Chapter 6

BENEFITS OF REDUCED MORBIDITY FROM AIR POLLUTION CONTROL: A SURVEY

MARK DICKIE and SHELBY GERKING
School of Social Sciences, University of Texas at Dallas, Richardson, Texas, 75083-0688; Department of Economics, University of Wyoming, Laramie, Wyoming, 82071-3985 (United States)

1 INTRODUCTION

Estimating human health benefits from reduced air pollution is important both to policymakers and academics. In the United States, the Clean Air Act and its subsequent amendments direct the U.S. Environmental Protection Agency to establish primary standards to protect human health, with special emphasis on the health of particularly sensitive population groups. Additionally, Executive Order # 12291 requires Regulatory Impact Assessments of major federal rules and regulations, making benefit-cost analysis of health oriented standards an important practical issue. From an academic viewpoint, valuation of improved health and other nonmarket commodities is a key aspect of applied welfare and environmental economics. Yet, until recently, methods used to compute benefits of reduced morbidity and mortality often have not been based on a measure of willingness to pay. As a consequence, there now is considerable interest in developing theoretically defensible and empirically feasible methods for valuing these benefits.

These two sources of interest in estimating the benefits of improved health have motivated a considerable volume of research. Relatively more research has been devoted to the mortality effects of air pollution and, more generally, to estimating the marginal value of safety. One reason for this emphasis is that death is more easily measured than illness or injury. Death is a one dimensional event, while there are varying degrees of illness and injury. However, benefits of reduced morbidity are equally important to obtain in light of the need to evaluate the reduction of nonfatal hazards.

This paper critically reviews methods for estimating benefits of reduced morbidity and suggests directions for future research. A corresponding recent survey of methods for estimating the marginal value of safety or "value of life" may be found in Fisher et al. (1986). Additionally, a somewhat older but still useful survey of morbidity benefit estimation has been prepared by Chestnut and Violette (1984). This review of morbidity benefit estimation surveys three methods. Section 2 surveys the cost of illness method and Section 3 surveys the contingent valuation method. The averting behavior method is discussed in Section 4. The averting behavior method is given the greatest attention because it is the least well known of the three methods. More extensive evaluations of the cost of illness and contingent valuation methods may be found, respectively, in Hu and Sandifer (1981) and Cummings et al. (1986). Implications and conclusions are presented in Section 5.

2 THE COST OF ILLNESS METHOD

The cost of illness (COI) method estimates the total cost which morbidity imposes on society. Total cost is defined as the sum of direct and indirect costs. Direct costs measure the value of resources devoted to the treatment of illness including (1) hospital care, (2) nursing home care, (3) home health care, (4) services of physicians, dentists, and other health specialists, (5) drugs, and (6) eye glasses. Indirect costs measure the value of lost productivity due to illness. Indirect costs usually are estimated by the wage multiplied by the time lost from work, often with some adjustment for the value of homemaker services. Losses associated with disutility of illness, such as for pain and suffering, are not included in cost of illness estimates.

Total costs may be estimated on either a prevalence or an incidence basis. The prevalence of a disease is the number of existing cases of the disease in a given time period. Prevalence based costs, then, are all costs associated with all cases of the disease in that time period. The incidence of a disease is the number of new cases of the disease that occur in a given time period. Incidence based costs are all discounted costs associated with new cases of the disease, from the onset of illness until recovery or death occurs. Prevalence and incidence are nearly identical for short term illnesses. Cooper and Rice (1972) provide widely used prevalence based illness cost estimates which update the earlier estimates of Rice (1966).

Hartunian et al. (1980) argue that prevalence based costs are more relevant for analyzing programs that would reduce the severity of existing cases of disease, while incidence based costs should be used for programs that involved prevention of additional cases of disease. As Chestnut and Violette (1984) point out, air pollution may be associated both with increased severity of existing diseases and increased incidence of illness. Thus, both prevalence and incidence based costs are relevant to pollution control questions. Prevalence-based costs are more available, however, and hence are used more often in COI studies.

To use the COI to value the impact of air pollution on morbidity, a two-step procedure often is employed. In the first step, the marginal effect of air pollution on health is derived from a physical damage function which relates a particular health effect to measures of air quality and a set of sociodemographic, medical, and perhaps lifestyle variables. In the second step, total direct and indirect costs attributable to air pollution are computed by applying COI estimates of the medical expenses and the value of time lost from work associated with the health response to air pollution. Seskin's (1979) paper is an important example of the two-step damage function approach. At least two important variations to this two-step procedure have been used by economists studying air pollution and morbidity. One variation is to define the dependent variable in the damage function in monetary units; for example, medical expenses could be regressed on air pollution and other variables to estimate the impact of air pollution on direct costs. The work of Jaksch and Stoevener (1974) and Bhagia and Stoevener (1978) illustrates the method of defining the damage function in value terms. The second variation on the two-step procedure is to estimate only the damage function without attempting to value the damage. Examples of damage function estimates without a valuation procedure may be found in Ostro (1983) and Portney and Mullahy (1983, 1986).

A fundamental criticism of the COI approach is that it does not estimate a theoretically correct measure of the benefits of improved health. In economic theory, the benefit of a good is measured as the amount of money which would make an individual indifferent between consuming and not consuming the good. When an individual's health improves, then, the economic benefit he enjoys may be measured as the maximum amount of money he is willing to pay for the increase in health. When his health worsens, the economic damage he suffers may be measured as the minimum amount of money he is willing to accept for the decrease in health.[1] While other measures of benefit or "value" could be proposed, perhaps of a philosophical or ethical nature, this review takes as given the notion that benefit estimates for policy evaluation and design should be willingness to pay (WTP) or willingness to accept (WTA) measures.

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[1] The benefit measures discussed in the text are "compensating variation" measures. Alternative measures of economic benefit or damage are provided by the "equivalent variation". The equivalent variation values a gain as the minimum willingness to accept to forego the gain; it values a loss as the maximum willingness to pay to avoid the loss.

The cost of illness measures neither WTP nor WTA. Harrington and Portney (1987) argue that the WTP exceeds COI because the latter accounts neither for the disutility effects of disease nor defensive expenditures for goods other than medical care. Additionally, in a recent theoretical analysis, Berger et al. (1987) rigorously show that COI underestimates WTP in all but a special case. As a consequence, alternative benefit estimation methods, including the contingent valuation method have received considerable attention.

3 THE CONTINGENT VALUATION METHOD

In applying the contingent valuation method (CVM), survey respondents are presented with a hypothetical situation describing how a change in morbidity will be accomplished and how payment would be made. Payment mechanisms include the use of iterative bidding, payment cards, and "referendum" questions. Regardless of which mechanism is adopted, however, the respondents are asked for their maximum willingness to pay for a specific reduction in morbidity or for their minimum willingness to accept for a specific increase in morbidity. In contrast to the COI, the CVM attempts to measure the appropriate theoretical quantity. However, data to implement the CVM must be obtained from primary rather than secondary sources.

CVM benefit estimates are subject to a number of possible biases which are discussed at length by Cummings et al. (1986) and in the paper by Navrud in this volume. One source of bias in data drawn from hypothetical situations, which is most relevant when dealing with public goods, is the strategic misrepresentation of preferences. For instance, a respondent who has a strong desire for a good may over-report his true willingness to pay if he feels that his bid will influence the good's provision, but that he will never actually have to pay this amount. This potential problem suggests that CVM studies in the morbidity area should focus on valuing changes in private health attributes rather than on valuing changes in environmental hazards. If private health attributes are valued, then the benefits stemming from environmental changes can be obtained by linking the CVM bids to dose-response or damage functions. Additional biases in the CVM benefit estimates may result if the individual is unfamiliar with the commodity or if the commodity is intangible or complex. As a consequence, more accurate bids may result when the respondent is asked to focus on health outcomes experienced in the very recent past rather than on outcomes experienced in the past year, or worse yet, on diseases which are a complex bundle of health attributes. Still other sources of bias include vehicle bias, where the method of payment may influence the results, and starting point bias, where an initial price suggested by the interviewer may influence the final value reported by the respondent.

Even in situations where these potential biases either can be avoided or minimized, the CVM bids obtained across all respondents frequently display an uncomfortably large dispersion. The mean bid sometimes is exceeded by its standard error. Moreover, the bids often display a marked skewness with the mean bid as much as five to ten times higher than the median bid (see Green et al., 1978 for examples of this phenomenon). In specific cases, this skewness may be at least partially accounted for by a few very large bids from respondents who either did not understand the question or were protesting the fact that it was asked. Detecting these bids, however, is difficult because very large bids also may be obtained from individuals in poor health who have been unable to find treatments which effectively improve their health.

Two main approaches have been used to apply the CVM to value air pollution-morbidity relationships. The first approach assesses WTP for health improvements; the resulting morbidity valuation can be related to air pollution with a separately estimated dose-response or damage function. Representative studies which focus on health improvements include Loehman et al. (1979), Loehman and De (1982), Berger et al. (1987), Rowe and Chestnut (1984), and Dickie et al. (1987). The second approach is to use the CVM to value reductions in air pollution directly. In this approach, respondents are given information on the health effects of air pollution prior to being asked the valuation question. The second approach assumes that respondents can implicitly estimate their own dose-response functions. Examples of the second approach may be found in the work of Brookshire et al. (1979), Loehman et al. (1984), and Schulze et al. (1983).

While the CVM is an improvement over the COI technique in the sense that the CVM estimates WTP, many economists and policymakers question the accuracy of contingent valuation estimates because of all the potential sources of bias which plague the technique. As a consequence, economists have begun to develop an alternative method of estimating the benefits of improved health, namely the averting behavior method.

4 THE AVERTING BEHAVIOR METHOD

The averting behavior method provides estimates of willingness to pay for health improvements based on individual's revealed preferences for health and health related goods. Unlike the cost of illness and contingent valuation approaches, the averting behavior method is based on an explicit model of consumer choice. The model has three key features. First, good health is assumed to be a direct source of satisfaction to the individual. Thus the method can, in principle, account for the disutility, or "pain and suffering" associated with ill health. Second, health is considered a determinant of time available both for work and for leisure activities. As a result, the model provides a basis for valuing time lost from both employment and nonemployment activities. Third, health is endogenous in the averting behavior model; that is, the individual can choose his state of health subject to relevant biological and economic constraints. Health is produced by a number of exogenous inputs, such as air pollution, as well as some endogenous inputs, such as medical care. The model predicts that, in response to a change in some exogenous input, the individual will adjust his consumption of the endogenous inputs in order to maximize the benefit (minimize the loss) he obtains from the exogenous change. Thus the model directly accounts for behavioral responses to air pollution changes.

4.1 Theoretical Considerations

Averting behavior models have a common underlying structure, subject to a few variations. This structure is

$$U = U(X, H) \tag{1}$$

$$H = H(V,\alpha) \tag{2}$$

$$I = r_X X + r_V V \tag{3}$$

where U denotes utility, X represents a composite good (or composite expenditures if $r_X = 1$), and H denotes the household output of interest, such as health or the cleanliness of the home. This output is produced in eqn. (2) by an averting behavior, V (which might be medical care in the case of health or the frequency of cleaning in the case of home cleanliness), and an exogenous variable or vector of exogenous variables α, which might be measures of air pollution. Equation (3) is a budget constraint where I is income and r_i is the price of good i, i = X, V. Often V is defined as averting expenditure with $r_V = 1$.

A few variations to this structure have been made. To analyze home cleanliness, Harford (1984) and Watson and Jaksch (1985) write r_V as a function of V and α, thus incorporating a tradeoff between the frequency of cleaning, V, and its intensity, measured by its unit price r_V. To analyze health issues, the budget constraint may be generalized to incorporate the value of time, as in Gerking and Stanley (1986). Another extension in the health area, made by Harrington and Portney (1987) and Berger et al. (1987), is to define a function M(H) giving medical and possibly other costs of illness as a function the health stock. Berger et al. further generalize the model to an uncertainty framework which accounts for health risks. Finally, Bartik (1988) focuses on the function V(H,) giving the amount of averting expenditure necessary to achieve output H given pollution α, rather than the primal production function $H(V,\alpha)$.

An interesting point about the averting behavior model is its close connection to hedonic price models. Bartik (1988) points out that in the averting behavior model, the household's opportunity locus is determined by pollution levels and the averting technology. In hedonic price models, this locus is determined by demand and supply equilibrium.

In this averting behavior model, the individual is assumed to maximize utility in eqn. (1) subject to the production function (2) and some variant of the budget constraint, (3). By totally differentiating the utility function with respect to pollution while holding utility constant at the constrained maximum, the following marginal WTP expression can be derived:[2]

$$\mathrm{WTP} = -(r_V/H_V)H_\alpha. \tag{4}$$

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[2] The WTP for a reduction in air pollution is the income change that holds utility constant despite the air pollution change, i.e. $\mathrm{WTP} = \partial I/\partial\alpha$ subject to $dU/d\alpha = 0$.

$$\partial I/\partial\alpha = r_X(\partial X/\partial\alpha) + r_V(\partial V/\partial\alpha),$$

$$dU/d\alpha = 0 = U_X(\partial X/\partial\alpha) + U_H H_V(\partial V/\partial\alpha) + U_H H_\alpha.$$

Two of the first order conditions, namely

$$U_X - \lambda r_X = 0$$

$$U_H U_V - \lambda r_V = 0,$$

when substituted into $dU/d\alpha = 0$ hold utility constant at the constrained maximum, yielding upon rearrangement

$$r_X(\partial X/\partial\alpha) + r_V(\partial V/\partial\alpha) = -(U_H/\lambda)H_\alpha.$$

Substituting this result into $\partial I/\partial\alpha$ and using $-U_H/\lambda = -r_V/H_V$ from the first order conditions leaves eqn. (4).

This expression states that the marginal benefit of a reduction in pollution is equal to the marginal cost of achieving the same improvement in health through the use of V. More specifically, six aspects of this benefit expression are worth noting. First, WTP is higher, the higher the full price and the lower the marginal productivity of the averting input V. This may explain why some contingent valuation surveys have found a negative association between health insurance and WTP: insurance lowers the full price of medical care. Second, if the marginal damage of air pollution (H_{α}) is higher (more negative) for those in poor health, then WTP would be higher as well. This would explain the finding in CVM studies that poor health is associated with higher WTP. Third, despite the fact that health enters the utility function, no utility terms appear in the WTP expression, making estimation of eqn. (4) relatively straightforward. Fourth, the WTP for health improvements can be obtained from the WTP for air pollution reductions simply by dividing both sides of eqn. (4) by H_{α}, an operation which results in $- r_V/H_V$ as the measure of the marginal benefit of health improvements.[3] Fifth, the WTP expression involves partial derivatives of the health production function rather than parameters from a reduced-form dose-response or damage function. A key difference between the dose-response and the health production approaches is the treatment of V. The averting behavior model treats V as a choice variable while in the dose-response approach, H is specified as a function of a variety of variables (possibly including averting inputs such as medical care), all of which are treated as exogenous. This distinction is important since most estimates of benefits of improved air quality are based on the two-step dose-response approach described in section 2. The sixth point to note about the benefit expression in eqn. (4) concerns its interpretation in terms of standard microeconomic theory. To simplify the exposition, interpret α as a measure of the air quality rather than of air pollution, so that α is a good. WTP is simply the price the individual would be willing to pay, at the margin, per unit of air quality. Let r_{α} denote this price. Now suppose that a market existed for air quality, with units of air quality traded at price r_{α}. The individual is assumed to choose X, V, and α to maximize utility in eqn. (1) subject to the budget constraint $I = Xr_X + Vr_V + \alpha r_{\alpha}$.

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[3] The WTP for marginal health improvements is the marginal rate of substitution between health and income: $- U_H/\lambda$, where λ is the marginal utility of income. The results in the previous footnote include $- U_H/\lambda = - r_V/H_V$, as in the text.

It is clear that whatever level of health is chosen in the utility maximization process must be produced at minimum cost. If the chosen level of health could be produced at lower cost, then more of the good X could be purchased while maintaining the same consumption of health, which would increase utility and violate the hypothesized utility maximization. The cost-minimizing producer of health facing given prices r_α and r_V would choose the levels of α and V so that the marginal rate of technical substitution between these two inputs was equated to their price ratio:

$$H_\alpha/H_V = -(r_\alpha/r_V). \tag{5}$$

This familiar tangency between an isoquant and an isocost line is illustrated in Fig. 1.

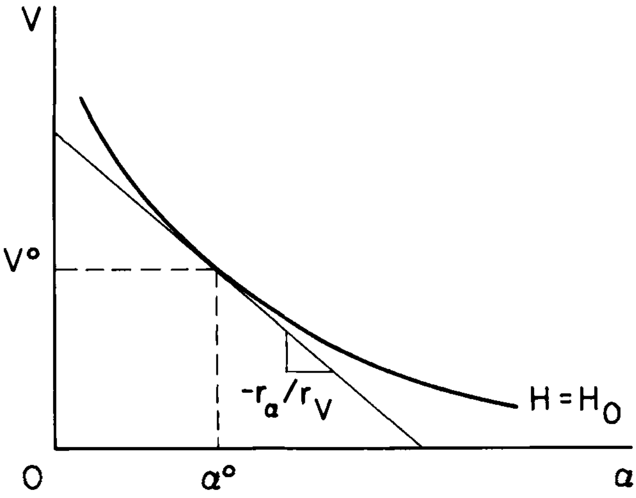

Fig. 1. Cost-minimizing production of health. The cost minimizing health producer who faced a market for air quality would equate the slope of an isoquant to the slope of an isocost line. When no market for air quality exists, cost minimizing production can be used to infer r_α.

In reality, no market exists for air quality, and the individual faces a given quantity of α rather than a given price r_α. Given some quantity α^0, the individual's chosen level of V, V^0, determines a point on an isoquant. Knowledge of the production function then allows determination of the slope of the isoquant at that point. Finally, observing the price r_V allows the willingness to pay for air quality, r_α, to be inferred. Algebraically, the WTP expression in eqn. (4) can be obtained by multiplying both sides of the cost-minimizing tangency condition in eqn. (5) by - r_V. Thus, the ABM allows inference of WTP through knowledge of the production function and prices.

Four additional issues have arisen in deriving WTP expression from averting behavior models: (1) the relationship between an individual's WTP and his expenditures on averting goods, (2) the relationship between an individual's WTP and his COI, (3) extending the model to nonmarginal welfare are analysis, and (4) extending the model to arbitrary numbers of averting goods and home produced commodities. Courant and Porter (1981) and Berger et al. (1987) have demonstrated that under plausible conditions, averting expenditure will be lower bound on marginal WTP. The Berger et al. comparison was made in the context of uncertainty and hence is not directly relevant here. The Courant and Porter comparison involved calculating averting expenditure while holding utility constant and hence is of limited empirical relevance. Bartik (1988) has shown that the change in averting expenditure will always be a lower bound to WTP, but the bound is not necessarily tight.

Harrington and Portney (1987) and Berger et al. developed theoretical comparisons of individual COI and WTP. Both groups of authors concur that under plausible conditions, COI is a lower bound on WTP. For example, Harrington and Portney demonstrated for the model above that WTP ≥ COI provided $dH/d\alpha < 0$ and $\partial V/\partial\alpha > 0$. That is, COI is a lower bound on WTP provided the total effect of pollution on health is negative and averting behavior increases with pollution. Both these conditions are plausible, but neither is a theoretical requirement of the model. The partial effect of pollution on health H_α is presumably negative, but the total effect $dH/d\alpha$ might be positive if increases in pollution resulted in more than offsetting increases in averting behavior. The sign of $\partial V/\partial\alpha$ similarly depends on the nature of the health production function. Thus it is likely although not certain that WTP ≥ COI.

The work of Bockstael and McConnell (1983) and Bartik (1988) extends the marginal welfare analysis presented above to the case of nonmarginal welfare changes. Bockstael and McConnell show that changes in the consumer's surplus area behind the demand curve for a necessary input can be used to approximate the WTP for pollution reductions. In the context of the model presented above, changes in α would shift the demand curve for V. If V is necessary to produce H, then the change in the area behind the demand curve for V approximate the consumer's WTP for reductions in α.

Dickie et al. (1987) extend the ABM to arbitrary numbers of home-produced commodities and averting goods. In the utility function of eqn. (1), H now represents a vector of n health attributes H_1, H_2, ..., H_n. In the budget constraint of eqn. (3), V now represents a vector of m averting goods V_1, V_2, ..., V_m, while r_V represents a vector of the m prices r_1, r_2, ..., r_m. Equation (2) is replaced by the n household production functions $H_i = H_i(V_1, V_2, ..., V_m; \alpha), i = 1, ..., n$.

The complications introduced by this generalization of the model are not trivial because of joint production. Joint production occurs whenever an averting good enters several production functions simultaneously. Several authors, notably Pollak and Wachter (1975), Hori (1975), and Bockstael and McConnell (1983), have demonstrated that the interpretation of the household production model in both positive and normative contexts is severely complicated by joint production. Dickie et al. consider whether the averting behavior model with joint production still yields a WTP expression which is a function only of prices and production function parameters.

In the extended averting behavior model, the WTP for a reduction in air pollution is

$$\text{WTP} = -\Sigma_i(U_i/\lambda)H_{i\alpha} \tag{6}$$

where U_i is the marginal utility of health attribute i, λ is the marginal utility of income, and $H_{i\alpha}$ is the marginal product of air pollution in the ith production function. If WTP is to be expressed as a function only of market prices and production parameters, it must be possible to eliminate the utility ratios (U_i/λ) from eqn. (6). Dickie et al. consider the m irst order conditions for the V_j shown in eqn. (7).

$$\begin{bmatrix} H_{11} & H_{21} & \cdots & H_{n1} \\ H_{12} & H_{22} & \cdots & H_{n2} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ H_{1m} & H_{2m} & \cdots & H_{nm} \end{bmatrix} \begin{bmatrix} U_1/\lambda \\ U_2/\lambda \\ \cdot \\ \cdot \\ U_n/\lambda \end{bmatrix} = \begin{bmatrix} r_1 \\ r_2 \\ \\ \\ r_m \end{bmatrix} . \tag{7}$$

where H_{ij} is the marginal product of the jth averting good in the ith production function.

This system of linear equations has a unique solution for the U_i/λ if and only if the rank of the system equals the number of unknowns (n). The system has rank n if the rank of the health technology matrix is n, which occurs if (1) $m \geq n$ and (2) n of its rows are linearly independent. That is, there must be at least as many averting goods as health attributes, and there must be no linear dependence among the health production functions.

This theoretical review yields several ideas important for applying the ABM to estimate WTP. First, under plausible conditions, an individual's averting expenditures and his cost of illness both are lower bounds on his willingness to pay. Second, the ABM works best when the number of averting goods is at least as great as the number of home produced commodities affected by pollution. In this case, calculation of WTP is relatively straightforward because the WTP expression can be reduced to a function of market prices and production function parameters which are in principle observable or estimable. Even when the number of averting goods is at least as great as the number of health attributes, however, the method fails to yield an easily estimable WTP expression if the rows of the household technology matrix are linearly dependent. Statistical tests of the rank of the matrix should be performed prior to estimating WTP. Third, the ABM may be incapable of estimating separate values for a comparatively large number of detailed health attributes, particularly if the attributes are highly correlated. In such a case it is likely either that the number of health attributes will exceed the number of averting goods, or that the correlation among health attributes will result in linear dependence in the household technology matrix.

Finally, Dickie et al. point out possibly the most serious limitation to the averting behavior model: the assumption that averting goods are not a direct source of utility. This problem is important because of the difficulty in identifying private goods that are purchased but do not enter the utility function. If some of the averting goods directly affect utility, then WTP reduces to a function of market prices and production function parameters only if the number of averting goods not entering the utility function is at least as great as the number of health attributes.

4.2 Empirical evidence

Economists have pursued two lines of empirical research related to averting behavior. One line of research, exemplified by the work of Smith and Desvousges (1986), Berger et al. (1987), and Rowe and Chestnut (1984) examines the existence and nature of averting responses to pollution. On the basis of these three studies, it appears that individuals attempt to mitigate the effects of air and water pollution in at least three ways: (1) by making expenditures on durable goods such as air purifiers and water filters, (2) by making expenditures on nondurables such as bottled water, and (3) by changing their daily schedule to avoid pollution exposure. None of the three studies incorporated both durable and nondurable expenditures and scheduling changes in the analysis, nor did they examine the price to effectiveness ratio of these averting activities.

A second line of research attempts to use the averting behavior model to make benefit estimates. There have been relatively few such studies; one reason for this outcome is that the simplicity and intuitive appeal of averting behavior WTP expressions are not achieved without cost. Chestnut and Violette (1984), for example, correctly argue that the model implicitly: (1) values the individual's time at his wage rate, (2) considers only private, as opposed to total, social costs of medical care, (3) allows for no interdependence of utility among friends and family members, and (4) considers only small (marginal) changes in pollution and health. Additionally, as noted by Gerking and Stanley (1986), the ultimate averting behavior, moving from an area to avoid exposure to environmental toxins, is not adequately captured in existing ABM approaches. Finally, from an implementation viewpoint, the ABM requires special primary data collection. This subsection surveys three recent attempts to use the ABM to estimate WTP; the work of Cropper (1981), Gerking and Stanley (1986), and Dickie et al. (1987).

Cropper treats health as a pure investment good which individuals desire only to reduce time spent ill and hence increase income. Since health is assumed to have no direct effect on utility, the model's WTP expression measures only consumer valuations of the effect of pollution on time lost from work. Cropper uses data from the Michigan Panel Study in Income Dynamics for three years during the 1970s. Cropper estimates that the average worker in the 1976 sample, who earned $6.00 per hour, would be willing to pay about $7.00 annually for a 10 percent reduction in annual average sulfur dioxide pollution. Cropper's work is noteworthy as an early attempt to incorporate behavioral adjustments to pollution into a benefit estimation technique. Her model provides a theoretical justification for using work loss days as a basis for estimating WTP, but the model suffers from the serious deficiency of not allowing health to affect utility directly.

The Gerking and Stanley model is similar to the one presented in section 4.1, where medical care is the averting good considered. The model generalizes Cropper's approach by allowing health to affect utility directly and by considering the time lost from both work and leisure activities. Gerking and Stanley estimate that fully employed individuals in a sample of households in St. Louis, Missouri during 1977-1980 would be willing to pay between \$18 and \$25 for a 30 percent reduction in ambient mean ozone levels. The work by Gerking and Stanley is important for at least two reasons. First, their work illustrates the derivation and estimation of a simple WTP expression when health is a direct source of utility. Second, their estimation method accounts for the simultaneity of medical care and health. The most serious problem with the paper is the inconsistency of the data and the model. The health effects measured were the existence and duration of chronic illness, while the pollution variables measured only recent exposure. If recent pollution is not representative of lifetime exposure, pollution coefficients may be biased, particularly if ill health induces migration to less polluted environments.

Dickie et al. (1987) model two health attributes, respiratory and nonrespiratory symptoms, and consider four durable averting goods: home and car air conditioning, home air purifying, and cooking with some fuel other than natural gas. The sample is split into two groups, one group including subjects with chronic respiratory impairment and the other including subjects with normal respiratory function. Each subsample has two averting goods which are correctly signed and statistically significant at conventional levels in the two health production functions. Thus, the number of averting goods equals the number of health attributes. The authors then test the null hypothesis that the determinant of the household technology matrix is zero. The hypothesis cannot be rejected at conventional significance levels, suggesting that joint production may pose a serious problem for using the averting behavior model to estimate WTP. Despite the negative outcome of the hypothesis test, Dickie et al. make WTP calculations indicating that the value of avoiding a symptom for one day is quite small, around \$1 per day. The Dickie et al. work is important in extending the averting behavior model to account for joint production, the most serious limitation of the work is the likely fact that the averting goods considered are direct sources of utility.

5 COMPARISON OF THE THREE METHODS

This paper has reviewed three methods for estimating the monetary damages associated with the adverse effects of air pollution on health: the cost of illness method, the contingent valuation method, and the averting behavior method. The three methods differ greatly with respect to the theoretical assumptions which underlie them. This section will briefly summarize these issues. First, however, it should be noted that there is at least one major difficulty shared by all three methods, namely, the estimation of the physical damage or health production function.

The estimation of such a function, whether for morbidity or mortality, involves a great deal of specification and measurement uncertainty. Specification uncertainty enters because the functional form of the relationship between air pollution and health and the proper set of explanatory variables are unknown. Additionally, some variables which might explain the relationship between air pollution and health are subject to the control of individuals, introducing the possibility of simultaneous equation bias. A key example of measurement error is in the measurement of pollution exposure. Individuals normally are matched to a pollution monitoring station somewhere in the vicinity of their residence, but the pollution levels measured at this station may be a poor indicator of actual exposure. For a more complete discussion of specification and measurement difficulties in estimating the health effects of air pollution, see Crocker et al. (1979) and Gerking and Schulze (1981).

Returning to the comparison of the three damage function estimation techniques, consider first the theoretical differences among them. The COI approach effectively assumes that individuals are ignorant of the health damages of air pollution and/or are unable to adjust their behavior to mitigate these damages. As Lave (1972) indicates, it is this assumption of individual ignorance that justifies the two-step approach of (1) estimating a physical damage function, and (2) simple multiplication of this damage function by some price schedule. In contrast, the ABM assumes that individuals rationally adjust their behavior to minimize the value of air pollution losses. Cropper (1981) argues that this process of rational adjustment does not require that individuals be fully aware of the effects of air pollution on health; rather, it need only be assumed that individuals adjust their behavior when they perceive some change in their health. The marginal conditions of the model, which require optimal adjustment to infinitesimal changes in pollution, however, seem more consistent with an assumption of complete knowledge on the part of individuals. As a practical matter, people must have at least some knowledge of an association between air pollution and ill health if averting behaviors such as spending less time outdoors and reducing indoor air pollution are to be used to produce benefit estimates. The CVM, when applied to measures of morbidity, does not require any knowledge at all on the part of respondents of the link between air pollution and health. Subjects value the health effect, and the association to air pollution is made by the analyst. If the CVM is applied to air pollution directly, however, it is assumed that respondents know their own damage function.

In addition to the degree of knowledge assumed, the three techniques differ in their treatment of behavioral responses to air pollution. The COI method and the CVM tend to ignore averting behavior; only the ABM directly accounts for behavioral adjustments to mitigate pollution effects.

Perhaps the most important distinction between these techniques is the interpretation of the values they produce. The COI estimates the monetary costs which illness imposes on society. It does not estimate WTP, nor does it include values for the disutility of illness. Both the CVM and the ABM, on the other hand, estimate individuals' WTP, and the WTP value includes the monetary value of the disutility of illness. The CVM estimates WTP on the basis of expressed preferences, while the ABM estimates WTP on the basis of revealed preferences. A comparison of WTP and COI is complicated by the fact that COI values tend to be for society as a whole, while WTP values are for individuals. This is significant because 68 percent of all health-related expenditures are made by third parties such as insurance companies (Chestnut and Violette, 1984). Thus, the costs faced by individuals do not reflect social costs.

A final, and perhaps the most practical, distinction between these three methods is the cost of implementing each. The COI approach seems the least costly to implement, since no primary data collection effort is required. Damage functions can be estimated from existing data sets and the Cooper and Rice cost estimates can be applied. The CVM is more costly to apply in that primary data collection on WTP and other economic variables is required. The ABM is the most costly, since the primary data collection effort must extend to the prices and quantities of averting behaviors.

A tradeoff emerges, then, between the costs of obtaining estimates of the value of air pollution damages and the type of estimates obtained. The COI is the least costly, but does not cover the disutility of illness and does not measure WTP. The CVM and the ABM are more costly because of the primary data collection efforts they require, but they do estimate WTP. The incremental cost of the ABM over the CVM is the price paid for revealed values, which some economists and policymakers would prefer to the expressed values produced by the CVM.

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