

4 VALUING ENVIRONMENTAL GOODS (2): THE HEDONIC PRICING METHOD

4.1 INTRODUCTION

Hedonic pricing (HP) derives from the characteristics theory of value, developed by Lancaster (1966), Griliches (1971) and Rosen (1974), with the first HP studies being published in the late 1960s and early 1970s (for example, Ridker and Henning, 1967; Anderson and Crocker, 1971). The method identifies environmental service flows as elements of a vector of characteristics describing a marketed good, typically housing. HP seeks to find a relationship between the levels of environmental services (such as noise levels or total suspended particulate levels), and the prices of the marketed goods (houses). HP has been used to value such things as noise levels around airports (O'Byrne et al., 1985), earthquake risks (Brookshire et al., 1985), urban air quality (Brookshire et al., 1982) and amenity values of woodland (Willis and Garrod, 1991).

In this chapter, the theoretical basis for HP is first considered, followed by an explanation of the method by which HP analyses are carried out. The chapter concludes by noting some of the problems associated with the technique.

4.2 THE CHARACTERISTICS THEORY OF VALUE

The characteristics theory of value, sometimes referred to as the Lancaster-Rosen approach, states that any given unit within a commodity class can be described by a vector of characteristics, z . For example, the commodity class could be housing, and the unit a particular house. The price for which a given unit can be sold is a function of these characteristics. Differentiating the unit price with respect to the quantity of any characteristic gives the implicit price of that characteristic. Individuals maximizing utility will re-arrange their purchases of the commodity until the marginal rate of substitution¹ between a composite commodity (which represents everything

4 VALUING ENVIRONMENTAL GOODS (2): THE HEDONIC PRICING METHOD

4.1 INTRODUCTION

Hedonic pricing (HP) derives from the characteristics theory of value, developed by Lancaster (1966), Griliches (1971) and Rosen (1974), with the first HP studies being published in the late 1960s and early 1970s (for example, Ridker and Henning, 1967; Anderson and Crocker, 1971). The method identifies environmental service flows as elements of a vector of characteristics describing a marketed good, typically housing. HP seeks to find a relationship between the levels of environmental services (such as noise levels or total suspended particulate levels), and the prices of the marketed goods (houses). HP has been used to value such things as noise levels around airports (O'Byrne et al., 1985), earthquake risks (Brookshire et al., 1985), urban air quality (Brookshire et al., 1982) and amenity values of woodland (Willis and Garrod, 1991).

In this chapter, the theoretical basis for HP is first considered, followed by an explanation of the method by which HP analyses are carried out. The chapter concludes by noting some of the problems associated with the technique.

4.2 THE CHARACTERISTICS THEORY OF VALUE

The characteristics theory of value, sometimes referred to as the Lancaster-Rosen approach, states that any given unit within a commodity class can be described by a vector of characteristics, z . For example, the commodity class could be housing, and the unit a particular house. The price for which a given unit can be sold is a function of these characteristics. Differentiating the unit price with respect to the quantity of any characteristic gives the implicit price of that characteristic. Individuals maximizing utility will rearrange their purchases of the commodity until the marginal rate of substitution¹ between a composite commodity (which represents everything

else they buy), x , and each characteristic, $z_i (i=1...n)$, is equal to the implicit price of that characteristic². Consumers will bid an amount $B_i[z, (.)]$ for an increase in the characteristic. If the market reaches equilibrium, then every consumer will be in a position where the marginal bid, $\delta B_i / \delta z_i$, is equal to the implicit price (that is, marginal cost) of the characteristic (Palmquist, 1991).

For example, house prices should reflect the capitalized value of environmental quality to the home-owner. The representative individual is assumed to have a utility function that is *weakly separable*. This, in general terms, means that the marginal rate of substitution between two goods, a and b appearing in an individual's utility function, is independent of the quantities of all other goods. The implication in HP is that, if the representative individual's utility function is weakly separable in housing, then a demand curve for environmental quality can be estimated ignoring the prices of all other goods (see Freeman, 1979). *Weak complementarity* is also assumed. That is, if the level of purchases of the private good (here, housing, h) is zero, then the marginal willingness to pay for, or marginal demand price of, environmental quality is also zero. Thus, HP is incapable of estimating non-user values and can only "pick-up" those elements of environmental quality change reflected by house prices.

4.3 HOW THE METHOD WORKS

This section follows Freeman (1979), which is an excellent introduction to early work on non-market good valuation. The first step in any HP study is to decide which environmental quality variable is of interest, and then to ascertain whether sufficiently disaggregated, spatial data are available, along with data on house prices and housing characteristics. Once this has been verified, the typical HP exercise proceeds in two stages: estimation of a hedonic price function and estimation of a demand curve for some element of environmental quality.

Stage One: Estimation of Hedonic Price Function

In this stage, the relationship between the environmental variable of interest and a related marketed good is estimated, including as explanatory variables all other characteristics thought to be relevant in determining the price of this marketed good. The choice of these explanatory variables is potentially crucial, for reasons that will become apparent. For example, house prices (P_h) within a city might depend on: site characteristics (S_i), such as the number of rooms, the size of garden and whether a garage is provided or not; neighbourhood characteristics (N_j), such as ethnic composition, crime rate and number of schools in the area; and environmental quality variables (Q_k), such as air quality and noise levels. The following hedonic price

equation can be estimated using ordinary least squares (OLS):

$$P_h = P(S_i, N_j, Q_k) \quad [i=1..m, j=1..n, k=1..l] \quad (4.1)$$

This equation allows implicit prices for each characteristic to be calculated. If (4.1) is linear, these implicit prices will be constants. However, linearity will only occur if consumers can "re-package" characteristics. As Rosen (1974) has observed, this is improbable. Householders cannot buy one characteristic of a given house (garden size, say) and combine it with a different characteristic of a second house (e.g. number of rooms) when making their purchase. Therefore, (4.1) is expected to be non-linear, giving implicit prices dependent upon the quantity of each characteristic consumed. But which non-linear form is most appropriate? In Figure 4.1, one possible partial relationship between house prices and some measure of environmental quality, Q_1 (air quality), is shown. As may be seen, as the air quality level increases, the price of a house rises (higher levels of Q_1 are thus desirable, *ceteris paribus*), but at a decreasing rate. The marginal cost of air quality thus falls as the level of air quality rises. An alternative possibility, not shown in Figure 4.1, is that house prices rise at an increasing rate as air quality rises; this means that the marginal costs of air quality are increasing. Both scenarios are plausible.

The implicit price of a given environmental characteristic is obtained from equation (4.1) by partially differentiating (4.1) with respect to the characteristic of interest. For example, for Q_1 , the implicit price would be:

$$\delta P_h / \delta Q_1 = P(S_i, N_j, Q_k) \quad (4.2)$$

This implicit price $\delta P / \delta Q$ is called the *rent differential*, r , and is a measure of the value of a marginal change in the environmental quality variable Q_1 . In equation (4.2), it is shown to be a function of the levels of all the variables in the hedonic price equation. Simplifying matters, under certain conditions the implicit price will depend only on the level of that characteristic. In Figure 4.1, the shape of the function relating house prices to Q_1 indicates that the implicit price falls as the level of air quality rises, as mentioned above.

The rent differential shows the marginal cost of buying an increase in the quality variable Q_1 and (if the housing market is functioning perfectly) the marginal benefit of a one unit increase in the quality variable (Freeman, 1974). A perfectly functioning market has perfect information flows. Also, all individuals trading in the market are able to adjust their buying behaviour, moving along the rent differential curve $\delta P_h / \delta Q_1$ until the marginal value to each of an improvement in environmental quality is equal to the marginal cost of that improvement, defined by the implicit price. In Figure

equation can be estimated using ordinary least squares (OLS):

$$P_h = P(S_i, N_j, Q_k) \quad [i=1..m, j=1..n, k=1..l] \quad (4.1)$$

This equation allows implicit prices for each characteristic to be calculated. If (4.1) is linear, these implicit prices will be constants. However, linearity will only occur if consumers can "re-package" characteristics. As Rosen (1974) has observed, this is improbable. Householders cannot buy one characteristic of a given house (garden size, say) and combine it with a different characteristic of a second house (e.g. number of rooms) when making their purchase. Therefore, (4.1) is expected to be non-linear, giving implicit prices dependent upon the quantity of each characteristic consumed. But which non-linear form is most appropriate? In Figure 4.1, one possible partial relationship between house prices and some measure of environmental quality, Q_1 (air quality), is shown. As may be seen, as the air quality level increases, the price of a house rises (higher levels of Q_1 are thus desirable, *ceteris paribus*), but at a decreasing rate. The marginal cost of air quality thus falls as the level of air quality rises. An alternative possibility, not shown in Figure 4.1, is that house prices rise at an increasing rate as air quality rises; this means that the marginal costs of air quality are increasing. Both scenarios are plausible.

The implicit price of a given environmental characteristic is obtained from equation (4.1) by partially differentiating (4.1) with respect to the characteristic of interest. For example, for Q_1 , the implicit price would be:

$$\delta P_h / \delta Q_1 = P(S_i, N_j, Q_k) \quad (4.2)$$

This implicit price $\delta P / \delta Q$ is called the *rent differential*, r , and is a measure of the value of a marginal change in the environmental quality variable Q_1 . In equation (4.2), it is shown to be a function of the levels of all the variables in the hedonic price equation. Simplifying matters, under certain conditions the implicit price will depend only on the level of that characteristic. In Figure 4.1, the shape of the function relating house prices to Q_1 indicates that the implicit price falls as the level of air quality rises, as mentioned above.

The rent differential shows the marginal cost of buying an increase in the quality variable Q_1 and (if the housing market is functioning perfectly) the marginal benefit of a one unit increase in the quality variable (Freeman, 1974). A perfectly functioning market has perfect information flows. Also, all individuals trading in the market are able to adjust their buying behaviour, moving along the rent differential curve $\delta P_h / \delta Q_1$ until the marginal value to each of an improvement in environmental quality is equal to the marginal cost of that improvement, defined by the implicit price. In Figure

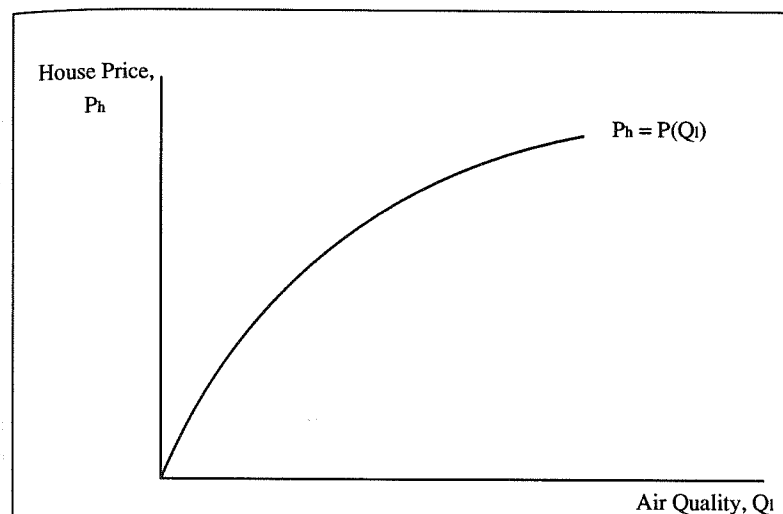


Figure 4.1 House prices and air quality

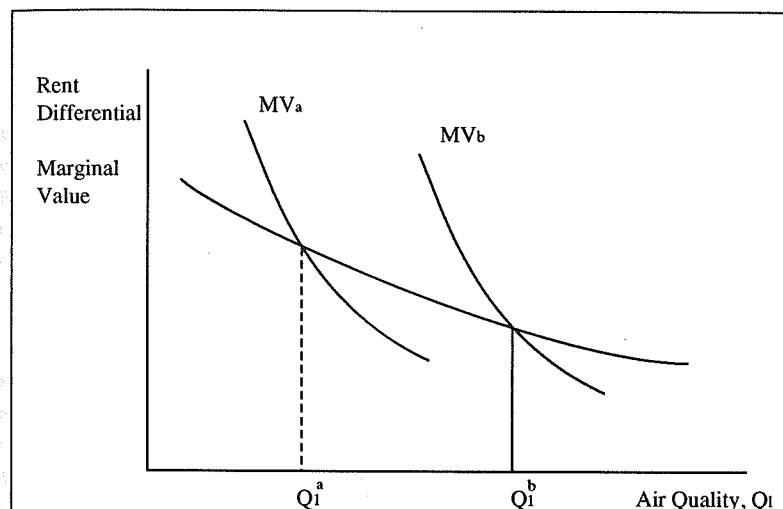


Figure 4.2: Individuals equilibrium in the housing market

4.2, the function MV_a represents the marginal valuation of air quality by individual "a", which declines due to diminishing marginal utility. Individual "a" will maximize his/her utility in this market by moving to point Q^a_1 where marginal benefits and costs are equal. Similarly, individual "b", with different preferences shown by MV_b , will choose the air quality level Q^b_1 . Thus, the implicit price (which is observed) can be used as a measure of the (unobservable) benefits of a marginal increase in air quality.

Stage Two: Estimating a Demand Curve

Stage Two of the HP process involves estimating a demand curve for environmental quality using the information gained from stage one. Equation (4.2) will be an inverse demand curve³ for Q_i only if all individuals affected by noise pollution are identical. The procedure for estimating a demand curve for Q depends on the assumptions about the supply side of the market. The case likely to be of most interest is a short-run situation where there are only a fixed number of houses in any air quality class. House-buyers must then bid for this fixed supply of heterogeneous units. If this is the case, an implicit demand curve for Q can be obtained by regressing implicit prices r against Q , socio-economic variables thought relevant such as income (Y) and age (A), and any proxy variables available which represent preferences. Estimating such a demand curve for areas within a city, with these areas indexed by "i", gives the inverse demand curve:

$$r_{ii} = P(Q_i, Y_i, A_i) \quad (4.3)$$

If (4.3) can be estimated, then the value of a non-marginal increase in Q_i can also be estimated by measuring the appropriate area under (4.3), using area averages for Y_i and A_i . Aggregate benefits can be found by summing these amounts across all areas.

If the supply of houses with given bundles of characteristics is variable, the supply function for houses with particular bundles of characteristics will also need to be considered. This supply will, of course, depend partly on the willingness of potential house-buyers to pay for each characteristic. In this situation, both supply and demand in the market must be estimated simultaneously.

4.4 PROBLEMS WITH THE HP METHOD

Omitted Variable Bias

As was remarked in section 4.3, the analyst must decide which factors to include as independent variables in the hedonic price equation (and, indeed, in the demand curve). This selection process can give rise to problems. If a variable which has a significant effect on house prices, and which is

correlated with hedonic price equation variables. This implicit prices (

Multi-Collinearity

Several of the independent variables may be closely related to each other, near a quarry, collinearity can cause coefficient estimates of these variables, even if the collinearity can be detected, estimates and, predictions (Ste

Choice of Functional Form

What functional form should be used? What functional forms have argued about this. Indeed, if it were possible to measure the implicit price of environmental quality, the theory does not support the use of a linear form and Allinson (1988) preferred functional forms. The functional form is a statistical and possibly parsimonious interpretation; (iv) expected predictions (for example, in house prices).

Functional forms have sensible interpretations. For example, et al. (1988) compared between predicted values were observed to a simulated analysis, then found that linear criterion.

Market Segmentation

Housing market composition, re

4.2, the function MV_a represents the marginal valuation of air quality by individual "a", which declines due to diminishing marginal utility. Individual "a" will maximize his/her utility in this market by moving to point Q^a_1 where marginal benefits and costs are equal. Similarly, individual "b", with different preferences shown by MV_b , will choose the air quality level Q^b_1 . Thus, the implicit price (which is observed) can be used as a measure of the (unobservable) benefits of a marginal increase in air quality.

Stage Two: Estimating a Demand Curve

Stage Two of the HP process involves estimating a demand curve for environmental quality using the information gained from stage one. Equation (4.2) will be an inverse demand curve³ for Q_i only if all individuals affected by noise pollution are identical. The procedure for estimating a demand curve for Q depends on the assumptions about the supply side of the market. The case likely to be of most interest is a short-run situation where there are only a fixed number of houses in any air quality class. House-buyers must then bid for this fixed supply of heterogeneous units. If this is the case, an implicit demand curve for Q can be obtained by regressing implicit prices r against Q , socio-economic variables thought relevant such as income (Y) and age (A), and any proxy variables available which represent preferences. Estimating such a demand curve for areas within a city, with these areas indexed by "i", gives the inverse demand curve:

$$r_{ii} = P(Q_i, Y_i, A_i) \quad (4.3)$$

If (4.3) can be estimated, then the value of a non-marginal increase in Q_i can also be estimated by measuring the appropriate area under (4.3), using area averages for Y_i and A_i . Aggregate benefits can be found by summing these amounts across all areas.

If the supply of houses with given bundles of characteristics is variable, the supply function for houses with particular bundles of characteristics will also need to be considered. This supply will, of course, depend partly on the willingness of potential house-buyers to pay for each characteristic. In this situation, both supply and demand in the market must be estimated simultaneously.

4.4 PROBLEMS WITH THE HP METHOD

Omitted Variable Bias

As was remarked in section 4.3, the analyst must decide which factors to include as independent variables in the hedonic price equation (and, indeed, in the demand curve). This selection process can give rise to problems. If a variable which has a significant effect on house prices, and which is

correlated with some or all of the included variables, is omitted from the hedonic price equation, this will influence the coefficients of the estimated variables. This leads to biased estimates for these coefficients and for the implicit prices (for a recent application, see Atkinson and Crocker, 1992).

Multi-Collinearity

Several of the independent variables included in the hedonic price equation may be closely correlated with each other. For example, if a house is sited near a quarry, as dust levels increase so do noise levels. Such multi-collinearity can result in a number of problems. These include imprecise coefficient estimates (high standard errors), and intuitively "wrong" signs on variables, even though the R^2 may be high (Maddala, 1979). Multi-collinearity can also bring about considerable instability in parameter estimates and, if serious, can reduce the confidence attached to model predictions (Stewart, 1984).

Choice of Functional Form

What functional form should be chosen for the hedonic price equation? We have argued above that the hedonic price equation is unlikely to be linear. Indeed, if it were linear, a demand equation could not be estimated because the implicit price for air quality would be constant. However, economic theory does not suggest which non-linear form is to be preferred. Garrod and Allinson (1991) have argued that there is unlikely to be one universally preferred functional form, and that, even for a given data set, criteria for functional form selection may be conflicting. These criteria, which are both statistical and practical, include (i) requiring as few parameter estimates as possible (parsimony); (ii) requiring that the parameters have clear economic interpretations; (iii) choosing the form which economizes on computing time; (iv) explaining the observed data well; and (v) making good predictions (for example, that the form chosen correctly predicts the change in house prices from a reduction in noise levels (Garrod and Allinson, p.3).

Functional forms that predict well (for example, flexible forms) may not have sensible interpretations for all the parameters to be estimated. Cropper et al. (1988) compared alternative functional forms in terms of the difference between predicted marginal values and actual marginal values. These actual values were observable in their study as they applied Monte Carlo analysis to a simulated data set: once a utility function has been specified in such analysis, then actual welfare measures can be calculated. Cropper et al. found that linear and linear Box-Cox functional forms performed best on this criterion.

Market Segmentation

Housing markets are often segmented on grounds such as ethnic composition, rental versus owner-occupied, and price bracket. Failing to

recognize such segmentation in an HP study, when it is present in reality, will result in biased coefficients in the hedonic price function; segmentation implies that demand parameters vary across segments. The HP analyst must recognize such segmentation and estimate separate hedonic price equations for each segment. But deciding how to divide up the housing market of a city can be a difficult problem. Michaels and Smith (1990) solved this problem by asking realtors (estate agents) in Boston to segment the housing market in that city. On the basis of price brackets, four distinct sub-markets were identified. Separate hedonic price equations were then estimated for each segment in order to value the disutility of living close to hazardous waste sites.

Expected versus Actual Characteristic Levels

In using the HP approach to value environmental attributes, current levels of environmental quality are assumed to influence house prices. However, house prices can also be influenced by expected changes in quality levels. For instance, the prospect of a by-pass in a busy residential zone can keep prices higher than in the absence of such expectations. The implicit price would fail to measure the valuation of current noise levels alone. If expectations are important, excluding them from the HP equation leads to omitted variable bias.

Restrictive Assumptions

HP gives an accurate estimate of the value of environmental quality only if (continuing the house price/air quality example): (i) All buyers in the housing market are perfectly informed of air quality levels at every possible housing location. (ii) All buyers in the market are able to move to utility maximizing positions (otherwise, marginal cost is not equivalent to marginal WTP). (iii) The housing market is in equilibrium; the vector of implicit prices is such that the market clears at all times. Clearly, these assumptions will never fully describe reality. Furthermore, the assumption of weak complementarity implies that only those environmental improvements that have an impact on the property market will be measured.

Finally, Kask and Maani (1992) have pointed out that HP applications to the value of changes in risky environmental events (such as the Brookshire et al. study of earthquake risks in California) are likely to produce biased estimates of consumer benefits of avoiding or reducing such risk. In choosing whether or not to buy a home in a safe area of San Francisco people are engaging in self-protection. When paying a premium for such a house, they reduce the probability of being located in an earthquake zone and thus reduce the expected loss from an earthquake. A problem arises in that individuals' subjective values of such losses are likely to be either less than or greater than the scientific (or endowed) probability of such events. This occurs for two reasons. First, studies have shown that people

recognize such segmentation in an HP study, when it is present in reality, will result in biased coefficients in the hedonic price function; segmentation implies that demand parameters vary across segments. The HP analyst must recognize such segmentation and estimate separate hedonic price equations for each segment. But deciding how to divide up the housing market of a city can be a difficult problem. Michaels and Smith (1990) solved this problem by asking realtors (estate agents) in Boston to segment the housing market in that city. On the basis of price brackets, four distinct sub-markets were identified. Separate hedonic price equations were then estimated for each segment in order to value the disutility of living close to hazardous waste sites.

Expected versus Actual Characteristic Levels

In using the HP approach to value environmental attributes, current levels of environmental quality are assumed to influence house prices. However, house prices can also be influenced by expected changes in quality levels. For instance, the prospect of a by-pass in a busy residential zone can keep prices higher than in the absence of such expectations. The implicit price would fail to measure the valuation of current noise levels alone. If expectations are important, excluding them from the HP equation leads to omitted variable bias.

Restrictive Assumptions

HP gives an accurate estimate of the value of environmental quality only if (continuing the house price/air quality example): (i) All buyers in the housing market are perfectly informed of air quality levels at every possible housing location. (ii) All buyers in the market are able to move to utility maximizing positions (otherwise, marginal cost is not equivalent to marginal WTP). (iii) The housing market is in equilibrium; the vector of implicit prices is such that the market clears at all times. Clearly, these assumptions will never fully describe reality. Furthermore, the assumption of weak complementarity implies that only those environmental improvements that have an impact on the property market will be measured.

Finally, Kask and Maani (1992) have pointed out that HP applications to the value of changes in risky environmental events (such as the Brookshire et al. study of earthquake risks in California) are likely to produce biased estimates of consumer benefits of avoiding or reducing such risk. In choosing whether or not to buy a home in a safe area of San Francisco people are engaging in self-protection. When paying a premium for such a house, they reduce the probability of being located in an earthquake zone and thus reduce the expected loss from an earthquake. A problem arises in that individuals' subjective values of such losses are likely to be either less than or greater than the scientific (or endowed) probability of such events. This occurs for two reasons. First, studies have shown that people

consistently over-value very low probability events, and consistently under-value high probability events (Lichtenstein et al., 1978; Viscusi and Magat, 1987). Second, people may have too little information, or information of too low a quality, to arrive at "correct" probabilities. The implication, as Kask and Maani show, is that hedonic prices may either over-estimate or under-estimate welfare changes (according to whether a low or high objective probability event is being considered, and to the amount and quality of information available to individuals).

4.5 CONCLUSIONS

As has been pointed out in the preceding section, there are many problems associated with the HP technique. Perhaps the most important of these are the assumptions made about the related market (the housing market, in this chapter). However, the method does make use of data on actual behaviour, unlike the contingent valuation method described in Chapter 3. Although this chapter on HP has concentrated on house prices and environmental quality levels, the technique is applicable to other goods. HP can be used to estimate the implicit price of any observable characteristic of any good, so long as the weak complementarity assumption holds. HP could therefore be used to estimate the value of the "green premium" on environmentally-friendly consumer goods, or the value of environmental risk on human health through wage differentials. Results from hedonic wage studies on the value of risk are mentioned in Chapter 6.

REFERENCES

- Anderson G and Bishop R (1986) "The valuation problem" in D Bromley (editor) *Natural Resource Economics* Boston: Kluwer-Nijhoff.
- Anderson R J and Crocker T D (1971) "Air pollution and residential property values" *Urban Studies* 8: 171-180.
- Atkinson S and Crocker T (1992) "Econometric health production functions: Relative bias from omitted variables and measurement error" *Journal of Environmental Economics and Management* 22 (1): 12-24.
- Brookshire D, Thayer M A, Schulze W D and d'Arge R C (1982) "Valuing public goods: a comparison of survey and hedonic approaches" *American Economic Review* 72: 165-178.
- Brookshire D S, Thayer M A, Tschirhart J, and Schulze W D (1985) "A test of the expected utility model: Evidence from earthquake risk." *Journal of Political Economy* 93, 369-389.
- Cropper M, Deck L and McConnell K (1988) "On the choice of functional form for hedonic price functions" *Review of Economics and Statistics* 70: 668-675.
- Freeman A M (1974) "Air pollution and property values: a further comment" *Review of Economics and Statistics* 56: 554-566.