Chapter - 5

The Measurement of Health Effects: Theory and Methodology for Estimation

Introduction

There exists a vast body of literature which seeks to address the problem of placing a monetary value on health. With increasing recognition of the adverse health consequences of air and water pollution, a simultaneous need grew for correctly assessing the impacts of both one-time and continuous changes in the health status of individuals. This chapter draws on the techniques for estimating the monetary value of changes in human health that are associated with environmental changes, in order to develop a model for establishing the important role played by contaminated water supplies and other socio-economic factors causing diarrhoeal diseases in Delhi.

A Short Review of Existing Concepts and Methods in Health Valuation

A starting point for measuring health effects is to distinguish between Morbidity and Mortality effects. The measure most commonly used for Mortality is the crude mortality rate for a population that measures the probability of an individual dying in a given period of time. It is defined as the ratio of the total number of deaths from all causes in a specified time period to the average number of persons in that population. In defining morbidity, the U.S. Public Health Service definition is one of the most widely quoted. Morbidity is defined as "a departure from a state of physical or mental well-being, resulting from disease or injury, of which the affected individual is aware", (Park 1997).
For purposes of analysing health effects of diarrhoeal diseases, it is morbidity that is of primary concern rather than mortality. There have been several ways of classifying morbidity in the literature. Amongst these, duration of the condition, type of symptom, and degree of impairment of activity have been most commonly used. Distinction is also to be made in terms of acute or chronic morbidity. Chronic morbidity refers to long term, indefinite cases of illness while typically cases like diarrhoea would be considered as acute morbidity which would have a well-defined time period.

An economic evaluation of the health effects of a change in an environmental or resource good, would focus attention on the changes in individual behaviour stemming from perceived adverse effects (reduction) on the individual's utility. An obvious question then arises on what constitutes an "adverse" change in an environmental or resource good. Economists have tried to answer this query on the basis of the concept of "Willingness-to-pay" as a measure of value. A change perceived by the individual who expresses or reveals a willingness-to-pay to avoid the effects of the change or requires compensation to experience it, would be termed as an adverse one. Thus, the role of socio-economic variables (education, nature of employment) in determining the individual's response to a particular episode of ill health, is of utmost importance in analysing morbidity effects.

While there are several ways of measuring morbidity as based on definitions of prevalence rates and incidence rates, for present purposes the incidence rate would be
most appropriate in studying the causal relationships between changes in exposure and changes in health status\(^1\). The incidence rate is defined as the number of new cases occurring in a defined population during a specified period of time. The corresponding morbidity measure would thus relate to all cases where the onset of morbidity occurs during the period considered and terminates either within that period or after it. The prevalence rate on the other hand measures the total number of cases (old and new) in the period of study and as such includes cases where the onset of morbidity has occurred before the period.

**Valuing Reductions in Morbidity**

A frequently used method for measuring morbidity has been based on the opportunity cost approach. It seeks to identify the real costs of illness by estimating lost productivity and output resulting from illness and, the increased expenditures on medical care. Thus, typically a dose-response relationship is estimated. However, this approach has been criticised as yielding a partial measure since it does not take into account the disutility associated with the symptoms and lost opportunities for leisure activities caused by the illness.

Critics of this approach have advocated the use of a willingness-to-pay approach on the grounds that it would yield a comprehensive benefit measure based on individual preferences. But the argument can be extended further when one moves from the

\(^1\)The logic behind using the incidence rate will become obvious in Chapter 7, where the empirical analysis has been presented.
individual to the society. The society's valuation of changes in health in the context of the developed world, differs from that of the individual in so far as certain costs such as those of medical insurance, and sick leave policies are a means of shifting individual costs to the society at large. It is imperative to understand that in the context of a developing economy like India, with large sections of the population classified as "poor", the value to "society" of avoiding or reducing illness could go much beyond the realms of individual willingness-to-pay based measures of benefit.

Models to Estimate Health Benefits

In 1972, Grossman developed a health production function that formed the basis of subsequent work in this field. Since his contribution, numerous models have been formulated to explore different aspects of the health production framework. Akin (1985), Strauss and Thomas (1995) and others have reviewed these models in the context of developing countries explicitly. Cropper (1981) explored the consequences of introducing explicit pollution variables in the health production function.

In the context of the present study, it is important to start with Harrington and Portney's (1987) work in extending the framework to a model deriving individual choices in terms of willingness-to-pay. Basically the health production function seeks to establish the relation of exogenous variables (for example, air pollution), and certain choice variables (for example, treatment costs), to a measure of health status of the individual. In the health production model in which pollution affects utility only
through health, willingness to pay is the reduction in the cost of achieving the optimal level of health made possible by the decrease in pollution.

Prior to the Harrington & Portney (1987) work the most common means of valuing health benefits (reduced morbidity) was the "Cost of Illness" approach. This approach equated benefits with the savings in direct expenses arising from illness or injury and the opportunity costs incurred, primarily in terms of foregone earnings due to illness (Cooper and Rice, 1976; Lave and Seskin, 1977). As discussed earlier this approach was criticised for not taking disutility arising from illness into account. Moreover, these techniques failed to take into account the averting and defensive expenditures made by individuals to protect their health status (Mishan 1974; Shibata and Winrich, 1983). Gerking and Stanley (1986) incorporated medical care as a choice variable in the individual's utility function and derived a first estimate for the marginal willingness-to-pay as a measure of the benefit from improvements in air quality.

Courant and Porter (1981) and Harford (1984) studied the changes in averting behaviour in a non-health context and came to the conclusion that averting expenditures could play an important role in over or under-stating benefits, while considering the willingness-to-pay approach for benefit estimation. These findings provide the basis for Harrington and Portney's attempts to develop a comprehensive model of health benefit estimation for arriving at the true willingness-to-pay. Their results as obtained from a constrained utility maximisation exercise were compared
with those obtained with the Cost of Illness approach and those that directly looked at defensive expenditures. Their findings theoretically prove that in most cases the cost of illness plus defensive expenditures sum total, is an underestimation of the true benefits. They conclude that the cost of illness can at best be used therefore as a lower bound for true benefits. Since then, there have been several studies which have sought to estimate health benefits of reduced air and water pollution by using willingness-to-pay as elicited through a contingent valuation exercise (Alberini et. al 1997).

The following sections develop a model for valuing the damages from contaminated water supplies. It is based on a model of consumer behaviour with utility maximisation.

**Theoretical Construct of the Model**

A utility function is defined as

\[ U = U(X, L, S) \quad \ldots \quad (1) \]

where \( X \) represents expenditures on all non-health related goods (household’s aggregate consumption) and has a price of unity, \( L \) is leisure time per period and \( S \) is time spent ill (number of days sick). The household derives utility from the consumption of \( X \) and \( L \), while \( S \) causes disutility. Thus, the first and second order derivatives are of the following nature:

\[ U_X, U_L > 0 ; U_S < 0 \]

\[ U_{XX}, U_{LL}, U_{SS} < 0 \]
Time spent ill \( (S) \) is modelled as a function of the exposure to contaminants \( (P) \) and averting or defensive behaviour \( (D) \) to reduce the likelihood of illness. Thus \( P \) could be a drinking water contaminant, and \( D \) could be a filtration system for the tap water. Thus, the health production function can be specified as:

\[
S = S(D,P) \quad \text{....(2)}
\]

and \( S_D < 0 ; S_P > 0 ; S_{DD}, S_{PP} > 0. \)

\( S \) is characterised as \( S = S(T_d, P) \), where \( T_d \) is time spent on defensive activities. In other words, the time spent ill is modelled as a function of the time spent in defensive activities, and the exposure to contamination. In the context of a low-income situation such as the one being analysed in this study, the time spent in defensive activities for generating adequate and safe water resources for the household, is an important consideration for most homes.

The household's budget constraint can then be specified as:

\[
I + wT = wL + X + wT_d + wS(T_d, P) + p_d T_d \quad \text{....(3)}
\]

where, \( I \) is total non-labour income; \( w \) is the wage rate; \( T \) is total time; \( p_d \) is out of pocket expense on defensive behaviour.

The household's decision-making problem can then be characterised as follows:

\[
\max \Lambda = U(X,L,S(T_d, P) + \lambda \left[ I + w(T - L - T_d - S(T_d, P) - X - p_d T_d \right]
\]

\[
+ \mu \left[ T - L - T_d - S(T_d, P) \right] \quad \text{....(4)}
\]

\(^2\) Further extensions to this model incorporating medical treatment costs, determined either by the number of sick days or endogenously within the optimising framework have also been developed.
With $T$ being the total time available and $\lambda$ being the Lagrange multiplier for Becker's (1971) full income constraint, the first order conditions are derived as:

$$\Delta x = U_x - \lambda = 0 \quad ......(5)$$

$$\Delta L = U_L - w\lambda - \mu = 0 \quad ......(6)$$

$$\Delta T_d = U_3 S_{T_d} - w\lambda S_{T_d} - w\lambda - \lambda p_d - \mu S_{T_d} - \mu = 0 \quad ......(7)$$

$$\Delta L = I + wT - wL - wS(T_d, P) - X - wT_d - p_d T_d \quad ......(8)$$

$$\Delta \mu = T - L - S - T_d \geq 0 \quad ; \mu (T - L - S - T_d) = 0 \quad ......(9)$$

Assuming that all individual's work for some positive hours, $\mu = 0$, and therefore equations 5 and 6 represent the trade-off between labour and leisure while equation 7 yields;

$$\frac{U_3 S_{T_d}}{\lambda} - wS_{T_d} - p_d = w \quad ......(10)$$

This optimality condition can be interpreted as follows.

$\lambda = U_x$ (from equation 1);

therefore condition (10) can be written as:

$$\frac{U_3 S_{T_d}}{U_x} - wS_{T_d} - p_d = w$$

The first term above, $\frac{U_3 S_{T_d}}{U_x}$ gives the marginal rate of substitution between $dU/dT_d$ and $dU/dX$ i.e. it gives the (implied) gain in utility (in terms of $X$), from a unit increase in $T_d$. The second term, $-wS_{T_d}$ is positive, (assuming that $w > 0$), since $S_{T_d}$ is negative by formulation. As time spent on defensive activities goes up sick time would reduce. Thus, $-wS_{T_d}$ gives the gain due to reduced sick time, valued at the wage rate. Therefore, $(\frac{U_3 S_{T_d}}{U_x} - wS_{T_d})$ gives the gross gain from an increase in $T_d$. The third term, $-p_d$ implies the expense incurred for defensive activities. Therefore, the right
hand side of the optimality condition gives the net gain from a unit increase in Td.

At the margin, the wage loss (w) corresponding to the unit increase in time spent on defensive activities, must equal the net gains (in terms of non-health consumption expenditure and reduced sick time) from the increase in time spent on defensive activities.

Valuation of Health Benefits Arising from a Change in P, the Exposure to Pollution

To value the health benefits arising from a reduction in P, the indirect utility function (V) can be specified which gives the maximum utility for a given set of parameter values (w, I and P, since the price of X is normalised to unity):

\[ V = V(I, P, w) \]
\[ = U(X, L, S(Td, P)) + \lambda [I + w(T - L - Td - S(Td, P)) - X - p_d Td] \]
\[ + \mu [T - L - Td - S(Td, P)] \]
\[ \cdots \cdots (11) \]

where, X,L,Td, \( \lambda \) and \( \mu \) are functions of the parameters I, P, w and pd.

If I, pd and w are fixed, a change in P from \( P_0 \) to \( P_1 \), brings a change from \( V_0 \) to \( V_1 \) where

\[ V_0 = V(I, P_0, w, p_d) \text{ and } V_1 = V(I, P_1, w, p_d) \]
\[ \cdots \cdots (12) \]

If \( P_1 > P_0 \), then \( V_1 < V_0 \). For fixed w and pd, to keep the individual indifferent to a
change in P would imply a change in I. As shown in figure 1, an increase in P from P_0 to P_1, forces the individual to move from V=V_0 to indifference curve V=V_1. Therefore, to leave the individual indifferent to the change in P, I must increase from I_0 to I_1. The benefit (corresponding to the willingness-to-pay) to the individual of the change in water quality is then computed as (I_1-I_0).

Holding V constant while P varies leads to I being defined implicitly as a function of P; (assuming that V_1 >0) thus, V_0 = V [I*(P), P]. Setting the total derivative of V with respect to P equal to zero along the indifference curve V = V_0, it follows that:

\[
dV/dP = (V_0 dI*(P)/dP) + V_P = 0, \quad \text{or,}
\]

\[
dI*(P)/dP = -V_P / V_1
\]

......(13)

**Figure 5.1**
\( dI^*(P)/dP \) is thus the marginal willingness to pay (be compensated) for a marginal decrease (increase) in \( P \). Since \( V \) is set equal to the initial level of utility \( V_0 \) in 12, equation 13 gives the compensating variation. Setting \( V \) equal to \( V_1 \) would yield the equivalent variation.

From equation 11,

\[
V_1 = \lambda \tag{14}
\]

and,

\[
V_p = (U_s - \lambda w - \mu) S_p \tag{15}
\]

\[
= (U_s - \lambda w) S_p
\]

using the first order conditions (equation 7),

\[
U_s - \lambda w = \lambda (w + pd) S_p / S_{td}
\]

so that,

\[
V_p = \lambda (w + pd) S_p / S_{td} \tag{16}
\]

and,

\[
dI^*(P) / dP = -V_p / V_1 = - (w + pd) S_p / S_{td} \tag{17}
\]

The marginal willingness to pay would therefore be computed as a function of the sickness (or dose-response) function \( S \). However, there is more to the \( S \) function than the estimation of a purely technical relationship. It maybe noted that since \( T_d \) is a choice variable for the individual, the ratio \( S_p / S_{td} \) depends on the characteristics of the utility function and the values of the parameters that the individual faces.

The total change in sick time may be derived as:

\[
dS/dP = (\delta S/\delta T_d \times \delta T_d/\delta P) + \delta S/\delta P
\]

or;

\[
dS/dP = S_{td} T_d p + S_p
\]

or;

\[
S_p / S_{td} = (dS/dP * 1/S_{td}) - T_d p \tag{18}
\]
Thus, the estimation procedure requires the estimation of a reduced form relationship between illness and the ambient pollution levels while controlling for other variables that affect health status. Such a health production function can be estimated using cross-section data on illness and defensive behaviour as per model specifications. In actual estimations of the health production function, one would also be controlling for other determinants of health status such as physical and socio-economic characteristics of age, sex, income and education.

Harrington, et al (1989) used a version of the model specified above to measure the economic loses arising from the outbreak of a waterborne disease. They applied the model in measuring the valuation of the consequences of a water contamination episode for the household sector. The paper lays stress on the need to distinguish between two distinct categories of losses that need to be valued - morbidity losses and losses in terms of actions taken by individuals to reduce their exposure to contaminants. The paper also makes a crucial distinction between individual losses and losses in terms of social welfare. Using a willingness -to-pay technique, for evaluating the individual’s economic losses, both individual and social values of the consequences of an outbreak of Giardiasis (a waterborne disease) is estimated. The model is more realistic in as much as it incorporates the fact that illness can affect worker productivity even on days when work is not missed. Alberini, et al (1996) used a similar model in investigating the effects of engineering variables and individual behaviour on diarrhoeal disease in Jakarta.
Estimation of the Model

A few clarifications

It has been suggested in the literature that illness may also affect worker productivity even on days when work is not missed. Thus Harrington et al. (1989) model the utility function as

\[ U^* (X, L, D; P) = F (D, P) U(X, L) \]

where, \( F \) is one's productivity in producing utility and \( D \) is defensive expenditures. It is assumed that this productivity factor affects one's work performance and hence wage income in a situation where the individual is self-employed. However, in the present formulation this has not been considered since:

1. The self-employment assumption is not valid for the majority of the sample that will be used in the study.
2. The present study seeks to model diarrheal illness; productivity factor is more relevant in the case of a lingering illness than for acute short term infections such as diarrheal diseases which are more incapacitating while they last and therefore the number of work days lost or sick time as \( S (T_d, P) \) is an acceptable formulation.

The other question that has been raised in the literature relates to the difference between social welfare arising from an improvement in health benefits and individual welfare. One of the major differences in this regard concerns taxation. However, it is to be noted that most of those covered in the sample under study are daily wagers from the lower socio-economic categories who do not fall within the formal taxation system.
Hence, tax revenue lost due to illness need not be accounted for. Secondly, paid sick leave and medical insurance are also non-existent and to that extent social value of lost work can be statistically approximated to the sum of the individual valuations.

**Estimation Procedure**

As described above, the utility maximisation exercise leads to a set of first order conditions which would solve for an optimal $T_d^*$ which would in turn be a function of $(w, p_d, I, P)$.

$$T_d^* = T_d^* (w, p_d, I, P) \quad \ldots \text{(E1)}$$

On substituting $T_d^*$ in $S$, we get the actual time spent ill as:

$$S = S(T_d^*, P) \quad \ldots \text{(E2)}$$

The model would therefore estimate (E1 and E2) using household level data to study how individual’s respond to a threat of contamination and illness.

(E1 and E2) can be estimated using household level data. One possible specification for both these equations is based on binary observed dependent variables. For example, for defensive behaviour, the variable capturing whether household’s boil drinking water or not can be defined to allow for a binary response specification.

Suppose that households engage in defensive behaviour if the value taken by a random variable $y_i^*$ is greater than zero. $y_i^*$ would be determined by individual/household characteristics (including the wage rate, non-labour income, costs of defensive measure).
behaviour) and some risk factors known to the researcher such as the count of coliforms in the water, or other such proxies for contamination such as the availability of toilets. These observable variables are summarised into a vector of regressors \((x_1)\). Further, in estimating any such model, one has to allow for risk factors that are known to the household in determining defensive behaviour but remain unaccounted for among the variables elicited by the survey. Such factors may include for example fluctuations in the quality of water that are not captured in a one time testing exercise, previous experience of illness, etc. Summarising these factors into a variable \(R^*\), the reduced form equation for defensive behaviour can be written as:

\[
y_1^* = x_1 \beta_1 + \gamma_1 R^* + \epsilon
\]

...(E3)

where \(\epsilon\) is a random error term. It is assumed that the coefficient \(\gamma_1\) is positive i.e. a higher value of \(R^*\), is associated with higher risk of diarrhoeal diseases and hence a higher level of defensive activities. Equation (E3) can be estimated using binary dependent variable techniques.

For the second reduced form equation relating illness with its associated determinants, a binary specification is assumed where a random variable \(y_2^*\), defined as

\[
y_2^* = x_2 \beta_2 + \gamma_2 R^* + \delta y_1^* + \eta
\]

.....(E4)

takes on a value greater than zero if diarrhoeal illness is observed in a household. Here \(x_2\) is also a set of individual characteristics and sources of risk (contamination of drinking water) for diarrhoeal disease that are available to the researcher. Again, unobservable risk factors \(R^*\) are included among the determinants of illness with \(\gamma_2\).
being positive implying that a higher risk of contamination leads to a higher likelihood of contracting the disease. Diarrhoea is controlled by defensive behaviour $y_1^*$, so that the coefficient $\delta$ should be negative. Equation (E4) is also estimated using binary response techniques. The error terms $\varepsilon$ and $\eta$ are assumed to be independent of each other. Since the risk factors are unobservable, these will be absorbed into the error terms $v_1 = \gamma_1 R^* + \varepsilon$ and $v_2 = \gamma_2 R^* + \eta$.

A probit regression of observed defensive behaviour on the selected regressors yields consistent estimates, provided it is assumed that $x_i$ is independent of the error $v_1$. However a probit regression of diarrhoeal illness on individual characteristics and defensive behaviour would yield inconsistent estimates because the hidden risk factors would introduce a correlation between defensive behaviour (one of the regressors here) and the error term $v_2$ in the illness equation. Therefore, the correct procedure to be adopted is as follows. It is to be noted that E3 is already expressed in reduced form as it contains only exogenous regressors. On substituting E3 into E4, a second reduced form equation is obtained where defensive behaviour is eliminated from the regressors and diarrhoeal disease depends only on individual or household characteristics and unobservable risk:

$$y_2^* = x_2 \beta_2 + x_i (\delta \beta_i) + [(\delta \gamma_1 + \gamma_2) R^* + (\delta \varepsilon + \eta)]$$

The error term of E5, (in brackets), is correlated with the error term of the first equation, $v_1 = \gamma_1 R^* + \varepsilon$. The covariance between the error terms of the reduced form
equations, E3 and E5, is equal to \((\delta \gamma_1 + \gamma_2) \gamma_1 V(R^*) + \delta \sigma_2 \varepsilon\), and is in general nonzero, implying that the probability of becoming ill is not independent of that of engaging in defensive behaviour. The quantity \((\delta \gamma_1 + \gamma_2)\) in particular can be interpreted as the net effect on illness of a change in the unobservable risk i.e. after the individual’s defensive actions. As a consequence of the nonindependence of the probabilities of defensive behaviour and illness, we can estimate E3 and E5 jointly as a (simultaneous equation) bivariate probit model (Greene, 1993). Such an estimation would imply the assumption that \(v_1\) and \(v_2\) are (jointly) normally distributed, and tends to behave reasonably well provided that the true distribution belongs to the exponential family of distributions. If that is the case then the estimates for the coefficients would be consistent and "robust" standard errors can be produced from the information matrix (I) and the matrix of cross products of the first derivatives of the log likelihood function (F), (i.e. from the matrix: \(I^{-1}F\)).

It is also to be noted that the parameters cannot all be identified separately. As with standard probit regressions the bivariate probit estimation exercise would lead to estimates of the ratios \(\hat{\beta}_1 = \beta_1 / \sigma_1\) and \(\hat{\beta}_2 = \beta_2 / \sigma_2\), where \(\sigma_1\) and \(\sigma_2\) denote the standard deviations of the reduced form error terms. Here \(\sigma_1\) and \(\sigma_2\) cannot be identified, nor can the two \(\gamma\) and \(\delta\).

The next chapter presents the sampling frame for the survey on the basis of which data was collected for estimating the damage assessment models, to arrive at health costs and willingness-to-pay measures for the sampled population.