Valuing Changes in Health Risks: A Comparison of Alternative Measures*

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I. Introduction

Essential to efficient provision of health, safety, and the environment is correct valuation of risks to human health. In a world of scarcity difficult decisions concerning tradeoffs between health and other desirables are unavoidable. In this paper we develop a model of health investment under uncertainty which yields a general expression for values of changes in risks to human health. The preference-based values of morbidity risks and mortality risks are ex ante dollar equivalents of changes in expected utility associated with risk changes. The preference-based values are related to two alternative measures, costs of illness and preventive expenditures, which are thought to be lower bounds on the value of risk reductions. We demonstrate that these alternative measures are not even special cases of the more general measure and that the size relationships among the three measures are complex. Also, we derive the relationship between the willingness to pay for risk changes and the consumer surpluses associated with health changes which occur with certainty.

The next section contains a brief review of the approaches to valuing changes in health.

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In section III we develop a model of health risks behavior and in the following section we describe the implications for estimation of the derived measures. Section V contains the results of an illustrative empirical endeavor which estimates and compares some of the alternative measures for changes in morbidity risks. Concluding remarks are given in section VI.

II. Approaches to Valuing Health

Costs of Illness

The approach traditionally used by health professionals to measure the benefits of improved health is based on avoidance of disease damages. This approach relies heavily on the idea that people are producers. According to Mushkin [21, 130–6] the yield from improvements in health is the labor product created plus the savings in health care expenditures. The value of health improvements is the sum of the reductions in labor market earnings losses (indirect costs) and the outlays for health care (direct costs). Numerous studies employ this costs of illness approach including Cooper and Rice [10] and Mushkin [22].

Several deficiencies in the costs of illness approach are: (1) the indirect costs are zero for retirees, full time homemakers, and others who do not work in the market, (2) an arbitrary decision must be made about forgone consumption expenditures, i.e., gross or net labor earnings, (3) individuals are viewed as having no control over their health or health care expenditures and (4) there is little basis in economic theory for the use of the costs of illness in benefit-cost analysis. An attempt has been made by Landefeld and Seskin [19] to reformulate costs of illness values to more closely approximate a theoretically correct measure, but their study primarily focuses on externalities. An approach more closely tied to individual optimization seems appropriate.

Household Production of Health and Preventive Expenditures

While the costs of illness approach concentrates on damages or costs following the onset of illness, individuals can and do incur costs in efforts to prevent illness from ever occurring. In the Grossman [15] model of consumption and production of the commodity "good health", individuals combine purchased goods such as medical care and their own time to produce health capital. The value of healthy time is the sum of two terms: (1) the increment in labor earnings which is possible and (2) the monetary value of the gain in utility associated with better health. Thus, the household production model gives a conceptual foundation for the relevance of labor earnings (indirect costs) for morbidity, but it also implies that a preference-based value will depend on the costs of producing health (preventive expenditures) and a utility, or consumption, value. An example of the household production approach is the Cropper [13] micro study of the effect of air pollution on days lost from work due to illness.[1]

The recognition that health is partly endogenous has also spawned the idea that health

1. Although Cropper [13] does obtain estimates of valuation of health changes, she does so only under very specific assumptions. The wage rate is multiplied by an expression derived from a particular production function in order to obtain the values of health changes. Gerking and Stanley [14] estimate the value of a change in health as the cost of preventive activity times an estimated ratio of marginal products of inputs in the health production function.

improvements permit a reduction in preventive expenditures and that the savings of preventive expenditures is the value of the health improvement. This general approach has been suggested as a way to measure the benefits of reducing pollution where the expenditures prevent not only damages to human health, but also damages to property and so forth. Courant and Porter [11] characterize the literature as having reached a limited consensus that such expenditures represent a lower bound to the total costs of pollution, a conclusion they dispute. However, the relation between preventive expenditures and the benefits of improved health has received little attention. We explore this relationship.

A General Framework for Valuation Under Uncertainty

At this point there appear to be disparate approaches to valuation of health and risks: costs of illness, willingness to pay and preventive expenditures. Assuming health improvements occur with certainty, research has proceeded using one approach or another, but only limited effort has been made to compare and reconcile the approaches.[2] A recent paper by Harrington and Portney [16] is noteworthy in that they show that under specific conditions, the costs of illness values for morbidity will be a lower bound on the theoretically preferred, willingness to pay values for morbidity. Neglect of preventive expenditures is a cause of the difference. Below we develop an eclectic model with endogenous health risks and derive the preference-based values for changes in health risks. The model considers morbidity and mortality and allows the probabilities of various health states and survival to be influenced by preventive activity and exogenous factors such as environmental quality. Terms for preventive expenditures and costs of illness in the benefit expression are identified for purposes of comparison with the conceptually correct willingness to pay. The model provides a framework for comparing values of health risks estimated using various techniques. The values derived are ex ante, dollar equivalents of changes in expected utility associated with risk changes. We show the relationship between our willingness to pay measure and the consumer surplus associated with changes occurring with certainty. Our empirical results for the value of morbidity risk reductions are based on this relationship.

III. Human Health Risk Reduction Benefit Model

Assume a person's utility depends on consumption expenditures and the state of health. Utility may be expressed as:

$$U = U(C,q) \tag{1}$$

where U is utility, C is consumption expenditures and q is a vector of health characteristics.[3]

A person does not know with certainty, however, what his health will be, or for a given state of health, whether or not he will survive the period in question. In order to incorporate

2. Chestnut and Violette [8] review in detail the approaches to valuation of changes in morbidity and the existing empirical studies. Notably, previous studies have not dealt with health risks.

3. C consists of both expenditures on market goods and services and on time, combined in fixed proportions. If the value of time is constant at the market wage rate, then consumption time expenditures are simply the product of the wage and the amount of time spent in consumption activities. Preventive expenditures (X) and costs of illness (Z) introduced later are also assumed to consist of expenditures on time and market goods combined in fixed proportions.

these uncertainties into the model, we specify probability of health characteristics and probability of survival functions. The probability density function for health characteristics, conditional on the levels of X and E, can be represented as:

$$h(q;X,E) \tag{2}$$

where X is preventive expenditures and E is any exogenous shift variable, such as environmental change. Thus, the health characteristic probabilities are not immutable, but rather are influenced by preventive measures chosen by the individual person and exogenous changes such as environmental improvement.

It is reasonable to assume that the healthier a person is, the greater are the chances of survival of a given period. In other words probability of survival can be expressed as an increasing (decreasing) function of good (bad) health characteristics:

$$p = p(q) \tag{3}$$

where p is the probability of surviving the period.

A final element of the model facilitates comparisons with the costs of illness approach for valuing health risk reductions. When in poor health, a person incurs costs such as medical expenditures and time lost from work and consumption activities. These costs will vary according to the degree of illness malfunctions that occurs:

$$Z = f(q) \tag{4}$$

where Z is the costs incurred as a result of illness. These expenditures reduce consumption, and provide no utility of their own.[4]

In this framework, a person chooses preventive expenditures (X) in order to maximize expected utility given the following full income constraint:

$$M = C + X + Z \tag{5}$$

where M is full income in the absence of any costs due to illness.[5] Although they provide no utility by themselves, preventive expenditures influence expected utility in three ways: (1) X increases the probability of being in good health, therefore increasing utility if alive; (2) X increases the probability of being alive; and (3) by increasing the probability of being in good health, X expenditures decrease illness costs, Z, that can be expected, increasing the amount of income expected to be left over for consumption. These benefits must be weighed against the direct loss in consumption made necessary by the preventive expenditures.

More formally, the individual's problem can be stated as

$$\underset{X}{\text{Max}}\, E(U) = \int_{-\infty}^{\infty} U(C,q)\, p(q)\, h(q;X,E)\,dq \tag{6}$$

4. Typically, the costs of illness approach only includes earnings lost or the value of time lost from work and excludes the value of time lost from consumption activities. Define $Z^* = Z - C_L$, where C_L is the value of time lost from consumption. In our empirical comparisons of the costs of illness and willingness to pay approaches later in the paper we employ the more widely used Z^* definition of costs of illness.

5. M is the sum of nonlabor income and potential earnings. Assuming the wage rate is constant, potential earnings are simply the product of the wage rate and the total time in the period. The individual's problem can be expressed in terms of the choice of X, rather than its goods and time components, because of the fixed proportions assumption for X, C and Z.

subject to the income constraint (5). Reexpressing the income constraint in terms of C and substituting it into (6), the individual's problem becomes

$$\underset{X}{\text{Max}}\, E(U) = \int_{-\infty}^{\infty} U(M - X - f(q), q)\, p(q)\, h(q;X,E) dq \tag{7}$$

where U, h and p come from equations (1), (2) and (3), respectively.[6]

The integral in (7) gives utility under different health outcomes weighted by the probability of the various outcomes. Different attitudes toward risk are allowed for through the shape of the utility function. When utility is expressed $U(M - X - f(q), q)$ it becomes apparent that preventive expenditures X directly reduce the amount of income left over for consumption. The term $p(q)$ in (7) adjusts utility by the probability of being alive. Assuming no utility if deceased, $U(M - X - f(q), q)\, p(q)$ gives expected utility conditional on the state of health. The density function $h(q;X,E)$ weights expected utility by the probabilities of different states of health. The integration over health states thus gives expected utility for the period.

The problem becomes more tractable if a single health outcome measurable as a zero-one condition is considered. An example is occurrence of a specified type of cancer as affected by environmental irritants. Another example is occurrence of traffic accidents due to poor visibility brought on by air pollution, provided the major cost is associated with the frequency of approximately uniformly severe accidents, rather than the severity of an individual accident being importantly related to the degree of visibility. Light symptoms resulting from contact with pollutants, such as coughing, headaches, and eye irritation are other examples as long as the principal effect is absence of unimpaired functioning rather than the degree of illness associated with the pollutant level. A damage function, where the degree of discomfort rather than presence or absence of discomfort is related to the level of pollution, would require a more extended analysis considering probabilities for more than two states of the world. Various degrees of symptoms along with their associated probability densities would have to be considered rather than just presence or absence of symptoms. The integral in (7) would not simplify as it does in the case where there is only one state of illness.

If health is a matter only of absence or presence of a deleterious condition, the probability density function $h(q;X,E)$ is discrete rather than continuous with probability concentrated at $q = 1$ for presence of the condition and $q = 0$ for absence of the condition:

$$\begin{aligned} h(q;X,E) &= H(X,E) && \text{if } q = 1 \\ h(q;X,E) &= 1 - H(X,E) && \text{if } q = 0 \end{aligned} \tag{8}$$

where $H(X,E)$ is the probability of the presence of the condition. In this case, the person

6. A more extended analysis might consider utility of heirs affected by bequeathment. Also, although the consumer's problem as expressed in equations (6) and (7) is single period in nature, it can be generalized to allow for multiperiod planning as has been done by Cropper [12]. In particular, suppose the probability density function, the probability of survival function, and the utility function all vary over time. Assuming an infinite planning horizon, the individual's problem can be restated as

$$Max\ E(U) = \int_T^{\infty} \left(\int_{-\infty}^{\infty} U(M_t - X_t - f(q_t), q_t; t)\, p(q_t, t)\, h(q_t, X_t, E_t, t) dq \right) dt.$$

The individual then chooses the path of X's over time that maximizes lifetime expected utility.

decides preventive expenditures at the beginning of the period and then takes the resulting chance of what the health outcome will be for the period.

Because of the discreteness of q when health is a matter only of the absence or presence of a condition, the integral in (7) simplifies to a sum of two discrete states corresponding to $q=0$ and $q=1$. Using (8), the individual's maximization problem is

$$\max_{X} E(U) = U_0 P_0 (1-H) + U_1 P_1 H \tag{9}$$

where $U_0 = U(M-X,0)$ is utility if free of the condition,
$U_1 = U(M-X-Z,1)$ is utility with the condition,
$P_0 = p(0)$ is probability of survival if free of the condition,
$P_1 = p(1)$ is probability of survival with the condition,
$H = H(X,E)$ is the probability of contracting condition.

Equation (9) states that the expected utility to be maximized is the sum of utilities in the absence and the presence of the deleterious health condition, weighted by the probabilities of contracting or not contracting the condition and of surviving. As can be seen from the expressions for U_0 and U_1, utility depends both on the presence or absence of the condition and on consumption, i.e., there is state dependence. The income constraint has been substituted into the utility function as in equation (7). In the discrete case, this constraint can be expressed as:

$$C = M - X \qquad \text{if } q = 0$$
$$C = M - X - Z \quad \text{if } q = 1.^{7} \tag{10}$$

Differentiating equation (9) with respect to preventive expenditures X and setting the result equal to zero gives the first order condition for a maximum:

$$F = -U_0' P_0 (1-H) - U_1' P_1 H - U_0 P_0 H_X + U_1 P_1 H_X = 0 \tag{11}$$

where U_0' and U_1' are the marginal utilities of income when $q=0$ and $q=1$, respectively, and H_X is $\partial H(X,E)/\partial X < 0$, the change in the probability of contracting the disease resulting from an extra dollar spent on prevention.[8] The first two terms give the decline in expected utility due to decreased consumption when an extra dollar is spent on defensive measures. The last two terms give the rise in expected utility due to decreased probability of contracting the disease as a result of the extra dollar spent on prevention. The first order condition for a maximum is that the sacrifice of consumption given by the first two terms must just offset the gain from the reduced probability of contracting the disease given by the last two terms.

In order for the individual to obtain a maximum, the second derivative of the expected utility function with respect to preventive expenditures must be less than or equal to zero. This second-order condition can be expressed as:

7. Note that for any given individual, Z is fixed once the disease is contracted. Thus each condition is of uniform severity. In a more extended analysis severity could vary and Z could be made to depend on other variables such as the price of medical care. Z could be made endogenous in the current framework if it were specified as a function of preventive expenditures.

8. Note that $-U_0' = -\partial U(M-X,0)/\partial M = \partial U(M-X,0)/\partial X$ and $-U_1' = -\partial U(M-X-Z,1)/\partial M = \partial U(M-X-Z,1)/\partial X$.

$$\Delta = U_0''P_0(1-H) + U_1''P_1H + 2H_X(U_0'P_0 - U_1'P_1) - H_{XX}(U_0P_0 - U_1P_1) \leq 0 \qquad (12)$$

where $H_{XX} = \partial^2 H(X,E)/\partial X^2$ and U_0'' and U_1'' are the second derivatives of utility with respect to income when $q=0$ and $q=1$ respectively.

IV. Valuation of Changes in Risks to Human Health

Willingness to Pay

Expressions for the marginal willingness to pay (*WTP*) for an exogenous reduction in health risks can be derived from this model. The totally differentiated expected utility function must be solved for the change in income that would be required to keep expected utility constant when there is an exogenous change. The individual would be willing to pay the negative of this compensating variation for the exogenous improvements in health risks. Holding expected utility constant by setting $dE(U)=0$, we can solve for the *WTP* measure:

$$-dM/dE = -[(U_0P_0 - U_1P_1)/\lambda]H_E - 1 + [(U_0P_0 - U_1P_1)/\lambda]H_X\,(dX/dE).^{9} \qquad (13)$$

$U_0P_0 - U_1P_1$ is the difference in expected utility when healthy and when ill. This is divided by $\lambda = U_0'P_0(1-H) + U_1'P_1H$, which is a weighted average of the expected marginal utility when healthy and the expected marginal utility when ill, with the weights being the probabilities of being healthy or ill. Thus λ can be interpreted as the expected marginal utility of income.

Allowing for optimal choice of defensive expenditures as individuals adjust to the exogeneous changes in health risks or the environment implies that equation (13) satisfies equation (11), the first order condition. Substituting the first order condition into the *WTP* expression given in (13) we get:

$$-dM/dE = H_E/H_X. \qquad (14)$$

This simplification allows the *WTP* measure to be expressed independently of the non-observable utility function, but instead in terms of the health risk function H. In particular, equation (14) gives the *WTP* for a change in environment as a ratio of the marginal product of the environment in reducing health risks and the marginal product of defensive expenditures in reducing health risks. This result is similar to the findings of others who suggest *WTP* for an environmental improvement can be expressed solely in terms of the production function [11; 14; 16].

To allow for a more intuitive interpretation of equation (14), recall that $H = H(X,E)$ and therefore

$$dH/dE = H_X(dX/dE) + H_E. \qquad (15)$$

Rearranging we have $H_E = dH/dE - H_X(dX/dE)$. Substituting this expression for the marginal product of the environment in reducing health risks into equation (14) we have:

$$-dM/dE = (1/H_X)(dH/dE) - dX/dE. \qquad (16)$$

9. Terms involving the partial derivative of U with respect to q disappear, because these terms are multiplied by dq, and $dq=0$ since q is set at either 0 or 1. Similarly, recalling that the costs of illness Z are given by $Z=f(q)$, $dZ = f'(q)\,dq = 0$, since again $dq=0$.

Writing this benefit expression in terms of utility by using the first order condition we have:

$$-dM/dE = -[(U_0P_0 - U_1P_1)/\lambda](dH/dE) - dX/dE. \tag{17}$$

This form of the benefit expression states that a person's *WTP* for an environmental improvement can be expressed as the sum of two terms. The first term is the dollar value of the expected difference in expected utilities when healthy or ill multiplied by the change in health risks due to the change in the environment or other exogenous factor. The second term is the change in preventive expenditures resulting from the exogenous change.

Our model yields an expression for willingness to pay which is ex ante in nature, i.e., before it is known whether or not the individual contracts the condition. The *WTP* value is the amount of income that must be taken away from both states to keep expected utility constant. It is defined by:

$$U_0P_0(1-H) + U_1P_1H - U(M-\tilde{X}-dM/dE,0)P_0(1-\tilde{H})$$
$$- U(M-\tilde{X}-Z-dM/dE,1)P_0\tilde{H} = 0 \tag{18}$$

where the tilde indicates the value of a variable after a change in E. In the context of uncertainty our willingness to pay, $-dM/dE$, is similar to what Smith [24] would call an option price. But since we do not specify market insurance or other opportunities individuals might have to change expenditures in each state of the world, our willingness to pay is not exactly an option price.

Comparisons to Preventive Expenditures and Costs of Illness

It seems natural to assume that people will pay a positive amount for an environmental improvement. This means that to keep expected utility constant in the face of an exogenous improvement in the environment, an individual's income would have to be reduced, i.e., $dM/dE < 0$ and a positive willingness to pay is equal to $-dM/dE$. Inspection of the benefit expression given in equation (17) reveals that *WTP* could be positive if both terms, the utility value and the preventive expenditure value, are positive. Since the total derivatives, dH/dE and dX/dE, show how risk and expenditures change after optimizing behavior, however, the terms cannot be unambiguously signed. For the total derivatives, the general and plausible results and accompanying conditions are summarized in Table I.

Preventive Expenditures. Consider the expenditure response of the individual to a change in the environment, dX/dE. Using the first order condition F shown in equation (11) and the implicit function rule, it follows that:

$$dX/dE = -F_E/F_X = -F_E/\Delta \tag{19}$$

where $\Delta < 0$ from the second order condition given by equation (12). The sign of dX/dE, then, is the same as the sign of F_E. Differentiating F with respect to E we get:

$$F_E = (U_0'P_0 - U_1'P_1)H_E - (U_0P_0 - U_1P_1)H_{EX} \tag{20}$$

which cannot be signed unambiguously. The implication is that dX/dE need not be negative in that preventive expenditures could increase with an environmental improvement. Nonetheless, under plausible conditions dX/dE will be negative. If $H_{EX} > 0$, which is the case if X and E are substitutes, and if $(U_0P_0 - U_1P_1) > 0$, which is the case if expected utility

Table I. Comparative Static Results of the Health Risk Model

	General Result	Plausible Results	Sufficient Conditions for Plausible Results
Preventive Expenditures	$dX/dE \gtreqless 0$	$dX/dE < 0$	$H_{EX} > 0$ and $(U_0 P_0 - U_1 P_1) > 0$ and $(U_0^1 P_0 - U_1^1 P_1) \geq 0$
Morbidity Risk	$dH/dE \gtreqless 0$	$dH/dE < 0$	$dX/dE < 0$ and $H_E > H_X\, dX/dE$. or $dX/dE \geq 0$
Willingness to Pay and Preventive Expenditures (Equation 17)[a]	$-dM/dE \gtreqless dX/dE$	$-dM/dE > -dX/dE$	$dX/dE < 0$ and $dH/dE < 0$
Willingness to Pay and Cost of Illness (Equation 21)	$-dM/dE \neq -Z(dH/dE)$	$-dM/dE \neq -Z(dH/dE)$[b]	Many exist
Willingness to Pay and Preventive Expenditures —Pure Morbidity Case (Equation 22)	$-dM/dE \gtreqless -dX/dE$	$-dM/dE > -dX/dE$	$dX/dE < 0$ and $dH/dE < 0$
Willingness to Pay and Costs of Illness —Pure Morbidity Case (Equation 22)	$-dM/dE \neq -Z(dH/dE)$	$-dM/dE > -Z(dH/dE)$	$dH/dE < 0$ and $dX/dE < 0$ and $U(C,0) > U(C,1)$ and $U(Z)/\lambda^{**} > Z$

a. Willingness to pay is equal to $-dM/dE$.

b It is implausible that $-dM/dE = -Z(dH/dE)$. A set of sufficient conditions for this result is $dX/dE = 0$, U is not a function of q, $U(Z)/\lambda^* = Z$, and $P_0 = P_1 = 1$.

when healthy exceeds the expected utility when sick, and if the difference between expected marginal utilities is small, then $F_E < 0$. If $F_E < 0$, then $dX/dE < 0$.

Change in Morbidity Risk. The risk response to a change in the environment, dH/dE, depends in part on dX/dE, as can be seen from equation (15). The sign of dH/dE is negative if $dX/dE < 0$ and if H_E is larger in absolute value than $H_X(dX/dE)$; the sign of dH/dE is also negative if $dX/dE \geq 0$. In other words, the sign of dH/dE is negative except when $dX/dE < 0$ and, what seems to be unlikely, the direct effect (H_E) is less than the indirect effect $H_X(dX/dE)$. While it is possible that the indirect effect can dominate even where there is evidence of counterproductive exogenous changes, alternative explanations have been offered as more plausible [26].

The upshot of this discussion is that while the two terms in equation (17) taken together surely imply that a positive amount will be paid for an environmental improvement, it is not strictly true that the terms separately will each imply positive payments. It is the case, however, that the payments for reductions in risk and preventive expenditures will be positive under the plausible conditions that X and E are substitutes and the direct effect of E on H dominating the indirect effect through dX/dE. Under these conditions the willingness to pay for an environmental improvement is the sum of the utility value of the reduction in risk and the savings in preventive expenditures. Also under these conditions the savings in preventive expenditures, dX/dE, is a lower bound on willingness to pay. If the conditions described above do not hold, then dX/dE is not necessarily a lower bound on WTP. Under no plausible conditions is dX/dE a special case of WTP.

Costs of Illness. On the basis of the benefit expression it is tempting to consider a value of exogenous improvement based solely on the costs of illness as a special case of the general WTP measure. Indeed, there might appear to be conditions under which the expression approaches being a special case of WTP. For instance, if (1) defensive expenditures are nonexistent or unchanging, and if (2) health does not enter the utility function directly, the WTP expression shown in equation (17) collapses to the first term, and the difference in expected utilities when healthy and ill only reflects the reduced level of consumption when ill due to the costs of illness incurred, Z. Even with these severe restrictions, however,

$$-Z(dH/dE) \neq -[(U(M-X)P_0 - U(M-X-Z)P_1)/\lambda^*](dH/dE), \tag{21}$$

where $\lambda^* = U'[P_0(1-H) + P_1 H]$. For expected costs of illness to equal WTP, additional questionable restrictions are necessary. For example, sufficient conditions are (1) and (2) above and (3) the monetary value of the utility of consumption be equal to consumption expenditures, $Z = U(Z)/\lambda^*$, and (4) the probability of survival be equal to one, $P_0 = P_1 = 1$. In fact, there are no plausible assumptions which can be made to simplify the WTP measure to cost of illness. It is even less likely that WTP will equal Z^*, the more commonly used cost of illness measure which excludes the value of lost nonwork time.

Morbidity Risk

For the sake of brevity and because considerable attention has been given to mortality risk in previous articles, we focus on valuing changes in morbidity risks.[10] For the pure morbidity case, there is no possibility of death whether healthy or ill, so $P_0 = P_1 = 1$. The general WTP expression, equation (17), simplifies to:

$$-dM/dE|_{P_0=P_1=1} = -[(U(M-X,0) - U(M-X-Z,1))/\lambda^{**}](dH/dE) - dX/dE$$

$$= -[(U_0 - U_1)/\lambda^{**}](dH/dE) - dX/dE \tag{22}$$

where $\lambda^{**} = U_0'(1-H) + U_1'H$ which is expected marginal utility of consumption for the morbidity case.

10. Although we concentrate on morbidity risks we should note another implication of our model for the costs of illness approach. Typically, costs of illness studies separately estimate the morbidity costs and the mortality costs and simply add them together [21;22]. Even if expected costs of illness were a good measure of WTP for morbidity only, the sum of the morbidity and mortality costs would not be a good measure of the correct joint valuation.

The relationship between WTP and preventive expenditures is again complex in that neither is unambiguously larger than the other. Again, however, under similar plausible conditions dX/dE is lower bound on WTP. This is illustrated in Table I.

As in the general case there is no reason to believe that WTP equals the expected savings in costs of illness, $-Z(dH/dE)$. Plausible conditions do exist, however, under which $-Z(dH/dE)$ is a lower bound on WTP. If $dH/dE < 0$ and $dX/dE < 0$, then $WTP > -Z(dH/dE)$ because $Z(dH/dE)$ ignores the savings in preventive expenditures. Even if we assume there is no change in preventive expenditures, there are two reasons why we expect $WTP > -Z(dH/dE)$. One reason is that health enters directly in the utility function and utility is enhanced by health; $U(C,0) > U(C,1)$. Another reason is that we expect the dollar value of utility lost due to losing Z dollars of consumption to costs of illness is more than Z. This relationship between the value of the utility of consumption and consumption expenditures, or labor earnings, has been explored in depth in the "value of life" literature. Conceptually it cannot be shown, strictly, what the empirical relationship should be [20]. Still, a representative theoretical conclusion is that the value of utility of consumption or earnings "usually" exceed their dollar value [2;3]. Reviews by Blomquist [4;5] and Jones-Lee [18] of the estimates of the value of mortality risks are consistent with the theoretical conclusion. The implication for our case of morbidity is that $U(Z)/\lambda^{**} > Z$. This relationship along with $U(C,0) > U(C,1)$ lead $WTP > -Z(dH/dE)$. If $dX/dE < 0$, then WTP exceeds $-Z(dH/dE)$ by an even greater amount. So, while we cannot definitely conclude that costs of illness measures produce a lower bound for willingness to pay, the lower bound conclusion seems plausible. These results are summarized in Table I.

Comparisons to Certainty Values of Morbidity

The willingness to pay expression in the pure morbidity case is shown in equation (22). The WTP holds expected utility constant in the face of an exogenous change in health risk. This can be compared to measures of certain changes in morbidity as follows. Define consumer surplus (CS) as the dollar amount which holds utility constant in moving from the certainly sick to the certainly well state. For an irreplaceable commodity such as health this measure is what Cook and Graham [9] call a ransom. In terms of our model, CS is the difference between the utility in the healthy state and sick state ($U_0 - U_1$) expressed in dollar terms by dividing by the marginal utility of income. The expected consumer surplus associated with an exogenous change in the environment is the product of CS and the change in the probability of the certainly well state caused by the exogenous change:

$$E(CS) = -CS(dH/dE) = -[(U_0 - U_1)/\mu](dH/dE) \tag{23}$$

where μ is the marginal utility of income.

Comparing equations (22) and (23), it is clear that the willingness to pay for changes in morbidity risks given by (22) is almost the expected value of consumer surplus, adjusted for changes in preventive expenditures. In other words, equation (23) is almost the first term of equation (22). The only ambiguity in this comparison comes in expressing the change in utility in dollar terms.[11]

11. In equation (22), λ^{**}, the expected marginal utility of income or money is used. Since λ^{**} is a weighted average of marginal utilities when healthy and when ill, if we assume the marginal utilities are the same, the problem is resolved. In general, it is not clear when these two marginal utilities will be equal, since differences in consumption levels and health status are involved. The relationship between the marginal utilities of income across states also depends upon

Previous studies which address the pure morbidity case have used consumer surplus in their valuation expressions since they have avoided the question of uncertainty. The empirical work reported in the next section also makes use of consumer surplus. Since it was difficult to appropriately incorporate uncertainty into our contingent valuation experiment we measured consumer surpluses associated with changes in morbidity. However, we are able to relate these consumer surpluses to willingness to pay through equations (22) and (23).

V. Empirical Study

Study Design

To further explore the relationship between willingness to pay for morbidity improvements and alternative measures, a contingent market valuation study was conducted. Through a survey interview individuals were endowed with additional symptom days and were asked to purchase reductions in certain light symptoms contingent upon the existence of a market for doing so.[12] The survey instrument was developed to make use of accepted techniques and improve upon them where possible in eliciting individuals' bids.[13] Based on our experience with focus groups and pretesting we chose to focus on seven light symptoms: coughing spells, stuffed-up sinuses, throat congestion, itching eyes, drowsiness, headaches and nausea. We chose also to present the contingent goods in the context of certain reductions rather than risk reductions. These choices were made due to our assessment that individuals had difficulty dealing with uncertainty and complicated life threatening situations in a short interview. Individuals were asked about the number of symptom days experienced in the previous year and the costs associated with each symptom. They were asked to rank the symptoms with respect to undesirability, state their values for additional symptom-free days and summarize their values on a tally sheet. Between September 1984 and January 1985 a total of 131 people were interviewed in Denver and Chicago using door-to-door and mall-intercept methods. Out of this small random sample, 12 observations were unusable because they were incomplete. Due to the limited scope of the sample we view this empirical study as illustrative.

Results

Our contingent valuation survey measures the consumer surplus associated with the certainty of avoiding days of light symptoms. In terms of the benefit expression in the pure

the opportunities to adjust expenditures across states. For instance, with actuarially fair insurance available the individual will equate marginal utilities across states, though this will not necessarily result in full insurance in the sense that levels of utility are equal across states [9]. But if the marginal utilities of income across states are close to each other, willingness to pay for a change in health risks is approximately equal to the expected value of consumer surplus, adjusted for changes in preventive expenditures.

12. Although economists have been hesitant to use contingent markets due to their hypothetical nature, the technique offers the distinct advantage of access to specific aspects of morbidity for which no explicit or analytically accessible implicit markets exist. Brookshire and Crocker [6] offer additional advantages of contingent market valuation. Acton [1] has used contingent markets valuation for health goods while Brookshire et al. [7] have used the technique for environmental goods.

13. The survey instrument is available upon request from Glenn Blomquist. A detailed description of the development of the survey instrument and the conduction of the survey can be found in Tolley et al. [25].

Table II. Consumer Surplus and Private Cost of Illness Comparisons

Symptom	Sample Size[a]	Mean Daily Consumer Surplus[b]	Mean Daily Private Costs of Illness[c]	No. Cases $CS > COI$	t-value[d]
Coughing Spells	25	$ 75.98	$12.17	21	1.44
Stuffed-Up Sinuses	43	27.32	6.79	37	1.94
Throat Congestion	24	43.93	14.27	20	1.60
Itching Eyes	16	48.48	14.56	12	.925
Heavy Drowsiness	5	142.00	1.80	5	2.52
Headaches	46	108.71	3.45	39	1.45
Nausea	17	47.88	2.50	14	1.29
All Symptoms Experienced	44	80.63	3.93	34	2.54

a. Only those experiencing the symptom are included.

b Consumer surplus for avoiding one extra day of the symptom

c. Calculated as expenditures on doctor visits and medicine net of insurance reimbursements plus lost earnings, expressed on a daily basis.

d Test of the null hypothesis that the mean consumer surplus is less than or equal to the mean private costs of illness.

morbidity case, equation (22), we are attempting to measure $(U_0 - U_1)/\lambda^{**}$, the dollar value of the difference in utility without and with the various symptoms. Our first task is to compare the consumer surpluses (CS) for the various light symptoms with the associated costs of illness (COI) to determine whether there is any empirical relationship between the two, and thus between the WTP of a reduction in health risk and the expected COI. Earlier we argued that it is plausible that $Z < U(Z)/\lambda^{**}$, and assuming $dX/dE < 0$, the willingness to pay, $-dM/dE$, should be greater than or equal to $-Z(dH/dE)$.

Table II compares the mean CS and private COI for the seven light symptoms and for the entire set of symptoms experienced in the previous year. The comparisons are made among those who have experienced each symptom in the previous year, i.e., those for whom we have COI data. The all-symptoms comparisons are made for those who did not experience combinations of symptoms together to avoid double counting in calculating COI. The private COI is calculated consistent with Z^*, the prevailing measure in the COI literature. It is the expenditures attributable to each symptom on medicine and doctor visits less any insurance payments plus any lost earnings. Both the individual CS and COI measures are expressed on a daily basis.[14]

Out of the sample of 119 individuals, the subsamples of those who had experienced the various symptoms in the previous year ranged in size from 5 for drowsiness to 46 for headaches. Within each of these subsamples, the mean CS always exceeds the mean COI. The t-values shown in the last column of Table II are significant at better than the .10 level for a one tail test for five of the seven light symptoms, and better than the .05 level for all symptoms taken together. Perhaps even more striking is the high percentage of individual cases for which $CS > COI$. Of the 176 CS-COI pairs across the seven light symptoms, $CS > COI$ in 148 cases. For all symptoms combined, $CS > COI$ in 34 of 44 cases. The statistical

14. The contingent valuation experiments were conducted for both one-day and thirty-day changes in the experience of the various symptoms. Implicit in the normalization to one-day changes is the assumption of constant marginal costs in the case of costs of illness and constant marginal utility in the case of consumer surplus.

significance of these results can be investigated using the nonparametric sign test [17,310–15]. For the seven light symptoms, if the *CS-COI* pairs had in fact come from the same distribution, we would expect that *CS* would exceed *COI* for 88 pairs. We can test whether 148 is significantly greater than 88 by using the binomial approximation to the normal distribution.[15] The calculated value of the test statistic is 9.04 which is significantly different from zero at greater than a .001 level of significance. For all of the symptoms experienced in the previous year, the test statistic is 3.62, further adding to the evidence that $CS > COI$.[16]

There is additional evidence which supports the finding that *CS* exceeds *COI*. We asked individuals to rank the reasons for their values for symptom relief. Focus group feedback led to development of a five-item list which covered most reasons. The reasons and the percentage of the 119 respondents who ranked the reason as the most important are: comfort (66%), loss of work at home (6%), loss of work away from home (12%), loss of recreation (2%), reduce medical expenses (12%) and other (2%).

We also estimated simple ordinary least squares regressions of *CS* on the private *COI*.[17] In each case the intercept is positive, and in most cases it is significantly different from zero. The slope term is never significantly different from zero. However, in the cases in which it approaches significance, it is positive. Thus, the regression results are consistent with the finding that *CS* exceeds *COI*, but suggest there is not a strong tendency for them to move together.

Implicit in our *CS-COI* comparison is the assumption that the symptoms which people experienced in the previous year are the same as those which they are bidding on in the contingent valuation experiments. For the light symptoms included in the survey any differences appear inconsequential. When the samples are limited to those who reported that their symptoms were the same, not worse or less severe than the contingent symptoms, the mean of *WTP* is still greater than the mean of *COI* for each symptom. The dollar differences increase for five of the seven symptoms and in the all-symptoms case, although the *t*-values are somewhat lower. The nonparametric sign test statistic is 11.78 for the seven light symptoms and 2.79 for all symptoms combined, and the regression results are similar to those described above.

Our empirical evidence suggests that the private *COI*, defined excluding time lost from consumption is less than *CS*. In order to investigate whether the exclusion of time expenditures is responsible for the result, we use other information available from the survey to construct an expanded *COI* measure. This measure is the cost of medicine and doctor visits net of insurance reimbursements plus the value of time lost from any activity (e.g., market, work, school, work at home).[18] This increases the measured *COI* to make it more com-

15. The standard deviation for calculating the normal distribution test statistic is constructed under the null hypothesis that the *CS-COI* pairs come from the same distribution. Under the null hypothesis, the probability that $CS > COI$ is $1/2$ and the variance for the binomial approximation to the normal distribution is $176 \times 1/2 \times 1/2 = 44$.

16. In a study of 82 asthmatics in Los Angeles, Rowe and Chestnut [23] also find evidence that is consistent with our result that $CS > COI$.

17. These and other results not reported in the paper are available upon request from the authors.

18. The value of time lost from market or nonmarket activity is measured by multiplying the number of days lost by the daily wage. This reduces the sample somewhat since not everyone in the sample worked in the previous year and thus reported a wage rate. We also expanded the definition of cost of illness even further to include days of market and nonmarket activity "hindered." This cost of illness measure is the same as above except that it also includes the number of days hindered multiplied by one-half the daily wage. The means tests, sign tests and regressions were all recalculated for this second expanded measure, and the results are very similar to those described for the first expanded cost of illness measure.

patible with Z in our model instead of Z^*. A comparison of the mean *COI* and *CS* for the various symptoms indicates that *CS* is greater than *COI* in six of seven cases (the exception is throat congestion), although the t-values are lower than before. The nonparametric sign test statistic for the comparisons across the seven symptoms is 4.68, which is again significant at greater than a .001 level. Regressions explaining *CS* produce positive (although smaller) constant terms and insignificant *COI* coefficients. Overall, the exclusion of lost consumption time does not appear to be the reason for our earlier finding. Our empirical results are consistent with the hypothesis that consumer surplus exceeds the private *COI*, whether or not the value of lost consumption time is included.

The next step is to generalize our results to the relationship between the willingness to pay and the expected *COI*. As mentioned earlier, if dX/dE in our benefit expression is negative, then our evidence also implies that the *WTP* exceeds the expected *COI*. In other words, if an exogenous change which lowers the probability of contracting an illness causes individuals to reduce their preventive expenditures, then $WTP = -[(U_0 - U_1)/\lambda^{**}](dH/dE) - dX/dE > -Z(dH/dE)$ since $(U_0 - U_1)/\lambda^{**} > Z$, and since individuals would also be willing to pay their preventive expenditure savings to avoid increases in health risks.

While our survey contains no direct evidence on the sign of dX/dE, there is some indirect evidence. Individuals were asked whether they made various defensive expenditures for health reasons: whether they purchased air conditioners, air purifiers, humidifiers for their home or car or made other preventive expenditures. Nontrivial proportions of the full sample made some type of preventive expenditure. But more interesting are the differences between those who did and did not experience at least one of the seven light symptoms.[19] While the percentages of the two groups are almost equal for the purchase of humidifiers, those who experienced at least one of the seven symptoms were more likely to make expenditures in the other three categories than those who did not. The difference is most pronounced for air conditioners. No one in the group not experiencing any symptoms purchased an air conditioner for health reasons but over 19% of those experiencing at least one of the seven symptoms did so. This pattern is consistent with a negative dX/dE in the following way. Assume that those who experienced the symptoms also experience worse exogenous environmental conditions, resulting in a higher probability of experiencing the symptom. Thus we observe an increase in the quality of the environment ($dE > 0$) in moving from those who experienced at least one of the symptoms to those who did not. The resulting change in preventive expenditures then appears to be negative. However, this explanation is only consistent with $dX/dE < 0$. The data in the survey do not allow for a strict test of the hypothesis.

If it is true that $dX/dE < 0$, then our empirical results are also consistent with the *WTP* being greater than the expected *COI*. This allows us to make statements about our theoretical model which incorporates uncertainty from our empirical results, which by prac-

19. The proportions of the full sample making various preventive expenditures, and the proportions among those who did and did not experience at least one of the seven light symptoms are as follows:

Preventive Expenditure	Full Sample	No Symptoms	One or more Symptoms
Air Conditioner	.155	.000	.194
Air Purifier	.113	.043	.130
Humidifier	.310	.318	.308
Other	.065	.056	.068

tical necessity are couched in terms of certainty and yield only consumer surplus estimates.

One final illustration helps show the usefulness of our empirical consumer surplus estimates. We know from equations (22) and (23) that *WTP* is approximately equal to $-CS(dH/dE) - dX/dE$. If, as is plausible, $dX/dE < 0$, then $-CS(dH/dE)$ is a lower bound on the willingness to pay. Since the contingent valuation experiment measures *CS*, if we assume some value for dH/dE, we can estimate a lower bound of the willingness to pay for the reduction of health risks. For example, in Table II we report that among those who experienced coughing spells in the previous year, the mean *CS* for avoiding one extra day of cough with certainty is \$75.98. These individuals had on average 35 days of coughing spells in the previous year. If we assume that the probability of having a coughing spell on any given day is constant throughout the year, the mean individual faces a .096 probability of having a coughing spell each day. A lower bound estimate of the *WTP* for a 10% reduction in the risk of a coughing spell on any given day for the mean individual is simply $-CS(dH/dE)$ or \$75.98 × (.096 × .10) = \$.73. The lower bound for a whole year's worth of 10% reductions is \$.73 × 365 = \$266.45. Lower bounds on *WTP*'s for the other symptoms can be similarly calculated. It should be stressed, however, that these lower bound *WTP* estimates, while useful for comparisons among approaches, should be used for policy purposes only with caution. Our small sample is most likely not representative of the entire U.S. population.

VI. Concluding Remarks

This paper compares preference-based willingness to pay (*WTP*) measures for human health risk reduction with the main alternative measures that are currently in use. An eclectic model allows us to derive preference-based values for changes in health risks which are then compared with the alternative approaches. The model incorporates partly endogenous health, uncertainty, mortality, and morbidity. In fact, pure mortality and pure morbidity, to which previous studies have been confined, are special cases of the more general framework. We then provide empirical evidence for the pure morbidity case.

In the general case, we find that the *WTP* measure for reductions in health risks consists of two terms: a utility term, which reflects the costs of illness (*COI*) as well as other factors; and a term reflecting preventive expenditures. It does not follow, however, that benefit measures involving the *COI* alone or preventive expenditures alone are special cases of our general *WTP* measure. It is difficult or impossible to specify truly reasonable assumptions under which the *WTP* measure collapses to a *COI* measure or a preventive expenditures measure. Our result is somewhat different from that of Harrington and Portney [16] in that their *WTP* measure for a certain reduction in morbidity is reduced to the *COI* measure under the assumptions that there are no preventive expenditures, and health does not enter the utility function directly.

Even the weaker result that the alternative benefit measures are lower bounds to the *WTP* measure does not necessarily hold in our more comprehensive model. Without additional assumptions, we cannot establish any general comparisons between the three measures. However, we do find a set of plausible assumptions under which some comparisons of the alternative benefit measures can be made. First, it is necessary to assume that the environment and preventive expenditures are substitutes in reducing health risks. Second, the direct effects of a change in the environment on health risks must outweigh the indirect effects, so $H_E > H_X(dX/dE)$. Third, the marginal utilities of consumption when healthy and ill must be approximately the same.

If the above assumptions are made, for the special case of pure morbidity, both expected *COI* and preventive expenditures will plausibly be lower bounds for willingness to pay. The *COI* approach understates the true *WTP* for several reasons. Costs of illness neglects the savings of preventive expenditures. Costs of illness does not allow for individuals to enjoy health directly. Also from related "value of life" findings the value of the utility of consumption exceeds consumption expenditures, so the utility lost due to expenditures lost resulting from *COI* is greater than the *COI*.

Preventive expenditures also may plausibly be a lower bound to *WTP*. The preventive expenditures are not a complete measure of the benefits of health risk reduction because the individual enjoys gains in expected utility as well as the expenditure savings. In general, though, preventive expenditures may be less than, equal to, or greater than *WTP*.

Our empirical work provides estimates of consumer surpluses and costs of illness in the certainty case for 7 light symptoms: coughing spells, stuffed-up sinuses, throat congestion, itching eyes, heavy drowsiness, headache, and nausea. The results suggest that consumer surplus exceeds *COI*, but there is no strong indication that they move together in any systematic fashion. Assuming that exogenous changes affecting health risks reduce preventive expenditures, our results also imply that the *WTP* for reduction in health risks which arises from our uncertainty based model exceeds expected *COI*. We then provide an illustrative lower bound estimate of the willingness to pay for risk reductions from our contingent valuation survey. The results of our empirical work should be viewed cautiously, however. Our sample of 119 individuals is rather small and is probably not representative of the entire U.S. population. Further empirical work should concentrate on larger, more representative samples and other morbidity symptoms and conditions. Also for policy purposes attention should be given to any externalities which cause a divergence between private and social values for health risk reduction.

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