Measuring the Benefits from Reduced Morbidity

By M. L. CROPPER*

The predominant view in economics is that individuals are unaware of the health effects of air pollution and therefore do not take them into account in making decisions (see Lester Lave). Given this view, the appropriate way to measure the morbidity benefits of a reduction in pollution is to estimate a damage function and then assign a dollar value to the predicted decrease in illness. This, together with any reduction in medical costs, is what an individual would pay for a decrease in pollution if he treated his health as exogenous.

Unfortunately, this approach is inconsistent with the view, widely held in health economics, that individuals can affect the time they spend ill by investing in preventive health care. Support for this view is provided by Michael Grossman (1972a, b, 1976) whose work indicates that individuals diet, exercise, and purchase medical services to build up resistance to illness. These findings suggest that, if persons in polluted areas perceive their resistance to illness decreasing, they will try to compensate by exercising more, smoking less, or getting more sleep. Conversely, an improvement in air quality should lead to a decrease in preventive health care, and the value of this must be added to the benefits of pollution control.

Human capital theory thus implies that the damage function approach, by ignoring the value of preventive health care, understates willingness to pay for a change in air quality. This conclusion, it should be emphasized, does not assume that individuals know precisely the medical effects of air pollution. All that is necessary for a person to try and compensate for the effects of pollution is that he feels worse when pollution increases.

This paper presents a simple model of preventive health care, similar to that of Grossman (1972a, b), and uses the model to define what a person would pay for a change in air quality. The model assumes that one can build up resistance to acute illness by increasing his stock of health capital; however, health capital decays at a rate which depends on air pollution. For acute illness, willingness to pay as derived from the model is greater than the benefit estimate computed using the damage function approach. To illustrate the size of this discrepancy, estimates of willingness to pay are computed using data from the Michigan Panel Study of Income Dynamics.

I. A Model of Investment in Health

The essence of the human capital approach to health is that each individual is endowed with a stock of health capital H, with measures his resistance to illness. This stock can be increased by combining time TH_t with purchased goods M_t to produce investment in health,

$$(1)\qquad I_t = TH_t^{\,1-\zeta} M_t^{\,\zeta} E_{1t}^{\,\xi_1} \dots E_{nt}^{\,\xi_n}$$

Outputs of equation (1) include exercise, rest, and nourishment. These will be affected by factors such as the individual's knowledge of health, or the presence of a chronic disease ($E_{1t}, \dots, E_{nt}$ in equation (1)).

For simplicity, suppose that investment in health exhibits constant returns to scale so that the marginal cost of investment is constant and independent of I_t. This is reflected in equation (2) which gives the marginal cost of investment π_t as a function of the price of purchased goods PM_t, and the wage

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W_t,

$$\pi_t = W_t^{1-\zeta} PM_t^{\zeta} E_{1t}^{-\xi_1} \dots E_{nt}^{-\xi_n} \tag{2}$$

Investment in health increases the individual's health stock H_t, according to

$$dH_t/dt = I_t - \delta_t H_t \tag{3}$$

Health capital also deteriorates at the proportional rate δ_t since resistance to illness would decline if no investments were made in health.

The main motive for investing in health is that health capital affects time spent ill, TL_t. For empirical work it is most appropriate to assume a threshold relationship between health capital and illness since a large number of persons (half of the Panel Study sample) report zero days of illness each year. A discontinuous relationship between H_t and TL_t, however, makes the solution to the individual's choice problem difficult. Let us therefore assume that the individual views the *log* of illness as a decreasing function of the *log* of health capital,

$$ln\, TL_t = \gamma - \alpha\, ln\, H_t \quad \alpha > 0 \tag{4}$$

This implies that time spent ill can be made arbitrarily small, although not zero.

Equations (3) and (4) suggest that the model, while appropriate for acute illness, should not be applied to chronic illness. In (4) a reduction in the health stock increases time spent ill; however, being ill in one instant does not reduce the stock of health capital in the next. This is reasonable only if TL_t refers to acute illnesses such as colds and the flu.

To simplify the model and facilitate estimation of willingness to pay (4) is assumed to be the only motive for investing in health. This reduces health to a pure investment good and implies that the only effect of health on utility is through the budget constraint.

In this case, the decision to invest in health can be separated from the decision to purchase other goods. First, a path of investment in health is chosen to maximize R, the present value of full income net of the cost of investment, then utility is maximized, given R. In the present model full income is the market value of the individual's healthy time. If Ω is the total time available at t, then $h_t = \Omega - TL_t$ is the amount of healthy time available. The present value of full income net of the cost of investing in health may therefore be written

$$\int_0^T (W_t h_t - \pi_t I_t) e^{-rt}\, dt \tag{5}$$

where T is length of life. The individual's problem is to choose the path of investment which maximizes (5) subject to (3) and (4).

When the marginal cost of investment is constant, the solution to this problem is simple: at each instant the individual chooses an optimal level of resistance H_t^*, and then determines the amount to invest in health from (3).[1] The optimal health stock is determined by equating the value of the marginal product of health capital, $W_t \partial h_t / \partial H_t$, to its supply price,

$$W_t \frac{\partial h_t}{\partial H_t} = \pi_t \left(r + \delta - \frac{d\pi_t}{dt} \frac{1}{\pi_t} \right) \tag{6}$$

The latter consists of three parts: the interest foregone by investing π_t in health rather than at the rate r; the depreciation cost $\pi_t \delta_t$, since each unit of health immediately declines by an amount δ_t; and a capital gain which accrues if the cost of investment is changing. If π_t is rising at approximately the rate of interest, then the right-hand side of (6) reduces to $\pi_t \delta_t$.

Substituting from (4) the optimal health stock may be written

$$ln\, H_t^* = \frac{1}{1+\alpha}(\beta + ln\, W_t - ln\, \pi_t - ln\, \delta_t) \tag{7}$$

$$\beta = \gamma + ln\, \alpha$$

[1]For this solution to be valid, the resulting value of I_t must lie between 0 and $\bar{I}$, the maximum I permitted at any t. (That $\bar{I}$ exists is guaranteed by the fact that Ω and nonlabor income are finite.)

while time spent ill is given by

$$\ln TL_t^* = \gamma - \frac{\alpha}{1+\alpha}(\beta + \ln W_t - \ln \pi_t - \ln \delta_t) \tag{8}$$

There are several ways that pollution could enter this model. The observation that individuals are ill more often in polluted environments could mean that pollution enters the equation for time spent ill, (4), with a positive coefficient. This, however, implies that two individuals with the same health stock are not really equally healthy. Instead, it seems preferable to assume that pollution physically alters the state of a person's health.[2] This can be accomplished by making the rate of decay of health capital a function of air pollution P_t,

$$\delta_t = \delta_0 e^{\tilde{\delta} t} P_t^{\psi} S_t^{\phi} \tag{9}$$

Equation (9) also implies that the rate of decay of health varies with age and with other factors, S_t, such as stress or pollution on the job.[3]

Adding equation (9) to the model means that it is more costly to build up resistance to illness in polluted environments, hence individuals in polluted areas will choose to maintain lower health stocks and will be ill more often than persons in cleaner areas. Proponents of the damage function approach might argue that this is unrealistic since individuals are unlikely to know the precise form of equation (9). All that is necessary, however, for an individual to choose a lower health stock is that he feels less healthy (perceives δ_t to be higher) when pollution increases. Knowing the precise relationship between δ_t and P_t is irrelevant in choosing H_t^*.

[2]It is also true that air pollution affects productivity of time spent exercising; however, not all time invested in health is affected in this way. It therefore seems inappropriate to incorporate pollution in the production function for health.

[3]In the paper δ_t is viewed as exogenous, hence the possibility of altering δ_t by moving or changing jobs is ignored.

II. The Value of a Change in Air Pollution

Let us now consider the value to an individual of a small reduction in pollution at time t. Since a change in P_t affects net income only at t, the value of a small percentage change in P_t is defined as

$$-\frac{dR}{dP_t}P_t = \left(\frac{d\ln TL_t}{d\ln P_t}W_t TL_t + \frac{dI_t}{dP_t}\pi_t P_t\right)e^{-rt} \tag{10}$$

The first term on the right-hand side of (10) is the value of the reduction in sick time caused by a reduction in pollution. This is unambiguously positive. The second term describes the change in investment costs caused by a change in pollution. Reducing pollution increases the optimal health stock which, from (3), increases I_t^*. A reduction in P_t, however, also reduces δ_t which lowers the gross investment necessary to maintain a given health stock. For the functional forms above the net effect of these factors is positive, implying that a reduction in air pollution reduces resources devoted to preventive health care and thus increases willingness to pay,

$$\begin{aligned} -\frac{dR}{dP_t}P_t &= \left(\frac{\alpha\psi}{1+\alpha}W_t TL_t + \frac{\alpha\psi}{1+\alpha}\pi_t \delta_t H_t^*\right)e^{-rt} \\ &= 2\frac{\alpha\psi}{1+\alpha}W_t TL_t e^{-rt} \end{aligned} \tag{11}$$

If equation (10) is compared with the measure of benefits computed under the damage function approach, it is clear that the latter understates willingness to pay. Following Lave and Eugene Seskin, the damage function approach would measure the value of the reduction in sick time caused by a reduction in pollution, plus any change in medical costs. Since medical costs are negligible for acute illness, the damage function measure would equal the first term on the right-hand side of (10). The second term, which measures the decrease in resources devoted to preventive health care, would be ignored. To indicate the magnitude of this term and to give some idea of the morbidity costs of air pollution, I present estimates of (10) based on data from the Michigan Panel Study of Income Dynamics.

III. Estimation of Willingness to Pay

To compute willingness to pay requires an estimate of $\alpha\psi/(1+\alpha)$, the elasticity of sick time with respect to pollution. Equation (8) suggests that this can be obtained by regressing the *log* of sick time on the *log* of pollution and other variables which determine the optimal health stock. Since a large number of persons report zero days of illness each year, the appropriate statistical formulation of the equation is a Tobit model,

$$(12)\quad \begin{aligned} &ln\, TL_{it} = \text{undefined} && \text{if } X'_{it}B + u_{it} \leqslant 0 \\ &ln\, TL_{it} = X'_{it}B + u_{it} && \text{if } X'_{it}B + u_{it} > 0 \end{aligned}$$

where

$$X_t = (1\, ln\, PM_t\, ln\, E_{1t} \ldots ln\, E_{nt}\, ln\, P_t\, ln\, S_t\, ln\, W_t\, t)$$

$$B' = \alpha(1+\alpha)^{-1}\big(\text{constant } 1-\zeta\; -\xi_1 \ldots$$

$$-\xi_n\; \psi\; \phi\; -(1-\zeta)\,\tilde{\delta}\big)$$

and $u_{it} \sim N(0, \sigma^2)$ for all t. Consistent estimates of (12) may be obtained by maximum likelihood.

Table 1 contains estimates of (12) for men between the ages of 18 and 45 from the Michigan Panel Study of Income Dynamics. The dependent variable is days lost from work due to illness, adjusted for differences in weeks worked. Independent variables, apart from the wage, either determine the rate of decay of health capital or affect the productivity of time invested in health.

Two features of the data should be noted. Since the dependent variable cannot be observed for persons too sick to work, the estimates in Table 1 are subject to selection bias. This problem is not serious, however, since only 3 percent of the sample is unable to work for health reasons. Secondly, the data support a threshold model such as (12) since approximately half of the sample reports zero days of illness each year.

Before computing willingness to pay, I comment briefly on the performance of the independent variables in Table 1. The first four variables measure factors which affect the rate of decay of health capital—air pollution, pollution at work, parents' income (which may affect δ_0), and race.[4] The first three of these consistently have the expected signs and are significant in six out of eight cases. Race, when significant, implies that being white increases the rate of decay of health capital. The second four variables affect the productivity of time spent investing in health. The presence of a chronic condition has a large negative impact on the productivity of time invested in health and is therefore positively related to sick time. Education, being married, and being cautious should increase the prevention received for a given expenditure of resources and are in most cases negatively related to illness.

The chief anomaly in the health equations is the behavior of the wage. A high wage, by increasing the value of healthy time, should increase H_t^* and reduce TL_t. In Table 1 the wage is either insignificant or positively related to illness. This could be caused by two factors. In the Panel Study the wage is computed by dividing labor income by hours worked. This is not a good measure of the marginal wage unless an individual receives the same wage for each hour worked. Secondly, as Grossman (1972b) has argued, the wage may act as a proxy for deleterious consumption habits, for example, eating rich food, which increase the rate of decay of health capital.

I turn now to estimates of willingness to pay. In Table 1 pollution is measured by the annual geometric mean of sulfur dioxide, which has been linked with acute illness in epidemiological studies. No other pollution variables are included since collinearity between pollutants leads to insignificant coefficients if several variables

[4]Age, which should also affect the rate of decay of health, was dropped from the equation for lack of significance.

TABLE 1—HEALTH EQUATIONS FOR MEN 18-45-YEARS OLD[a]

Independent Variable	Interview Year[b]		
	1970	1974	1976
Constant	3.5474	−1.2320	−0.5084
	(1.1253)	(0.9599)	(0.9014)
$Ln(SO_2$ Mean)	0.2879	0.3168	0.3189
	(0.2140)	(0.2076)	(0.1828)
Works in Manufacturing[c]		0.5001	0.4828
		(0.3659)	(0.3133)
Parents' Income	−0.1832	−0.1310	−0.0150
	(0.0936)	(0.1182)	(0.0953)
Race	0.7318	0.3768	−0.2950
(1 = White)	(0.2697)	(0.4052)	(0.3084)
Has a Chronic	1.1972	0.6515	0.9347
Health Condition	(0.4582)	(0.2862)	(0.2602)
Years of Schooling	−0.1317	−0.1091	0.0496
	(0.0795)	(0.1170)	(0.0508)
Marital Status	−0.9678	0.9321	−0.6639
(1 = Married)	(0.5098)	(0.4550)	(0.3828)
Risk Aversion	−0.3970		
Index[d]	(0.0881)		
Ln(Wage)	0.7492	−0.0899	0.1719
	(0.2873)	(0.3553)	(0.2813)
σ	2.1460	2.1586	2.1689
	(0.1824)	(0.2656)	(0.1931)
n	361.	247.	335.

Sources: All variables are from the Michigan Panel Study of Income Dynamics except SO_2 which is from the U.S. Environmental Protection Agency.

[a]The dependent variable in each equation is the *log* of [work-loss days/(days worked + work-loss days)] × 365. Standard errors appear beneath coefficients.

[b]Each interview year corresponds to the previous calendar year.

[c]Not available in 1970.

[d]Not available in 1974, 1976.

appear together. SO_2 should therefore be regarded as a pollution index and willingness to pay estimates viewed as indicators of the order of magnitude of willingness to pay. For the interview years 1970, 1974, and 1976, the mean of SO_2 is asymptotically significant at the .10 level or better (one-tailed test); furthermore its coefficient is approximately 0.3 in each year, despite differences in the specification of the health equation.

Consider now the amount an individual would pay for an x percent reduction in pollution. According to (11) this amount is

$$(13) \qquad 2(x/100)\frac{d\,ln\,TL_t}{d\,ln\,P_t}W_tTL_t$$

In equation (12) the elasticity of sick time with respect to pollution is equal to $\Phi(X_{it}'B/\sigma)$, the probability of being ill, times the coefficient of the *log* of pollution. Since $\Phi(X_{it}'B/\sigma)$ can be approximated by the fraction of the sample which is ill, $\Phi(X_{it}'B/\sigma) \doteq 0.5$ in each year, implying that the elasticity of sick time with respect to pollution $\doteq 0.15$.[5] The expected value of TL_t, calculated at the sample mean of X_{it}, is approximately 40 hours in each interview year.[6]

Equation (13) thus implies that the average person in the 1976 sample, who earned \$6.00 per hour, would pay \$7.20 annually for a 10 percent decrease in the mean of

[5]Evaluated at the sample mean of X_{it}, $\Phi(X_{it}'B/\sigma)=$ 0.57 in 1970, 0.50 in 1974, and 0.53 in 1976.

[6]$E(ln\,TL_{it})=X_{it}'B\Phi(X_{it}'B/\sigma)+\sigma\phi(X_{it}'B/\sigma)$. If this expression is evaluated at the sample mean of X_{it}, $E(TL_t)$ is, respectively, 46, 38, and 41 hours in 1970, 1974, and 1976.

SO_2. The damage function approach, by contrast, would put the value of a 10 percent reduction in pollution at only $3.60. In a city with one million prime-aged men, this would understate the value of a 10 percent reduction in air pollution by $3,600,000 annually. Ignoring adjustments to pollution, therefore, could sizably understate the value of an improvement in air quality.

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