ECONOMIC VALUATION OF AIR POLLUTION

Chandra Shekhar Sharma*
R. K. Singh**

ABSTRACT

Over the last 20 years, there has been a number of valuation studies carried out in the context of air pollution in Europe and North America. The pervasive effects of the pollutants in air have raised the importance of valuation in developing countries too. In order to estimate the economic impacts, complex modeling of the physical relationship between the emission, transport and chemical reactions in the atmosphere of air pollutants and their effects on the environment are required. It also requires the understanding of how marginal changes in the emission levels will affect our welfare. It is recognized that air pollution is one of the most difficult areas for valuation primarily because of scientific uncertainty about effects and their link to human welfare and because many ecosystem services affected are not marketed and have no pre-assigned market value. In this paper, various approaches used in the valuation of air pollution are reviewed.

DIRECT VALUATION TECHNIQUES

STATED PREFERENCE APPROACH

The idea behind stated preference method is to estimate the value of non-marketed good, through surveys, which reveal their Willingness to Pay (WTP) or Willingness to Accept (WTA) for change in some provision of environmental quality. It measures the ex-ante (before the change) values. The main technique is Contingent Valuation (CV). Alternatively, people can be asked to make tradeoffs among different alternatives, from which their WTP can be statistically inferred from Choice Experiments (CE). A hypothetical scenario is created during a survey in which the respondent is asked how much they would be willing to pay through some voluntary contribution. Like CV, CE is a

* Reader, Department of Commerce, Shri Ram College of Commerce, University of Delhi, Delhi.

** Senior Lecturer, Department of Commerce, Shri Ram College of Commerce, University of Delhi, Delhi

hypothetical method that asks people to make choices based on a constructed model rather than to reveal their monetary value directly.

Respondents rank the alternatives according to most preferred to least preferred. The WTP/WTA can be asked in different forms of elicitation formats such as open ended questions, dichotomous choice, bidding games and payment cards. CV is the most widely used technique and can be used to value both use and non-use values. It has found application in valuation of health impacts due to reduction in air pollution. Rowe, D'Arge and Brookshire (1980) have used the approach to examine visibility reductions caused by coal-fired plants through iterative bidding techniques. A more refined approach has attracted the researchers referred as 'Conjoint Analysis', which allows direct valuation of attribute components. The approach has been used to account for multidimensional nature of environmental values and to the constructive nature of human preferences derived from multi-attribute utility theory (MAUT) by Kwak, Yoo and Kim (2001). The method involves first asking MAU structured questions attribute-by-attribute, which allow the researchers to infer the preferences and WTP of each respondent. After this, the respondents are directly asked to state their preferences. They applied the technique to seek values of specific damages due to air pollution in Seoul, Korea through a survey of random population of 172 households. The response rate for the survey was 93.0%. The most and least preferred attribute levels were chosen which were then ranked according to the importance. The respondents supplied weights consistent with the ranks and WTP estimates were extracted from this information. They used Tobit model and estimated the variables for experience, sex, marriage, age, education, years, income, soil, visibility, agricultural damage, mortality and morbidity. The overall results showed that there is a considerable scope for the approach in environmental valuation. However, due to long, tedious task, Russell et al. (2001) seems less clear if the approach is of the same significance practically as it is theoretically. Two specific methods of conjoint analysis are Contingent Ranking and Rated Pair format. The former method ranks the set of attribute bundles while in the latter respondents choose between pair of choices. Whatever the form, the objective is to make a hypothetical situation as factual as possible due to which more and more details in the model and survey instrument is being incorporated.

THEORETICAL MODEL

In the model, Halvorsen (1996) considered a representative consumer whose two-priced utility depends on the consumption of private goods (X in one period, and Z in period two), his health condition (h), and on damages on the natural environment (K). The consumer's expected utility depends on whether he will be ill (s) or well (w) in the future with probabilities Π and 1-Π, respectively. An improvement in the air quality will reduce the probability of the individual of becoming ill and damage to the natural environment. It is assumed an improvement in air quality will reduce the probability of becoming ill in next period only. However damage to the natural environment is affected in both periods. The consumer is assumed to minimize his total expenditures over the two periods subject to a given total discounted expected utility (U). If the government does not take action to improve air quality, the consumer will not take this into consideration, because air quality is a public good. The total expenditure function is then defined by :

$$C = C\left(p_x, p_z, \overline{U}, h_s, h_w, K, \Pi\right) = \min p_x X + p_x Z$$

such that $\Pi U\left(Z; h_s; K\right) + \left(1 - \Pi\right)U\left(Z; h_w; K\right) + U\left(X; h; K\right) = \overline{U}$

where p_x and p_z is the price for good X and Z respectively.

If there is an improvement in air quality, it will reduce both Π and K. The individual has to pay for a reduction in the air pollution in the form of disease in tax revenue. The individual's compensating variation for an increase in air quality is the maximum amount of income he is willing to forego to be indifferent to no improvement at all. Suppose the initial state is denoted as (Π^0, K^0) and the state after an improvement in air quality (Π^1, K^1) where $\Pi^1 < \Pi^0$, $K^1 < K^0$. The consumer's willingness to pay for this air quality improvement is given by :

$$CV = C\left(p_x, p_z, h, \overline{U}, \Pi^0, K^0\right) - C\left(p_x, p_z, h, U, \Pi^1, K^1\right)$$

This CV will be positive if air quality is improved, and negative if it is reduced. The reason is that the consumer needs to use less income to maintain a given utility level when air quality improves.

DATA REQUIREMENTS

A survey must conducted. Because of the need to describe in detail the good being valued, interviews are often quite time-consuming. It is also very important that the questionnaire be extensively pre-tested to avoid various sources of bias. A report of NOAA Panel on Contingent valuation (1993) lay down a fairly complete set of guidelines compliance with which they define an ideal CV survey (Annexure 1).

ESTIMATION PROCEDURES

Multivariate statistical techniques are used to estimate valuation function that relates socio-economic and demographic characteristics of the households with the WTP responses. Ordinary Least Squares (OLS) is suitable for the open-ended questions but for dichotomous choice questions it leads to biased results. Instead a logit, probit or tobit model is used to estimate value of goods. This is due to the fact the explanatory variables may be either quantitative or qualitative or a mixture. Here the dependent variable may either take a 0 or 1 value. Both logit and probit models guarantee that the estimated probabilities lie in the range of 0-1 and that they are nonlinearly related to the explanatory variables. In tobit, value of the regress and are not available for some variables although value of the regressor are available for all the variables and hence is sometimes used in CVM.

EXAMPLE

Stated Preference – Choice Experiment has been used to valuate air pollution in Hamilton-Wentworth. A questionnaire was prepared to estimate respondents' concerns about air quality, which included air quality attributes such as black odour, black fall out, visibility and health effects. In order to assess willingness to pay, a monthly change in property taxes or rental payments was used. The questionnaires were mailed to a sample of residents using the estimated model and willingness to pay was calculated to be approximately $58 per month to decrease the number of hospital admissions for cardio-respiratory diseases from 18 to 12 per month and decrease the number of extra deaths from 2 per month to one per month, $23 per month to decrease the number of days with black fallout per month from 3 to 2, $19 per month to decrease the number of monthly bad odour days from 4 to 3, and $14 in order to lower the number of monthly poor visibility days from 3 to 2 per month. All of the estimated coefficients were statistically significant at conventional levels.

LIMITATIONS AND OTHER ISSUES

The underlying assumption of the methodology is that the consumer is the best judge of his interests and that the consumers' ability to rank preferences is rational. This leads to inherent bias in the technique. The success or failure of CV thus depends on whether the respondents can capture the essence of the problem and reveal their true preferences. There are many potential sources of bias discussed in the literature. These include strategic bias, information effects, hypothetical bias, elicitation method, embedding and protest bidding. Halvorsen (1996) has shown that sequential valuation procedure may create significant ordering effects. Much consideration has been given to whether the improvements in question design could reduce the problems encountered.

STRATEGIC BIAS

It pertains to non-revelation of true values of the respondents. They may influence the estimates by underestimating or overestimating their WTP as per the desirable situation. they may underestimate if they know the information revealed by them will be collected and would affect the future policy such as in the form of increased taxation. Overestimation may be due to the free – rider problem as they are aware somebody else will pay for the environmental change.

INFORMATION EFFECTS

This bias may arise as a result of information disclosed by the interviewer, which has its effects on the respondents. The questions should be clear and unambiguous. Information bias may also occur via the starting point of bids as some surveys has predefined ranges of values to guide responses.

HYPOTHETICAL BIAS

This amounts to the potential error bound to arise due to the hypothetical nature of the market. Since the situation is not real, it may lead to increased bid variances. The answers may be inaccurate because the observed behaviour may not be consistent with the preferences revealed by the respondents, as they may not be able to predict what would be in the real situation as opposed to a hypothetical survey leading to uncertainty, doubt and irrationality.

ELICITATION METHOD

Since CV estimates of WTP are based on the survey responses, the choice of elicitation method is of chief concern. The main elicitation methods are :

a) *Open-ended questions* – In this, respondents are simply asked to state their maximum WTP for the good being valued thus generating direct estimates. This has often been criticized for it is difficult to answer.

b) *Dichotomous choice (DC) / Referendum format* – It is easier to answer accurately. Respondents determine whether their WTP is more or less than the specified amount using "yes" or "no" response to questions.

c) *Bidding game* – It is conducted through either personal/ telephone interview. An initial bid is posited (starting bid) by an interviewer and the respondent bids via bidding vehicle (method of payment for the good i.e. utility bills, sales tax, entrance fees etc.). It was observed by Rowe, D'Arge and Brookshire (1980) that information bias and strategic behaviour of he respondents may seriously affect the valuations derived from iterative bidding. Protest is also common when respondent value the good but is not willing to pay for real situation.

d) *Payment Card (PC)* – The interviewer offers a range of values and asks the respondents to circle the highest amount that they would be willing to pay. The interviewer shows a card, which portrays what people in their respective general income category would pay on an average for selected public services. It has been found experimentally by Jordan and Elnagheeb (1994) that PC is far superior to the referendum model.

The effect occurs when the WTP for one good is found to be insignificantly different from the WTP for a more inclusive good. In other words, whether the good is evaluated on its own or as a part of wider good. Kahneman and Knetsch (1992) raised the issue of embedding effects where the value of a particular good as perceived by respondents is sensitive to the number of goods to be valued. Individuals were thought to purchase moral satisfaction through their WTP. They were criticized on the grounds of statistical, data handling procedures, poor information and inadequate design of the question framework, rather than the underlying theory, which resulted in embedding.

ORDERING EFFECTS

The estimates of WTP tend to vary depending upon the sequence in which the good is valued. Halvorsen (1996) focused in his study on ordering effects showing how the expressed value of a particular good in a sequence of several goods depends on where in the sequence it is valued. These effects arise when a sequential valuation procedure is applied to a simultaneous problem and the respondents are given imperfect information about the decision problem. For example, to isolate the effects of particulate matter on health would depend where in the sequence is it valued out of health, visibility, soiling etc.

PAYMENT VEHICLE BIAS

It has been found that WTP varies according to the payment vehicle or the mode of financing such as general tax, local tax, annual payments, utility bills, entry fees etc. Thus the controversial means should be avoided and use the means likely to be used in the real situation.

INDIRECT VALUATION TECHNIQUES

HOUSEHOLD PRODUCTION FUNCTION

Household production function (HPF) is based on the behaviour of the consumer in the market – behaviour that is revealed through his expenditures on various goods and purchases in the market. The technique involves analyzing data from market transactions in goods and services and establishment of relationship between these private goods and various measures of environmental quality. The individual would tend to maximize utility subject to budget and time constraints. For example an environmental good such as a lake can be valued by observing the costs that an individual incurs to travel thousands of kilometers i.e. travel costs to satisfy himself. Similarly, installation of air purifiers and/or air conditioners defends an individual from the health impacts of air pollution. By observing the amount of money spent to defend against the environmental bad i.e. defensive expenditures determines the value that an individual places on the environment. This approach is sometimes preferred by policy makers, as it is closer to reality since in real world, preferences are not directly observable but are discovered through the actual behaviour of the consumers in the market. HPF includes two techniques - defensive expenditures method and travel cost method, which are discussed below.

DEFENSIVE EXPENDITURE METHOD

Defensive expenditure method or Advertise behaviour method estimates benefits as the change in spending on goods that are substitutes for cleaner environment. It reveals the individual's demand and thereby marginal willingness to pay for an improved health, safety or environmental quality based on the observed behaviour on protective opportunities. For instance, to reduce the effect of material soiling as a result of air pollution, individuals would spend some amount on cleaning or repainting material surfaces; use protective covers or move to new locations depending on his preference. His preference would not only depend on pure technical conditions but also on economic conditions of substitution opportunities (Bresnahan and Dickie, 1995). The basic assumption is that defensive expenditures, wh·h are made to reduce or counteract the impacts of pollution, are perfect substitutes for reductions in the level of pollution effects experienced by an individual.

A number of theoretical studies exist for defensive expenditure method. Its applicability in the literature is limited to the effect of material soiling and health problems in case of air pollution. The various examples of defensive measures for air pollution quoted by Bartik (1988) are cleaning or repainting exterior of house, installation of air purifiers or air conditioners, visit to the doctors or move away from the pollution source. Watson and Jaksch (1982) estimated the household benefits from reduced particulate matter soiling using demand and supply functions. A demand curve is estimated based on the assumption that households prefer more cleanliness to less while the supply curve is shifted as the air quality changes. Changes in welfare are then estimated. Gerking and Stanley (1986) used a simple model to examine explicitly the relationships among willingness to pay for reduction in air pollution and changes in defensive expenditures. Their model does not involve any utility term in order to make the estimations relatively simpler. Also, previous research expresses marginal willingness to pay solely in terms of marginal rate of technical substitution. Shogren and Crocker (1991) under certain assumptions claim that unobserved utility terms or the uncertainty cannot be eliminated from the expressions. Some of the more refined models have been developed by Bresnahan and Dickie (1995) to incorporate multiple averting actions since some individuals use to or more protective actions to avoid pollution.

THEORETICAL MODEL

The theoretical model has been derived by Courant and Potter (1981), Bartik (1988) and many others. Consider a case of an individual who is subject to air pollution (P) from outside. He however, is interested in his personal environmental quality within his house (Q). So he purchases air purifier or any other equipment to reduce the level of air pollution within the house. Thus his defensive expenditures are denoted by D (Q, P), the expenditures necessary to achieve his personal environment when the outside air pollution is P. Now, he allocates his personal income (Y) between the purchase of composite consumption goods (X) and on the level of personal environmental quality to be achieved. In this case, the outside pollution affects utility only through its affect on the cost of goods required to achieve desired environmental quality and does not enter explicitly in the utility function. According to Watson and Jaksch (1982), air quality can enter the consumer's utility function directly or be treated as a production function shifter that do enter the utility function. The problem of the household is to choose X and Q to maximize direct utility within the budget constraint.

$$\underset{X,Q}{\text{Max}}\, U(X,Q) \qquad (1)$$

such that $$X + D(Q,P) = Y \qquad (2)$$

Equation (1) indicates that it is necessary to adjust X and Q so as to maximize utility. Equation (2) states that expenditures on X and on defensive measures must equal income (Y).

The first order conditions of this problem reduces to

$$U_Q / U_x = D_Q \qquad (3)$$

i.e. the household chooses Q and X to equate the marginal value of personal environmental quality to its marginal cost.

The household's utility is a function of model's two exogenous (independent) variables, pollution and income. To maximize utility, V, given by indirect utility function, Lagrangian equation is set up, when X and Q are optimally chosen.

$$V = V(P, Y) = U(X^*, Q^*) + \lambda(Y - X^* - D(Q^*, P)) \tag{4}$$

where V (P, Y) is the indirect utility function, X^* and Q^* are the optimal choices. The optimal consumer choice is represented by the point of tangency between the budget constraint and an indifference curve (which represents the utility). To find the income needed to keep utility constant as pollution changes, totally differentiate the Lagrangian with respect to P and Y and set the utility change to zero. To resulting needed compensation for a small pollution change is

$$-V_P / V_Y = D_P \tag{5}$$

Thus a small reduction in pollution lowers the money needed to spend on defensive equipments. D_P is the savings in defensive expenditures needed to reach the original level of personal environmental quality and the consumer's willingness to pay (WTP) for improved air quality.

However, as pointed out by Courant and Porter (1981) and Bartik (1988), D_P does not equal to the actual change in defensive expenditure because Q^* will change. The actual change in defensive expenditure is

$$dD / dP = D_P + D_Q(dD^* / dP) \tag{6}$$

With an increase in air pollution, the cost of achieving the desired level of personal environmental quality increases, so the consumer makes do with slightly higher level of indoor air quality by saving his defensive expenditures. Here, the observed defensive expenditures will be less than the marginal willingness to pay thus leading to understatement. In contrast, if the consumer's expenditures become much more intensive to achieve greater level of personal environmental quality when the outside pollution becomes more worse, his defensive expenditures will overestimate marginal WTP. Now, if defensive expenditures are predictably higher or lower than WTP, defensive expenditures may provide upper or lower bound on WTP. Bartik (1988) also points out the key advantage of these upper and lower bounds, as they require less information than more exact measures. The model is theoretically correct and has been assessed for construct validity by Laughland et al. (1996). Construct validity is concerned with the consistency of empirical measures with theoretical relationships. This has received little attention over the past years. Empirical results by Laughland et al. indicate that contingent valuation and averting cost measures have a low correlation. However more research and studies needs to be conducted to arrive at the validity measures.

The extension of the environmental model is shown by Courant and Porter (1981) when the air quality directly enters the utility function, a case to be considered as people are exposed to both outer as well as inside air quality. Due to direct influence of air quality on well-being, it becomes less clear on the appropriateness of using avertice expenditures as a measure of WTP.

DATA REQUIREMENTS

The data requirement is two-fold; exogenously determined levels of risk such as the ambient concentration of the pollutant and endogenous quantities which may be identified as protective actions such as doctor visits, medical expenditures, diagnostic tests etc. Inputs about the demographic characteristics need to be supplemented with the other information. A formal description of all possible factors, which affect health production as well as knowledge about the defensive activities such as use of air conditioners, cooking gas, exhaust fans, pollution masks is also required. In addition, asset income and wage rate should be known.

Data about the health status and demographic characteristics with detailed information on number of days of sickness, number of visits to the doctor, expenditures on medicines, number of days stayed indoors to avoid pollution, extra miles traveled to avoid polluted areas and other socio-economic characteristics like family size, age and sex composition of the family, education level of family members, occupation, gross annual income, family monthly household expenditures can be obtained through survey in India. Air pollution concentrations can be obtained from the Central Pollution Control Board Publications.

ESTIMATION PROCEDURES

Simultaneous equation methods such as 3 SLS are used for the estimation of parameters. Alternatively, Generalised Method of Moments (GMM) can also be used.

CHOICE OF FUNCTIONAL FORM

Logit model is commonly employed under the assumption that the utility disturbances are independent across the various options. A modified approach called the nested logit is often used that allows for the fixed correlation within particular subsets of the household's options.

EXAMPLE

A study by Murty, Gulati and Banerjee (2003) for the urban areas of Delhi and Kolkata provided estimates for measuring benefits from reducing air pollution. They considered a general health production model (Annexure 2) and solved the system of simultaneous equations comprising of health production function, demand for mitigating activities, and the demand for averting activities. The variables used in the estimation of model consist of endogenous variables and a number of exogenous variables. The primary data about the health status and socio-economic characteristics were collected for a sample of 1250 households from each city through surveys.

The formulated structural model used in the estimation is specified as follows:

$$\ln Y_{1i} = \alpha_1 + \beta_1 \ln X_{1i} + \beta_2 \ln X_{2i} + \beta_{3i} + \beta_4 \ln X_{4i} + \beta_9 \ln X_{9i} + \beta_6 \ln Y_{2i} + \beta_7 \ln Y_{3i} + u_{1i} \quad (1)$$

$$\ln Y_{2i} = \alpha_2 + \beta_7 \ln X_{1i} + \beta_8 \ln X_{2i} + \beta_{10} \ln X_{5i} + \beta_{11} \ln X_{6i} + \beta_{12} \ln X_{7i} + \beta_{13} \ln Y_{9i} + \beta_{14} \ln Y_{1i} + \beta_{15} \ln Y_{3i} + u_{2i} \quad (2)$$

$$\ln Y_{3i} = \alpha_3 + \beta_{16} \ln X_{1i} + \beta_{17} \ln X_{21} + \beta_{18} \ln X_{5i} + \beta_{19} \ln X_{8i} + \beta_{20} \ln X_{9i} + \beta_{21} \ln Y_{1i} + \beta_{22} \ln Y_{2i} + u_{3i} \quad (3)$$

The endogenous variables are health status of the household (Y_1); doctor visits (Y_4) and mitigating activity (Y_2) and averting activities (Y_4). The various exogenous variables are household air pollution exposure index (X_1), chronic disease index (X_2), family size (X_3), index for habits (X_4), awareness for air pollution borne diseases (X_5), ratio of females to size of households (X_6), gross annual household income (X_7), index for indoor pollution (X_8), exposure to NO_x index (X_9) and city dummy (X_{10}).

The parameters were estimated using 3 SLS and GMM methods of estimation. Given the estimates of household health production model. The household marginal willingness to pay (MWP) for reduction of one microgram of SPM/m^3 could be estimated as

MWP = δ (Sick days)/ δ Exposure (SPM) + δ (Medical expenses) / δ Exposure (SPM) + δ (Averting activity) / δ Exposure (SPM) (4)

The medical expenses are measured in monetary terms. The monetary value of sick days is calculated by estimating the income loss to the household due to sick days assuming seventy percent of urban household members are working members and on an average, family members suffered six days of sickness during the recall period of six months. The averting activity is measured as an ordered variable taking the value in the range of 0 to 4. The annualized monetary gains to the entire urban population due to reduction of exposure to SPM from the current average to the safe level, corresponding to 200 $\mu g/m^3$ SPM is Rs.4896.6 millions for Delhi, Rs.2999.7 millions for Kolkata and Pooled Rs.7896.3 millions.

LIMITATIONS

The assumption of perfect substitutability poses the limitation as in practice 'perfect substitutes' do not exist because in certain cases disutilities associated with the pollution cannot be averted by further spending on the substitutes. For example, some of the health effects due to air pollution cannot be averted using defensive expenditures hence may not enter the model. This may lead to underestimation of the results. Another problem associated with the technique is that it does not account for the additional beneficial effects, which may arise as a result of averting activities. Bartik (1988) argues this may make the model more complicated. He further states that the information on household's valuation of defensive measures for non-defensive reasons such as use of air conditioners, which purify the air, and provides cooling could be used to develop the better estimates to measure benefits. This is known as joint production i.e. avertive expenditures may also provide benefits other than environmental improvement. Uncertainty is yet another issue that leads to difficulty in model specification. Courant and Porter (1981) have shown empirically that avertive expenditures in general are not true estimates of the marginal willingness to pay.

The technique could be fairly expensive in context of developing countries. Also, biasness may result in, as it is solely dependent on surveys. The method is constrained by the ability to pay by the target population.

TRAVEL COST METHOD

The underlying theory of the Travel cost method (TCM) comes from neoclassical demand theory and is based on the weak complementarity notion developed by Maler for estimating demand for environmental quality changes (Menz and Mullen, 1985). It estimates the travel costs to the recreational site. The visits to the site and environmental quality are weak complements if, when no visits are taken, the individual is indifferent to the level of environmental quality. The method involves the derivation of the demand equation for an outdoor non-priced recreation activity and estimation of the users' consumer surplus required for calculating the net economic value. For instance, in figure 2.1, D_0 is the demand for a recreational site at some pre-existing environmental quality E_0. D_1 is the new demand curve after a policy change at the new improved environmental quality Q_1. The price line is fixed P_0, i.e. say the admission fee. The number of visits before the implementation of policy is V_0 and the consumer surplus is shown by area A. After the policy, the number of visits increases to V_1 and consumer surplus increases to area shown under the triangle A+B. The change in the consumer surplus represents the incremental benefits of improving the quality from E_0 to E_1. It is used to estimate the use values and excludes the non-use values. There are three approaches described in the literature : Zonal Travel Cost Method (ZTCM), Individual Travel Cost Method (ITCM) and Random Utility Model (RUM).

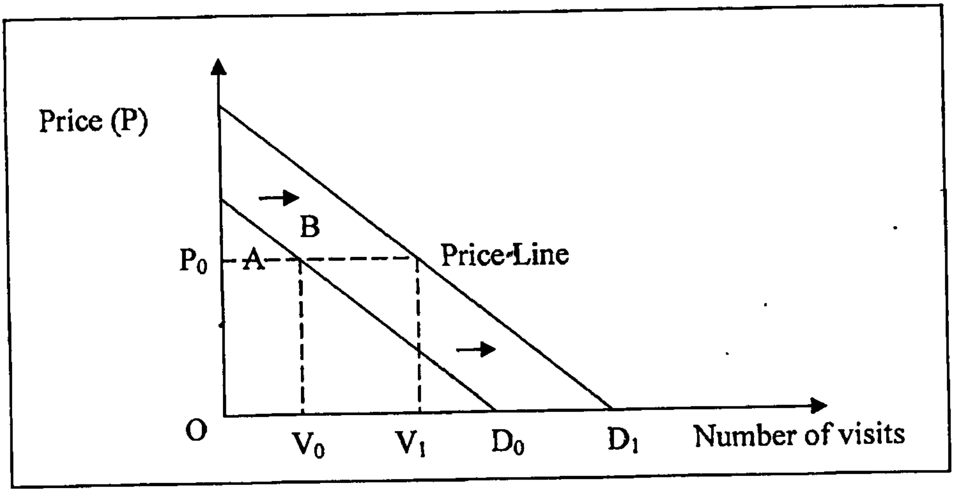

Figure 2.1 Value of improvement to a site

Source : Callan and Thomas, 2000, p.229.

The early studies relied upon ZTCM. In this methodology, data are collected on site from the visitors relating to their point of origin and the number of visits to the site in the specified time period. The area surrounding the site is divided into various zones of origin from where the associated travel cost of calculated. Using the data, the trip generating function is estimating using multiple regression once the independent and dependent variables have been addressed. This is used to derive the demand curve and eventually the total consumer surplus or the economic benefits from a recreational site. Although straightforward, the method has often been criticized by many researchers because of the underlying assumptions. Smith and Kopp (1980) demonstrated that the underlying assumptions involving the objective of the trip for a single purpose, the amount of time spent on the site during each trip and the expenses incurred during travel can impact substantially the estimates of consumer surplus derived from the model. Bowes and Loomis (1980) argues the need for correction of heteroskedasticity error which is bound to arise as a result of unequal population in different zones if Ordinary Least Square is to be used. They suggest the use of Generalised Least Squares (GLS) in such situations as it leads to lower variances. Vaughen and Russell (1982) discussed the incorporation of site characteristics in the travel cost framework.

Another approach in the literature focuses on the ITCM, which is considered to be more reliable however it is data intensive. The approach is similar to ZTCM but uses survey questions as a valuable supplement to observed data in the travel cost models (Englin and Cameron, 1996). A trip generating function is specified which is used to derive a demand curve. The integration of demand curve gives the consumer surplus and finally aggregate consumer surplus is estimated.

The third technique is the use of Random Utility Model (RUM) which allows the effects of multiple sites (with different attributes) to be incorporated in a way that measures benefit. The concern has been on defining individual's choice set in the RUM (Parsons and Hauber, 1988; Haab and Hicks, 1997). Parsons and Kealy (1995) have presented demand theory based on Bocksteal, Hanermann and Kling's participation function for analyzing number of trips taken in a random utility model for recreation. RUM however does not account for the time estimates, which is spent at the site and the time taken to reach the site. An important disadvantage of this model is the independence of irrelevant alternatives (IAA) property. This property requires that all the alternatives be perceived as distinct and independent. In other words, the attributes and costs associated with one site should be uncorrelated with the other site. A partial solution to this problem is solved through nested logit model wherein welfare effects are estimated (Kling and Thomson, 1996). Englin and Shonkwiler (1995) developed a negative binomial count data model of recreation demand to correct for truncation and endogenous stratification. They demonstrated that any count data framework provides both per trip welfare measures and the quantity demanded measures that are needed to find total measures. The sample is truncated because of the exclusion of non-users and is endogenously stratified because the likelihood of certain persons being sampled depends on the frequency of their site visits.

Travel cost method has been used to value the benefits of recreation and has focused almost exclusively on damage to fish populations in the context of air pollution. Muller and Menz (1985) valued recreational fishing lost as a result of acid deposition in the Adirondack mountains in the north-east of U.S. Based on 'angler days' lost, annual costs of air pollution were estimated. Brown and Mendelsohn (1984) developed a different form of travel cost method using the hedonic approach. The demand for the site characteristics can be revealed by regressing travel costs on the bundle of characteristics that each potential site possesses. This approach has certain advantage for the resource manager or the public agency that can maximize the benefits by allocating the scarce resources efficiently as the method values each characteristic of the good. Pendleton and Mendelsohn (2000) have shown the results of HTC and RUM are comparable in determining the impact of global warming on fish catch rates. They further show that both the models are equally valid and can be used to value recreation sites. Research has shown that doubling of atmospheric carbon dioxide would have some impact on freshwater sport fishing in the Northeast United States and using Random Utility Model as well as Hedonic Travel Cost model have predicted $4.76 million loss of $20.5 million net benefit depending on the climate scenario. The method has developed considerable interest in the recent literature.

THEORETICAL MODEL

A simple model of travel cost is presented with a single environmental good and later extends it to the case of multiple goods.

Suppose the consumer choose a site with air quality 'q'. Let the visits to the site be 'v' and market goods 'x'. The out-of-pocket expenses associated with a single trip be p_0. Again suppose the consumer works for L hours at a wage w to earn a certain income. The utility maximization problem can now be defined as :

$$\text{Max } U(x, v, q) \tag{1a}$$

Such that

$$W L = x + p_0 v \tag{1b}$$

The consumer also faces a time-budget constraint that must be appended to the utility maximization problem :

$$T = L + (t_t + t_v)v \quad (1c)$$

where T is time available to devote to site visits and work, t_t and t_v are the travel time associated with a single round trip visit to the site and the on-site time associated with a single visit respectively.

Equation (1c) can be substituted in question (1b) to eliminate L and thus reduce the maximization problem to

$$\max U(x, v, q) \quad (2a)$$

such that

$$wT = x + [p_0 + w(t_t + t_v)]v$$

$$\equiv x + p_v v \quad (2b)$$

where

$$p_v + p_0 + w\ (t_t + t_v) \quad (2c)$$

The demand function for visits to the site can be obtained on solving the maximization problem.

$$v = f\ (p_v, q, y)$$

where y is income (wt).

If the consumer chooses multiple sites, then equation (3) can be included to modify to include the price of substitute sites. Thus if there are three sites, A, B and C the demand for any one site (e.g. site A) will be a function of the prices of visiting the other sites as well as the quality of other sites :

$$v_A = f_A(p_A, p_B, p_C, q_A, q_B, q_C, y) \quad (4)$$

It is difficult to implement the model empirically with many substitute sites. One of the approaches to simplify the choice problem is Random Utility Model (RUM).

Suppose a consumer has the options to visits the sites *i* = 1, 2, .../. Each site is described by a set of attributes, q_i, and an access price, p_i - the travel cost. The consumer also consumes unrelated market goods x, which is assumed to have a price of 1. Visiting site *i* is hypothesized to give a certain amount of utility, which depends on the price of visiting *i* (not the price of substitute sites) and the quality of site *i* :

$$u_i = f(\beta, p_i, q_i, y) + \varepsilon_i \qquad (5)$$

where β is a set of parameters to be statistically estimated and ε_i is an error term that represents factors that are unknown.

Choosing a site *i* over site *j* means the utility from *i* is higher than the utility from *j* :

$$u \geq u_j \text{ for all } j \qquad (6)$$

Having statistically estimated β in equation (5) the demand for trips to site *i* as a function of quality of the site and the price of a visit can be computed. This can be used to examine the changes in demand when the quality of the site changes.

The central assumption is that visit costs are taken as indication of recreational value. Englin and Cameron (1996) points out little within-person variation in prices in a travel cost model unless the number of time periods are large or the intervals between time series observations are long as people do not move frequently. Also the study utilized the convention that the opportunity cost is one-third of the respondent's hourly wage. The underlying assumption being that the time is valued at a fixed percentage of wage rates. The method assumes that the kind of trips undertaken is unaffected by the change in costs.

DATA REQUIREMENTS

The data requirement for the approach is substantial. The early literature used origin zone data recording point of origin of visitors and number of visits made to the sites with the associated travel costs. Economic and demographic characteristics of the populations in each origin zone are attached to each observation. The zonal travel cost model could take account of socio-economic characteristics based on the aggregate information from each zone through census data. The second type of data requires individual records of recreational benefits relating to the number of visits to the site, recreational preferences, socio-economic characteristics, etc. which may be obtained through questionnaire surveys. In addition the purpose of the visit as well as the range of environmental quality attributes for the site and the substitute sites are needed. Information on substitute sites has been largely ignored in the conventional models, as it is very been an important issue of concern to be included in the model.

ESTIMATION PROCEDURES

The conventional continuous estimation technique such as Ordinary Least Square (OLS) can be inappropriate. Englin and Cameron (1996) used Poisson regression technique as the trip data were non-negative integers and using OLS implies some valuation to the recreational site even if the site is not visited. Also, OLS estimates exhibited heteroskedastic disturbances. The use of logit models is suggested by Kling and Thomson (1996).

CHOICE OF FUNCTIONAL FORM

Although there is no particular functional form suggested for TCM, but logarithmic forms are often used in comparison to linear forms.

EXAMPLE

Mullen and Menz (1985) estimated the net economic value of the Adirondack recreational fishery resulting from damages due to acidification from significant sources of sulphur and nitrogen oxide emissions. They assumed anglers' willingness to travel to exhibit weak complementarity to environmental quality at the site and defined demand function as :

$$D = D\left(P_t, P, EQ, SE\right) \quad (1)$$

where D is demand for the site, P_t is the price of travel t the site including time and money costs, P is set of all other prices, EQ represents environmental quality at the site and SE are socio-economic characteristics.

They amended the standard travel cost model to account for the large number and diversity of sites, which comprise the Adirondack fishery. The first stage demand curve may be stated as :

$$D_i^j = f\left(AP_i^j \sum^{m \neq j} AP_i^m, SE_i\right) \quad (2)$$

i = 1, ..., n origin zones,

j = 1, ..., m fishery types

where D_i^j represents demand, in days, per angler population from zone i for sites of fishery-type j, AP_i^j is an accessibility index for fishery types, and SE_i is a vector of socio-economic and preference variables for anglers in origin i.

The accessibility index is defined as :

$$AP_i^j = \sum_{k=1}^{l} \left(A_k^j / P_{ik} \right) \quad (3)$$

where A_k^j is the measure of the surface water acreage of fishery type j available at site k and P_{ik} is price or round trip travel costs from origin i to site k. Because visitation to fishery type j should also depend upon accessibility of alternative types of angling opportunities, the demand equation for each fishery type contains substitute accessibility indices to reflect the range of alternatives that exist at an array of travel costs from each origin zone.

They utilized Zellner's Seemingly Unrelated Regression (SUR) technique to jointly estimate the demand for each of the alternative fishery type and used double log format as it produced more significant and stable parameter estimates. The final form of the demand equation was estimated as :

$$\ln\left(D_i^j + k\right) = \beta_0^j = \beta_1^j \ln AP_i^j + \sum^{m \neq j} \beta_2^{jm} \ln AP_i^m \beta_3^j \ln SE_i + \varepsilon_{ij} \quad (4)$$

where $\beta_0, \beta_1, \beta_2, \beta_3$ are parameters to be estimated and ε_{ij} is a zero-mean error term.

The estimated equations were used to generate an aggregated demand curve for each fishery by predicting total days visited at a set of hypothetical fees simultaneously imposed on all sites. The area under the aggregate demand curve represents the net economic value (NEV) of the resource, which may be calculated by integration of an equation representing the aggregate demand curve between the limits zero to the maximum hypothetical fee. Alternatively, the NEV can be approximated by calculating the cumulative summation of the aggregate days estimated, as ΔF_k^j is incremented by \$1 from zero to the maximum fee. The latter procedure was employed by the authors and per angler day values were obtained by dividing NEV by the estimated number of angler days when $\Delta F_k^j = 0$. Total angler values for the Adirondack fishery were estimated by multiplying per day values by actual visitation. The loss to anglers from acidification damage is approximate by the area between two ordinary demand curves for the fishery, which was calculated as $1.07 million.

LIMITATIONS

The method depends on the collection of detailed data and surveys so can be extremely expensive and time consuming. Moreover the surveys itself may impose sampling biases. The assumption that people perceive and respond to travel expenditures in the same way, as they would respond to changes in admission costs is doubtful. Potential problems may arise due to differences in tastes or the preferences of the consumers and also due to the availability of the substitute sites. Individuals living closer to alternative sites may impose different value to the site under investigation. It is believed that visitation rate decreases with the increase in the distance. Another critical issue discussed in the literature associated with the travel cost method is the time-cost. The use of the wage-rates, defining and measuring opportunity cost of time, valuation of time of children and adolescents participants are some of the problems often cited. It is not only significant to note the time taken during travel but also the amount of time spent at the site. At times, high value of recreational activities with low travel time is not captured in the method (Bishop and Herberlein, 1979). The travel cost method and the utility function assumes separability in the underlying model. Results will be biased if the utility function is not separable. Multi-purpose, multiple-site trips also poses empirical problems. Congestion effects are usually ignored in the studies. The choice of the functional form is yet another issue which may lead to bias parameter estimation (Mullen and Menz, 1985).

The omission of certain variables such as travel time and congestion variables and the prices of qualities of relevant substitutes have been the major source of discussion amongst the researchers. Allen, Stevens and Barrett (1981) demonstrated that the bias due to model misspecification is likely to vary from situation to situation. Caulkins, Bishop and Bouwes (1985) analysed a situation, which can cause either a negative, or positive bias in Travel cost model estimates when travel costs to alternative sites are omitted. Bias also depends on the degree of correlation between the omitted price and the included price. Kling (1989) further shows for a single site, if the omitted price is uncorrelated with the included own price, no bias exists in the welfare estimate. On the other hand, bias will occur for multiple sites even if the omitted price is not correlated with the included price. Another strategy to minimize omitted variables is the use of panel data, which retains the economic relationship and nets out the individual heterogeneity which may arise due to the respondents' answers to survey questions, differences in the individuals' beliefs about nature or other various available opportunities.

HEDONIC PRICE METHOD

Hedonic price method is another revealed preference technique that measures economic values for environmental services from observed market behaviour. The technique measures only the use values. It is based on the weak complementarity assumption. Weak complementarity is defined by Maler to occur if the quantity demanded of a private good is zero, the marginal utility or marginal demand price of environmental quality is zero. For example, the marginal value of air quality over a particular residential site would be zero for those who did not live at that site (Freeman, 1979). Thus the information on the demand for a private good, which is a weak complement of air quality, can be used to determine the benefits associated with the improvement in the air quality by measuring the area under the old and new demand curves. The basic procedure is to define a market commodity, specify its various attributes and develop a functional relationship between them. This is then used to estimate hedonic price function using multiple regression techniques that gives hedonic price coefficient. The coefficient is known as the marginal implicit price of the attribute. It is the additional amount paid by any household to choose a house with the additional amount of that characteristic other things being equal. This is further used to estimate the willingness to pay for better air quality.

Ridker and Henning (1967) were the pioneers to confirm that air pollution affects the property values. Rosen (1974) gave the first conceptual model and determined the marginal implicit price by taking derivative of the hedonic price function with respect to air pollution. This was followed by extensive research on hedonic models by Freeman (1974), Palmquist (1984). In one of the recent studies by Kim, Phipps and Anselin (2003), efforts were made by incorporating spatial effects in the hedonic model, which received little attention in the previous studies. Spatial effects, if ignored, could result in errors in the estimation of standard regression analysis. They used an explicit spatial econometric methodology in conjunction with a basic hedonic housing price model to measure marginal value of air quality improvement in Korea with respect to sulphur dioxide and nitrogen oxides. Spatial lag model used by them led to the measurement of both direct (due to housing and neighbourhood characteristics) and indirect effects (as a result of spatial interaction) that cannot be captured by non-spatial techniques. Another advantage is avoidance of biased and inconsistent estimators when spatial dependence is present but is ignored.

The most common application in the literature has dealt with the impact of air pollution on residential housing values. Smith and Huang (1995) using prohit analysis, estimate that hedonic models have been successful in supporting a connection between air quality conditions in different residential sites in the city and housing prices. In yet another study they list marginal WTP estimates of 37 studies on particulate pollution between 1967 and 1988 but none of the studies extend to non-marginal WTP for air quality improvement. The range for these estimated marginal values lies between zero and $98.52 for a one-unit reduction in total suspended particulates. Chattopadhyay (1999) carries out the estimation of non-marginal changes in air quality in the study models. of Chicago household market and found the households on an average were willing to pay more for particulate matter than sulphur dioxide. Portney (1981) has suggested a methodology for evaluating certain environmental risks by using estimates of air pollution effects on both property values and human health risks. A unique application of hedonic price method has been applied by Stanton and Whitehead (1995) to derive demand for an energy resource. They found an implicit market for low sulphur coal used in electricity production, which would provide a prediction of the price for sulphur dioxide emissions permits in the emerging market. Using the implicit price of sulphur dioxide, they estimated the cost of removing one ton of sulphur dioxide by power plant location.

In the following section, two cases are considered : The impact of air pollution on residential housing and the impact on the wages or labour.

HEDONIC PROPERTY VALUE MODEL

Hedonic property value model is used to estimate benefits to local households of reducing air pollution to the safe level. A number of studies have confirmed the association between air quality and land values. The most common model is Rosen's two-step procedure (1974) where implicit price function is determined from competitive equilibrium between buyers (consumers) and sellers (producers), which can then be used to determine the demand for environmental quality. Equilibrium is described by the intersection of demand and supply equations. The market is assumed to be competitive and the income effects are removed, in other words, wages remain constant. Now, the consumer with income Y is ready to bid certain amount of money (0) to buy a house with air quality z thereby maximizing his utility. Thus θ (z_i) is the marginal rate of substitution between z_i and money or the implicit marginal valuation the consumer places on z_i at a given level of utility and income. The point at which the bid function is just tangent to the price function is the point that gives maximum utility to the consumer. Also, the producer offers the house at a price ϕ, to obtain a particular profit level (Π). Producer equilibrium is represented by the point of tangency between the price line and the offer curve. The implicit price function p(z) corresponds to the common point when the bid function of the consumer and the offer function of the producer just match each other in market equilibrium. This is shown in figure 2.2.

The estimated hedonic price functions do not identify the demand and supply, it only reveals the marginal price of air quality at different concentration levels. The marginal willingness to pay can be estimated from the data obtained from incomes, taste variables such as age, education, etc. of the consumers (Y_1). Data can also be obtained from the suppliers on specific technological differences and other shift variables (Y_2). These can be represented by the marginal demand price and marginal supply price.

$$p_1 z = F^i(z_1, z_2, \ldots\ldots, z_n, Y_1) \qquad (1)$$

$$p_1(z) = G^i(z_1, z_2, \ldots\ldots, z_n, Y_2) \qquad (2)$$

Freeman (1974) defines the implicit price function as rent function, which gives an opportunity locus for the households. The slope of this gives the marginal purchase price function. He further points out that the slope of hedonic price function can be interpreted as marginal willingness to pay of all households if the income and utility does not change. It is actually the wiliness to pay for higher property values of interest as it exposes the households to a lesser risk of death or illness from air pollution.

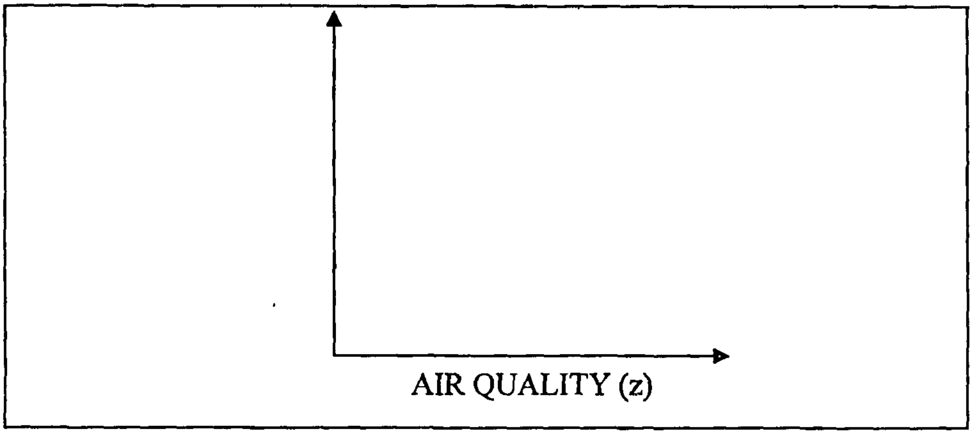

Figure 2.2 : Equilibrium between consumer and producer showing offer function (ϕ) and bid function (θ)

THEORETICAL MODEL

The model assumes that there is a wide range of characteristics among which choices can be made and it is these characteristics or the attributes of a good, which are valued. Also, expenditures on housing are assumed to be weakly separable from other consumer expenditures.

Let z be a vector of housing attributes and x be the composite good that is taken as numeraire.

$$z = (z_1, z_2, \ldots, z_n) \tag{3}$$

Consider the utility function of the individual as

$$U = U\,(x, z) \tag{4}$$

which is subject to budget constraint

$$Y = x + P(z) \tag{5}$$

where Y is income and P(z) is the price of the house with attributes z.

Palmquist (1984) argues that the budget constraint may be non-linear. So income or expenditure variable must be adjusted to equation (3) by adding $\sum_{i=1}^{n} P_{zi} z_i$ to both sides where P_{zi} is the marginal price of the characteristic z_i in order to avoid biased estimates of the coefficients of the price variables in the demand regressions. If P(z) is then subtracted from each side we get

$$Y_a \equiv Y - P(z) + \Sigma P_{zi} zi = x + \Sigma P_{zi} zi$$

where Y_a is the adjusted income.

The partial derivative of the price of the house with respect to any of the attributes say z_i is the implicit marginal price of that attribute i.e. the additional amount paid by any household to choose a house with the additional amount of that characteristic, other things being equal. This gives the marginal willingness to pay for one more unit of z or the marginal rate of substitution between the attributes z_i and x.

$$\frac{\partial P}{\partial z_i} = \frac{\partial U / \partial z_i}{\partial U / \partial x} \tag{6}$$

Equation (6) can be used to derive demand functions for particular amenities or characteristics of interest in the second stage. Once the demand functions are identified, hedonic slope can be used to measure the WTP for a small increase in an attribute.

DATA REQUIREMENTS

The data requirements are substantial which include selling price or the rental price, structural characteristics of house, neighbourhood characteristics, socio-economic characteristics and the environmental characteristics. Information about demographic characteristics is also needed including age and sex composition in the family, the education level of family members, occupation, gross annual income of the family, family monthly average household expenditure.

The source of data varies from one country to another. For instance, in U.S. data on dwelling and household attributes may be obtained from specific agencies like Federal Housing Administration, which records information on house sales, selling price, income, family size, race, marital status, as well as the census tract in which the house is located. The housing prices can also be based on respondent estimates or from the office of realtors in the local area. Neighbourhood attributes can be compiled from the census records while data on aggregate property tax rates can be obtained from State Department of Revenue Publications (Chattopadhyay, 1999). Chattopadhyay has given the formula to calculate the annual nonhousing expenditure data, which is obtained by multiplying the monthly payment by 12 to arrive at annual payment for each household, which is then subtracted from the purchaser's annual income. Monthly payment can be calculated as :

$$P = RA\ (1+R)^N / ((1+R)^N - 1)$$

where P = monthly payment, R = annual interest/12, N = 360

An important component of the data set is the location of the houses. Air quality data can be obtained from the specific agencies dealing with the Air Quality Monitoring in that particular location. These agencies monitor air quality daily for various pollutants at different stations. Sometimes dummy variables or qualitative variables may be introduced to estimate the implicit price through the hedonic price model.

ESTIMATION PROCEDURES

The method of Ordinary Least Square (OLS) may not be applicable when simultaneous estimation of implicit price function and demand is required. In this case, the implicit price function may be dependent on some of the random errors. As Epple (1987) points out random components may arise because of measurement error and/or unmeasured characteristics of demanders, suppliers, and products. If an explanatory variable is correlated with the stochastic disturbance term, OLS estimators are not only biased but also not consistent and hence may yield seriously misleading results. Such an identification issue was raised by Brown and Rosen (1982), Bartik (1987), Epple (1987), Palmquist (1988) and others. They propose a way to identify the structural coefficients by imposing restrictions on functional form with the assumption that prices are generated by a single hedonic price equation. Alternatively, data from multiply markets or spatially distinct markets can be used to estimate separate hedonic equation for each market thus allowing identification of demand functions. Another approach is the use of instrumental variables that are truly exogenous and correlated with the attributes but uncorrelated with the composite error term. The identification problem needs to be addressed otherwise the estimates will simply reproduce the information contained in the price schedule.

Murdoch and Thayer (1988) estimates hedonic price equations using mean visibility for the California South Coast Air Basin and compared it with the probabilities of various levels of visibility occurring as independent variables. The test indicated the rejection of mean specification.

CHOICE OF FUNCTIONAL FORM

A range of functional forms have been applied in various studies. In general it is found that non-linear forms give a better estimate of data such as log and semi-log. Bender, Gronberg and Hwang (1980) have investigated the use of simple linear, log-linear in both stages and the translog quadratic Box-Cox combination on a hypothetical air pollution program which involves uniform reduction of air particulates. The results indicated the use of more flexible form i.e. quadratic Box-Cox forming both stages of Rosen demand estimation procedure. Chattopadhyay (1999) explored the effect of functional form restrictions by considering six variants of a generalized Box-Cox form for the hedonic housing price equation, as well as two different forms for the utility function, namely Diewert and Translog.

EXAMPLE

Murty, Gulati and Banerjee (2003) estimated aggregate consumer surplus benefits to the households of Delhi and Kolkata using hedonic property price function.

Marginal willingness to pay (MWP) function for air quality was obtained separately for each city as well as using the pooled data for both cities.

They defined the price of ith residential location to be a function of structural (S_i), neighbourhood (N_i) and environmental characteristics (Q_i).

$$P_{hi} = P_h(S_i, N_i, Q_i)$$

They further defined utility function for which the individual chooses the utility maximizing bundles of housing characteristics

$$U(X, S_i, N_i, Q_i)$$

where X is a component private good. This is subject to budget constraints and calculated the implicit marginal price using equation (6) of the theoretical model.

The second step involved the computation of MWP for the improvement in the air quality. If there is an improvement in the environment characteristics from q_j^0 to q_j^1, the value individual places on such an improvement (B_{ij}) could be estimate with respect to q_j.

$$B_{ij} = \int_{q_j^0}^{q_j^1} b_{ij}(q_i, Q_i^*, S_i, N_i, G)\,\delta\, q_j$$

where q_j is the choice of environmental amenity, Q^* is vector of environmental characteristics, G_i is socio-economic characteristics.

The equations for estimation are described as :

$$\ln(Y_1) = \alpha_1 + \beta_1 \ln(X_1) + \beta_2 \ln(X_2) + \beta_3 \ln(X_3) + \beta_4 \ln(X_4) + \beta_5 \ln(X_5) + \beta_6 \ln(X_6) + \beta_n \ln(X_7) + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} \ln(X_{10}) + \beta_{11} X_{11} + \beta_{12} \ln(X_{12}) + \beta_{13} \ln(X_{13}) + \beta_{14} \ln(X_{14}) + \beta_{15} \ln(X_{15}) + \beta_{16} \ln(X_{16}) + \beta_{17} \ln(X_{17}) + u_1$$

$$\ln(Y_2) = \alpha_2 + \gamma_{19} \ln(X_{19}) + \gamma_{20} \ln(X_{20}) + \gamma_{13} \ln(x_{13}) + \gamma_{21} \ln(X_{21}) + \gamma_{11} \ln(X_{11}) + u_2$$

where the variables are defined as monthly rent(Y_1), structural characteristics of house-covered area (X_1), number of rooms (X_2), indoor sanitation (X_3), distance from business centre (X_4), distance from National highways (X_5), distance from slums (X_6), distance from industry (X_7), distance from shopping centre (X_8), environmental variables - perception about air quality (X_{10}), perception about water quality (X_{12}), dummy for adequacy of green cover (X_{11}), SPM (X_{13}), SO_2 (X_{14}), NO_x (X_{15}), other variables-business or salaried class (X_9). The variables for second equation are Marginal willingness to pay (Y_2), annual gross family income (X_{19}) square of SPM (X_{20}).

Now, the implicit marginal price from the model with respect to SPM is estimated as

∂ (Monthly rent)/ ∂ (SPM) = [Coefficient of SPM in equation(1)] * Monthly rent/SPM

This equation has been used to estimate MWP for reducing SPM concentration by 1 $\mu g/m^3$. By multiplying the estimate of MWP by the amount of SPM concentration required to be reduced to reach its safe level, an estimate of monthly welfare gain to a representative household in each city could be obtained. The annual benefits from reducing the SPM concentration to safe level in Delhi and Kolkata are respectively estimated as Rs.46655.2 million and Rs.2665.3 million.

LIMITATIONS

The technique reflects only those impacts of which individuals are aware (Calthrop and Maddison). In other words, it does not measure the non-use value. It is based on the assumption that market is efficient and perfect information exists. The two major econometric issues are that of parameter identification which arise due to market mechanism by which hedonic prices are generated and the endogeneity of housing attributes. The selection of an appropriate functional form is another issue of investigation. Other issues often discussed in the literature in the hedonic price model are the measurement of neighbourhood quality where the variables such as income and racial composition generally used as proxies for standard of living and racial effects.

Hedonic price studies may ignore the problems of mobility restrictions. For example, transaction costs may prevent the consumer from moving to other parts as a result of change in the air quality. According to Palmquist (1988), this makes the welfare analysis very complex. He proposes the use of distance functions, which represent normalized willingness to pay for a vector of characteristics relative to some level of utility. It is useful for measuring welfare when quantities change. A major problem with such studies is that of multicollinearity i.e. the explanatory variables appear to be highly collinear (Giley and Pace, 1995). For instance, during the measurement of environmental quality, suspended particulate matter may be collinear to sulphur dioxide. If this occurs then, the regression coefficients are indeterminate and their standard errors are not defined. Although there are no sure methods to remove this but some approaches such as using prior information, combining cross sectional and time series data (pooled data), transforming data, omitting a highly collinear variable, factor analysis could be of some help. However, care should be taken during omission of data such that it does not lead to specific bias.

HEDONIC WAGE APPROACH

Hedonic wage technique, like hedonic price approach is based on the actual utility maximization model and the behaviour of the consumers. It has been applied to wage rate to calculate implicit prices for air pollution. This method is also used in wage-risk analysis to estimate the value of statistical life and have been applied in dose response techniques. Here, the job is characterized by various attributes including the risk of death. Hedonic wage function is determined from the equilibrium in labor market as a result of compensation and offer curves. This is used to value small change in the risk level. For example, the value of a cleaner environment can be inferred from the compensation that people require to bear the risk of higher level of air pollution, which poses health risk.

As mentioned in various literature Thaler and Rosen (1976) are the first to suggest that labor market could be viewed as an example of hedonic market. Clark and Kahn (1989) adopted a two-stage approach to value environmental amenities based on actual utility maximizing behaviour of individuals. In the first stage, the marginal price of amenity characteristics were estimated using a simple hedonic wage model while in second estimated marginal price was regressed against a range of socio-economic characteristics and environmental amenities to derive willingness to pay function. The technique in general has been widely used in wage-risk analysis in relation to occupational hazards. In the context of air pollution, Bayless (1982) uses the approach however is not used in the developing countries as the model assumes that perfect competition exists in the market and complete information is there.

THEORETICAL MODEL

Like the hedonic housing approach, hedonic wage model is based on the actual utility maximizing behaviour of individuals. Here the underlying assumption is that, given mobility and time, households migrate between cities for better air quality and would be willing to accept lower wages for better air quality. The model cited there has been adopted from the work Shanmugam (1997) study, which follows the work of Viscusi (1993).

Let Y be the initial asset and W(p) be the schedule of earnings for the jobs. Probability of an event that leads to death/injury be p and the probability that the workers remain healthy be (1-p).

Suppose U(x) denotes the utility of being healthy state and V(x) denotes the utility of being injured or dead for any consumption level x which is equal to Y+W(p) and λ be the shadow price of the good constant. It is assumed that wage and utility functions are twice differential.

The workers optimal choice among hazardous job alternatives is determined by maximizing the lagrangian given by

$$L = (1-p)U(x) + pV(x) + \lambda[x - Y - W(p)] \quad (1)$$

The job with the optimal risk p is determined by solving the following first order conditions for a maximum as well as budget constraint :

$$L_x = 0 = (1-p)U(x) + pV(x) + \lambda \quad (2)$$

$$L_p = 0 = -U + V - \lambda W_p \quad (3)$$

$$\lambda = 0 = x - Y - W(p) \quad (4)$$

Solving for W_p produces the result :

$$W_p = U - V/(1-p)U_x + pV_x > 0 \quad (5)$$

Totally differentiating the first order conditions (2-4) and solving for resultant equations using Cramer's rule, the second order condition can be solved as :

$$W_{pp} < \{-(W_p)^2[(1-p)U_{xx} + pV_{xx}] - 2W_p[V_x - U_x]\} - \{pV_x + (1-p)U_x\}^1 \quad (6)$$

In equation (6), the right hand side is positive due to plausible restrictions stated above on the utility functions. Thus, the compensating wage differentials result in (5) implies that the curve relating W to p must have a positive slope if workers are to be attracted to jobs along with it. The choice of a job will satisfy the second order conditions for an optimum given by (6) if the wage premium per unit of risk declines with the level of p, is constant, or increased with p at not too great rate.

The basic approach is to determine the wage equation

$$w_i = \alpha + \sum_{m=1}^{M} \Psi_m x_{im} + \gamma_0 p_i + \gamma_1 q_i + \gamma_2 q_i WC_i + u_i$$

where w_i is worker i's wage rate, α is constant term, the x_{im} are differential personal characteristics and job characteristics variables for worker i (m = 1 to M), p_i is the fatality risk of worker i's job, q_i is the job's nonfatal risk, WC_i reflects the workers' compensation benefits that are payable for worker i's job injury, u_i is a random error term reflecting unmeasured factors that influence the wage rate and remaining terms are the coefficients to be estimated.

The model assumes that the worker be rather healthy than not (i.e. $U(x) > V(x) > 0$). The marginal utility of consumption is positive and greater in health state (i.e. U_x, $V_x > 0$) and the marginal utility of consumption is diminishing or the workers are either risk averse or risk neutral (i.e., U_{xx}, $V_{xx} < 0$). According to Viscusi (1993), if individuals are risk averse, the second order conditions may not be met.

DATA REQUIREMENTS

Large individual data sets on worker behaviour including demographic and job characteristics are essential to determine the wage equation. The risk measure needs to be estimated requiring the inputs for fatality risk and nonfatality risk. Thus the identification of job attributes is crucial. Wage rates and the demographic characteristics can be obtained from the Occupational Wage Survey conducted by Bureau of Labour Statistics. However the problems may arise in the developing countries as the medical data is unsatisfactory. The life expectancy, availability of medical resources is quite poor.

Data needs to be collected on the variables, which affect earnings such as education age, union status.

LIMITATIONS

There are specific problems on the assumption underlying the hedonic model that individuals choose jobs on the basis of perfect information and that there are no mobility restrictions. An individual may continue his job in an area of lesser environmental quality due to lack of opportunities in better environmental conditions. Differences may arise due to perceived risks and actual risks faced by the workers leading to specification bias. Inclusion of nonfatal risk avariable sometimes is difficult because of correlation between the health risk variable and nonfatality measures and due to differences in data sources and the reference population. Another source of error may be the non-inclusion of life expectancy, which may also influence the hedonic wage equation. According to Krupnick et al., the approach measures compensation received by prime-aged men for immediate risk reduction whereas the exposure to air pollution may have delayed effects. It may overstate the compensation received by older people who have fewer life years remaining.

DOSE-RESPONSE TECHNIQUE

Dose-response technique is considered as the most defensible technique and most frequently used in the literature to value health impacts and material damage. It is categorized under physical linkage approach which estimates benefits based on a technical relationship between and environmental resource and the user of that resource. The technique involves establishing a relationship between the cause of damage (dose) and the associated environmental impact (response) and the valuation of changes in environmental quality through changes in productivity, impacts on health, natural resources, and loss of human capital. Since there is a great deal of uncertainty on the estimates, upper and lower bounds are provided to indicate ranges within which the actual health effects are likely to fall. Estimated increment in annual health effects associated with unit change in pollutants by Ostro (1994) is shown in Table 2.1. In contrast, Banzhaf, Desvousges and Johnson (1996) used Monte Carlo simulation technique to quantify the uncertainties in their estimates of valuing externalities associated with the electricity generation from coal-fired plants. The researchers evaluated three scenarios – rural, metropolitan and urban for finding the impacts on health, materials, visibility, and agricultural damages from particulate matter, sulphur dioxide, nitrogen oxides, ozone, carbon monoxide and lead. They estimated the change in concentrations and demographic data for each receptor, and combined these with the parameters of concentration – response functions to estimate the number of new cases of the illness. These were then multiplied by the WTP per case to estimate total damages. Monte Carlo simulation was performed by allowing the parameters from the concentration-response functions, the background health data, and WTP estimates to vary, keeping the pollution concentrations (as they were without standard errors) and the demographic data fixed. With repeated samples the resulting distribution of final damages were estimated from which they calculated confidence intervals. The damages associated with the particulate matter were the highest ranging between $530 to $6054 followed by Pb, nitrogen oxides, sulphur dioxide, ozone and carbon monoxide all had smaller per-ton damages.

Table 2.1

Summary table of dose-response functions : Estimated increment in annual health effects associated with unit change in pollutants

	Pollutants (Units)			
	PM 10 ($10\mu g/m^3$)	**SO_2 ($10\mu g/m^3$)**	**Ozone (pphm)**	**NO_2 (pphm)**
Premature mortality (% change)	0.96	0.48		
Premature mortality/100,00	6.72			
RHA/100,000	120.0		7.70	
ERV/100,000	235.4			
RAD/person	0.575			
LRI/Child	0.016			
Asthma Symptoms/ asthmatic	0.326		0.68	
Respiratory symptoms/ 1,000 children	1.83		0.55	
Chronic bronchitis/ 100,00	612.2			
MRAD/Person			0.34	
Respiratory symptoms/ 1,000 children		0.18		
Respiratory symptoms/ Adults		0.10		
		0.10		
Eye irritations/Person			0.266	

Note : RHA = Respiratory hospital admissions; ERV = Emergency room visits;

RAD = Restricted activity days; LRI = Lower respiratory illness;

MRAD = Minor restricted activity days; PPHM = Parts per hundred million

Source : OSTRO B. (1994)

HEALTH IMPACTS

Most of the studies on health impacts have been done in U.S. and the United Kingdom that relate information on changes in ambient air quality for different pollutants to different health outcomes. Methodology outline by Ostro has been largely adopted (Wells, Xu and Johnson, 1924; Zaim, 1997). Recent research such as in Netherlands (Zuidema and Nentjes, 1997) was however concentrated on using country specific data to establish Dose Response Relationships (DRR). Particulate matter has been of chief concern in the literature (Pearce, 1996; Pearce and Crowards; Zaim, 1997; El-Fadel and Massoud, 2000).

Dose response functions can be used for the mortality effects or even for lesser impacts such as respiratory hospital admissions (RHA), restricted activity days (RAD), minor restricted activity days (MRAD), asthma attacks, acute respiratory symptoms, chronic bronchitis, eye irritation and so on. A significant relationship between the concentration of the pollutant and the impacts is established. Lave and Seskin (1973) demonstrated a close association between air pollution and mortality and estimated significant magnitude of the relationship between them. Valuation of these effects due to air pollution is then conducted knowing the size of the population at risk and the concentrations of the pollutants to which a person is exposed. This further requires application of stated preference technique or revealed preference technique for example hedonic wage differential, value of statistical life (VSL), restricted activity days (RAD) or cost of illness (COI) approach.

a) *Cost of illness approach (COI) :* COI measures direct value of medical costs for treating illness and lost wages due to illness or lost productivity. It fails to capture the benefits associated the value of avoiding pain and suffering or the losses associated with the value of time.

b) *Hedonic wage differential :* It estimates the value of environmental quality on the basis of compensation that the workers receive to bear the risk of working in poor environmental quality.

c) *Value of statistical life (VSL) :* It deduces the value that individuals are willing to pay to reduce risk to avert death.

d) *Restricted Activity Days (RADs) :* It is used to value morbidity or acute illness during which a person is not able to undertake all of his normal activities.

THEORETICAL MODEL

Ostro (1994) discusses the basic methodology for valuation of health impacts. The central assumption is the absence of threshold below which a pollutant is harmless. The effects of air pollution on various health outcomes are estimated. This is followed by calculation of slope (b) of dose response function that gives an estimate of the change in the prevalence of a given health effect associated with the change in air quality. This slope is multiplied by the susceptible population (POP_i) exposed to the effects of the air pollutants. Next step involves the determination of the change in air quality (dA_j), which is dependent on the policy issues and the available data. A range of estimates are provided due to the presence of uncertainty and thus not restricted to a particular or average value.

Health effects (H) are related to ambient air quality by

$$dH_i = b.POP_i.dA_j \quad (1)$$

where dH_i = change in health effect i,

b = slope of dose response function

POP_i = population at risk from health effect, i

dA_j = change in ambient air quality for jth pollutant

Ambient air quality is related to emissions either through some diffusion model or through an approximation involving a relationship.

$$dA_j / A_j = dE_j / E_j \quad (2)$$

where E is equal to emissions.

Each health effect has a unit economic value P_i so that

$$P_i dH_i = P_i b.POP_i.dA_j \quad (3)$$

And the sum of damages D, from pollutant j is :

$$D_j = \Sigma_i P_i dH_i \quad (4)$$

DRFs have been adopted in developing countries from the developed nations given the time, cost and the problems encountered in data availability assuming that human reaction is similar in different locations.

DATA REQUIREMENTS

Dose response functions are obtained from the published epidemiological literature. This requires statistical inference based on either time-series studies or cross-sectional data sets. Time-series examines the changes in a health outcome in a given area over time. Cross-sectional studies on the other hand, estimate the change for a given point of time across various locations, thus examines spatial differences. The literature predominantly concentrates on the time series studies as the population, income level, access to medical care, age distribution and demographic characteristics remain constant over time in comparison to environmental and metereological conditions. It also eliminates the problem associated with the omission of variables. Sometimes 'panel data', which combines data on different monitoring points across time, is often used. The ambient air quality data and data on morality and morbidity effects such as records of hospital outpatient visits, hospital admissions and emergency room visits need to be collected. Also, information about the affected population and the socio-economic characteristics in a given area is needed.

ESTIMATION PROCEDURES

The most commonly applied technique is the Ordinary Least Squares (OLS). It calculates the parameters of the model that minimizes the sum of the squares of the residuals. Other model used is Generalised Least Squares (GLS) that is OLS on the transformed variables that satisfy the standard least square estimates. Poisson regression approach is commonly employed in the literature.

CHOICE OF FUNCTIONAL FORM

Calthrop and Maddison (1996) state that either functional form could be used to accommodate the relationships depending on the flexibility. The validity of the functional forms can easily be checked by the use of variety of models.

LIMITATIONS

Dose response approach fails to account for averting behaviour and understates the true willingness to pay (Calthrop and Maddison, 1996). In fact in most of the studies exposure to the population is usually ignored (Pearce, 1996). The absence of dose response functions for long-term exposures could result in nonrevealation of true damage. One of the major sources of uncertainty is the existence of threshold, which may lead to overestimation, or underestimation of health benefits. It is highly uncertain to account for the pollution levels below which no further beneficial health benefits are realized from further control. If the dose response functions are non-linear then the statistical procedures will not be correct.

The difficulty in identification of all the variables and in isolating the impacts due to various pollutants may be a significant problem. It is believed that it is easy to control for factors such as smoking and diet but 'social status' forms a significant issue. The biological pathway by which various pollutants affect the health is not known. Finally, unreliability due to statistical methods employed may lead to bias results (Calthrop and Maddison, 1996). Multicollinearity problem may result in the omission of one or more important variables.

MATERIAL DAMAGE

Material damage has been largely due to air pollutants such as sulphur dioxide, nitrogen oxides and other acidifying substances in the atmosphere which cause damages in terms of surface erosion, loss of thickness of coating or loss of weight. These damages are established by dose response functions. Some of the dose response functions for building materials used by Gregory et al. for estimating the cost of damage in UK arising from a typical UK coal fired power station are given in Table 2.2. They adopted these functions from National Materials Exposure Programme (NMEP), 1993.

Multicollinearity, synergistic effects and meteorological effects are some of the problems of concern. Also, dose response functions are not available for all the materials (Gregory, Durk and Gamble, 1996).

Table 2.2

Dose-response functions for building materials

Limestone	$SR = 10.15 + (0.34*SO_2) + (0.0046*Rain) + (26.93*H^+)$
Calcareous sandstone	$Sr = 11.23 + (0.44*SO_2) + (0.0018*Rain) + (27.03*H^+)$
Mild steel	$SR = 23.44 + (0.748*SO_2) + (0.0033*Rain)$
Aluminium[a]	$Sr = 0.203 + (0.00248*SO_2) + (0.000318*Rain)$
Paint[b]	$Sr = 15.8*f + (0.119*SO_2) + (0.017*H^+)$

[a]Sr = surface recession in µm pa (the rate at which the surface is eroded); SO_2 = annual mean SO_2 in µg/m³ (concentration of SO_2 in the atmosphere); *Rain* = total rainfall in mm; H^+ = total H^+ in g/m³ (acidity of rain water).

[b]Sr = surface recession in μm pa; H^+ = acid deposition in meq/m^2pa; f = time of witness defined as 1-exp(-0.121*Rh(100-Rh)); Rh = average relative humidity%

Source : Gregory, Durk and Gamble (1996).

CARBON SEQUESTRATION

The ever-increasing threat of global warming due to increased concentrations of carbon dioxide, the principal green house gas, has brought the attention to think of ways and means for the net reduction of CO_2 in the atmosphere. It is believed one of the major sources of build up of atmospheric carbon other than combustion of fossil fuels is land use practices such as deforestation, conversion of forested area for agricultural purposes that reduce the stock of carbon held in trees, other biomass and in the soils. Considerable literature has developed over the past several years examining the potential of forests to reduce the expected rise in the levels of carbon dioxide. It is established that afforestation (conversion of non-forest land to forest) can offset carbon dioxide emissions to substantial amounts as trees and other forest vegetation generally store more carbon in their biomass than other land uses such as agriculture.

The issues addressed in the literature are conversion of non-forested land into forested area, expansion of the area of forests through afforestation of agricultural lands, improved management of natural forests, reducing deforestation, setting aside existing forests from harvest etc. The early research approaches were based on the average costs of establishing forest plantations that were used to derive point estimates (planting some fixed area and allowing it to mature) associated with particular sequestration levels. Later, a cost function was developed using discounted measures (Sedjo et al., 1995). Discounting accommodates the time distribution, which was ignored in the previous studies. Another advantage is the comparison of cost per unit carbon with the alternative strategies of reducing emissions.

Earlier studies did not account for the various factors which influenced the land enrolment decisions such as high conversion costs associated with the reversibility of forest land to agricultural land, cost of acq2uiring skills for the conversion, slow returns from the forest products, nonmarket benefits like recreation. Thus following studies that of Stavins (1999),. Plantinga et al. (1999) were based on methodology whereby econometric models of land use to simulate the effects of forest subsidies. The subsidies increase the relative net returns to the forestry, which in turn increases the area of land under forests and finally increase carbon sequestration. All this work however ignored the impacts on biodiversity since all the effects are difficult to quantify. A recent attempt to incorporate these impacts associated with the costs of afforestation into the carbon sequestration policy was made by Matthews, Connor and Platinga (2002).

Newell and Stavins (2000) examined the sensitivity of carbon sequestration costs to changes in critical factors, nature of management and deforestation regimes, silvicultural species, relative prices and discount rates. Higher discount rates led to higher sequestration costs as the present value equivalent sequestration decreases. Higher agricultural prices led to higher marginal costs or reduced sequestration. Retarded deforestation can sequester carbon at substantially lower costs than increased forestation. They found that the cost of carbon sequestration could be greater if the trees are periodically harvested rather than permanently established. McCarl and MacCallaway (1993) showed similar results to timber harvesting. When trees are harvested, carbon sequestration will be affected as carbon is dissipated soon after harvest, carbon in wood products will be released as those products undergo processing, and carbon sequestration on commercial timberlands may be reduced due to reduction in timber holdings in response to market forces disrupting the conversion of CO_2 to carbon. However, enrollment costs would be lower as landowners now do not receive revenue from selling timber. More refined models are being developed such as FASOM (Forest and Agricultural Sector Optimization Model) which is dynamic and price endogenous (Alig et al., 1997) in contrast to Stavins model where agricultural and forestry product prices are treated as exogenous (Annexure 3). Adams et al. (1999) used Timber Assessment Market Model (TAMM) and North American Pulp and Paper Model (NAPAP) to show greatest change in management actions are needed when large neat-term increments are required while land area change is largest when long-term increments are needed.

THEORETICAL MODEL

The econometric model presented here is as developed by Stavins (1999) where a risk-neutral landowner seeks to maximize the present discounted value of the stream of expected future returns. The first step is to derive optimal land allocation rules from profit maximization problem where a landowner is confronted with the problem of converting the land for agricultural use or forested land as both yield returns with different periodicity. The various factors that a landowner considers are agricultural and forestry revenues for the area, agricultural costs of production, and the costs of converting land from a forested state to use as cropland. The econometric models for carbon sequestration are hence concerned with the dynamic simulation models (used to model allocation decisions that produce returns in later periods) that can provide better estimates of the true costs of carbon sequestration

$$\max_{\{g_{ijt}, v_{ijt}\}} \int_0^\infty \left[\left(A_{it} q_{ijt} - M_{it} \right) \left(g_{ijt} - v_{ijt} \right) - C_{it} \alpha^{P_{it}} g_{ijt} + f_{it} S_{ijt} + W_{it} g_{ijt} - D_{it} v_{ijt} \right] e^{r_j^t} dt \qquad (1)$$

subject to : $S_{ijt} = v_{ijt} - g_{ijt}$ (2)

$$0 \le g_{ijt} \le g_{ijt} \qquad (3)$$

$$0 \le v_{ijt} \le v_{ijt} \qquad (4)$$

where i indexes countries, j indexes individual land parcels, and t indexes time;

uppercase letters are stocks or present values; and lowercase letters are flows. The variables are :

A_{it} = present value of typical expected agricultural revenues per acre in country i and time t;

q_{ijt} = index of feasibility of agricultural production (including effects of soil quality and moisture);

g_{ijt} = acres of land converted from forested to agricultural use (deforestation);

v_{ijt} = acres of cropland returned to a forested condition (forestation);

M_{it} = expected cost of agricultural production per acre, expressed as present value of future stream;

C_{it} = average cost of conversion per acre;

P_{it} Palmer hydrological drought index (to allow precipitation and soil moisture to influence conversion costs);

f_{it} = expected annual net income from forestry per acre (annuity of stumpage value);

S_{ijt} = stock (acres) of forest;

r_t = real interest rate used by landowners for investment decisions, linked with their private pretax rate of return;

W_{it} = net revenue per acre from one-time forest harvest (prior to conversion to agricultural use);

D_{it} = expected present discounted value of loss of income (when converting to forest) due to gradual regrowth of forest (first harvest occurs in t + R, where R is rotation length);

g_{ijt} = maximum feasible rate of deforestation; and

v_{ijt} = maximum feasible rate of forestation.

Forestation occurs if a parcel is cropland and

$$\left(F_{it}^{*} - A_{it} \cdot q_{ijt} + M_{it}\right) > 0 \qquad (5)$$

where F_{it}^{*}, delayed net forest revenue, equals $F_{it} - D_{it}$ and $F_{it} - f_{it} / r_i$. This implies a parcel of cropland should be converted to forestry use if the present value of expected net forest revenue exceeds the present value of expected net agricultural revenue. On the other hand, deforestation occurs if a parcel is forested and :

$$\left(A_{it} q_{ijt} - M_{it} - C^{\alpha^{P_{it}}} - FN_{it}\right) > 0 \qquad (6)$$

where FN_{it}, net forest revenue, equals $F_{it} - W_{it}$. That is, a forested parcel should be converted to cropland if the present value of expected net agricultural revenue exceeds the present value of expected net forest revenue plus the cost of conversion.

These inequalities imply that all land in the country will be in the same use in the steady state. In reality, heterogeneous land is observed where counties are a mix of forest and farmland. If conversion costs are allowed to be heterogeneous across land parcels (within counties) and flood control projects affect conversion costs as well as agricultural feasibility (yields), then the conversion cost term in equation (1) is multiplied by q_{ijt}. Such unobserved heterogeneity can be parameterized within an econometrically estimable model so that the individual necessary conditions for land use changes [equations (5) and (6)] aggregate into a single-equation model, in which the parameters of the basic benefit-cost relationships and of the underlying, unobserved heterogeneity can be estimated simultaneously :

$$FORCH_{it} = FORCH^{a}_{it} \,.\, D^{a}_{it} - FORCH^{c}_{it} + \lambda_I + \phi_{it} \qquad (7)$$

$$FORCH_{it}^{a} = \gamma_a \left[d_{it} \cdot \left[F\left[\log\left(q_{it}^{ij}\right) - \mu\left(1 + \beta_2 E_{it}\right) / \sigma\left(1 + \beta_3 E_{it}\right)\right]\right] + \left(1 - d_{it}\right) - [S/T]_{i,t-1}\right] \qquad (8)$$

$$FORCH_{it}^{a} = \gamma_C \left[d_{it} \cdot \left[1 - F\left[\log\left(q_{it}^{x}\right) - \mu\left(1 + \beta_2 E_{it}\right) / \sigma\left(1 + \beta_3 E_{it}\right)\right]\right] + [S/T]_{i,t-1} - 1\right] \qquad (9)$$

$$d_{it} = \left[1 / 1 + e^{(N_t + \beta 1 E_{it})}\right] \qquad (10)$$

$$q_{it}^{ij} = \left[\left(F_{it}^{*} + M_{it}\right) / A_{it}\right] \qquad (11)$$

$$q_{it}^{x} = \left[\left(FN_{it} + M_{it}\right) / \left(A_{it} - C_{it}^{\alpha^{P_{it}}}\right)\right] \qquad (12)$$

where all Greek letters are parameters that can be estimated econometrically;

$FORCH_{it}$ = change in forest land as a share of a total county area;

$FORCH^a_{it}$ = forestation (abandonment of cropland) as a share of total county area;

$FORCH^c_{it}$ = deforestation (conversion of forest) as a share of total county area;

D^a_{it} and D^c_{it} = dummy variables for forestation and deforestation respectively;

λ_i = a county level fixed effect parameter

ϕ_{it} = an independent (but not necessarily homoscedastic) error term;

γ_a and γ_c = partial adjustment coefficients for forestation and deforestation;

d = probability that agricultural production is feasible;

q^Y_{it} = threshold value of (unobserved) land quality (suitability for agriculture) below which the incentive for forestation manifests itself;

q^X_{it} = threshold value of land quality above which the incentive for deforestation manifests itself;

μ = mean of the unobserved land quality distribution;

σ = standard deviation of that distribution;

E_{it} = index of share of county artificially protected from periodic flooding

S = stock (acres) of forest;

F = cumulative, standard normal distribution function;

T_{it} = total county area; and

N_i = share of a county that is naturally protected from periodic flooding.

Dynamic simulations are then employed using current/expected values of all variables to generate baseline predictions of future forestation and/or deforestation and effectiveness of the programmes is measured relative to these baselines. For this various policies are considered. One such policy proposed by Stavins (1999) is to offer a subsidy for every acre of agricultural land that is forested. At the same time imposed a tax for each acre of land that is deforested. Letting Z represent the subsidy and tax, the threshold equations for forestation and deforestation becomes :

$$q^{ij}_{its} = \left[\left(F^*_{its} + Z_{it}\right) + M_{it} - K_{it}\right] / \left[A_{it}\right] \quad (13)$$

$$q^{X}_{its} = [FN_{its} + (M_{it} + Z_{it})]/[A_{it} - C^{\alpha Pit}_{it}] \quad (14)$$

where

F^{*}_{its} = delayed net forest revenue (F_{its} – D'_{its}), now subscripted by s to indicate species, and set equal to zero for the case of permanent (unharvested) stands;

K_{it} = establishment costs associated with planting a pine-based tree farm.

Thus a dynamic simulation based upon all the above-mentioned equations will generate a baseline quantity of forestation/deforestation over a given time period. By carrying out simulations for various values of Z over the period and subtracting the results of each from the baseline results, we can trace out the supply curve of net carbon sequestration, in which the marginal costs of carbon sequestration measured in dollars per ton, are arrayed in a schedule with net annualized carbon sequestration (relative to the baseline).

DATA REQUIREMENTS

The study area is selected with the details of the species, climate, soil type, biodiversity, carbon densities, net area and land use pattern. Land use pattern can be obtained from the existing reports of concerned agencies or from satellite imageries. Public owned forests are usually not considered. The choice of species mix over time is a potential tool in meeting carbon flux targets. For example, Adams et al. (1999) show that hardwood and softwood grow at different rates and sequester different amounts of carbon. The carbon in trees, litter and soil should be taken into account. Other factors should include cost of establishment of forests, opportunity costs of land due to displacement of crops by trees, sociotechnical implications and expected benefits from product sales. Costs of establishment include the cost of acquisition of the land and stand establishment. Net returns from forestry are the timber revenues while agricultural returns are the present discounted value of per-acre net revenues from croplands and pasture. A brief outline of the information flow to calculate sequestration potential is shown in figure 2.3.

Studies primarily rely upon panel data. Cross-sectional data is more important than time-series data, as spatial variation exists arising from spatial differences in land rents, species composition, cropping patterns etc.

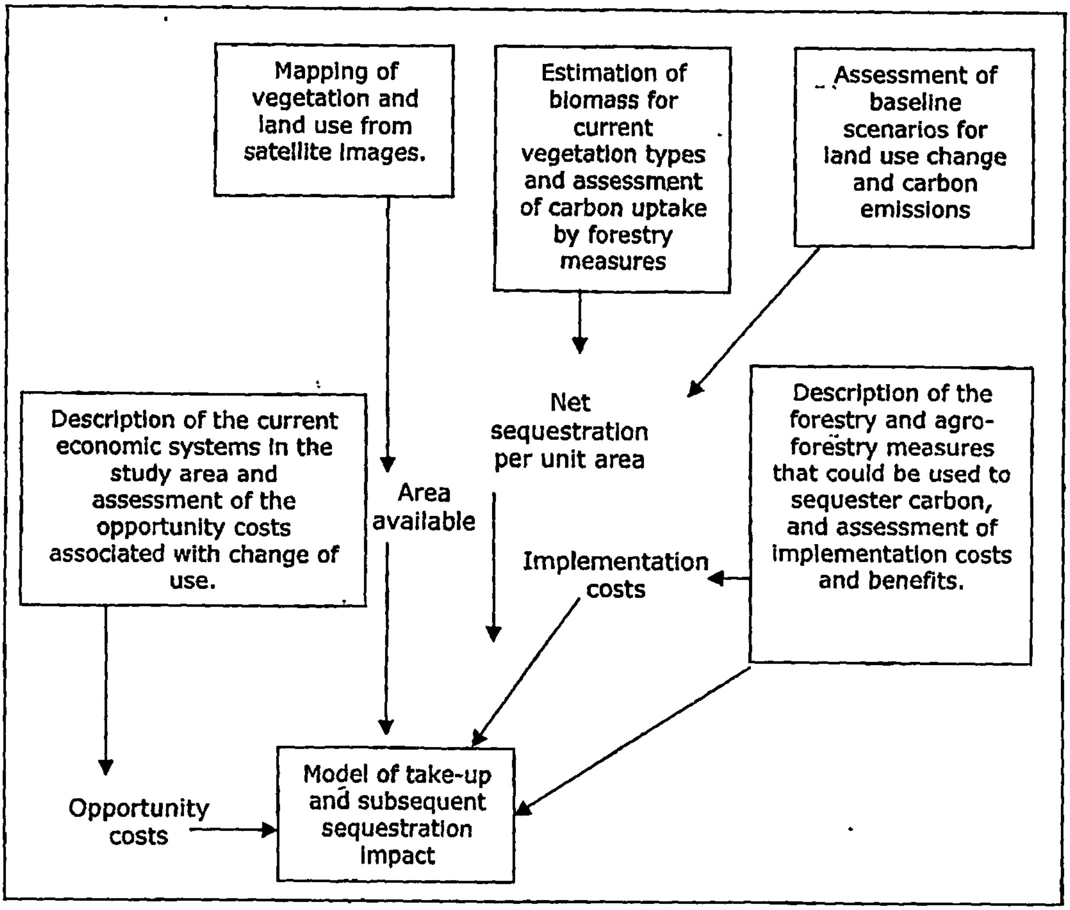

Figure 2.3 : Outline of the information flow to calculate sequestration potential of an incentive/service payment-based forestry program.

Source : De Jong B.H.J., Tipper R. and Montoya-Gomez Z., 2000.

EXAMPLE

Platinga and Mauldin (2001) used econometric land use models to estimate the costs of carbon sequestration for Maine, South Carolina and Wisconsin. The average cost of carbon sequestration is calculated as the total subsidy divided by the total carbon sequestered. Two scenarios are considered : one with no timber harvesting (Scenario A) and the other with timber harvesting (Scenario B) for a program lasting from 2000 to 2060. Enrollment is restricted to agricultural land and total enrolment is restricted to 25% of each state's agricultural land base to ensure that feedback effects on stumpage and crop prices are negligible. For each state, total land enrolled, the total carbon sequestered after 60 years, the total subsidy and tree establishment costs, and average costs per unit of carbon equal to total costs divided by total carbon are reported. In Marine, only 138 thousand acres are enrolled in total, whereas 710 and 2558 thousand acres are enrolled in South Carolina and Wisconsin, respectively. The total carbon sequestered after 60 years by all three programs is approximately 250 million metric tons in Scenario A and 120 million metric tons in Scenario B. In Scenario A, the average cost of sequestering 10 million metric tons of carbon in Maine and South Carolina is approximately $ 48 and $5 respectively. Sequestration of 48 million metric tons of carbon in South Carolina costs about $23. For the same amount approximately 116 million metric tons of carbon can be sequestered in Wisconsin. The low cost is due to poor quality of agricultural land that can be enrolled for afforestation.

LIMITATIONS

One of the problems mentioned by Niskanen (1998) is that of 'free rider', where the carbon sequestration costs are distributed locally, and yet expected benefits occur on a global level. Another major problem is that in most of the studies agricultural and forestry product prices are treated as endogenous. Timing is a critical issue. Although beneficial, the approach cannot totally offset fossil fuel emissions.

OTHER TECHNIQUES

Abatement Cost Method

Abatement cost method is a technical assessment of the cost to environment based on the least cost strategy. This method approaches the problem of valuation from the supply angle. This is a valuation, which reflects the cost to maintain the environmental quality at a constant level. A study by Hartman et al. (1997) uses cost of abatement for seven major air pollutants in US manufacturing sectors which vary by pollutant and sector thus revealing that the cost of abatement by command-and-control in the U.S. to be very high. Mendelsohn (1980) estimated the benefits of air pollution control techniques of coal fired power plants in terms of the resource cost and effectiveness in reducing the damages based on the healthy days lost. Depending on the value of the health days, the efficacy of the technique for abatement is established.

It assumes that all firms are technically efficient. This may impose limitations. Also uncertainty is involved related to availability of raw materials and inherent difficulty in aggregation of data. The conventional models did not account for joint production and multiple outputs. Murty and Kumar (2001) reviewed the methodology for estimating the cost of pollution abatement. They highlight the potential of distance function method, which avoid many of the limitation in conventional methods such as production, profit and cost function. The estimation of distance function requires only the quantity data on inputs and outputs and not the price data, which could be used to estimate the firm specific shadow prices or marginal cost of abatement for bad outputs. It has the advantage of modeling multiple output and joint production technology without requiring behavioural-hypothesis.

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