costs of each program.

Footnotes

[1]It should be noted that it does not matter whether the model measures willingness to pay for quiet or damage due to noise. Since quiet is the absence of noise, the two values should be equivalent in magnitude, but opposite in sign. For the most part, Chapter IV will concentrate upon determining the willingness to pay for quiet. The reason for this is that since quiet is a "good" the standard economic models of consumer choice, in which the individual chooses among goods so as to maximize utility for a given income level, can be utilized without modification.

[2]A. Thomas King, *Property Taxes, Amenities and Residential Land Values* (Cambridge: Ballinger Publishing Co., 1973), p. 5.

[3]J. P. Nelson, "Residential Choice, Hedonic Prices and the Demand for Urban Air Quality," Unpublished Paper, the Pennsylvania State University (July 1975), p. 3.

[4]This discussion is a more rigorous development of the hedonic technique that has already been introduced in Section 3.2 of Chapter III.

[5]G. S. McDougall, "Hedonic Prices and the Demand for Local Public Goods," Unpublished Paper, Wichita State University (August, 1975), pp. 3-5.

[6]John Meullbauer, "Household Production Theory, Quality, and the Hedonic Technique," *American Economic Review*, 64 (December, 1974), p. 977.

[7]R. G. Ridker and J. A. Henning, "The Determinants of Residential Property Values with Special Reference to Air Pollution," *Review of Economics and Statistics*, 49 (May, 1967), pp. 246-257.

[8]This debate, along with the Ridker and Henning article, is discussed in detail in Section 3.2 of Chapter III.

[9]Nelson, "Residential Choice, Hedonic Prices and the Demand for Urban Air Quality," p. 6.

[10]A. Myrick Freeman, "Air Pollution and Property Values: A Further Comment," *Review of Economics and Statistics*, 56 (November, 1971), p. 555.

[11]Sherwin Rosen, "Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition," *Journal of Political Economy*, 82 (1974), pp. 51-54.

[12]A. M. Polinsky and S. Shavell, "The Air Pollution and Property Value Debate," *Review of Economics and Statistics*, 57 (February, 1975), pp. 100-104.

[13]It should be noted that this is not a standard utility function because it incorporates a mix of "value" and "quantity". What is being implicitly assumed to derive a function of this form is that the prices of housing characteristics other than quiet remain constant so that a composite commodity, v, can be utilized to represent all of those characteristics.

[14]Ridker and Henning, "The Determinants of Residential Property Values with Special Reference to Air Pollution," pp. 246-257.

[15]A. S. DeVany, "An Economic Model of Airport Noise Pollution in an Urban Environment," in *Theory and Measurement of Economic Externalities*, ed. by Steven Lin (New York: Academic Press Ltd., 1976), pp. 205-214.

[16]Hans-Werner Mary, *The Influence of Aircraft Noise Annoyance on Single-Family House Prices: A Case Study of Edmonton's Industrial Airport*, Unpublished M.A. Thesis, University of Alberta, 1975.

[17]A breakdown of the distribution of observations among the various noise levels can be found in Appendix B.

[18]For comparison purposes, the regression results using the variable QUIET rather than QUROOT appear in Appendix C. The regression analysis was also conducted using the level of noise as an independent variable. The results of this analysis appear in Appendix D. Since the variable QUIET was defined simply as the reverse of NOISE, these regression results parallel those of Table 4-2. As expected, the best fitting regression equation was one that used a non-linear term for the noise level, in this case the level of noise squared. Thus, the results presented in Appendix B use the variable NOISE2, where:

$$\text{NOISE 2} = \text{NOISE} \times \text{NOISE}$$

It should be noted that while the coefficient associated with QUROOT in Table 4-2 is positive, the coefficient associated with NOISE2 is negative. This again is to be expected if quiet is an environmental amenity and noise a disamenity.

[19]The effective tax rate (ETR) is a measure of tax burden developed by Wallace E. Oates in his article "The Effects of Property Taxes and Local Public Spending on Property Values: An Empirical Study of Tax Capitalization and the Tiebout Hypothesis," *Journal of Political Economy*, 77 (1969), pp. 957-971. The effective tax rate is defined as:

$$\text{ETR} = \frac{\text{Total Property Taxes}}{\text{Market Value of Property}}$$

If property taxes are capitalized into house prices, it would be expected that a negative relationship exists between ETR and property value, *ceteris paribus*.

It has already been assumed that the consumers' utility functions are separable (see Chapter III) in order to generate the theoretical model on which these empirical results are based. Thus, the empirical results rest on the assumption that separable, homothetic and identical utility functions describe the preferences of individuals affected by noise.

[21]Kevin Lancaster, *Introduction to Modern Microeconomics* (Chicago: Rand-McNally Publishing Co., 1974), pp. 97-98.

[22]Meullbauer, "Household Production Theory, Quality and the Hedonic Technique," p. 979.

[23]Muth, *Cities and Housing*, pp. 199-200.

[24]It should be noted that if the calculation of the elasticity of substitution had begun on a different indifference curve, say at the average priced house with a level of quiet of 25 units, an elasticity different from 2 would have been generated. Thus, there are different σ's for different indifference curves.

[25]The average house was located in an area with an NEF contour of 24. Since the index of quiet is defined as 60 - NOISE, this means that the average level of quiet was 36.

[26]The elasticity of substitution between points A and B can be calculated as follows:

$$\sigma_{AB} = \frac{1286 - 1322}{1322} \cdot \frac{-122.5}{-120.5 - (-122.5)} = 1.7$$

This calculation is possible because information is available about the ratio of goods consumed at point B' which also applies to point B. If the utility function is assumed to be homothetic, then the marginal rate of substitution at B' (which is equal to the price of quiet at q = 37) is equal to the MRS_B.

[27]At this point it should be noted that when the price function is of the form $P_q = 735 \cdot q^{-\frac{1}{2}}$, the individual consumer faces a nonconvex budget constraint set because the market price of quiet declines as the quantity of quiet purchased rises. Thus, for the model to generate an interior optimum (*i.e.* consumer purchases *both* housing characteristics and quiet) it is necessary to assume that the curvature of the indifference curves is greater than the curvature of the budget curve.

[28]This difference between the Ridker-Henning measure and the one suggested in this chapter can be highlighted by examining a larger change in quiet. If the average level of quiet had been $\bar{q} = 25$, the average price of quiet would have been $\bar{P}_q = 735(25)^{-\frac{1}{2}} = 147.0$. If the level of quiet was changed by 15 units to q - 40, Ridker and Henning would estimate the average benefits to be $2205. The measure provided in this chapter would yield a willingness to pay for the same increase of $1932.

Statistics Canada, 1971 Census of Canada, *Population and Housing Characteristics by Census Tracts: Edmonton.*

CHAPTER V

SUMMARY AND POLICY IMPLICATIONS

This thesis has attempted to provide both a theoretical and an empirical framework in which the problem of aircraft noise can be analyzed. In the broadest context, aircraft noise can be considered to be an external diseconomy that reduces the utility levels of individuals residing in proximity to an airport or along aircraft flight paths. As is demonstrated in Chapter II, the existence of an external diseconomy can lead to an inefficient allocation of resources with too much air transport services or too little noise abatement (and, thus, too little quiet environment) being provided to society simply because the air transport industry does not bear the full costs of its operations. To determine an efficient allocation of resources, or at least what constitutes a movement towards efficiency, requires that it be possible to derive a measure of society's willingness to pay for quiet, or conversely, the costs of aircraft noise.

Several difficulties arise in the measurement of the willingness to pay for quiet. Quiet is not a private good transacted in a singular market like most private goods. Rather, it is a good produced and consumed jointly with other housing characteristics so that a market price for quiet is not readily observable. At the same time, the provision of a quiet environment possesses public good characteristics so that if the level of quiet is changed for one individual, it is also changed for all other individuals residing in the affected area. This means that willingness to pay cannot be determined by simple survey techniques as individuals will have a tendency to either under- or over-estimate the damage due to aircraft noise, to avoid paying their share of the costs of any noise abatement program.

Thus, the main emphasis of this thesis has been twofold. First, in Chapter III, an attempt has been made to formulate a theoretical model capable of measuring the willingness to pay for quiet. It was found that property value studies, first initiated by Ridker and Henning, could be used to estimate the willingness to pay for exogenous changes in the level of quiet under certain restrictive conditions (particularly, if the area was "small and open"). More generally, it was also demonstrated that the original Ridker-Henning method of imputing willingness to pay was incorrect, and that a more precise measure required information about how individuals were willing to substitute between quiet and other housing characteristics. Secondly, the thesis concentrated on deriving empirical estimates of the willingness to pay for quiet in the City of Edmonton. This was accomplished by the use of the hedonic regression technique. House prices were regressed against a vector of housing characteristics, quiet included, so that the implicit marginal price of quiet could be determined. It was empirically found that the marginal price of quiet varied with the level of quiet such that the marginal price declined as the level of quiet increased. By assuming that individual preferences for quiet and other housing characteristics were both identical and homothetic it was possible to utilize the marginal price function to derive an estimate of how individuals were willing to substitute between quiet and other housing characteristics (the marginal rate of substitution). This estimate of the marginal rate of substitution was then used to calculate an estimate of the willingness to pay for changes in the level of quiet. The results of this empirical analysis appeared in Chapter IV.

The analysis presented in this thesis can also be used to assess the policies currently in effect to deal with the problem of aircraft noise in the City of Edmonton. These policies were originally discussed in Section 1.4 of Chapter I.

The first policy considered was the responsibility of the City of Edmonton's Assessment Department. This policy was first instituted in the late 1950's and involves a reduction of from two to eight percent in the assessed values of houses located in areas affected by aircraft noise. Thus it is designed to compensate, through reduced property taxes, houseowners in high noise areas. The question that arises is what is the impact of this policy and does it result in a more efficient allocation of resources?

This policy is supposedly designed to provide a form of annual compensation to individuals so as to offset the costs of aircraft noise. Yet, the empirical results shown in Table 4-2 suggest that it will achieve neither objective. In the first instance, a reduction in property taxes will decrease the effective rate of taxation (the variable TAX in Table 4-2) associated with the particular property. The regression analysis indicates that this reduction in the effective tax rate will increase the total property value because the coefficient associated with the variable TAX is negative in sign. For example, if an average-priced home was located in the noisiest area and if the eight percent reduction in assessed property value was translated into an eight percent reduction in yearly property taxes, the effective tax rate would be 0.1% points lower (about $37 per year in taxes) than if it were located in an area with no aircraft noise. This 0.1% decrease in the effective tax rate would increase the property value by $1,192 according to the coefficient attached to the variable TAX in Table 4-2. If the tax reductions were being *fully* capitalized into increased house price this would imply a real rate of time discount of about four percent. Since four percent is not an unrealistic figure to expect, it may be possible to conclude that tax reductions are fully, or close to fully, capitalized into increased house prices.

Thus, the only individuals who actually benefit from the tax policy are those who owned a house in the noise area when the policy was first implemented. Reduced property taxes are capitalized into increased property values so that subsequent owners of the affected houses essentially "pay" for the compensation. Thus, the tax policy is not a continuous form of compensation.

At the same time, the reduction in assessed values does not fully offset the costs of aircraft noise. If the policy was totally effective, the coefficient associated with the variable QUROOT in Table 4-2 should not be significantly different from zero meaning that the level of quiet (or noise) should not affect house prices. Since this coefficient is significantly different from zero and of the appropriate positive sign, the tax policy, with its two to eight percent reduction in assumed values, does not fully compensate for all of the costs associated with aircraft noise.

The question can also be raised as to whether this type of compensation policy is consistent with the achievement of an efficient allocation of resources. In Chapter II, it was argued that the victims of an undepletable external diseconomy like aircraft noise should be neither taxed nor compensated, so that they bear the full social cost of their location decision. If no compensation is forthcoming, individuals will tend to geographically separate themselves from the source of the external diseconomy, thus reducing the total costs of the externality. It can be concluded then, that if the City of Edmonton's compensation policy is at all "successful", it may in fact lead to an inefficient allocation of resources by encouraging individuals to live in proximity to the Industrial Airport.

The second policy in effect in the City of Edmonton is the Central Mortgage and Housing Corporation policy with respect to the granting of NHA financing for houses located in areas affected by aircraft noise. CMHC will not grant financing for houses located in an area with an NEF value greater than 35 and will only grant financing for houses located in an area with an NEF value between 25 and 35 if adequate sound insulation is installed. This is essentially a zoning policy designed to restrict residential development in high noise locations. The policy appears to be consistent with the achievement of an efficient allocation of resources because it encourages geographic separation between the source and victims of the external diseconomy. However, it is an unnecessary policy because if the victims of the externality are not compensated in any way, they bear the full social cost of their location decision. Thus, it can be expected that individuals would naturally tend to separate themselves from the sources of aircraft noise, making the CMHC policy redundant. However, this assessment of the CMHC policy ignores the fact that it may be *politically* necessary to utilize zoning in order to prevent individuals from locating in proximity to an airport and *then* attempting to secure compensation for the aircraft noise they are enduring at that location.

The third policy discussed in Chapter I was the recommendations that arose from the master plan for airport services developed jointly by the City of Edmonton and the Canadian Air Transportation Administration. One of the recommendations that came out of this study was that the utilization of the Industrial Airport be reduced by building a satellite airport outside of the City of Edmonton to handle privately-owned light aircraft. This recommendation was developed without considering whether it was "economically efficient", that is, whether the benefits produced by such a move exceeded the costs involved.

One of the problems associated with an economic evaluation of such a move is that many of the benefits, such as the reductions in aircraft noise, that are anticipated could not be measured. However, this thesis indicates that a measurement to estimate the value of one such factor, noise, is possible. By following the procedure outlined in Chapter IV and by estimating what changes in the level of noise could be expected from some particular planned change in the usage of the Industrial Airport (or any airport, for that matter) the willingness to pay for the additional quiet created by that plan could be estimated. This measure could then be used as *one* input into an economic evaluation designed to assess the economic efficiency of any proposed change in the operation of the Industrial Airport.

This thesis has provided both a theoretical and an empirical framework in which the problem of aircraft noise can be analyzed. It should be recognized, however, that there are several limitations to the analysis. To derive the empirical estimates of the willingness to pay for quiet it was necessary to assume that individual preferences were both identical and homothetic. These restrictive assumptions could not be empirically substantiated because of the limited amount of data available. This suggests that the techniques developed within this thesis must be applied with caution and with a due recognition of their limitations. At the same time, the measurement of the willingness to pay for changes in the level of quiet correctly applies only to marginal changes. Infra-marginal or "large" changes in the level of quiet that alter the basic supply and demand characteristics of the market cannot be evaluated using the methodology developed in this thesis.

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APPENDIX A:

THE RELATIONSHIP BETWEEN THE ELASTICITY OF SUBSTITUTION AND WILLINGNESS TO PAY

Given that the utility function is $U(v,q)$, the movement from point A to D in Figure 4-1 entails no change in the level of utility as it is a movement *along* the indifference curve I_0. Such a movement must result in the total differential of the utility function, dU, being zero:

$$dU = U_q dq + U_v dv = 0 \tag{1}$$

where U_q is the partial derivative of U with respect to q and U_v is the partial derivative of U with respect to v. If v and q were independent of each other, the above equation could be used to solve for dv. But this is not the case, as:

$$dq = -\frac{U_v}{U_q}dv \tag{2}$$

where U_v/U_q is the marginal rate of substitution (MRS) between q and v. This means that the second-order differential must be used to solve for dv, where the second-order differential of U is given by:

$$d(dU) = d^2U = U_{qq}(dq)^2 + U_{vv}(dv)^2 + 2U_{qv}dq\,dv \tag{3}$$

Substituting the value of dq obtained from equation (2) into equation (3) yields:

$$d^2U = U_{qq}\left(\frac{-U_v}{U_q}dv\right)^2 + U_{vv}(dv)^2 + 2U_{qv}dv\left(\frac{-U_v}{U_q}dv\right) \qquad (4)$$

Rearranging terms in equation and multiplying that equation by

$$\frac{vq}{vq} \cdot \frac{U_qU_v(qU_q + vU_v)}{U_qU_v(qU_q + vU_v)} \text{ yields:}$$

$$d^2U = -\frac{dv^2}{U_q^2}\left[-U_{qq}U_v^2 + 2U_{qv}U_qU_v - 2U_{vv}U_q^2\right]$$

$$\cdot \frac{vq}{vq} \cdot \frac{U_qU_v(qU_q + vU_v)}{U_qU_v(qU_q + vU_v)}$$

$$= -\frac{dv^2}{U_q^2}\ \frac{U_qU_v(qU_q + vU_v)}{qv}$$

$$\left[\frac{vq(-U_{qq}U_v^2 + 2U_{qv}U_qU_v - 2U_{vv}U_q^2)}{U_qU_v(qU_q + vU_v)}\right] \qquad (5)$$

Since the elasticity of substitution can be defined as:[1]

$$\sigma = \frac{d(v/q)/(v/q)}{d(U_q/U_v)/(U_q/U_v)} = \frac{U_qU_v(qU_q + vU_v)}{qv(-U_{qq}U_v^2 + 2U_{qv}U_qU_v - U_{vv}U_q^2)}$$

equation (5) reduces, by substitution, to:

$$d^2U = \frac{U_v(qU_q + vU_v)}{U_q(qv)} \cdot \frac{-dv^2}{\sigma} \qquad (6)$$

The solution of equation (6) for the value of dv simply involves a rearranging of terms, so that:

$$dv^2 = qv \cdot \sigma\left[\frac{-d^2U(U_q)}{U_v(qU_q + vU_v)}\right] \qquad (7)$$

The value of dv is determined by taking the square root of equation (7):

$$dv = \sqrt{qv \cdot \sigma\left[\frac{-d^2U(U_q)}{U_v(qU_q + vU_v)}\right]} \qquad (8)$$

The value $dv = V_1 - V_2$ is always positive because the right-hand side of equation (8) is always positive. The values q, v, U_q and U_v are positive and σ can only take on values ranging from zero to infinity. If the indifference curves are strictly convex to the origin, d^2U will always be less than zero.[2]

Footnotes

[1] R. G. D. Allen, *Mathematical Analysis for Economists* (London: The MacMillan Press, Ltd., 1971), p. 342.

[2] *Ibid.*, p. 497.

APPENDIX B:

DISTRIBUTION OF DATA OBSERVATIONS

In order to determine whether the empirical observations of the multiple listings real estate transactions adequately reflected variations in the level of aircraft noise in the City of Edmonton, it is necessary to examine the distribution of those observations over the different NEF values. The 352 observations were distributed in the following manner:

NEF Value	Number of Observations	Per Cent
NEF ≥ 35	10	3%
30 ≤ NEF < 35	33	10%
25 ≤ NEF < 30	97	27%
NEF < 25	212	60%
	352	100%

As can be seen from the above table, the majority of observations come from the low-noise (NEF < 25) zone. This reflects the fact that the higher noise areas affect a smaller area of the city. However, the observations do appear to reflect a variation in the level of noise as about 40% of them do correspond to higher noise areas.

APPENDIX C:

ESTIMATED HEDONIC PRICE EQUATION (QUIET AS AN INDEPENDENT VARIABLE)

Estimated Hedonic Price Equation
(Quiet as an Independent Variable)

Dependent Variable: PRICE

Independent Variables	Estimated Coefficient	Standard Error	T-Statistic
CONSTANT	37,079	5,325	6.96*
FLOOR	1,425	231	6.15*
AGE	-539	101	-5.35*
BATH4	5,367	831	6.46*
BROOMS	1,295	726	1.78*
FIRE	5,406	1,508	3.58*
DGAR	5,656	1,103	5.12*
TWO	-5,391	1,235	-4.36*
DUP	-3,363	1,814	-1.85*
DBASE	3,079	811	3.79*
BRICK	6,410	2,914	2.20*
LSIZE	110	36	3.10*
DCBD	-1,339	378	-3.54*
DZ2	-1,147	1,239	-0.93
DZ3	-519	1,482	-0.35
TAX	-1,190,860	171,086	-6.96*
QUIET	119	89	1.34**

Number of Observations = 352

R^2 = .6015

*Significant at the 95 percent level of confidence, one-tailed test.
**Significant at the 90 percent level of confidence, one-tailed test.

APPENDIX D:

ESTIMATED HEDONIC PRICE EQUATION (NOISE AS AN INDEPENDENT VARIABLE)

Estimated Hedonic Price Equation I
(Noise as an Independent Variable)

Dependent Variable: PRICE

Independent Variables	Estimated Coefficient	Standard Error	T-Statistic
CONSTANT	42,909	4,198	10.22*
FLOOR	1,420	231	6.15*
AGE	-537	101	-5.34*
BATH4	5,370	830	6.47*
BROOMS	1,278	726	1.76*
FIRE	5,388	1,507	3.58*
DGAR	5,651	1,102	5.13*
TWO	-5,377	1,234	-4.36*
DUP	-3,318	1,814	-1.83*
DBASE	3,068	811	3.78*
BRICK	6,437	2,912	2.21*
LSIZE	112	36	3.15*
DCBD	-1,339	377	-3.55*
DZ2	-1,173	1,239	-0.95
DZ3	-479	1,482	-0.32
TAX	-1,195,050	171,037	-6.99*
NOISE2	-2.65	1.73	-1.53**

Number of Observations = 352

R^2 = .6221

*Significant at the 95 percent level of confidence, one-tailed t-test.
**Significant at the 90 percent level of confidence, one-tailed t-test.